

DISSERTATION

POTENTIAL ENVIRONMENTAL IMPACTS
FROM CROPPING-PATTERN AND LAND-USE CHANGES
UNDER THAILANDS'S ETHANOL PRODUCTION MANDATE

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ABSTRACT

POTENTIAL ENVIRONMENTAL IMPACTS FROM CROPPING-PATTERN AND LAND-USE CHANGES UNDER THAILANDS'S ETHANOL PRODUCTION MANDATE

The primary energy source meeting demand in Thailand is oil, especially in the transportation sector, which has resulted in energy import dependency and environmental impacts (Energy Policy and Planning Office, 2012). To reduce energy import and carbon emission the Thai government has announced a plan, known as “Low Carbon Society” policy that promoted bioenergy use (Ministry of Energy, 2012). The main bioenergy strategy of the Thai government is promotion of ethanol production. Ethanol production targets have been set at 3.0, 6.2, and 9.0 million liters per day, in 2008-2011, 2012-2016, and 2017-2022, respectively (Ministry of Energy, 2012).

The main feedstocks for ethanol production in Thailand are cassava and molasses, a by-product from refining cane sugar. The cultivation areas of these energy crops are thus expected to increase and intensify due to expansion on ethanol production. In 2010, it was estimated that 1.61 million tonnes of cassava and 2.19 million tonnes of molasses could serve as feedstock for ethanol production of 2.25 million liters per day. Based on licensed ethanol plants and the ethanol production target for 2022, demand for cassava and molasses from the Thai ethanol industry would increase up to at least 14.34 and 3.96 million tonnes per year. While the current

molasses production could serve this feedstock demand, the enormous increase in demand for cassava would significantly increase land-use for cassava cultivation.

The ethanol production has been promoted for the purpose of energy security, GHG emission reduction, and economic development. However, it is unclear that the ethanol target of the Thai government is possible in both economic and political terms regardless of the cropping land-use change and thus the environmental impacts. Moreover, the planning, monitoring, and setting suitable cultivation area for ethanol feedstock could help to reduce its negative impact on land use change, deforestation, and biodiversity loss (Scarlat and Dallemand, 2011). This proposed study thus focuses on three interrelated topics: the economic and political feasibility of enacting these mandates; the potential cropping land-use change under realistic scenarios; and the potential environmental impacts of these changes. The objectives for each of these are as follow:

1. To evaluate the current economic and political feasibility to produce nine million liters per day of ethanol. The economic feasibility regards to estimate adequacy of ethanol feedstock crops and cultivate areas as compared to other major competing crops benefit. The political feasibility issues regards the competition of interests among influential parties that play important roles in the Thai energy and agricultural industries, such as the government itself, oil companies, and farmer associations.

2. To assess on the outcome of cropping land-use change when ethanol target is introduced. The significant increase in ethanol and feedstock demand is expected to dramatically alter crop cultivation areas. Moreover, energy crops and competitive crop prices would also impact on farmers' decision. Thus, individual farmers' economic decision when adopting ethanol feedstock crops to be cultivated instead of other competitive crops will be investigated. Various

scenarios cropping land-use change when ethanol mandate is implemented and subsequent will be studied in-depth by using the Multi-criteria Analysis and Geographic Information Systems (GIS).

3. To estimate the environmental impacts of Thai ethanol mandate under these various scenarios. Ethanol mandate implementation does not only directly affect GHG reduction, but also effects GHG balance due to cropping land-use change. Other environmental impact such biodiversity can also be measured. Based on a range of realistic alternative scenarios of cropping land-use change, the range of impacts on several measures of environmental quality will be estimated. The CENTURY model will be used to account soil carbon sequestration as GHG balance. Meanwhile, the nitrous oxide, methane, and biodiversity loss from cropping land-use change are discussed.

ACKNOWLEDGEMENTS

“If I have seen further than others, it is by standing upon the shoulders of giants.”

Isaac Newton

First of all, I would like to thank all researchers who dedicated their lives to improve our world. Next, I would like to express my deepest gratitude to my family, both to my mom and to my wife, who never left me even when the greatest darkness came over my life. I cannot thank enough the Royal Thai Government and Khonkaen University for funding my Ph.D. studies. I would like to especially thank to Kittinun Worraanuwanakul and Land Development Department of Thailand for precious land-use geographic (GIS) data using in this study. Many thanks to Yao Zhang, Steve Williams, and Trung Nguyen for teaching me CENTURY model, as well as correcting my results. I also owe a great deal of thanks to my best friend, Warong Suksavate, for introducing me to ArcMap. Last, but not least, this dissertation would not have been completed without the support and motivation from my adviser, Gregory D. Graff, and my dissertation committee. I have really appreciated the way that you have treated me as we have worked together.

TABLE OF CONTENTS

ABSTRACT	ii
ACKNOWLEDGEMENTS	v
LIST OF TABLES	viii
LIST OF FIGURES	ix
Chapter 1. Is Thailand's ethanol production target of 9 million liters per day economically and politically feasible?	1
1.1 Introduction	1
1.2 The current Thai fuel market	2
Oil Price Structure in Thailand	5
Policies regulating the gasoline market in Thailand	7
1.3 The Thai ethanol market	9
The ethanol feedstock in Thailand	11
The price of ethanol in Thailand	17
Thailand's ethanol policies	20
1.4 Forecasting the impact of the Thai government's ethanol target on cassava	21
Forecasting domestic ethanol demand	21
Forecasting ethanol supply	28
Forecasting feedstock requirements	29
Forecasting total demand for cassava	33
Summary of forecasts	41
1.5 Ethanol stakeholder groups in Thailand	43
1.6 Conclusion and discussion	45
References	49
Chapter 2. Cropping and land use changes likely to result from increased demand for cassava feedstock under the Thai government's ethanol policy	52
2.1 Introduction	52
2.2 Literature Review	55
2.3 Data and Methods	56
2.4 Results	76

2.5 Conclusion and discussion	86
References	90
Chapter 3 Projected environmental impacts resulting from land-use and cropping changes under the Thai ethanol policy.....	92
3.1 Introduction	92
3.2 Background	94
3.2 Method and study data	97
CENTURY Model	97
Study data.....	98
3.3 Result.....	102
SOC sequestration.....	103
N ₂ O emission.....	105
CH ₄ emission.....	107
Total GHGs emission.....	109
Biodiversity.....	112
3.4 Conclusion and discussion	114
References	116
Appendix.....	123

LIST OF TABLES

Table 2.1 The area attributes used for assigning cassava suitability scores	63
Table 2.2 The suitability scores and weights of area attributes and penalty factors.....	65
Table 2.3 The statistic data of area, production, yield, cost, income, and distance comparing before and after reallocated area	76
Table 2.4 Area and production of rice and corn, resulting from cassava area reallocation.....	80
Table 2.5 The statistic of distance from parcels to biorefineries, in kilometers, comparing before and after reallocation.....	81
Table 3.1 Soil texture classes and bulk density	99
Table 3.2 The soil loss from cassava cultivation in Thailand and other countries in Asia.....	101
Table 3.3 The modelled scenario of land use reallocations in Thailand, based on weather and soil types.	104
Table 3.4 SOC loss or gain for each regional climate and soil types over the long run (30 years), given different copping changes	104
Table 3.5 The SOC loss or gain in term of CO ₂ emission from reallocated area over long run (tonne CO ₂)	105
Table 3.6 The N ₂ O emission or (reduction) from cassava, corn, and rice cultivation based on the scenario (tonne N ₂ O per year).....	106
Table 3.7 The CH ₄ emission or (reduction) from cassava, corn, and rice cultivation based on the modelled land use change scenario (tonnes of CH ₄ per year).....	108
Table 3.8 The CH ₄ emissions increase or reduction from rice cultivation area based on the modelled land use change scenario (tonne CH ₄ per year).....	109
Table 3.9 Accumulated net GHGs emission increase or (reduction) based on the direct land use change in term of GWP (tonne CO ₂ eq.) in 10, 30, and 50 years from 2013.....	110

LIST OF FIGURES

Figure 1.1 Shares of crude oil and condensate supplied on the Thai market, by source, in 2010...	3
Figure 1.2 The actual production of oil refineries in Thailand, by source, in 2010.	4
Figure 1.3 Shares of retail gasoline on the Thai market, by source, in 2010.....	4
Figure 1.4 The structure of factors determining the retail gasoline retail price in Thailand.	6
Figure 1.5 The components of gasoline and gasoline-ethanol blend retail prices in Thailand in December 2010.	7
Figure 1.6 The quantity of ethanol production, consumption and export in Thailand.	10
Figure 1.7 The quantity of ethanol consumption blended in each gasoline type in Thailand.	10
Figure 1.8 The major primary crops could serve as ethanol feedstock in Thailand in 2011.	12
Figure 1.9 The total cost of ethanol production in Thailand based on (Yoosin and Sorapipatana, 2007)'s study and average crop prices from 2006- 2011.....	13
Figure 1.10 The total cost of ethanol production with uncertainty of all feedstock prices.....	13
Figure 1.11 The number and capacity of ethanol refineries in Thailand in 2013, by feedstocks and operational status.....	16
Figure 1.12 The ethanol, retail pure gasoline, and molasses price in Thailand, 2007-2012.....	19
Figure 1.13 The total registered cars and new registered cars in Thailand, 2007-2012.	21
Figure 1.14 Numbers of gasoline-powered automobiles on the road in Thailand, by type of engine fuel compatibility 2007-2012	23
Figure 1.15 The improvement of average fuel efficiency of cars in Thailand.	25
Figure 1.16 Low, middle, and high demand scenarios for fuel ethanol in Thailand based on projected types of gasoline-engine automobiles and their respective fuel consumption.....	27
Figure 1.17 Actual and forecasted range of domestic ethanol consumption in Thailand, based on four scenarios of future automobile numbers, gasoline-engine types, and ethanol blend utilization patterns	28
Figure 1.18 Total potential ethanol refinery production capacity in Thailand, 2013-2022	29
Figure 1.19 Cassava and sugarcane demand for ethanol production.....	31
Figure 1.20 Land requirement of cassava and sugarcane for ethanol feedstock	32
Figure 1.21 The proportions of cassava consumption in Thailand.....	34
Figure 1.22 Actual and baseline forecast of quantities of cassava demanded (in millions of tonnes), assuming non-ethanol utilization of cassava remains at current (2012) levels while utilization for ethanol grows according to midline forecasts.....	38
Figure 1.23 Actual and baseline forecast of land requirements for cassava cultivation based on baseline demand forecast illustrated in Figure 1.22, assuming cassava yields remain constant at current (2012) levels	38
Figure 1.24 Actual and forecasted range of cassava quantity demanded (in millions of tonnes) under varied scenarios.....	39

Figure 1.25 Actual and forecasted range of land requirements for cassava cultivation in Thailand under varied scenarios of demand, without yield improvements (panel a) and with annual yield improvements of 2.4 percent (panel b)	40
Figure 2.1 Ethanol demand and supply in the Thai market	58
Figure 2.2 Current land-use for major crops' cultivation and cassava-based ethanol refineries' location.....	61
Figure 2.3 Distribution of cassava suitability scores across all 587 biophysical categories.....	65
Figure 2.4 The average profit per hectare of major crops (baht per hectares), from 2007-2011 ...	67
Figure 2.5 Average cost (baht per ha) and yield (tonnes per ha) from previous analysis	68
Figure 2.6 Estimated cost and yield based on suitability ranking from Land Development Department.....	69
Figure 2.7 Estimated per-hectare cost, yield, income, and profit from cassava cultivation, as a function of cassava suitability scores.....	70
Figure 2.8 Percentage of current cassava areas for cassava cultivation major negative factors....	71
Figure 2.9 Considerations for ranking parcels by profitability of producing and transporting cassava for ethanol feedstock.....	73
Figure 2.10 The diagram of assigned cassava area algorithm	75
Figure 2.11 Distribution of suitability scores before and after reallocating cassava areas.....	78
Figure 2.12 National average cassava yield in Thailand from 1960 to 2013	78
Figure 2.13 Land from other major crops incorporated into new cassava cultivation area and production volumes.....	79
Figure 2.14 Reallocation of land into and out of cassava cultivation and cassava-based ethanol refineries' location.	82
Figure 2.15 Reallocation of land-use from major crops' cultivation and cassava-based ethanol refineries' location in Nakornratsema province.....	84
Figure 2.16 Area of cassava use for ethanol and food, and biorefineries' locations.	85
Figure 3.1 The average of monthly total precipitation (a), monthly maximum and minimum temperature (b) in Nakornsawan, Khonkaen, and Prachinburi station from 1961-2012.	99
Figure 3.2 Schedule of cassava, rice, corn, and soybean cultivated pattern in Thailand.....	100
Figure 3.3 GHGs emission from cassava-based ethanol relative to that from conventional gasoline in Thailand.....	111
Figure A.1 SOC change from introduction of cassava into rice area, from 1977 to 2113.	123
Figure A.2 SOC change from introduction of cassava into corn area, from 1977 to 2113.	124
Figure A.3 SOC change from introduction of rice into cassava area, from 1977 to 2113.	125
Figure A.4 SOC change from switching out of cassava to grassland, from 1977 to 2113.	126

Chapter 1. Is Thailand's ethanol production target of 9 million liters per day economically and politically feasible?

1.1 Introduction

An increase in ethanol production and consumption to meet the Thai government's target of 9.0 million liters per day would require numerous resources for ethanol supply as well as substantial efforts to encourage ethanol demand. Although the cost of ethanol production is currently higher than the price of gasoline, the Thai government is promoting ethanol production and consumption. The impact of ethanol production on the Thai economy has both advantages and disadvantages, benefits and costs, which are distributed unevenly among different stakeholders, including the public, farmers, and oil companies.

Economically, ethanol production may result in some benefit for the public, largely due to stabilization of prices and improved balance of trade, as well as for farmers, largely due to increased demand for ethanol feedstock crops. Oil companies could lose some profits, largely due to reduced demand for conventional gasoline. Altogether, it is expected that ethanol production can make energy prices more stable, support higher crop prices, and promote rural incomes.

This chapter will examine the structure of oil and ethanol markets in Thailand, the Thai government's fuel policies, and will discuss the major stakeholders likely to be affected by the proposed changes in the Thai transportation fuel market. Furthermore, the potential for development of sufficient ethanol feedstock and new ethanol refineries will be explored. The political feasibility of this proposed policy will be examined in qualitative terms, within a "public choice" framework, comparing the welfare gain and losses and the relative bargaining

power of the major stakeholder groups that stand to be affected. Finally, the first order economic feasibility of the policy will be explored with some simple ethanol demand and supply projections. The fundamental question in Chapter 1 is simply this, given current economic and political circumstances, is it even feasible for the Thai ethanol production target of 9.0 million liters per day to be achieved?

1.2 The current Thai fuel market

There are three sectors of the oil industry from upstream to downstream in Thailand: (1) extraction, (2) refining, and (3) distribution and retail.

Upstream, there is a significant domestic Thai industry engaged in extracting crude oil and condensate; however, domestic production is not sufficient to meet domestic demand for gasoline refining. In 2010, similar to other importing petroleum countries, Thailand imported most of its crude oil and condensate, accounting for 77 percent of total domestic petroleum refining. Only 23 percent, or about 248,000 barrels per day, was domestically extracted. And even less, a mere 30,000 barrels per day of domestically produced oil was exported.

The first tier of the industry consists of ten major crude oil and condensate providers in 2010. The two main producers are Chevron, which in 2010 accounted for 56 percent of total domestic supply and PTT Group (formerly the Petroleum Authority of Thailand) which accounted for another 25 percent of total supply (Ministry of Energy, 2010). The PTT Group was privatized in 2001, but is still majority owned by the Ministry of Finance which holds 51 percent of the total shares in PTT (The Stock Exchange of Thailand). Moreover, the Thai government collects revenue including a petroleum royalty and Special Remunerator Benefits (SRBs) from

petroleum operations. Revenue from crude oil and condensate extraction in 2010 was about \$8 billion (Ministry of Energy, 2010).

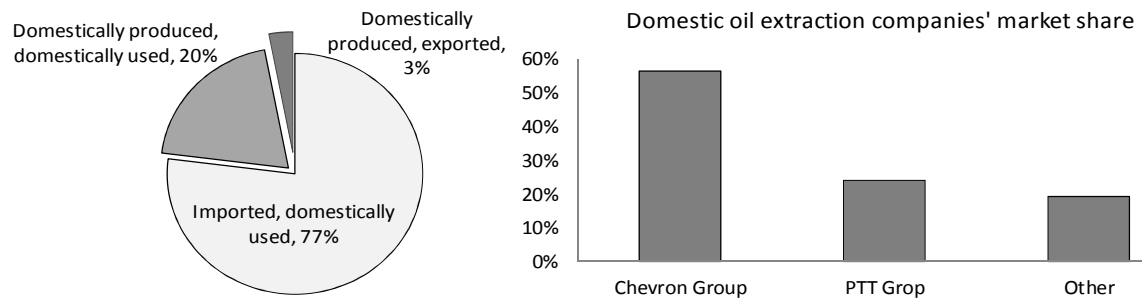


Figure 1.1 Shares of crude oil and condensate supplied on the Thai market, by source, in 2010.

The middle tier of the industry is oil refining. In 2010, the total capacity of all eight refineries in Thailand was about 1,120,000 barrels per day (Energy Policy and Planning Office, 2012). However, the actual refining of the seven operating refineries was about 962,000 barrels per day or 86 percent of total capacity. The five main refinery companies are Thai Oil Public (TOP), IRPC, Star Petroleum Refining (SRPC), Bangchak Petroleum (BCP), and PTT Global Chemical (PTTGC). Together, these five have about 827,000 barrels per day or 86 percent of total refinery capacity. The PPT Group has an ownership interest, ranging from 27 to 49 percent of shares, in all five of these companies. The other two main refining companies, ESSO and RPC, produced about 125,000 and 10,000 barrels per day or 13 percent and 1 percent of the total, respectively.

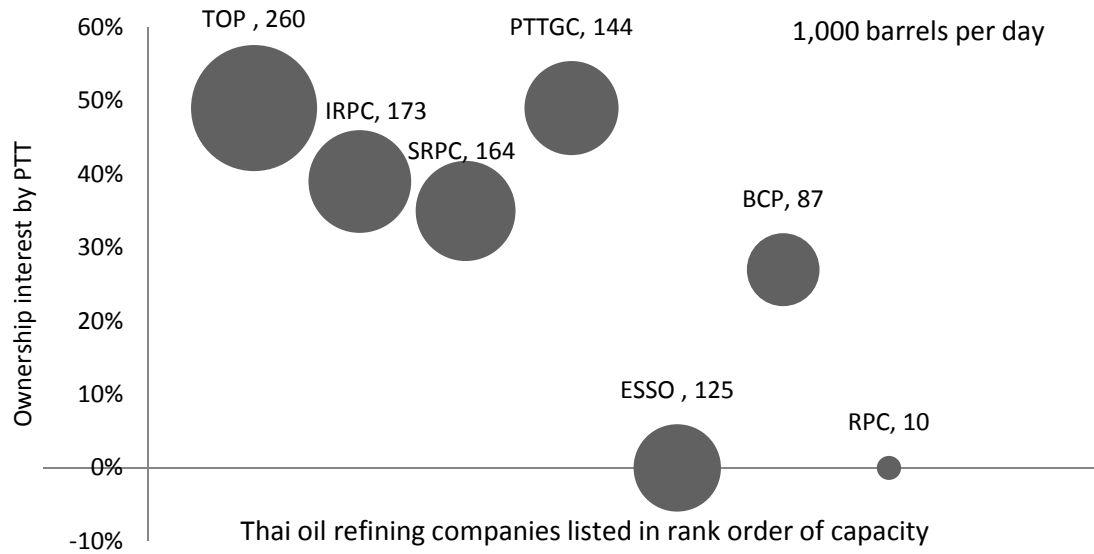


Figure 1.2 The actual production of oil refineries in Thailand, by source, in 2010.

Finally, the downstream segment of the industry consists of distribution and retail sale. About 20.62 million liters per day of gasoline were sold in Thailand in 2010. The top five retail companies, accounting for 83 percent of total market share, were PTT, Esso, Shell, Chevron, and Bangchak with 29, 16, 13, 13, and 12 percent respectively.

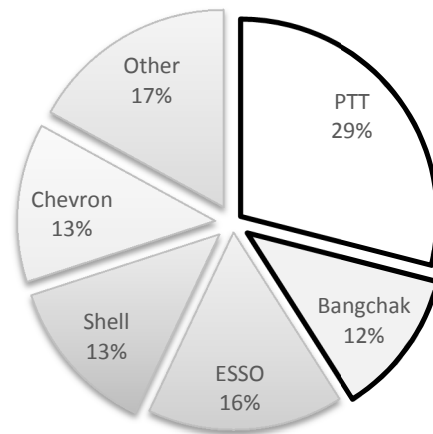


Figure 1.3 Shares of retail gasoline on the Thai market, by source, in 2010.

There are six formulations of gasoline on the Thai fuel market: (1) pure gasoline with an octane rating of 91, (2) pure gasoline with octane 95, (3) an E10 gasoline-ethanol blend with an octane rating of 91, (4) an E10 gasoline-ethanol blend with an octane of 95, (5) an E20 gasoline-ethanol blend with octane 95, and (6) an E85 gasoline-ethanol blend with an octane of 95. The two most important classes are E10, octane 91 and E10, octane 95, which together account for 78 percent of the retail market. E85 is only available from the domestic companies, PTT and Bangchak, which are both controlled by the Thai government and which together account for 41 percent of the total retail gasoline market.

In a nutshell, the Thai government plays an important role in each sector of the Thai oil industry, from upstream to downstream, largely through its controlling interest in the PTT Group.

Oil Price Structure in Thailand

Crude oil and gasoline prices in Thailand—while they do reflect underlying forces of supply and demand—are, nonetheless, highly managed by government policy. The structure of crude oil and gasoline prices depends to a great extent on which tier of industry is being considered. In the upstream segment of the value chain, crude oil prices are fundamentally based on world crude oil prices. In the middle tier of the industry, the ex-refinery gasoline price in Thailand is based on the “Mean of Platts Singapore” (MOPS) fuel oil price in the Singaporean spot market as a benchmark. On top of this base price is added import costs and adjustments for to obtain an import parity price. In the downstream segment of the value chain—even though crude oil and refined gasoline prices are based on world price—retail gasoline prices are controlled by the Thai government through a range of regulatory tools, such as the Thai energy fund, the energy conservation fund, and various taxes. The actual retail gasoline price seen by

Thai consumers is determined by the ex-refinery gasoline price, as well as adjustments due to excise and other taxes, fee assessments for the Thai energy fund and the energy conservation fund, and a regulated market margin, as illustrated in Figure 1.4.

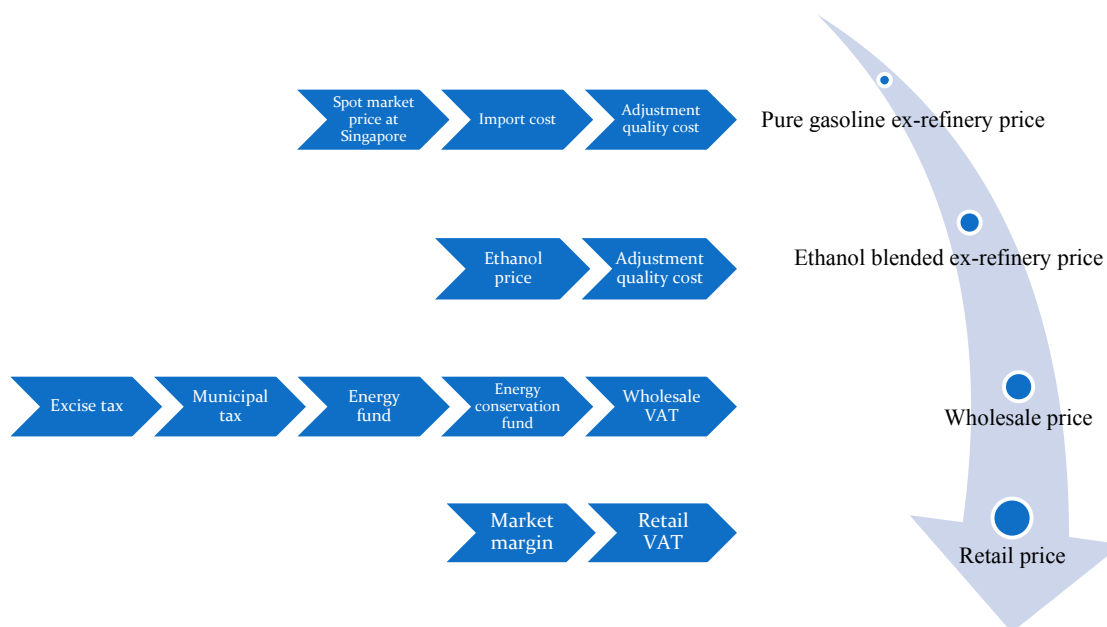
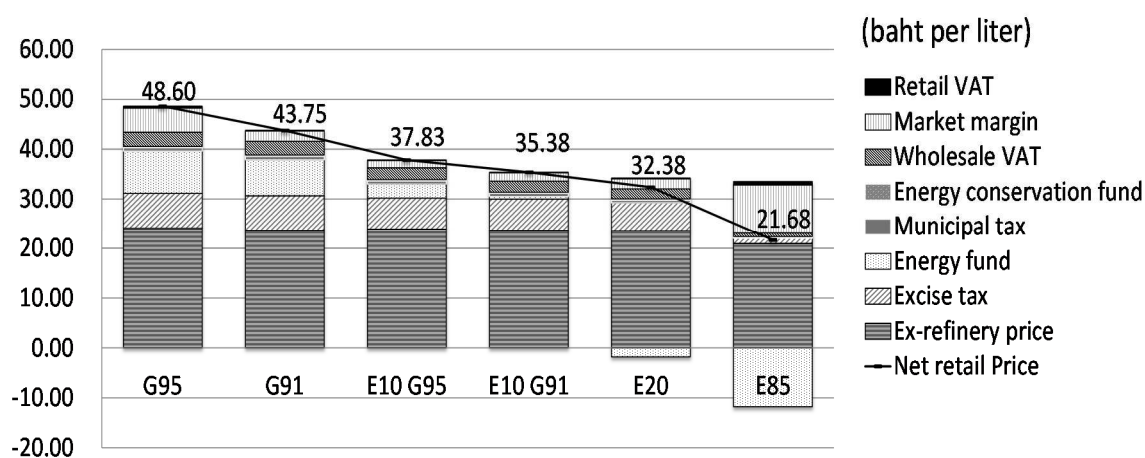


Figure 1.4 The structure of factors determining the retail gasoline retail price in Thailand.

In 2012, conventional gasoline prices in Thailand were about 2-fold the prices of the E85 gasoline-ethanol blend, even though the ex-refinery prices were about the same. The big difference in retail prices came from difference in excise taxes, energy fund allocations, and marketing margin adjustments. While conventional gasoline was taxed at 7 Thai baht per liter and charged about 8.50 baht per liter in assessments for the Thai energy fund, E85 gasoline was taxed only 1.05 baht per liter and received a credit of 11.8 baht per liter from the Thai energy fund. The incentive for selling ethanol blended gasoline was the tax exemptions that made the price of ethanol blended gasoline lower than the price of conventional gasoline (Sorda et al.,

2010). Both E20 and E85 gasoline-ethanol blends were promoted by lower excise taxes and credits from the Thai energy fund. However, the marketing margin on E85 gasoline was also set at a higher level to encourage retailers, as shown in Figure 1.5.



Data source: (Energy Policy and Planning Office)

Figure 1.5 The components of gasoline and gasoline-ethanol blend retail prices in Thailand in December 2010.

Policies regulating the gasoline market in Thailand

The Thai government's main regulatory tools for manipulating retail gasoline prices are an excise tax and the Thai “energy fund”. The excise tax on conventional gasoline has generally been higher than the excise tax on ethanol-blended gasoline. And, as a rule, the greater the ethanol blend, the lower is the excise tax. However, the excise tax rate, which is enacted by the Thai Cabinet, is not easily adjusted.

The Thai energy fund, operated by the Energy Fund Administration Institute "EFAI" (an independent public agency), is a more flexible instrument for manipulating gasoline prices. The EFAI was established by the Thai Cabinet in 2004 to manage the stabilization of fuel retail prices in Thailand in order to mitigate the impact of oil price fluctuations on inflation (Energy Fund

Administration Institute). The Thai energy fund is used to adjust domestic retail energy prices relative to global crude oil prices. For example, when global oil prices increase, the domestic retail oil price is subsidized by the energy fund. On the other hand, when global oil prices decline, the domestic retail oil price is regulated higher than normal market prices, with assessments made to put money back into the energy fund. Furthermore, the Thai energy fund is an important tool for differential governmental promotion or relegation across different types of energy use, by adjusting the rates of assessments of subsidies for each energy type.

The EFAI is directly operated by Energy Policy Committee (EPC). The EPC creates fuel retail price policy and authorizes adjustments in the fund's rates for each fuel type (Energy Policy and Planning Office). Revenue of the energy fund come from kerosene, gasoline, diesel, and bunker oil importers and producers, interest on assets managed under the fund, and the Thai government budget. The main expenditures are currently to subsidize ethanol, biodiesel, Liquid Petroleum Gas (LPG), and flexible fuel vehicles (FFVs). Moreover, the EFAI, as an independent public agency, can issue bonds or borrow from financial institutions or public sources when the energy fund is in deficit (Energy Fund Administration Institute, 2010).

1.3 The Thai ethanol market

The domestic use in Thailand of ethanol as a transportation fuel has steadily increased from 0.44 million liters per day in 2007 to 1.01 million liters per day in 2011. In 2007, virtually all ethanol use was in the form of E10 gasoline blends. The ethanol volumes contained in E10 blends steadily increased until 2009, when E20 and E85 blends were introduced. Since then, the volume of ethanol in E10 has actually decreased, while the volume accounted for by the other blends have increased significantly.

At the same time, ethanol exports from Thailand have dramatically increased from just 0.04 million liters per day in 2009 to 0.83 million liters per day in 2012. In 2011, the main importers of Thai ethanol were the Philippines, Japan, and Korea (Department of Alternative Energy Development and Efficiency).

Domestic ethanol production had increased around three-fold, from about 0.7 million liters per day in 2007 to 2.2 million liters per day in 2012. Based on the Thai government's target, ethanol production should reach to 6.2 million liters per day in the period of 2012-2016. Current ethanol production capacity, in 2014, is about 4.79 million liters per day.

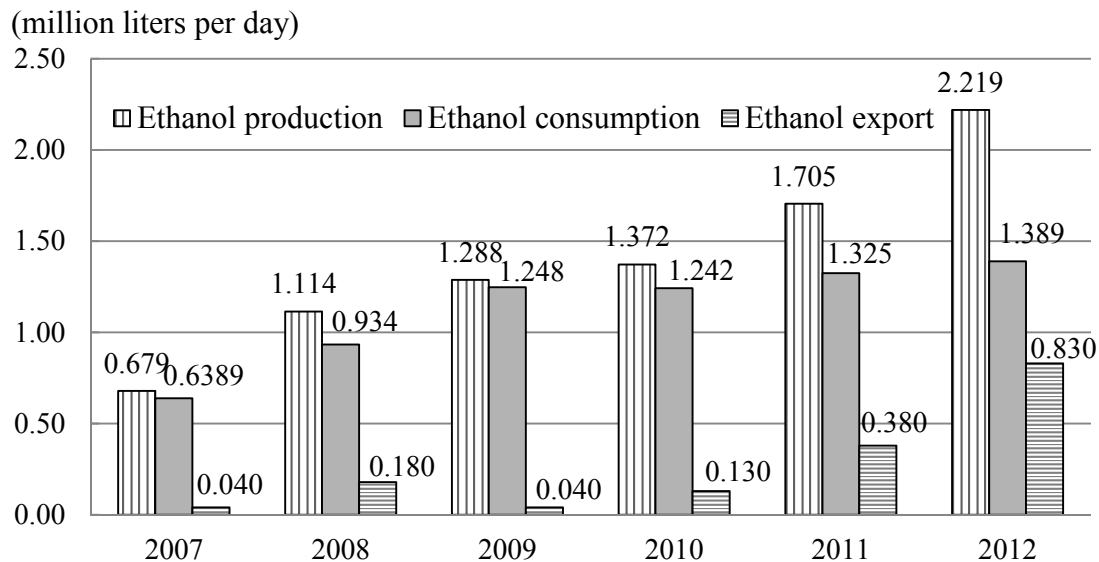


Figure 1.6 The quantity of ethanol production, consumption and export in Thailand.

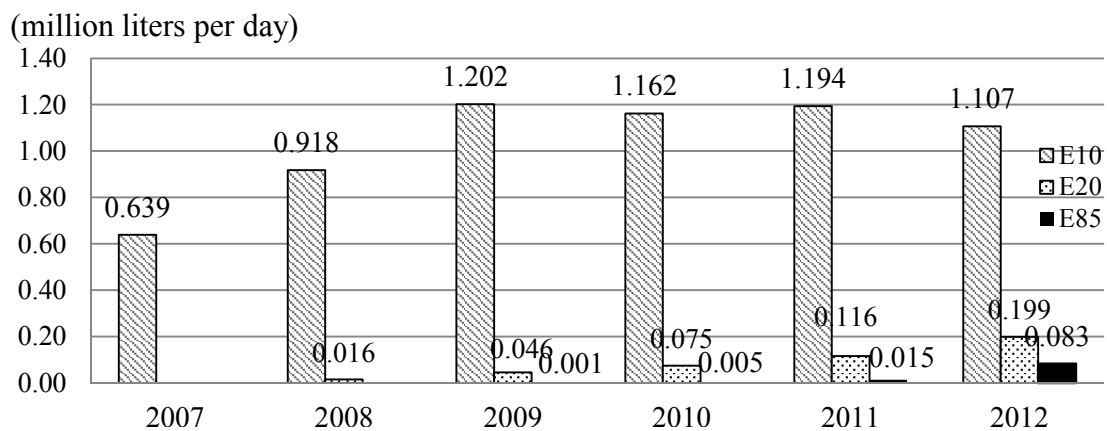


Figure 1.7 The quantity of ethanol consumption blended in each gasoline type in Thailand.

The ethanol feedstock in Thailand

Although the most significant crops for ethanol in many countries are maize, sugarcane, and wheat, in Thailand the most important are cassava and sugarcane. Based on a 2008 analysis of the security of ethanol feedstock in Thailand, most Thai ethanol was being produced from molasses, a byproduct of the cane sugar refining process, which at the time accounted for about 92 percent of all ethanol produced. The Thai ethanol industry requirements for molasses and cassava were about 1.18 and 0.15 million tonnes per year, respectively. But, with the rapid growth in ethanol production, the composition of feedstock appears to be shifting.

Current ethanol feedstocks in Thailand are primarily molasses and cassava, as well as a smaller amount of sugarcane due to the available supply, lower feedstock cost, and production flexibility of cassava-based ethanol.

Cassava, already widely produced for cassava chips (used as animal feed) and starch, is the third ranking crop in terms of overall crop production in Thailand. In 2011, the cassava production was around 21.91 million tonnes, while maize production was only around 5.02 million tonnes. Although sugarcane was the highest production, 95.95 million tonnes, most of sugarcane was produced cane sugar. Meanwhile, cassava was produced starch and chips which had a lower value added.

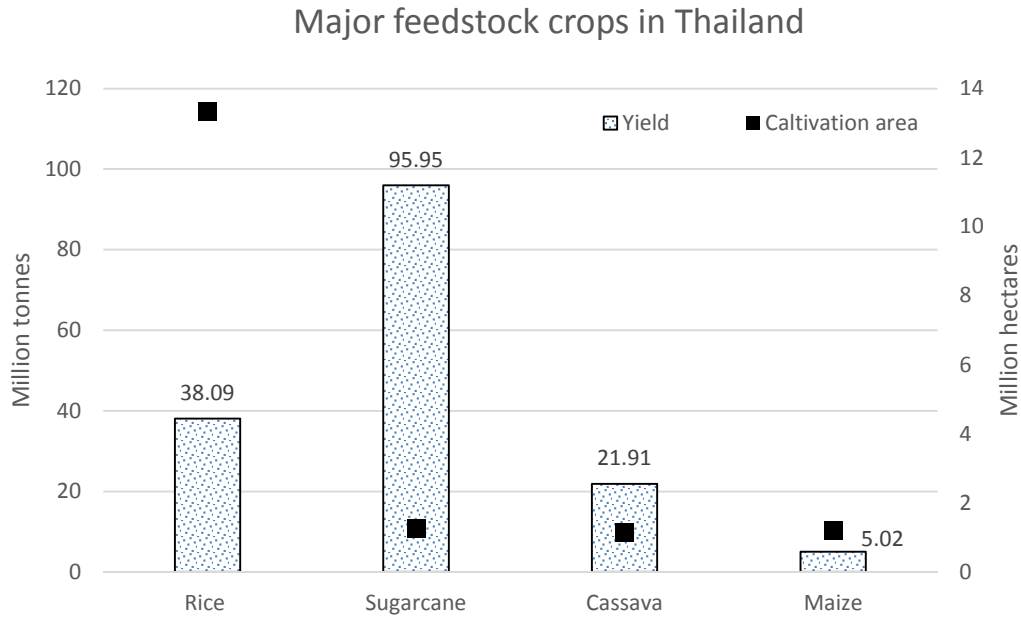
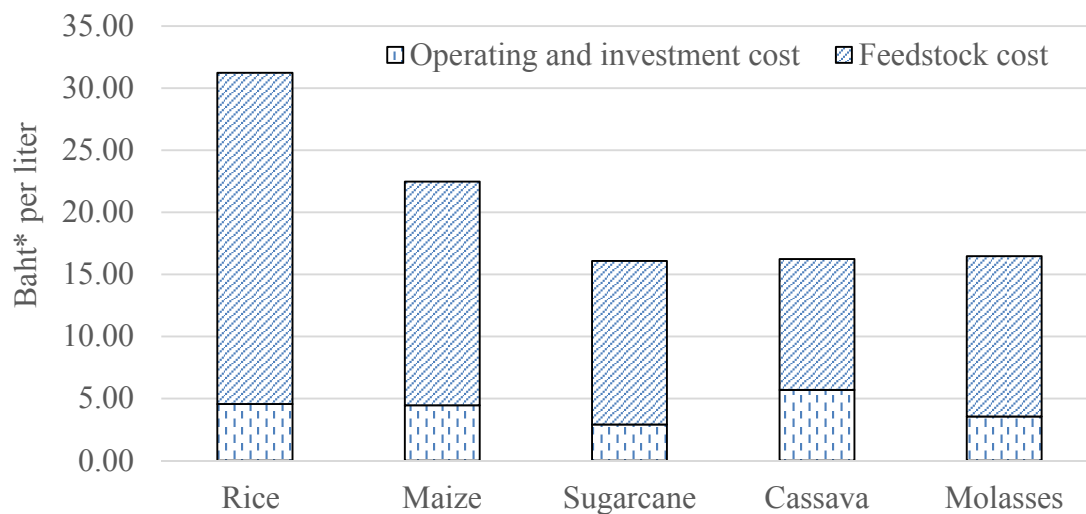


Figure 1.8 The major primary crops could serve as ethanol feedstock in Thailand in 2011.

The result of comparing cost of ethanol refining among various feedstocks in Thailand showed that sugarcane and molasses provided the lowest operating and investment cost, while cassava, maize and rice required the higher costs (Yoosin and Sorapipatana, 2007). However, feedstock cost is a major cost of an ethanol refining. Based on conversion factors and average crop prices from 2006 to 2011, cassava feedstock provided the lowest feedstock cost. And then total cost of ethanol refining from cassava, sugarcane, and molasses was about equal.

The increase in feedstock prices has a significant impact on the total ethanol cost. Figure 1.10 shows the total cost of ethanol produced from sugarcane, cassava, and molasses when the feedstock prices change. The cassava-based ethanol is the most advantage when all crop prices increase more than 10 percent equally.



* The currency rate is about 33 baht per \$1.

Figure 1.9 The total cost of ethanol production in Thailand based on (Yoosin and Sorapipatana, 2007)'s study and average crop prices from 2006- 2011.

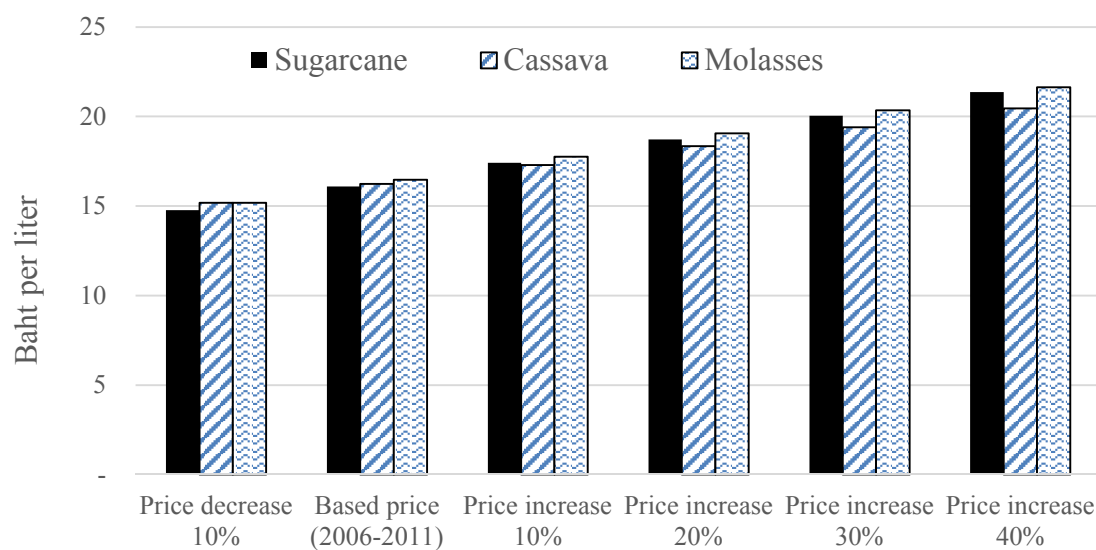


Figure 1.10 The total cost of ethanol production with uncertainty of all feedstock prices.

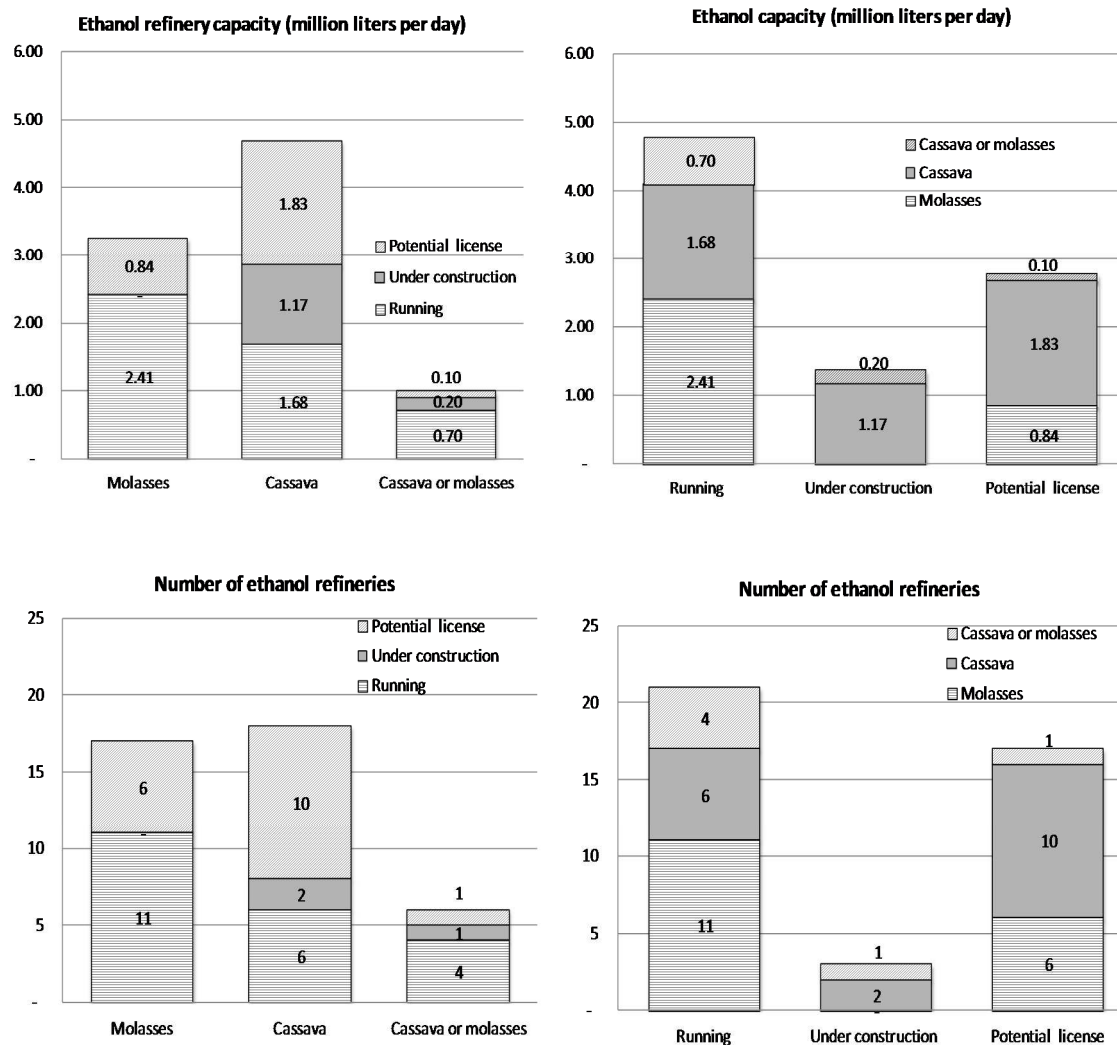
Furthermore, cassava provides more flexibility than sugarcane in term of harvesting, investment, and marketing. Cassava cultivation period is about eight to twelve months, while sugarcane cultivation period is more than twelve months per crop and three crops in each plantation. Cassava could be harvested any times all around year because of flexible market. On the other hand, there are only seven months for sugarcane harvesting period due to the cane sugar mills' running. Investment of cassava production is significantly lower than sugarcane. In 2011, the cassava cultivation cost was around 32,000 baht per hectare, while sugarcane cultivation cost, average of three rotations, was about 50,000 baht per hectare (Office of Agricultural Economics).

For marketing, cassava can be sold at any collecting centers, around the cultivation areas normally. On the other hand, sugarcane cultivation is generally under contract farming with cane sugar mills. Then the sugarcane product would be supplied for only the cane sugar mill with which farmers had signed the contract. Most of the cane sugar growers would not break the contract due to the fact that the cane sugar mills have a strong relationship with sugarcane growers by supporting loans, fertilizers, and herbicides (Piewthongngam et al., 2007). Moreover, Thai sugarcane price, set by the committee from sugar growers' association, sugar mills, and Thai government, is a function of cane sugar price. If the cane sugar mills can make more predicted profit, the additional sugarcane price will be more added up, called final price. So, the price of sugarcane for sugar should normally be higher than price of sugarcane for ethanol feedstock.

Based on data from Department of Alternative Energy Development and Efficiency and Department of Industrial Works, nameplate capacity of refineries that are either already running or under construction is 6.16 million liters per day. About 46 percent of this ethanol production

capacity will be from 10 new cassava ethanol refineries, while the remaining production is from 11 existing sugar-molasses ethanol refineries. In addition, 20 new ethanol refineries have been licensed for construction, mostly designated for using cassava as feedstock. Altogether, considering operating, pending, and licensed refineries, there is expected to be 41 refineries operating in Thailand by 2020, with a combined capacity of producing 8.93 million liters of ethanol per day. About 52 percent of this overall capacity will be derived from cassava and another 11 percent can utilize multiple feedstock, including either cassava or sugar molasses. It is expected that, at that point, more than half of Thai ethanol will be produced from cassava.

In a nutshell, even if the main ethanol feedstock in many countries is maize or sugarcane, the ethanol in Thailand would be mainly derived from cassava. As a result, cassava can provide lower feedstock cost and more flexible in term of procurement and cultivation than sugarcane.



Data source: (Department of Alternative Energy Development and Efficiency) and (Department of Industrial Works)

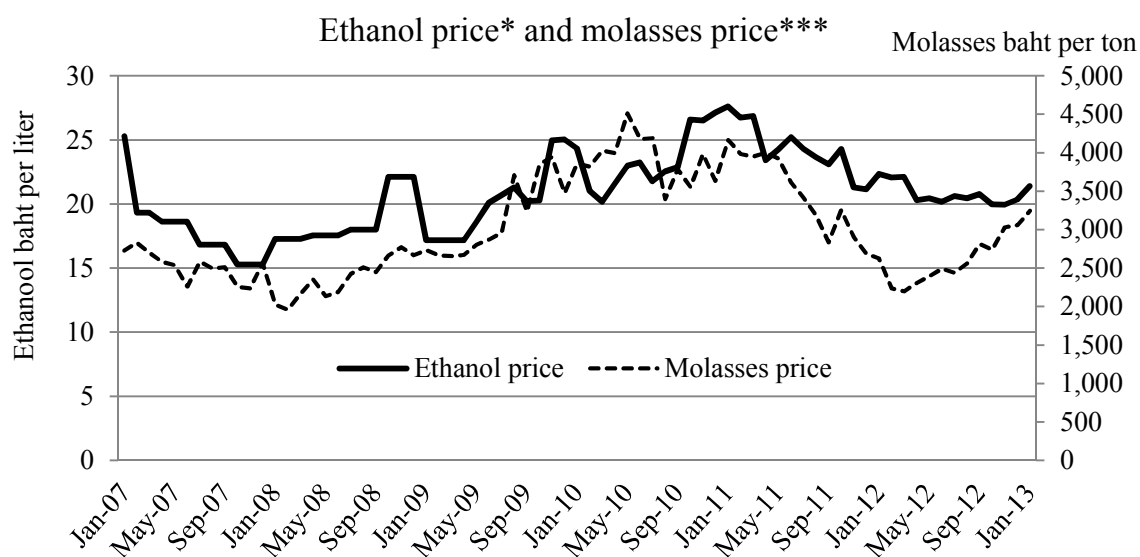
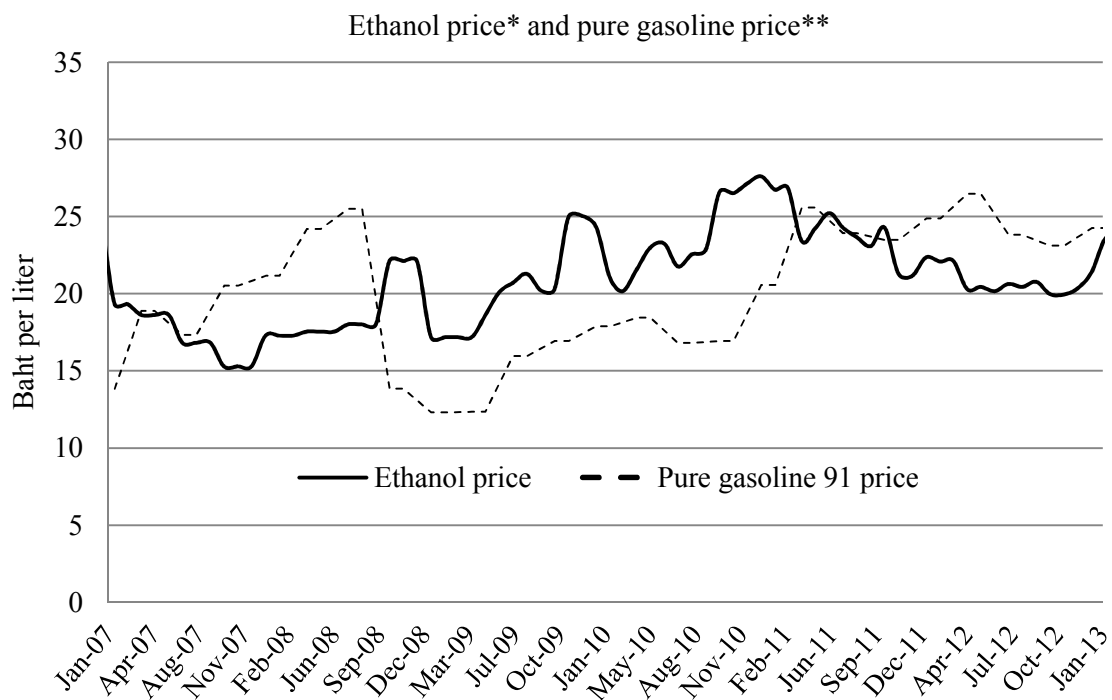
Figure 1.11 The number and capacity of ethanol refineries in Thailand in 2013, by feedstocks and operational status.

The price of ethanol in Thailand

The monthly reference ethanol price in Thailand is determined by the government's Energy Policy Committee (EPC), who endorses national energy policies and national energy management and development plans. The reference ethanol price is used for setting excise tax rates and the rate of subsidies from or contributions to the Thai energy fund; however, the real purchase ethanol price seen by consumers will typically differ from the reference price, largely based on costs of production for different feedstock types. Normally, production costs of ethanol from cassava is higher than from molasses (Bank of Thailand, 2012)

In 2007, the ethanol reference price was calculated by an import parity method, based on the Free On Board (FOB) Brazilian ethanol price, plus freight cost, insurance, and transaction costs. However, due to the lack of an FOB Brazilian ethanol price in 2009, the EPC set up a “cost plus” pricing mechanism to calculate an ethanol reference price for Thailand. This cost-plus method, based on a weighted average of ethanol production costs from molasses and cassava, has been used in Thailand since 2009. In 2012, the EPC set the relative weights of molasses and cassava ethanol at 62:38 in the pricing formula, partly due to the subsidy on cassava for ethanol production. The cassava price subsidy had been set at 2.75 to 2.90 baht per kilogram, compared to farm prices of about 1.75 to 2.02 baht per kilogram, with a target quantity target at 10 million tonnes of production during February to May in 2012 (Department of Internal Trade). However, actual ethanol production from molasses is higher than the planned share. Thus, the ethanol price weight at 62:38 inflated the ethanol reference price. In 2013, the EPC adjusted the calculation of the ethanol reference price based on the weights of real ethanol prices at the refinery (Energy Policy and Planning Office).

The ethanol price in Thailand has varied from about 15 to 29 baht per liter, while the pure gasoline (octane 91) price has varied from about 12 to 26 baht per liter (Figure 1.12). The pure gasoline price has fluctuated more than the ethanol price. In 2009 and 2010, the ethanol price was higher than the gasoline price, due to the fact that the gasoline price had sharply decreased while the molasses price increased. Moreover, ethanol prices are highly correlated with feedstock prices. As shown in Figure 1.12, the molasses price from 2008 to 2010 increased from 2,000 to 4,500 baht per ton, which in turn induced an ethanol price increase.



Data source: * (Department of Alternative Energy Development and Efficiency)

** (Energy Policy and Planning Office)

*** (Office of Agricultural Economics)

Figure 1.12 The ethanol, retail pure gasoline, and molasses price in Thailand, 2007-2012.

Thailand's ethanol policies

Having established an ethanol production target of 9 million liters per day by 2022, the Thai government has implemented a number of policies to promote ethanol supply as well as to expand consumer demand in Thailand. These include an excise tax exemption, an ethanol consumption subsidy, promotion of flexible fuel vehicles (FFVs) purchases with tax rebates, and a minimal ethanol blend requirement for all gasoline sold in Thailand.

First, while an ethanol excise tax is charged for beverage ethanol production, the excise tax is exempted for ethanol exported for energy uses. Second, the Thai energy fund is the main source for ethanol subsidies, under which the higher the share of blended ethanol, the higher the subsidy. For example, E85 is subsidized at about 11 baht per liter while conventional gasoline is charged about 7 baht per liter. This makes the conventional gasoline price two-fold higher than the E85 price. Moreover, there is a lower retail price on FFVs, due to reducing the automobile sales tax, also subsidized by the energy fund. Increase in the nation's FFV fleet is expected to increase overall ethanol consumption due to their ability to use E85.

Finally, the most impactful policy has been setting a minimal ethanol blend for gasoline. Ethanol has been an option to use as a fuel oxygenator, for air quality purposes, in place of Methyl Tertiary Butyl Ether (MTBE) which had been added to gasoline at 10 percent since 2003. E20 and E85 gasoline was introduced in 2008. Now, MTBE blended gasoline has been banned, and an ethanol blend of at least 10 percent is required in all gasoline for air quality purposes.

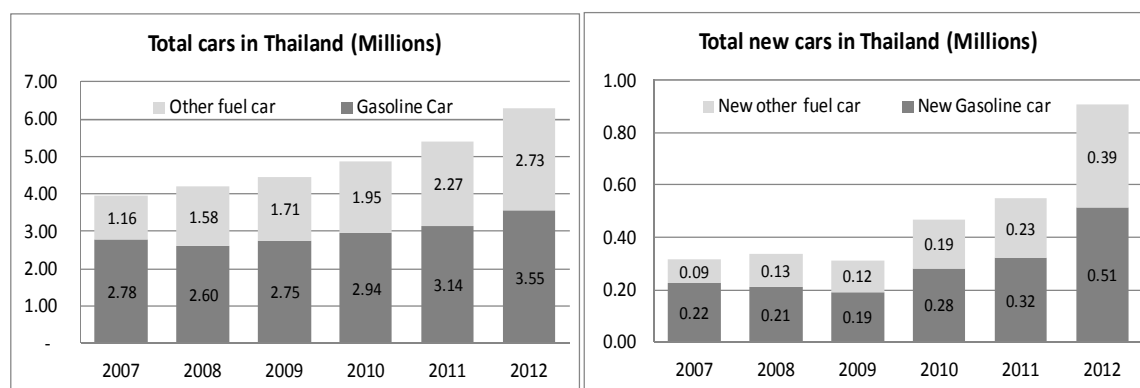
1.4 Forecasting the impact of the Thai government's ethanol target on cassava

To estimate of cassava demand, the ethanol demand and supply will be forecasted firstly, and then the ethanol feedstock requirement, cassava demand and acreage will be projected. Finally, the results of previous studies in Thailand will be compared to our results.

Forecasting domestic ethanol demand

While the Thai government has set an ethanol production target of 9 million liter per day by 2022, it is not immediately clear whether the Thai economy is even close to being capable of utilizing such a quantity of ethanol given the composition of the car fleet in Thailand. As a first look, ethanol demand was estimated based on reasonable assumptions about changes in the car fleet in Thailand.

First of all, the number of each type of gasoline-engine cars in Thailand was estimated. From 2007 to 2012, the total number of cars in Thailand grew from about 4 to 6.3 million, of which 60 to 70 percent had gasoline engines. This proportion was used to calculate new gasoline cars being introduced to the fleet at about 0.2 to 0.5 million cars per year.



Data source: (Department of Land Transport)

Figure 1.13 The total registered cars and new registered cars in Thailand, 2007-2012.

To calculate the cars in each gasoline type we designate:

G_t = Gasoline cars in year t

NG_t = New gasoline cars in year t

$E10_t$ = E10 gasoline cars in year t

$E20_t$ = E20 gasoline cars in year t

$E85_t$ = E85 gasoline cars in year t

In 2007, $E10_{2007}$ was given from G_{2007} . This year all cars were E10 gasoline cars because of the national standard, after 2007 all new cars sold in Thailand have been capable of using the E20 gasoline-ethanol blend.

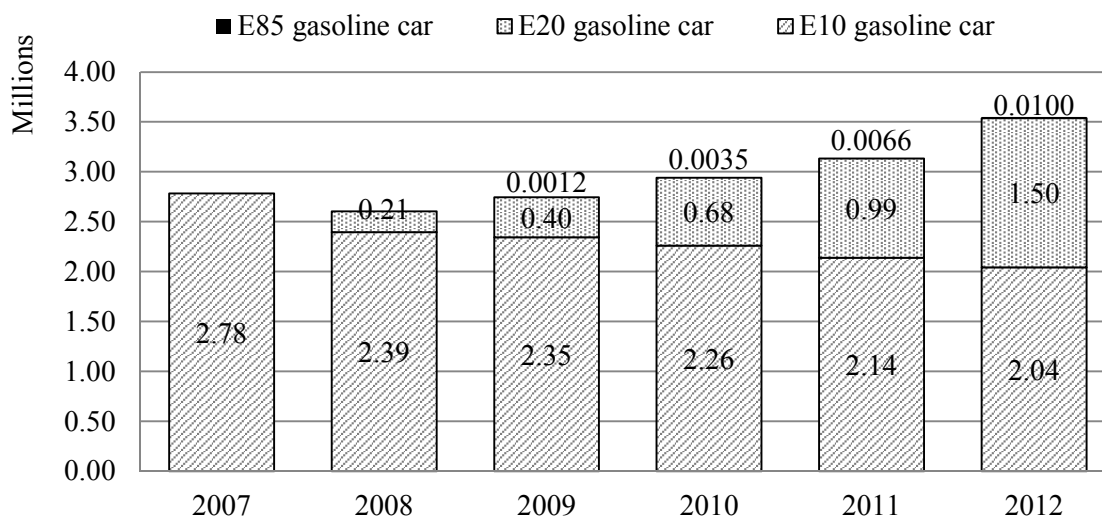
In 2008, there were no E85 (FFV) cars due to the car technology in Thailand. $E20_{2008}$ was given based on NG_{2008} . Then, $E10_{2008}$ was calculated from $G_{2008} - E20_{2008}$.

From 2009 to 2012, $E85_t$ numbers were given. $E20_t$ was calculated from $NG_t + E20_{t-1} - E85_t$. And, $E10_t$ was computed from $G_t - E20_t - E85_t$.

The projected number of cars capable of using each gasoline-ethanol blend are shown in Figure 1.14 below. E20 compatible cars significantly increased from 2008 to 2012. As well, the number of gasoline stations carrying E20 increased ten-fold from 2008 to 2013, while gasoline stations that carried E85 were very rare in 2008 and were still only 5 percent of all gasoline stations in Thailand in 2013.

Next the total car population growth rate, new car growth rate, and old car discharge rate were calculated. The total car population growth rate was estimated at 6.9 percent per year from data on cars from 1989 to 2012, while the new car introduction rate of 10 percent was computed

from data on gasoline cars. The difference of total car growth rate and new car introduction rate was the rate of old car discharge, at 3.1 percent.



Data source: (Department of Land Transport)

Figure 1.14 Numbers of gasoline-powered automobiles on the road in Thailand, by type of engine fuel compatibility 2007-2012

The third step is to estimate the number of each type of car likely to be introduced from 2013 to 2022. Five scenarios are run, with varied growth rate assumptions in each car type:

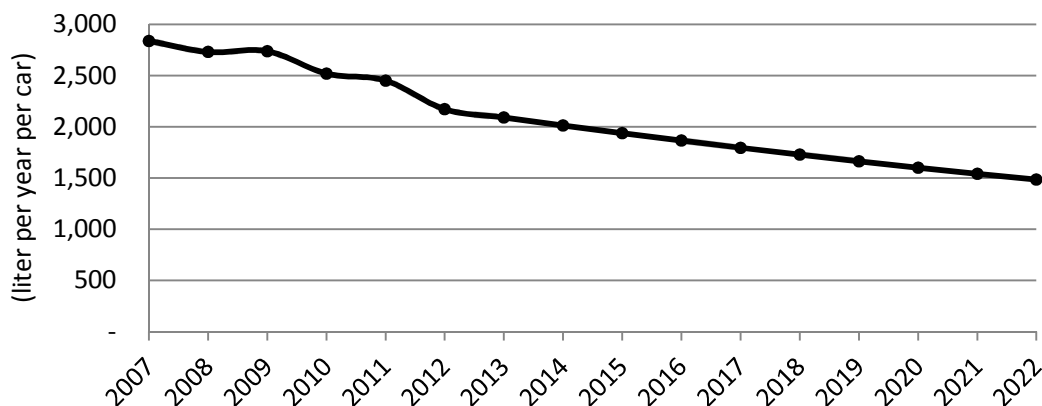
1. The lowest scenario assumes that all cars used only E10 gasoline and E10 gasoline cars make up the total increase of total car population per year.
2. The second to lowest scenario assumes that only new E10 gasoline cars contributed to the increase of 6.9 percent of total cars per year. The number of E20 and E85 cars are constant.
3. The mid-line scenario assumes that new cars were distributed between E20 and E85 gasoline car, while E10 gasoline cars were discharged at 3.1 percent. The E20 gasoline cars increased at 9.8 percent, while the E85 gasoline cars increased 0.2 percent. The distribution of

growth rate in E20 and E85 gasoline car was the proportion of E20 and E85 gasoline cars among all new cars in 2012.

4. The high scenario assumes that all new cars are either E20 or E85, while E10 gasoline car was discharged at 3.1 percent. E20 cars are assumed to increase at 8 percent, while the E85 cars are assumed to increase at 2 percent. The overall growth rate is still 6.9 percent.

5. The highest scenario assumes that all new cars are equally distributed between E20 and E85 compatible cars, while E10 gasoline car are discharged at a rate of 3.1 percent. Both E20 and E85 gasoline car increase at a rate of 5 percent (Department of Land Transport).

The forth step is to adjust the combustion rate of the car fleet to reflect the increasing fuel efficacy of newer model cars. The data of all gasoline cars and all gasoline consumption from 2007 to 2012 were used to estimate the combustion rate (fuel efficiency) in term of liter per year per car. The gasoline combustion rate in 2012 was about 2,200 liter per year per car, but was observed to decrease at the rate of 3.7 percent per year.



Data source: Calculate from (Department of Land Transport) and (Energy Policy and Planning Office)

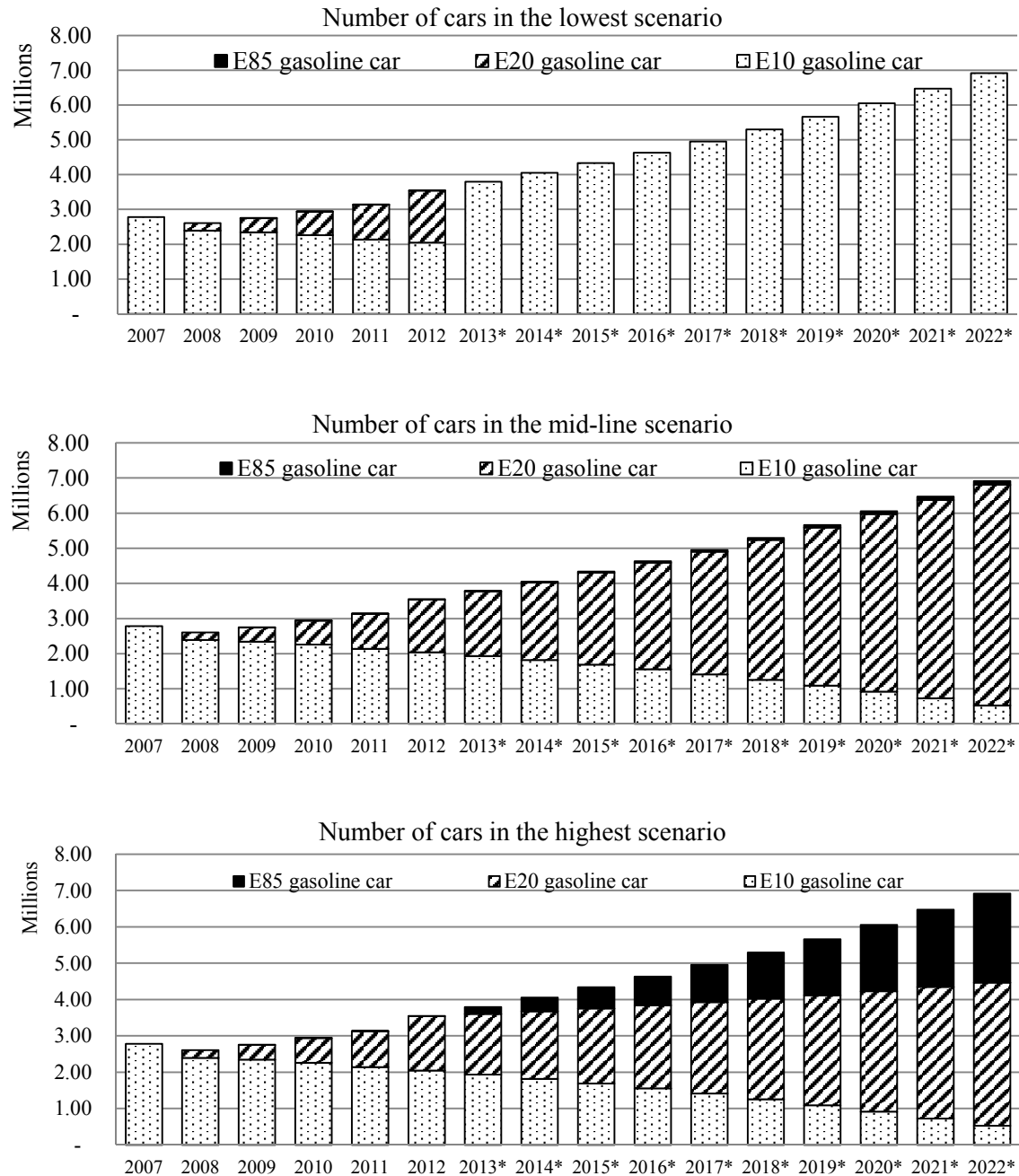
Figure 1.15 The improvement of average fuel efficiency of cars in Thailand.

Finally, the gasoline consumption in each car type and each year were calculated. The gasoline consumption was calculated from the number of cars time combustion rate with E10 gasoline as the base line. The utilization of E20 gasoline was adjusted by energy content at 97 percent of E10 gasoline. Similarly, E85 gasoline was adjusted by energy content at 74 percent of E10 gasoline. After that, ethanol consumption for each year was computed.

Results of this exercise show an increase of cars from 2.8 to 6.9 million from 2007 to 2022. All of the cars in 2022 are assumed to be E10 gasoline cars in the lowest scenario, while most of cars in 2022 are assumed to be E20 gasoline cars in the mid-line scenario. The highest scenario results in 57 percent of cars being E85 gasoline cars and 35 percent being E20 gasoline cars in 2022.

Across these different growth scenarios Thai cars are calculated to consume anywhere from 3.50 to 14.94 million liter per day of ethanol in 2022, compared to the Thai government's target at 9 million liters per day. In the medium high scenario, in which E20 gasoline cars are

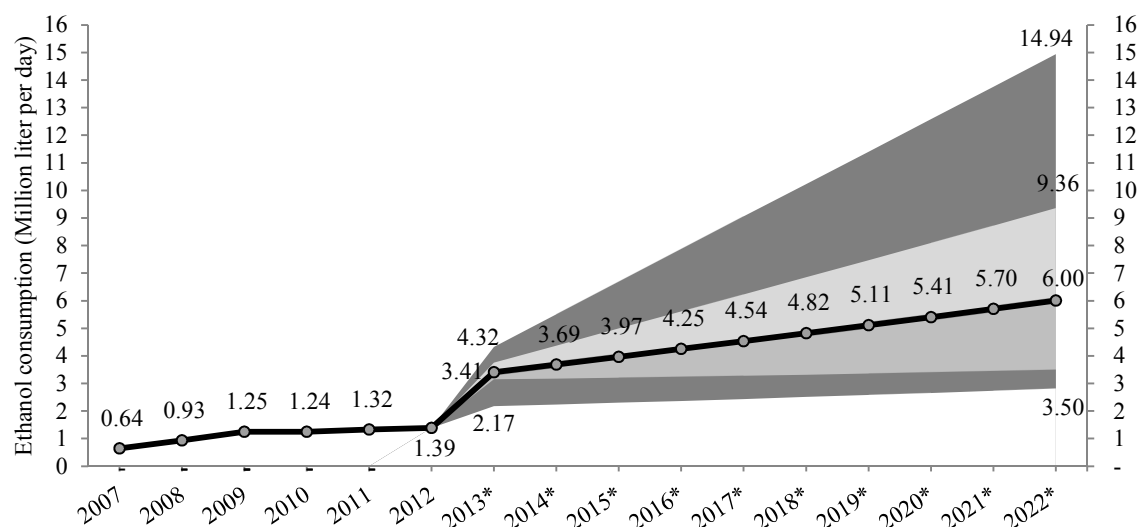
assumed to increase by 8 percent and E85 gasoline cars by 2 percent per year, Thailand would consume around 9.6 million ethanol liters per day. Meanwhile, in the mid-line scenario Thai cars would demand around 6 million liter of ethanol per day. At the low end, the scenario with new cars that are only E10 compatible consumes only 3.5 million liters of ethanol per day. The increase in the FFV fleet significantly impacts ethanol demand. The mid-line scenario, expanding the current proportion of E20 and E85 gasoline cars, results in domestic consumption of ethanol at 6 million liters per day. The remaining 3 million liters per day would have to be exported if the Thai government's production target is achieved.



Data source: (Department of Land Transport) for years 2007-2012

*annual values forecast by authors for years 2013-2022

Figure 1.16 Low, middle, and high demand scenarios for fuel ethanol in Thailand based on projected types of gasoline-engine automobiles and their respective fuel consumption



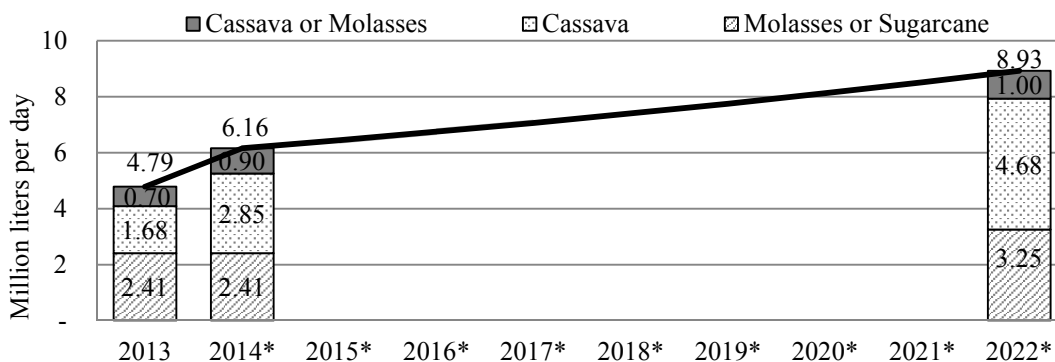
Data source: Calculate from (Department of Land Transport), (Department of Alternative Energy Development and Efficiency), and (Energy Policy and Planning Office)

** Annual values forecast by authors under varied scenarios for years 2013 through 2022*

Figure 1.17 Actual and forecasted range of domestic ethanol consumption in Thailand, based on four scenarios of future automobile numbers, gasoline-engine types, and ethanol blend utilization patterns

Forecasting ethanol supply

The supply of ethanol production can be forecast based on currently licensed refinery data. In 2013, there were 21 refineries with capacity of 4.79 million liters per day. Half is produced from molasses or sugarcane. In 2014, three more refineries will be added, with a capacity of 1.37 million liter per day from cassava or multiple feedstocks. Based on the remaining 17 ethanol refinery licenses, capacity could increase by an additional 2.77 million per day in the future. This assumes that the capacity linearly increases to 8.93 million liter per day in 2022.



Data source: (Department of Alternative Energy Development and Efficiency) and (Department of Industrial Works)

*forecast by authors

Figure 1.18 Total potential ethanol refinery production capacity in Thailand, 2013-2022

Forecasting feedstock requirements

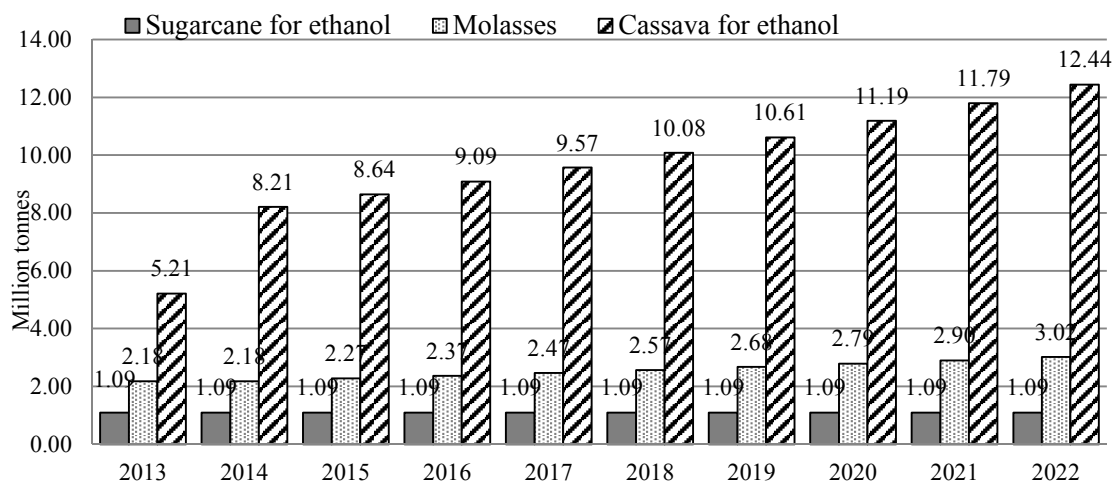
Cassava, non-food-grade sugarcane, and molasses, a byproduct from the Thai sugar refining industry, are expected to remain the main feedstock for ethanol production in Thailand for the foreseeable future. Cassava production in 2012 was about 29.4 million tonnes from an area of 1.38 million hectares, or about 21 tonnes per hectare. Of this, 0.51 million tonnes of cassava was used to produce 0.23 million liters per day of ethanol, while other domestic uses accounted for 7.4 million tonnes. The remaining 21.5 million tonnes of cassava were exported. 9.97 million tonnes of fresh cassava were converted into 2.24 million tonnes of starch for export. The remaining 11.50 million tonnes were export as cassava chips. If this exported chip was used to produce ethanol, it could produce an additional 5.25 million liters of ethanol per day, based on the current conversion factor of 166.7 liters of ethanol per ton of cassava (Silalertruksa and Gheewala, 2010).

Similarly, Thailand produced 98.4 million tonnes of sugarcane from 1.28 million hectares in 2012. Primarily it is just a byproduct of cane sugar production, molasses that is used as an

ethanol feedstock. Molasses production accounts for about 5 percent of the sugarcane. Thus, there was 4.92 million tonnes of molasses in 2012. About 2 million tonnes were used for liquor, animal feed, and export. The remaining 2.92 million tonnes of molasses could be refined to ethanol. With the conversion factor of 250 ethanol liters per ton of molasses (Silalertruksa and Gheewala, 2010), 2 million liters of ethanol per day could be produced.

Normally, all of the sugarcane harvest is reserved for cane sugar milling and sugar production. The only ethanol made directly from sugarcane is produced from sugarcane cultivated in areas with naturally-occurring cadmium contaminated soils. There were 0.63 million tons of sugarcane production in this area, all of which was used solely for ethanol production. With a sugarcane-ethanol conversion factor of 76.92 liters per ton (Silalertruksa and Gheewala, 2010), 0.14 million liters of ethanol per day could be produced.

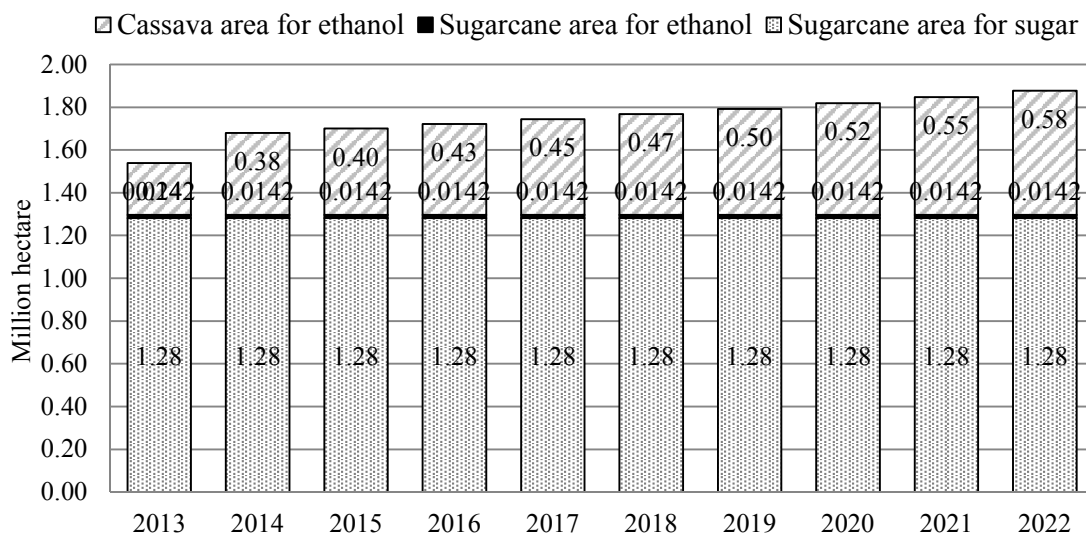
Based on the existing and forthcoming ethanol refineries' stated capacities, requirements of cassava, molasses, and sugarcane would be around 12.44, 3.02, and 1.09 million tonnes per year in 2022 respectively, assuming sugarcane production remains largely constrained to producing refined sugar for the sugar market.



Data source: annual values forecast by authors

Figure 1.19 Cassava and sugarcane demand for ethanol production

The area of sugarcane cultivated solely for ethanol production is only about 14,000 hectares, from the Measod region in northwest Thailand where naturally occurring cadmium content in the soils renders the sugarcane unfit for human consumption. Meanwhile, three million tonnes of molasses can be produced from current cane-sugar refining. So, the total area of sugarcane cultivation is constant at around 1.28 million hectares per year. The requirement of cassava cultivation area for ethanol production increased from 0.24 to 0.58 million hectares per year. The overall cultivation area related to ethanol feedstock is around 1.54 to 1.88 million hectares.



Data source: annual values forecast by authors

Figure 1.20 Land requirement of cassava and sugarcane for ethanol feedstock

Other studies estimate that demand for molasses, sugarcane, and cassava will increase to about 2.5, 4.2, and 13.2 million tonnes per year as the result of Thai government's target in 2022 (Silalertruksa and Gheewala, 2010).

To summarize, about 0.23 million liters per day of sugarcane ethanol can be made from about 1.09 million tonnes of cadmium tainted sugarcane production per year. Another 2.18 million liters per day of ethanol in the first two years and 3.02 million liters per day by 2022 will be made from molasses, utilizing virtually all molasses production, of about 3.02 tons by 2022. The rest of the demand for ethanol will be met by production from cassava, which will require from 5.21 to 12.44 million tonnes of cassava per year. The cassava would be more important than molasses or sugarcane because of many reasons. The cassava has more value added in term of domestic agricultural industry. Even if production of cassava-based ethanol per hectare is lower than sugarcane-based ethanol, the cost of cassava per liter of ethanol is lower. The cassava harvesting is more flexible than sugarcane. Moreover, the Thai government has paid an

important role in development of cassava sector, especially in term of biochemical and chemical engineering (Ubolsook, 2010). As the potential yield gap improvement and compatible with technology, cassava would be the main potential feedstock of ethanol in Thailand (Sriroth et al., 2010).

Forecasting total demand for cassava

Cassava is one of the most widely cultivated crops in Thailand. The main uses of cassava are for chip, pellets, starch, and ethanol feedstock. From 2006 to 2012, the average exported cassava was about 70 percent of total production, which consisted of starch, chips, and pellets. In term of fresh cassava tonnage requirements, starch and chip are the main export products. Meanwhile export demand for starch and chips have increased by 8 percent and 2.5 percent, respectively, over the last 16 years. Export demand for pellets decreased by 29 percent a year. Cassava domestic use was constant as well. The increase in cassava production has all been for exported starch and chips. Thus far, only 2 percent of cassava production has been utilized as ethanol feedstock due to the limitation of cassava ethanol refineries (Office of the Agricultural Futures Trading Commission, 2011).

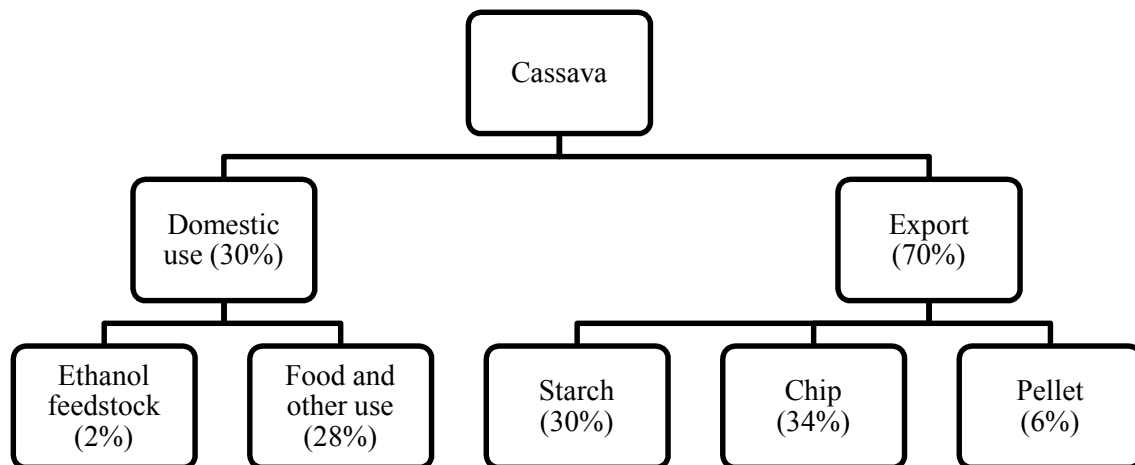


Figure 1.21 The proportions of cassava consumption in Thailand

In 2012, cassava production was 29.40 million tons. Around 21 million tonnes equivalent of fresh cassava was exported while 8 million tonnes equivalent of fresh cassava was used domestically (Office of Agricultural Economics).

(Ubolsook, 2010) (2010) estimates supply and demand of Thai cassava for ethanol feedstock and other uses, for both domestic and exported uses within a CGE model. The price elasticities of cassava for ethanol feedstock demand and other use demand, starch and animal feed, were quite low, -0.12 and -0.43 respectively. That means the increase in cassava price impacts cassava demand only slightly. Meanwhile, (Raweejarutrueang, 2010) (2010) studied the import demand of major trading countries for Thai cassava products, chips, unmodified starch, and modified starch, from 1996 to 2008. Over the five-year period from 2004-2008, about 90 percent of chips were exported to China in which price elasticity of demand was quite high, -4.09. Unmodified cassava starch accounted for about 56 percent of total starch exports, while modified starch was about 44 percent. From 2004-2008, 43 percent of the unmodified starch was exported to Taiwan where demand was quite inelastic, around -1.3. Another 39 percent of

unmodified starch was exported to China, which had greater demand elasticity, at about -4.53. About 74 percent of the modified starch was exported to Japan and Indonesia where demand was relatively inelastic, less than -0.67. The remaining 26 percent of modified starch was exported to China, again with greater price elasticity of demand, at -2.11. These results show that exported chips face fairly elastic demand, while exported cassava starch faces demand that is quite inelastic.

As domestic demand for cassava as an ethanol feedstock increases, this will drive up prices for cassava, which will have two effects. Higher prices will mean that some of the quantity demanded for other uses will decrease, depending upon the price elasticity of demand in each of those categories, which reflects, in part, the availability of close substitutes for each of those uses. Higher prices for cassava will also stimulate expansion of cassava production.

While a full analysis of likely adjustments requires consideration of the general equilibrium, at least within these segments of the Thai economy and its main trade partners, to consider the range of possible variation in cassava demand, we run four scenarios, in which we vary assumptions about changes in cassava exports and sources of cassava feedstock:

1. In the “Low” scenario it is assumed that price elasticity of exported starch and domestic food uses is relatively low, and thus quantity demanded will remain constant, with however a levelling off of recent growth in these segments. In contrast, price elasticity of exported chips is assumed to be quite high, since demand for them has been quite volatile over recent years. Thus, in this scenario cassava chip exports are readily transferred to domestic use for ethanol feedstock, due to the higher value added of this use of the agricultural product. It is also assumed that price elasticity of exported pellets is relatively high, such that the quantity exported will decreased by 30 percent per year.

2. Next, in the “Mid-low” scenario or the base-line scenarios, it is assumed that price elasticity for domestic food uses is relatively low (as in the previous scenario), and therefore remains constant, while the price elasticity of demand for exported chips is again assumed to be high, such that they are transferred to domestic ethanol feedstock. While, again, high price elasticity of demand for exported pellet means they decrease by 30percent. The one difference is that price elasticity of demand for exported starch is assumed to be lower, and those exports continue to increase at their recent rate of 8 percent per year.

3. Then, in the “Mid-high” scenario, the price elasticity of domestic food use, exported pellet, and exported starch are assumed to be relatively low and quantities remain relatively constant. The price elasticity of exported chips is assumed to be lower than in the previous scenarios and therefore quantities exported are expected to increase by 2.5 percent instead of being transferred to domestic use for ethanol feedstock.

4. Finally, the “High” scenario results in the highest level of aggregate cassava demand. In this scenario price elasticities for all current uses are assumed to be relatively low, such that quantities of domestic food use and exported pellets are expected to remain constant, while quantities of exported starch and exported chips are expected to increase by 8 percent and 2.5 percent respectively.

Based on the data of elasticities, the most likely scenario is under the Mid-low scenario. If domestic food use remains relatively constant, the quantity exported as pellet decreases, the quantity exported as starch increases, and the quantity exported as chip is transferred to domestic use for ethanol feedstock, the resulting increase in new demand for cassava feedstock for ethanol will drive total fresh cassava demand up from 29.4 to 41.38 million tonnes in 2022. Assuming

cassava yields remain constant at 21.48 tonnes per hectare, the area of cassava cultivation will need to expand to around 1.94 million hectares in 2022, an increase of 0.56 million hectares.

Examining the range of demand scenarios the possible demand for cassava ranges from 29.83 to 56.05 million tonnes in 2022. The mid-line scenario, in which higher price elasticity of cassava chip exports means they are transferred to domestic use as ethanol feedstock and the low price elasticity of starch exports means they are increased by 8 per year along current trends, resulted in a total cassava demand of around 41 million tonnes in 2022. This increase in cassava demand, interestingly, was mostly from exported starch, not from ethanol. The highest scenario for cassava demand was around 56 million tonnes, in which demand for exported chips and starch both increased and any demand for ethanol feedstock needed to be added on top of other already existing uses.

With cassava yield calculated at 21.37 tonnes per hectare, the average yield in Thailand seven years ago, the cultivation area would be from 1.40 to 2.62 million hectare in 2022. In the mid-line demand scenario, the cultivation area increased to 1.94 million hectare, increasing by 0.56 million hectare. However, considering that yield improvements in Thai cassava cultivation since 1992 have averaged at 2.4 percent per year (Food and Agriculture Organization of the United Nations). If this rate of yield improvement is continued to 2022, the cassava cultivation area will be smaller, ranging from 1.10 to 2.07 million hectares. The midline forecasted area increase will be only from 0.15 to 0.698 million hectares.

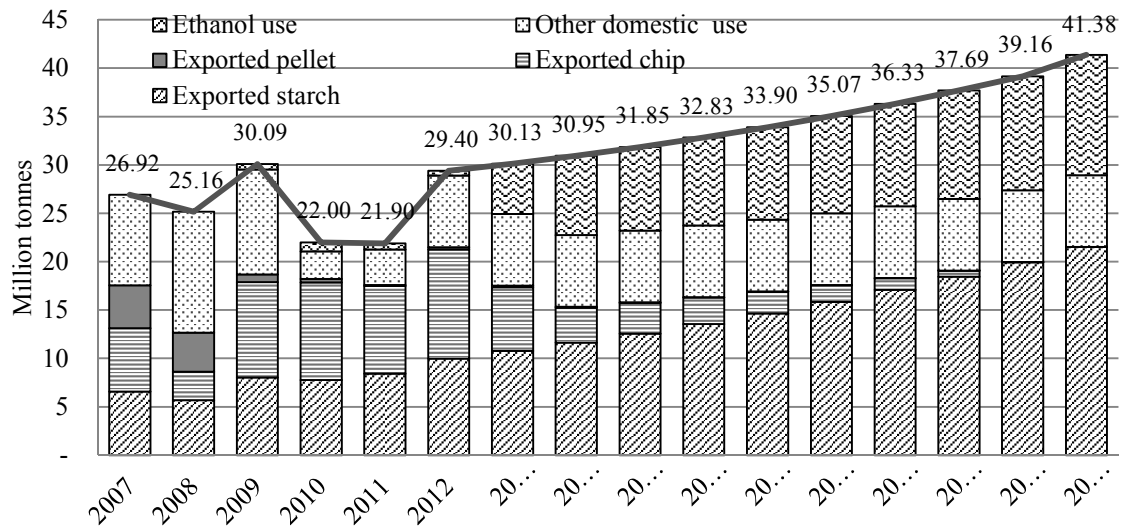


Figure 1.22 Actual and baseline forecast of quantities of cassava demanded (in millions of tonnes), assuming non-ethanol utilization of cassava remains at current (2012) levels while utilization for ethanol grows according to midline forecasts

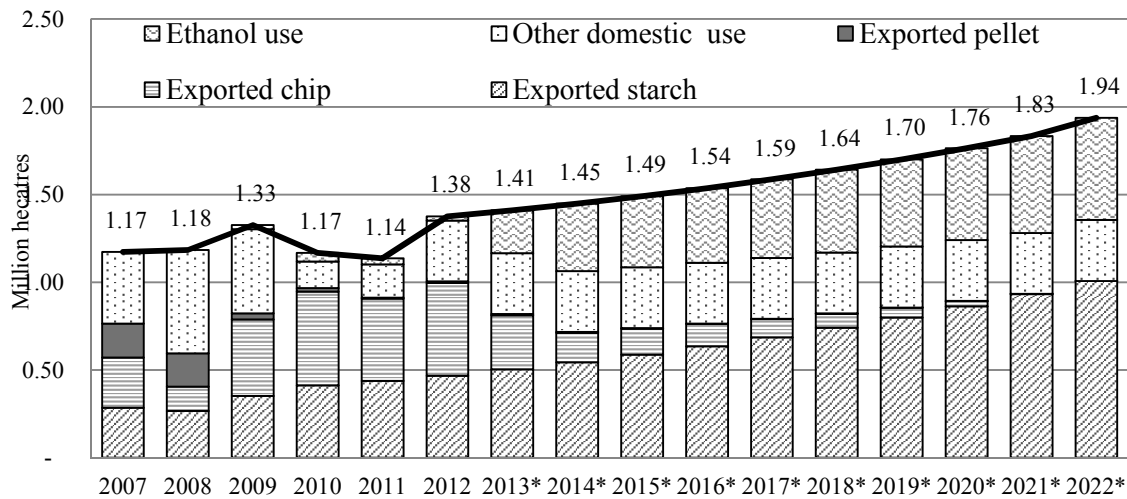
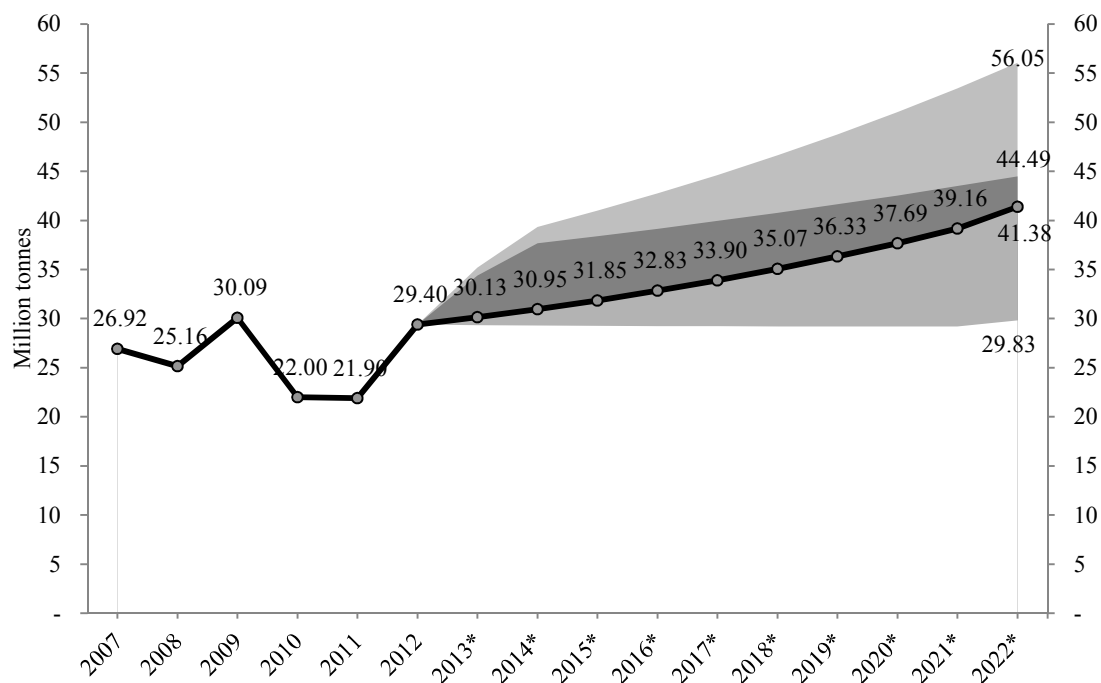


Figure 1.23 Actual and baseline forecast of land requirements for cassava cultivation based on baseline demand forecast illustrated in Figure 1.22, assuming cassava yields remain constant at current (2012) levels

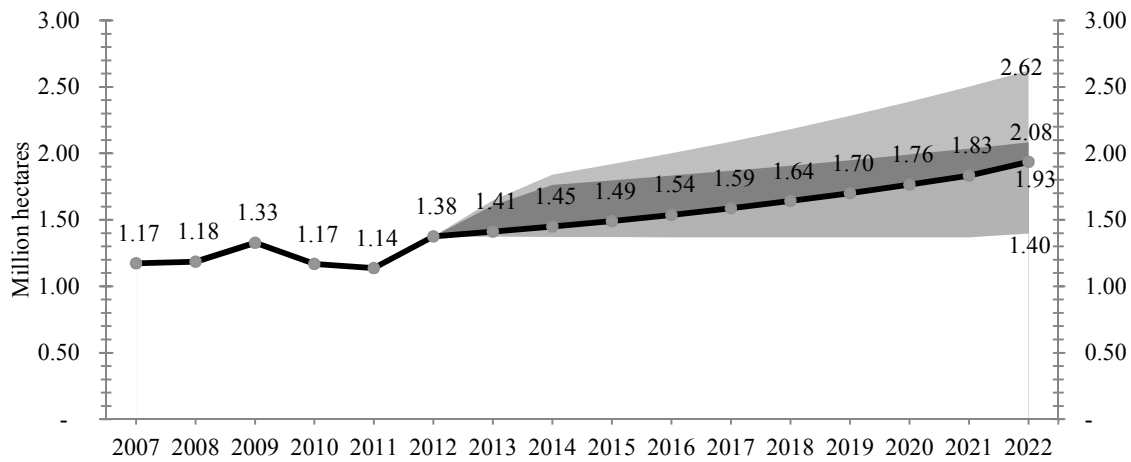


Data source: (Office of Agricultural Economics), (Department of Alternative Energy Development and Efficiency) and (Department of Industrial Works)

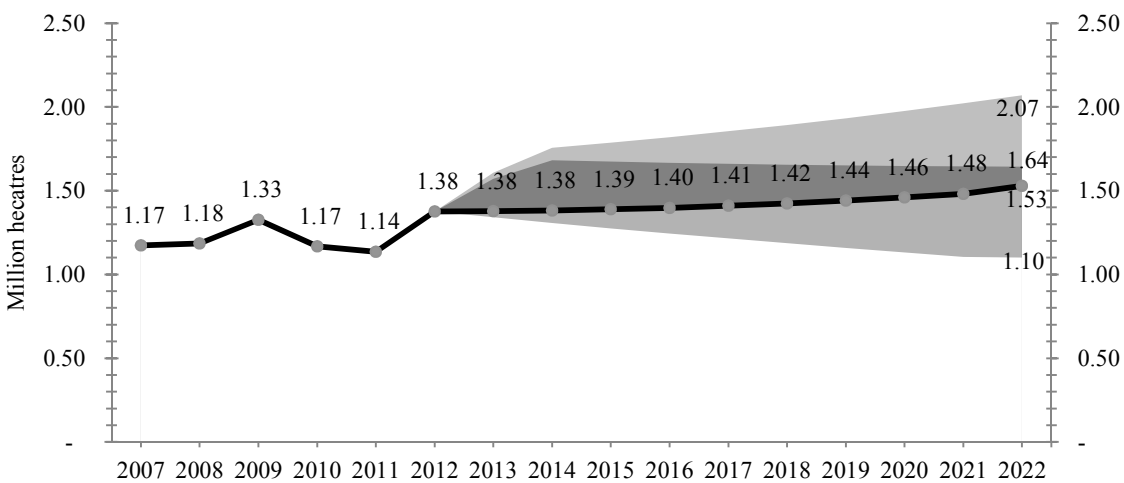
* estimated annual values by authors, based upon the scenarios

Figure 1.24 Actual and forecasted range of cassava quantity demanded (in millions of tonnes) under varied scenarios.

Panel a:



Panel b:



Data source: (Office of Agricultural Economics), (Department of Alternative Energy Development and Efficiency) and (Department of Industrial Works)

* estimated annual values by authors, based upon the scenarios

Figure 1.25 Actual and forecasted range of land requirements for cassava cultivation in Thailand under varied scenarios of demand, without yield improvements (panel a) and with annual yield improvements of 2.4 percent (panel b)

Summary of forecasts

In summary, ethanol consumption, based on estimated changes in the Thai car fleet in the next nine years demonstrates the feasibility of domestic ethanol demand increasing to 9 million liters per day. The level of adoption of flexible fuel vehicles (FFVs) which can utilize the E85 blend, is the main factor that will determine growth in domestic ethanol use. The high demand scenario, which assumed a proportion of new E20 and E85 gasoline cars entering the national fleet at 80 percent and 20 percent respectively, could create demand for ethanol of around 9.36 million liter per day. However, availability of E85 gasoline, which today is only offered at about 5 percent of gasoline stations in Thailand, would need to be widely expanded at the same time. In the mid-line scenario, without such FFV promotion, it is estimated that ethanol demand could reach 6 million liters per day. As a result, ethanol exports would have to account for the remaining 3 million liters of ethanol production per day.

Currently, name-plate capacity of existing Thai ethanol plants is 4.79 million liter per day. The Thai government's ethanol target at 6.2 million liters per day in 2012-2016 and the eventual target of 9 million liters per day in 2016-2022 is therefore possible in terms of economic and technical capacity. However, current ethanol production, at 2.2 million liters per day, is far below the current target, mostly due to the shortage in domestic demand. This is largely due to the composition of engine-fuel compatibilities of the national stock of automobiles on the road in Thailand.

Cassava is expected to be the main source of growth for ethanol feedstock in the future. Sugarcane will continue to have higher-value uses in being processed for cane sugar, and other crops, such as maize, are likely to lag behind cassava in terms of resource productivity and profitability. Increase in demand for cassava for ethanol feedstock is expected to decrease

exported cassava chips. In the mid-line scenario, the total cassava demand was forecasted at around 41 million tonnes and cassava for sole ethanol feedstock is around 12.44 million tonnes in 2022. This amount of cassava requires 1.94 million hectares of cultivation area, given current yields and productivity. Comparing to the previous studies based on the Thai government's ethanol target at 9 million per day, (Ubolsook, 2010) found that the expected cassava-based ethanol is 5.4 million liter per day in 2017-2023. Overall cassava demand for both ethanol feedstock and other uses, is about 39 million tonnes in 2019. The cassava demand for sole ethanol feedstock is about 11.61 million tonnes, and the cassava acreage increases from 1.23 to 2.26 million hectares in 2010 to 2019. Moreover, (Wianwiwat and Asafu-Adjaye, 2013) found that overall cassava demand and acreage increase about 50 percent of current amounts, increasing from 29.4 to 44 million tonnes and from 1.38 to 2.06 million hectares in the long term. Our cassava demand result, 41 million tonnes, was in the range of previous studies, from 39 to 44 million tonnes. Meanwhile, our cassava acreage requirement, 1.94 million hectares, is slightly lower than the previous studies, 2.26 and 2.06 million hectares.

With currently a total of 5 million hectares of total crop cultivation area, the resulting increase in cassava cultivation land requirements will either alter other crop areas or put increased pressures on the environment. However, cassava yield improvement, as if continued at recent rates of around 2.4 percent per year, will reduce cassava land use from 1.94 to 1.53 million hectares for the same cassava supply.

1.5 Ethanol stakeholder groups in Thailand

A political economy or ‘public choice’ approach to policy analysis typically views a governmental policy as being advocated or pressured by those stakeholder groups within society who seek to maintain their maximal well-being. Taxes and subsidies that alter interest groups’ well-being are determined by those groups’ political influence (Becker, 1983). So, it is important to consider the contribution of those stakeholder groups affecting the Thai government ethanol policy. The promotion of bioenergy industry in Thailand directly impacts on both the ethanol and the oil industry. The players in ethanol production can be expected to benefit while the players in oil industry might lose some benefits.

Ethanol stakeholder groups can also be divided into the supply and demand side. On the supply side, the main stakeholders who benefit from ethanol promoting policies are cassava farmers, cassava bio-refineries, and the sugar industry because increases in ethanol demand raises their welfare. On the other hand, the main stakeholders who might be disadvantage from ethanol legislations are petroleum companies since increase in bioenergy production could reduce the price for gasoline. However, such effects are not entirely clear, and increase in biofuels might raise gasoline consumption, as well, depending upon governmental policies (De Gorter and Just, 2009).

The Thai government promotes biofuels for the purpose of energy security, improving the trade balance, improving the domestic economy, creating jobs in the agricultural sector, and improving farmers’ income (Zhou and Thomson, 2009). Based on the Thai government’s target, 25 percent of total energy consumption in 2022 should be from renewable energy (Kumar et al., 2013). While bioenergy promotion can increase demand for both ethanol and conventional gasoline, the welfare of oil-importing countries is estimated to increase by 2.9 to 4.1 percent

(Hochman et al., 2010). So, the Thai government has strong reasons to support the domestic bioenergy industry, but the composition of policy measures taken might depend on pressure from stakeholders.

Thai farmers can be expected to benefit from feedstock demand and crop price increases. In 2012, the Thai population was 64 million. About 13.5 percent of the total population are sugarcane and cassava growers (Office of Agricultural Economics). These farmers pay an important political role in voting. They also establish powerful farmer institutions, such as the North Eastern Tapioca Trade Association (NETTA), the Thai Tapioca Trade Association, and the Cane and Sugar Board. Low agricultural commodity prices, especially for cassava and paddy rice, have made big trouble for successive Thai governments. Thus, any increase in crop prices could secure votes from a large population of supporters.

The bio-refineries stand to benefit directly from ethanol subsidies and other policies to stimulate demand. The total of 41 ethanol plants, either operating, under construction, or under license, can produce about 9 million liters of ethanol per day. Definitely, an increase in demand for ethanol will increase the economic welfare of these bio-refineries. And generally, when size of a stakeholder group (such as this set of biorefiners) is relatively small relative to the number of taxpayers, the more concentrated interest group are often more politically successful, for example, the case of farmers and farmer associations in developed countries (Becker, 1983).

The consuming public do benefit from policies to promote ethanol promotion if ethanol production costs are comparable to conventional gasoline. The volatility of gasoline prices cause economic problems that ultimately increase the public's costs of living. In the long term, the

domestically produced alternative energy could reduce the impact of gasoline price fluctuations on the Thai economy.¹

It is expected that petroleum companies might lose benefit because of the ethanol substitution and loss of market share, at least in the pre-refinery segment of the petroleum value chain. In 2010, most of crude oil, 80 percent of the total, was imported from middle-eastern countries. Only 20 percent, about 150,000 barrels per day, was extracted domestically in Thailand. So, in fact, ethanol production might not adversely affect the petroleum extracting companies, but might only reduce oil importing activities. Moreover, the main oil production company in Thailand belongs to the PTT Group in which the Ministry of Finance holds 51 percent of the shares. Downstream, the oil refineries and fuel retailers might lose some benefits because of lower gasoline consumption. In 2010, the seven refineries produced about 960,000 barrels of fuel per day. About 19.30 million liter of pure gasoline and 1.24 of pure ethanol were sold. It is expected that a share of pure gasoline consumption would be replaced when the level of ethanol production reaches 9 million liters per day.

1.6 Conclusion and discussion

Increases in ethanol production and consumption in Thailand, based on the Thai government target set at 9 million liters per day, we conclude ultimately are economically and politically feasible. The current strategies of the Thai government to promote ethanol consumption include setting a minimal ethanol blend and maintaining a difference between the

¹ However, the increase in biofuel production could, under some policy scenarios, induce more gasoline consumption. If gasoline combustion increases, that will create more GHG emissions and energy dependency. See DeGorter and Just (2009) and Hochman, Rajagopal, & Zilberman (2010).

retail price of pure gasoline and the retail price of higher ethanol blends. The Thai energy fund, with its assessments and subsidies, and excise taxes are the main tools for retail price regulation.

Forecasted domestic ethanol consumption in Thailand ranges from 3.50 to 14.94 million liters per day. The number of FFVs on the road in Thailand significantly impacts ethanol demand. The current proportion of E20 and E85 compatible cars, which characterizes the mid-line scenario, could domestically consume ethanol at 6 million liters per day. The remaining 3 million liters per day, if the Thai government's production target of 9 million liters per day is achieved, would have to be exported. The domestic consumption of 9 million liters per day is economically possible if expansion of the FFV fleet and the prevalence of E85 stations is encouraged.

Domestic ethanol production capacity, based on currently licensed refineries would be about 9 million liters per day by 2022. Cassava is expected to be the major ethanol feedstock, with refining capacity at 4.68 million liters per day. Meanwhile, molasses and sugarcane feedstock demand is expected to remain stable at current levels. Cassava demanded for ethanol could increase to 12.44 million tonnes per year, requiring cassava cultivation on an additional 0.58 million hectares. Moreover, from these scenarios, possible cassava demand for all purposes--including exported starch, exported chips, and domestic food use--could range from 29.83 to as high as 56.05 million tonnes in 2022. Based on average yields reported in 2007, cassava cultivation area would need to be from 1.40 to 2.62 million hectares, increasing 0.02 to 1.24 million hectares from the current area. However, cassava yield improvement at the recent rates of 2.4 percent per year could even reduce cassava areas from current levels or would at least limit expansion of cassava areas to no more than 0.69 million additional hectares.

The main political stakeholder groups expected to benefit from ethanol promotion policies are farmers, bio-refineries (including the sugar industry), and the consuming public, while petroleum companies may be disadvantaged, at least in the downstream blending, distributing, and retailing segments of the oil industry. The Thai government, however, plays an important role from upstream to downstream in the petroleum industry, largely through its controlling interest in the PTT Group Company. Therefore, the ethanol promotion policies should be politically feasible due to the benefits on public and related industries. Even though the oil industry may be disadvantaged, the Thai government, who authorizes access to this industry, could get more benefit from other sectors.

The goals used to justify promotion of ethanol are to increase energy dependency, reduce GHG emissions, and support rural incomes. However, if massive expansion in ethanol production requires significant increases in cassava cultivation, an additional outcome could be alterations in the environment and reductions in biodiversity due to an increase in acreages, cropping intensity increases, cropping pattern changes, and even land use changes. A significant increase in feedstock demand could increase food prices, if there are price pressures to switch land from food production to energy feedstock production. As well, price subsidies on ethanol blended gasoline could induce more oil consumption thereby reducing oil dependency and increasing GHG emissions. Thus, impact of the Thai government's ethanol target should be more intensively considered to the topics of food security, cropping patterns and land use change, environment impacts, and biodiversity reduction.

In a nutshell, the Thai ethanol target at 9 million liters per day in 2022 could be economically and politically feasible. The Thai government plays an important role in transportation energy markets and has set an aggressive set of ethanol policies. The promotion of

FFVs and E85 gasoline stations could be an important strategy to increase ethanol demand. The ethanol supply is concomitant increase in demand for cassava feedstock as well as cassava acreages. While cassava yield improvements will reduce the extra land use requirements, it is unclear to what extent the government's ethanol policies will impact food security, land use change, and environmental impacts.

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Chapter 2. Cropping and land use changes likely to result from increased demand for cassava feedstock under the Thai government's ethanol policy

2.1 Introduction

The Thai government has enacted the national ethanol target of 9 million liters per day by 2022. To produce that quantity of ethanol, it is expected that demand for cassava as the primary feedstock will grow significantly. Some studies have estimated that, by 2022, cassava demand and cultivation area in Thailand could increase almost two-fold from current levels (Ubolsook, 2010; Wianwiwat and Asafu-Adjaye, 2013). Such predictions fuel concerns that competition between food and energy crops, given limitations of natural resources, will become an increasingly intractable problem (Godfray et al., 2010).

To investigate the impact of ethanol mandate policies on economic development and food security, a number of studies have estimated the reallocation of land use at a national level using economic model such as computable general equilibrium (CGE) (Chen et al., 2011; Evans, 2012; Golub and Hertel, 2012; Keeney and Hertel, 2009; Khanna and Zilberman, 2012; Villoria and Hertel, 2011). The CGE model has play a important role in implementation of a policy decision providing global economic impacts. However, the method have substantial data requirements at the national level in terms of interaction among global price, global quantity and high-quality social accounting matrixes. The models also strongly rely on assumptions, complex processes, and special program. The results provide only impact of global interaction on economy and national level of land-use change, while this study focuses on the impacts of the policy combining with economics and environmental factors on regional or spatial land-use change that CGE model could not solve.

Other economic studies have used a partial equilibrium (PE) model considering both economic factors and environmental impacts (Schmitz et al., 2014). Moreover, an alternative method emphasizes regional level analysis of land use change considers Geographic Information Systems (GIS) –based spatial data on land attributes, topology, transportation cost, feedstock demand, and other economic variables, albeit at constant prices (Das et al., 2012; Graham et al., 2000; Husain et al., 1998). This method required less data and provides concrete results at a regional scale. Moreover, strategies to deal with agricultural production shortages, including the closing of yield gaps, increasing production limits, and reducing waste could dramatically increase agricultural supply in some crops or regions (Godfray et al., 2010). Modern techniques of geospatial data analysis have improved ability to track yield improvements at multiple scales (Foley et al., 2011).

A number of policy strategies have been recommended to deal with tradeoffs at the national scale between bioenergy production and food security, including creating zoning maps, setting an appropriate production scale, standardizing biofuel production, and supporting suitable demand side policies. Multi-criteria analysis and GIS are useful tools to support such strategies for reducing yield gaps as well as managing cropping and land use decisions (Phalan, 2009). Many studies have assigned land use and cultivation patterns for biofuel feedstock production as well as environmental impacts using biophysical and economic factors such as transportation costs and crops' profitability, again all using spatial data (Zhang et al., 2010).

In Thailand, the most significant strategies to achieve the Thai government's ethanol target have been recommendations to improve cassava yields and increase sugarcane areas (Silalertruksa et al., 2009). However, a regional or national scale analysis of land use and crop allocation from the impact of ethanol target has not been undertaken. Chapter 1 concluded that

the vast majority of the increase in ethanol production required to meet the Thai government's target of producing 9 million liters of ethanol by 2022 would be met by expansion of cassava production (rather than sugarcane or other crops). Chapter 1 provided estimates of the mandate's impact on cassava feedstock demand. This study investigates the potential reallocation of cassava cultivation area under that growth in demand, considering the geographic location of ethanol biorefineries, each refinery's specific cassava demand based on its capacity, and realistic GIS-based data on current cropping and land use patterns, as well as soil type and climate-based estimates of land suitability for cassava cultivation. The results represent a realistic possibility for cropping changes of cassava and other major crops in Thailand. Direct land-use changes between cropping and nonagricultural uses are examined as well as tradeoffs between cultivation of food and energy crops.

This chapter is organized as follows. The next section provides a review of the literature. The third section introduces the methodology developed for this study. Then, the fourth section shows the sources of data. Section five provides the results, and the final section discusses the results and limitations of this study.

2.2 Literature Review

This study follows upon an emerging literature utilizing spatially explicit data at a grid-cell or plot level to optimize allocations of cropping patterns and acreages or to estimate impacts of policy changes on such cropping and land use patterns. For example, GIS-based data of production, transportation cost minimization, and alternative land-use competition were utilized to identify the best locations for producing biomass energy products in Minnesota (Husain et al., 1998). GIS and optimization models were used to calculate areas of energy crop cultivation and the location of ethanol biorefineries, considering transportation costs, in the state of Tennessee (Graham et al., 2000). That analysis considered current crop profits, energy crop cultivation costs, and yields in each 1-km² grid cell across the entire state. Switchgrass and willow were considered as the potential energy crops. The distance from farm to biorefinery, cost of transportation, and location of the biorefinery were each computed. The results of the model assigned cultivation of energy crops in each grid cell within the state. Similarly, multi-objective optimization models and GIS were used to recommend land use and cultivation patterns for biofuel feedstock production in southwest Michigan (Zhang et al., 2010). A spatially explicit iterative modeling framework (SEIMF), including GIS, a biophysical and biochemical process model, and a multi-objective optimization model, were utilized to estimate the environmental impact of biofuel crop expansion scenarios.

Such methods have also been used to allocate different land parcels to different types of use—including urban settlements, forests, food crop cultivation, and energy crop cultivation—in India (Das et al., 2012). A “suitability” score, which considers both biophysical and economic factors, is calculated for each land-use type in every 2 km² cell on the map grid. Biophysical factors considered for each grid cell include climate, soil attributes, and topography. The

economic factors considered for energy crop cultivation include distance from each grid cell to the nearest biorefinery and the profit margin for each crop. Land use in each grid cell is reallocated based on a combination of that cell's suitability score and the demand for energy feedstock by nearby biorefineries. These methods provide an estimated reallocation of areas for energy feedstock and food cultivation based on a combination of agronomic suitability and distance.

2.3 Data and Methods

This study follows the literature of GIS-based optimization models. This study focuses on parcel-level patterns of cropping and land-use changes necessary in order to meet both ethanol-feedstock, food, and animal feed demand for cassava while. This study computed GIS-based suitability areas for cassava have been obtained from the Thai governmental departments, included polygon of agronomic suitability for cassava cultivation area, other major crops' current land-use tracking land-use change every double years from 2006 - 2012 in ration of 1:25,000, road connection in the whole country, soil attributes including soil types and other significant attributes such slope and flooding, precipitation levels, and areas' size (Land Development Department, 2010). Meanwhile, the ethanol refineries included data of locations, feedstock types, production capacity, and running status obtained from (Department of Industrial Works; Ministry of Energy, 2009).

Using estimates of the profitability of cultivating cassava, based on the detailed ranking of suitability for cassava cultivation by individual land parcel, this analysis projects a reallocation of cassava cultivation in Thailand in order to meet the Thai government's production target of 9 million liters of ethanol per day.

This section outlines the steps taken to make that reallocation of land. The following section introduces the results of the analysis. It should be noted that, given the large number of variables involved, it is not possible to evaluate any sort of optimal land use allocation. The most accurate way to describe this analysis is that it projects a reasonable scenario indicating what magnitude of impact the Thai government's ethanol production target is likely to have on cropping patterns and land use changes within Thailand.

It is important to note that, while according to projections in chapter 1 it will take until 2022 for new cultivation requirements to be realized in a gradual manner, the analysis in this chapter simplifies the change in cultivation areas in a single reallocation from “before” to “after”, shifting from the current cropping and land-use pattern observed circa 2013, to a new pattern projected to meet full feedstock demand under the ethanol production target while also maintaining cassava production for projected domestic food and feed as well as export demand under adjusted prices.

a. Projected demand for cassava under the ethanol mandate

Given increased demand for ethanol feedstock, Chapter 1 projects the Thai cassava market would reach an equilibrium quantity, after adjusting for substitution and trade effects, at 41.38 million tonnes of cassava per year, compared to current estimated production of about 39 million tonnes. It is reasonable to expect that the portion of demand coming from the ethanol market is likely to remain quite stable, at 12.44 million tonnes of cassava per year, while the rest 28.94 million tonnes are for food and animal feed. In figure 2.1, based on data of current biorefineries' capacity plus the expected capacity of licensed ethanol refineries coming into production, ethanol supply is set at 8.9 million liters a day, Q_e . The supply curve for ethanol is kinked, given this production quantity Q_e is a minimum set by government policy. At sufficiently high prices

the quantity supplied may exceed Q_e , at which point the supply curve slopes, reflecting the marginal costs of quantities supplied above Q_e . In addition, the ethanol demand curve is kinked at the minimal ethanol usage requirement in Thailand, representing the mandated 10 percent ethanol blend in gasoline. The ethanol demand curve at quantities greater than the minimal requirement, Q_r , is downward sloping. Increase or decrease of ethanol demand, represented by outward or inward shifts of the demand curve, effect ethanol price; however, within a fairly wide range of variation in demand, the ethanol quantity remains constant at Q_e . The equilibrium quantity of ethanol could change if the demand for ethanol dramatically increases, such as D'' . However, such high demand for ethanol would likely only be an irregular case, due to the tempering effects of substitution or competition with gasoline. Thus, with the normal range of variation in ethanol demand, intersecting along the constant vertical portion of the ethanol supply curve, the quantity demanded of cassava feedstock is likely to remain stable at the amount required to produce Q_e .

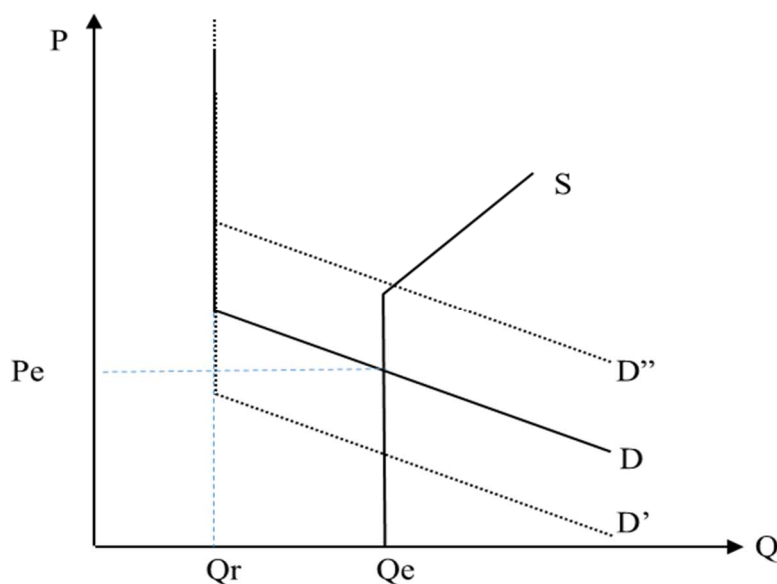


Figure 2.1 Ethanol demand and supply in the Thai market

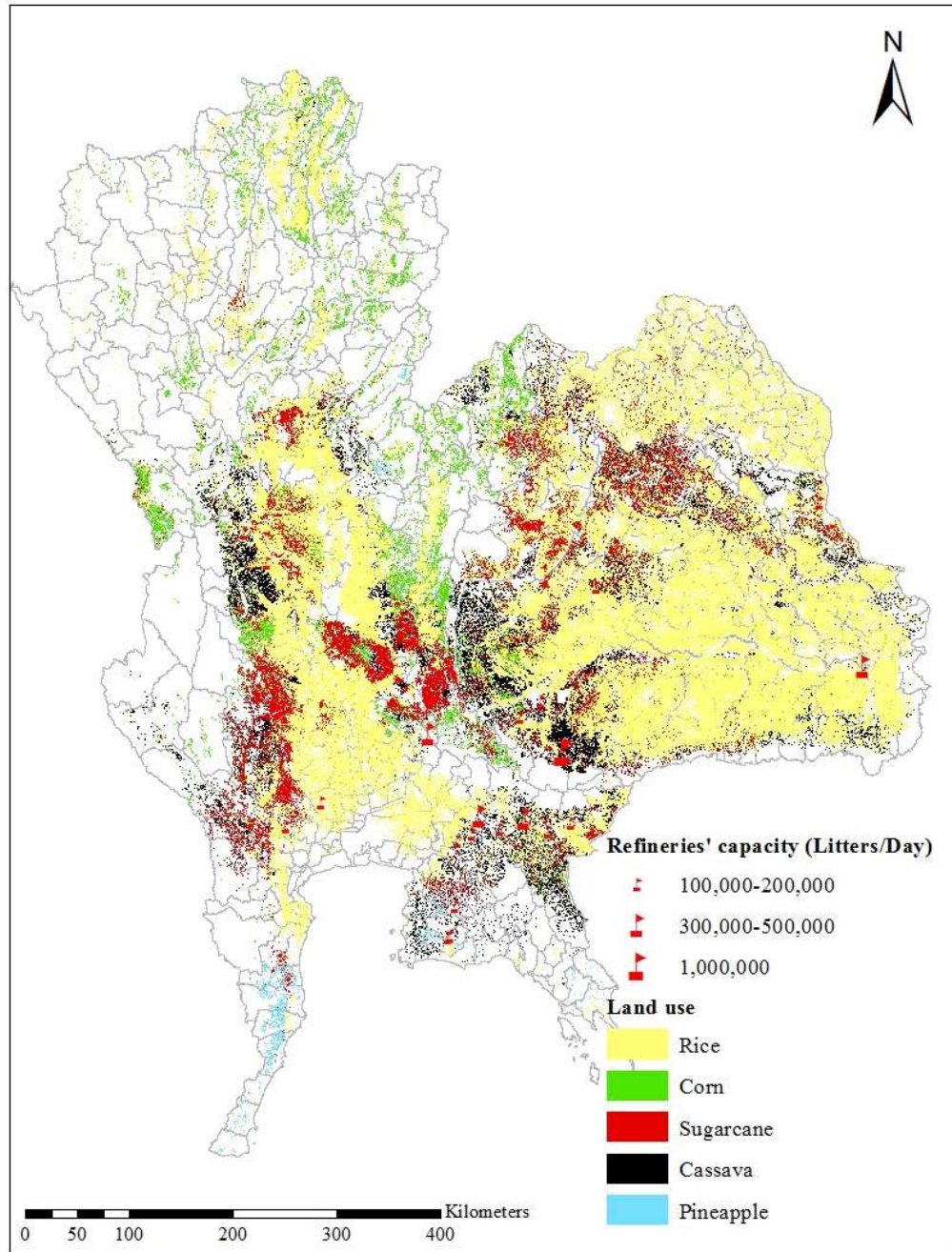
b. Assessing current area of cassava cultivation

Identifying current cassava cultivating areas, along with identification of which crops are currently being cultivated within areas potentially suitable for cassava requires combining several data sources. GIS-based cassava suitability areas were last updated in 2013 (Land Development Department). This data shows current cassava areas, but it does not indicate which crops are being grown in other, non-cassava areas. Land parcels which are indicated as being used for cultivation of other crops were updated using the major crops land-use database (Land Development Department, 2010), including rice, sugarcane, pineapple, corn, and perennial orchards. These two layers of data were joined together.

Following the joining of layers, these data were adjusted in scope to include just the cassava suitable areas. At this point, current land-use, both of cassava and other major crops, together with soil attributes and other criteria were retained. Finally, as a cleaning step, some redundant connecting land parcels having identical attributes were combined together into single parcels. The result is a database of current land-use for major crops within Thailand, as shown in Figure 2.2.

These suitability cassava area (Land Development Department, 2010) and other land-use areas (Land Development Department) are the best of available land-use data in Thailand. However, the cassava cultivation area reported in this GIS-based (Land Development Department, 2010) is quite different from cassava acreage data reported by The Office of Agricultural Economics (OAE). The cassava cultivation area in the GIS-based is about 2.02 million hectares, while the cassava coverage according to OAE is only 1.39 million hectares (Office of Agricultural Economics). These differences are due to data collecting methods, surveying (by Office of Agricultural Economics) versus satellite map interpretation (by Land

Development Department). It is felt that the satellite imagery provides a more accurate representation of actual cultivation area in 2013.



Data source: Database of current land-use for major crops in Thailand gathering from (Land Development Department, 2010) and ethanol refineries from (Department of Industrial Works; Ministry of Energy, 2009).

Figure 2.2 Current land-use for major crops' cultivation and cassava-based ethanol refineries' location.

c. Identifying locations of ethanol biorefineries utilizing cassava feedstock

In addition to the spatial profile of current cassava supply, data from the Thai Department of Alternative Energy Development and Efficiency was used to determine the location and capacities (and thus feedstock requirements) of the 24 biorefineries that utilize cassava (Figure 2.2). This locational data is crucial to the analysis, as costs of transporting cassava feedstock to these points can be incorporated into the model of cropping decisions.

d. Ranking the suitability of agricultural lands for cultivation of cassava

In Thailand, the suitability of land for cassava cultivation has previously been evaluated by matching the crop's requirement with soil attributes, assigning a score of one of four levels of suitability, ranging from high-suitability to unsuitability (Chitchumnong, 2009). This simple four point scale, however, is too coarse for the purpose of determining which land parcels, and where, are most likely to be utilized to meet increased demand for cassava as ethanol feedstock. Instead, cassava suitability was ranked on a 100 point scale utilizing many of the same underlying data.

For this study, involving suitable cassava cultivation area, the focus was on agricultural areas in the north, northeast, and center of Thailand, covering about 44 million hectares. The current cassava cultivation area, at 2 million hectares, is only about five percent of the total cassava-suitable areas analyzed. The most significant other major crops currently grown within the cassava-suitable areas are rice, sugarcane, corn, and pineapple. Particularly, based on competitive crops' profitability, potential cassava cultivation area in Thailand may be as much as 14 million hectares.

A suitability score is given to each land parcel in the study area, regardless of current cropping coverage, based on cassava's agronomic requirements and that parcel's reported soil attributes, following Food and Agriculture Organization (FAO) methods (Chitchumnong, 2009).

The scores and weights given to each soil attribute, as well as climate and topology attributes, were adapted from a cassava study in Vietnam (Giap et al., 2003) and study of zoning for cassava cultivation area in Thailand (Chitchumnong, 2009). There are 62 soil types in the land-cover database for Thailand. Each soil type can, further, be combined with five levels of soil drainage, three levels of soil fertility, soil depth, and upper soil PH, two levels of soil cation exchange capacity (CEC) and soil base saturation (Gibbs et al.), as well as four levels of topography and precipitation rating on cassava cultivation suitability as showed in table 2.1.

Table 2.1 The area attributes used for assigning cassava suitability scores

Criteria	highly suitable ← area attributes → unsuitable				
soil drainage	best	good	neutral	bad	worst
soil fertility	high	-	medium	-	low
soil depth (Dean and McMullen)	> 150	-	50-100	-	0-50
upper soil PH	5.5-7.0	-	7.0-8.0	-	4.0-5.5
soil cation exchange capacity (CEC)	high or quite high	-	-	-	medium
soil base saturation (Gibbs et al.)	high or medium	-	-	-	low
slope	flat or slightly undulating	undulating		rolling	hilly
precipitation (rainfall in mm.)	1,100-1,500	900-1,100 or 1,500-2,500		500-900 or 2,500-4,500	< 500 or > 4,000

Data source: (Chitchumnong, 2009)

Moreover, other criteria such as flooding risk, ridgeline designation, and main recommended usage of that soil type will be assigned as penalty factors of unsuitability area for cassava cultivation. Due to the fact that these criteria have a strong impact on cassava production, but they could be combined with other best soil and precipitation attributes. The

penalty factors were assigned to adjust that these unsuitable areas will be considered as the lowest priority for cassava cultivation.

Combining these criteria, 587 distinct soil biophysical categories are generated. A one hundred interval scale was used to assign a suitability score to each of these categories. The criteria used and weighted scores are shown in table 2.2 and as following:

$$S_i = \left(\sum_{j=1}^m \alpha_j B_{ik} \right) - \left(\sum_{l=1}^o \gamma_l P_{ih} \right)$$

Where S_i is suitability score of soil categories i^{th} .

α_j is weighted suitability scores; $\sum_{j=1}^m \alpha_j = 1$.

B_{ik} is soil attributes and precipitation condition scores; $0 \leq B_{ik} \leq 100$.

γ_l is adjusted penalty score.

P_{ih} is penalty factors of unsuitability area for cassava cultivation; $P_{ih} \in [0,1]$.

Table 2.2 The suitability scores and weights of area attributes and penalty factors

α or γ	Criteria	highly suitable \leftarrow given scores \rightarrow unsuitable				
area attributes and precipitation conditions (B_k)						
0.20	soil drainage	100	80	40	0	-100
0.10	soil fertility	100	-	50	-	0
0.05	soil depth	100	-	50	-	0
0.05	upper soil PH	100	-	50	-	0
0.05	CEC	100	-	-	-	50
0.05	BS	100	-	-	-	50
0.25	slope	100	70		40	-100
0.25	precipitation	100	80		20	0
penalty factors of unsuitability area for cassava cultivation (P_h)						
1	ridge area	35				
1	flooding area	35				
1	recommended soil for rice paddy	20				
1	recommended soil for vegetable	10				
1	beach	5				
1	rock or gravel area	5				

The cassava suitability scores in each category were thus based on biophysical criteria. The 587 categories were assigned suitability scores ranging from 0 to 90, with a mean of 44.0 and standard deviation of 25.2 (Figure 2.3). Subsequently, these scores are utilized in yield and income estimations for each category.

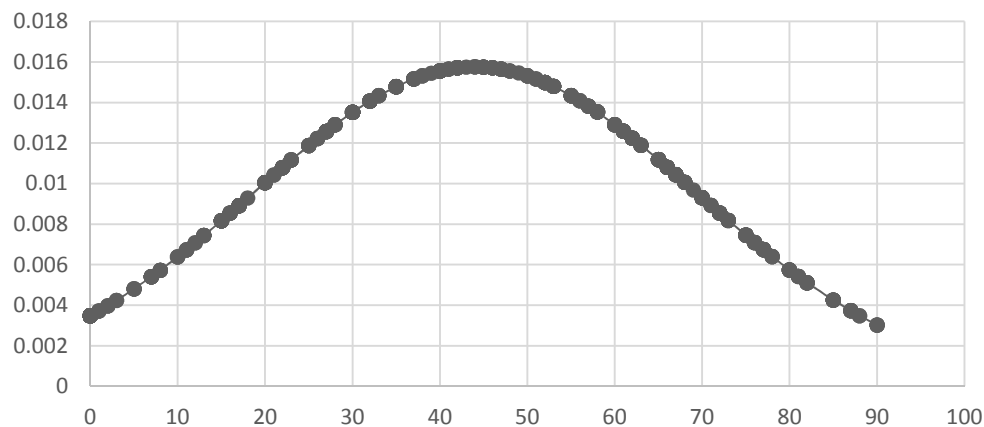
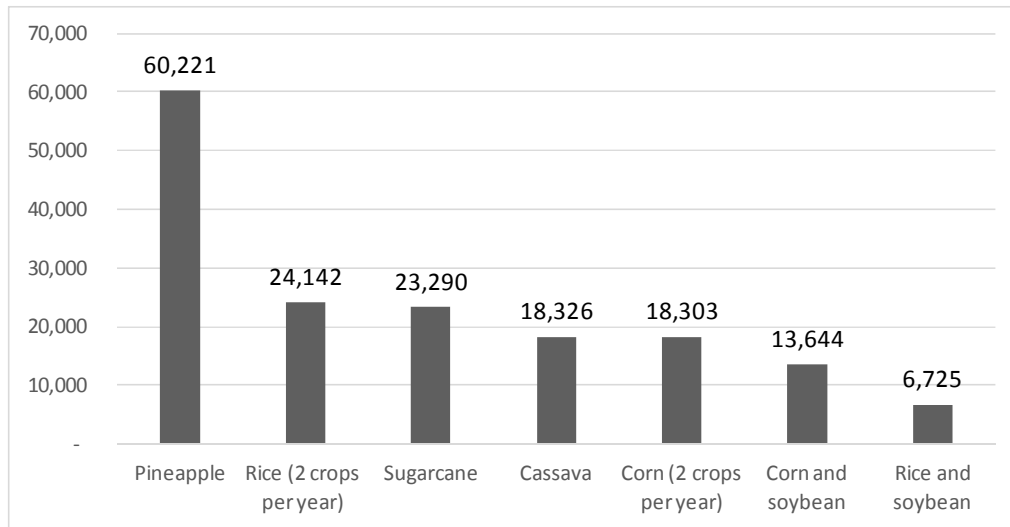


Figure 2.3 Distribution of cassava suitability scores across all 587 biophysical categories

e. Estimating production costs and yield for cassava, relative to other major crops

Cost of production and yield per hectare were estimated based on current score and cost & yield depending on previous cassava suitable area study (Chitchumnong, 2009). Income and initial profit without transportation cost per hectare were calculated using average cassava price from 2010 to 2014.

Based on the majority crops in Thailand, the average profit per area of cassava was compared to that of rice, corn, sugarcane, and pineapple as the other crops most likely to be grown on a given land parcel. The average profit of cassava from 2006-2011 was about 18,326 baht per hectare, higher than most other crops' profit, but lower than profit of sugarcane, pineapple, and two rotations of rice per year in irrigated areas (Figure 2.4).



Data source: (Land Development Department, 2010) and author's calculation

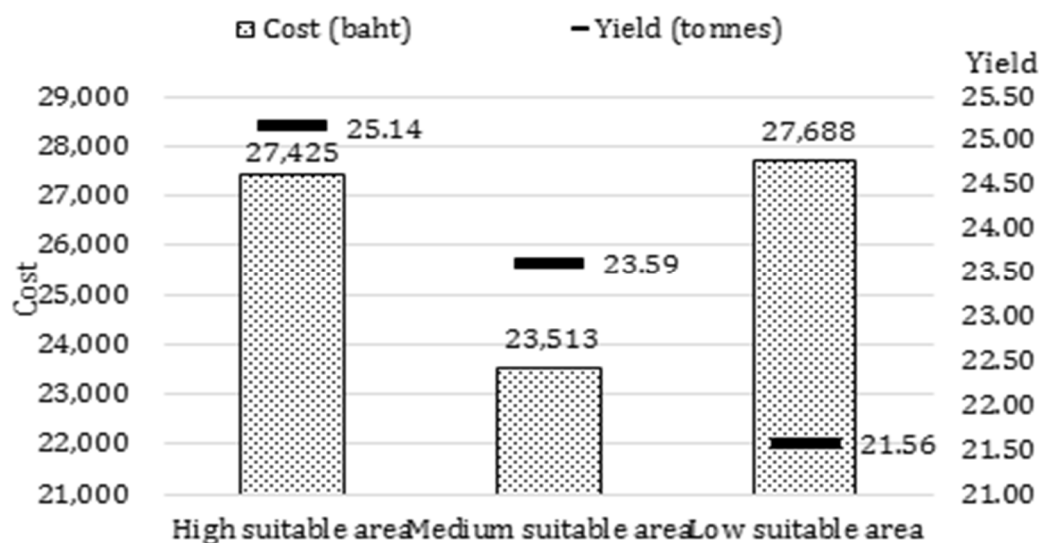
Figure 2.4 The average profit per hectare of major crops (baht per hectares), from 2007-2011

Normally, growing period of cassava, sugarcane, and pineapple takes about twelve months. Meanwhile, rice and corn are grown and harvested within four months. After the seasonal rice and first rotation of corn, the second crops could be cultivated by either rice, corn, or soybean. Double rotation of corn areas, however, were rare, only 2 percents of total corn areas (Chen et al., 2011). Most of double rice and corn cultivation were grown in irrigated areas, while the mixed of rice or corn with soybean were in non-irrigated areas.

The profit of both rice and corn with soybean, normally in non-irrigated areas, was lower than cassava's profit. Thus, these areas could be transferred to cassava areas. Unfortunately, the irrigation areas were not mentioned in the dataset, so double crops of paddy rice, normally in irrigated areas, was still included in the calculation even though its average profit was higher than cassava's profit. However, the suitable scores for cassava on these areas were very low due to the soil attributes. Then, these areas were never reallocated to cassava cultivation in the calculation.

Meanwhile, profitability of sugarcane and pineapple were higher than that of cassava, so they were not considered as potential cassava areas. Moreover, the average total cost of most crops including cassava were around 1,000 baht per hectare, while cost of sugarcane and pineapple were quite high, about 2,000 and 3,000 baht per hectare respectively (Office of Agricultural Economics). To switch from other crops to sugarcane and pineapple farmers incur a much higher switching cost and available market. Based on the assumptions that most farmers have a limitation of the investment, so cassava area is not switched to sugarcane and pineapple area as well.

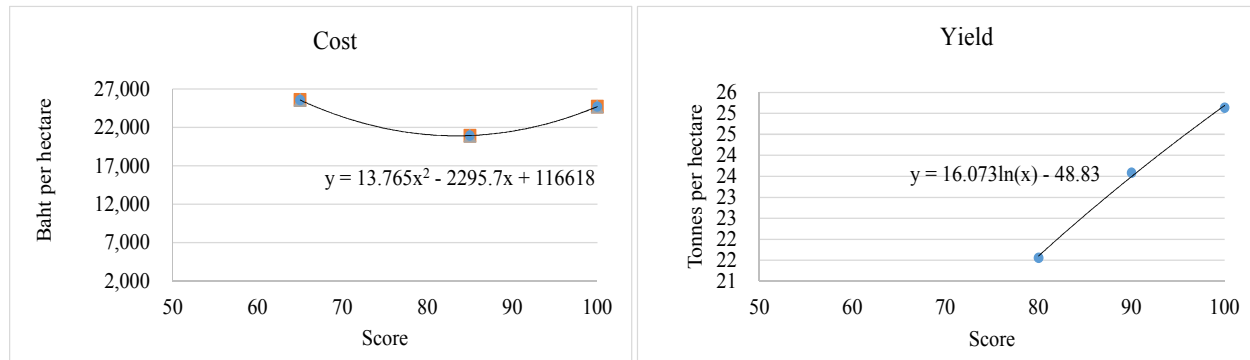
The cost of production from previous cassava suitability studies showed that costs for both the highest and lowest suitability scores for cassava were around 27,000 baht per hectare, while the medium suitability level realized lower costs due to lower fertilizer use (Figure 2.5) (Chitchumnong, 2009). On the one hand, the more suitable area provided the higher yield. It should be note that this study had no cost and yield data of cassava grown in unsuitable areas.



Data source: (Chitchumnong, 2009).

Figure 2.5 Average cost (baht per ha) and yield (tonnes per ha) from previous analysis

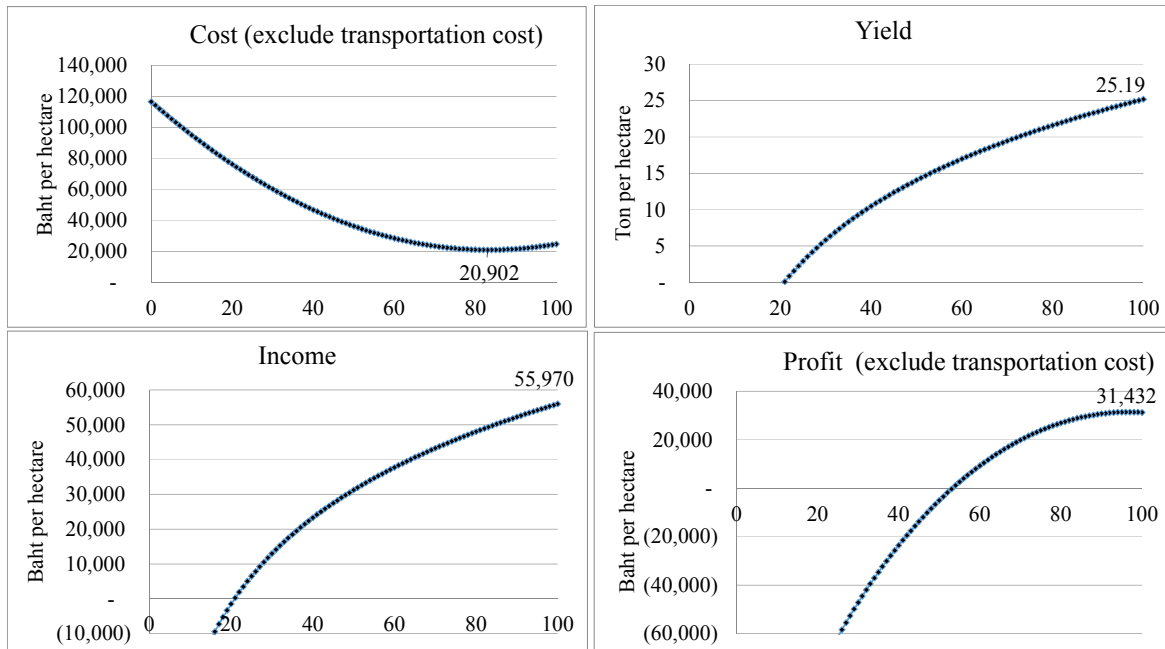
In this analysis, costs were predicted based on fit by a polynomial equation fit to these values and yields were calculated by logarithmic equation fit to values on previously reported costs, yields, and suitability levels (Figure 2.6).



Data source: Land Development Department and Authors' calculation

Figure 2.6 Estimated cost and yield based on suitability ranking from Land Development Department.

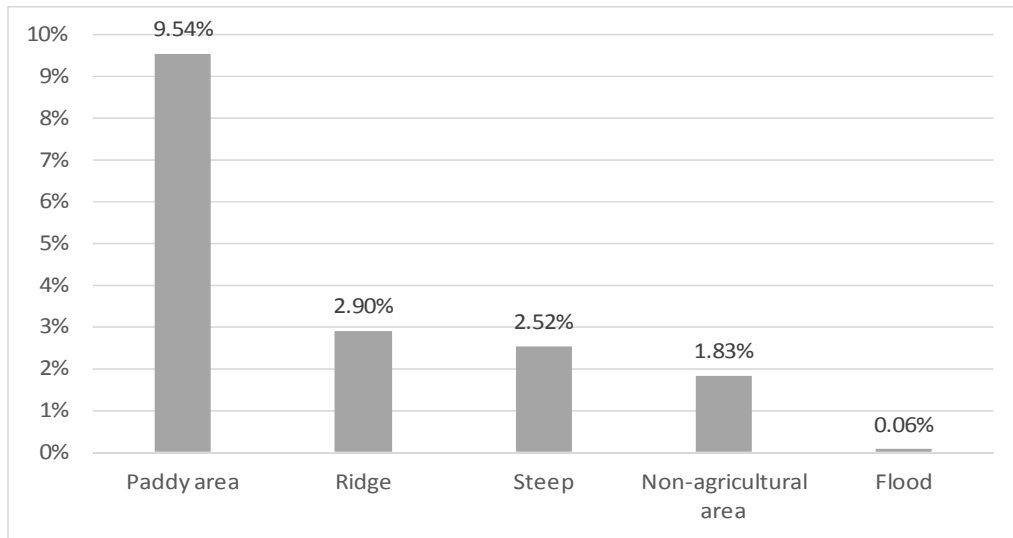
The coefficients in these equation and the scores were applied to create new costs and yield estimates for each parcel, were it to be used to grow cassava. The lowest cost, 20,902 baht per hectare, was at the suitability score of 83 (Figure 2.7). The maximum yield was about 25.19 tonnes per hectare. The lower scores did not provide any appreciable production, and therefore parcels with such scores would not be considered candidates for switching into cassava. The maximum initial profit, prior to considering transportation costs, was 31,432 baht per hectare, whereas suitability scores under 54 gave negative profits. Indeed, the yields and costs should be estimated by crop production model, but due to the numerous uncertainty factors, these data were estimated by simple history data. The results, however, were discussed and adjusted based on an opinion of Thai cassava yield modelling expert (Banterng, 2015) and previous studies (Banterng, 2015; Sarma and Kunchai, 1991). They suggested that the cassava yields were likely about 10, 15-20, and 25 tonnes per hectare in inferior, moderate and superior soil quality respectively.



Data source: Authors' calculation

Figure 2.7 Estimated per-hectare cost, yield, income, and profit from cassava cultivation, as a function of cassava suitability scores.

The significant factors of score estimation were soil types, precipitation, slope, ridge areas, flood areas, and recommended crops for that soil types. Particularly, in current cassava cultivation areas, most soil types were considered suitable for field crops, while about 11 percent of the designated current cassava area was considered to be non-agricultural area or to be suitable for paddy rice (Figure 2.8). Moreover, the flood-prone, sloped and ridge areas made up about 5.48 percent of current cassava cultivation areas. These unsuitable areas for cassava cultivation, about 0.34 million hectares, were considered not likely to have continuously produced cassava.



Data source: Authors' calculation

Figure 2.8 Percentage of current cassava areas for cassava cultivation major negative factors

f. Estimating total current supply of cassava, based upon soil suitability data

This total supply estimated from the suitability cassava area spatial data set is considerably higher than the more official supply numbers reported by OAE: about 39 million tonnes, compared to 30 million tonnes, respectively. The estimated yields based on GIS imagery data and official yield data from OAE, however, were not as divergent, at 19.39 and 21.88 tonnes per hectare, respectively.

As the result, the additional cassava supply required to meet the Thai government's ethanol production target in this study is considerably lower than the additional requirements cited in other studies (Ubolsook, 2010; Wianwiwat and Asafu-Adjaye, 2013). This higher starting point, in terms of current levels of production, may be justified, however, because the GIS satellite imagery collecting data on total Thai cropping coverage is likely more accurate than estimates derived econometrically from responses to farmer surveys.

g. Calculating costs of transporting cassava harvests from cassava cultivating plots to biorefineries

The distances from land parcels to the closest biorefinery were calculated from data of road connections in Thailand using OD cost matrix network analysis, a routine available in the suite of ArcMap geoprocessing tools. From these distances, transportation costs per tonne were calculated. To calculate OD cost matrix analysis, in the first step, all land-use parcels were grouped based on the nearest biorefinery by using Service area analysis in ArcMap geoprocessing tools. After that, in each biorefinery service area, the distance from all land parcels to biorefinery were calculated by OD cost matrix analysis. Next, these distances were grouped into eight categories based on distance range and cassava transport costs per tonne assigned in national cassava subsidy program (North Eastern Tapioca Trade Association, 2013). Then, the transportation cost per area in each parcel was calculated based on distance category, cost per tonne, and cassava yield.

h. Calculating final profits of cassava production for ethanol feedstock

Then, cassava profits per hectare for delivered ethanol feedstock were calculated as illustrated in Figure 2.9. Production costs per hectare, c , are estimated as a function of the suitability score, $s=[0,100]$, for each given plot, as determined previously from biophysical characteristics (Figure 2.7, panel a). Yield, in tonnes per hectare, y , is estimated separately as a function of the suitability score, s , for each given plot. The per hectare income equation is simply $I(s) = p * y(s)$ where p is the average cassava price. The per hectare farm-gate profit, before transport, is $\pi(s) = I(s) - c(s)$. Finally, profitability after delivering cassava as ethanol feedstock is determined by netting out transportation costs to determine $\Pi = \pi(s) - t(d)$ where

transportation costs, t , are a function of the distance in kilometers, d , along the road network from the given plot to the nearest cassava biorefinery's location.

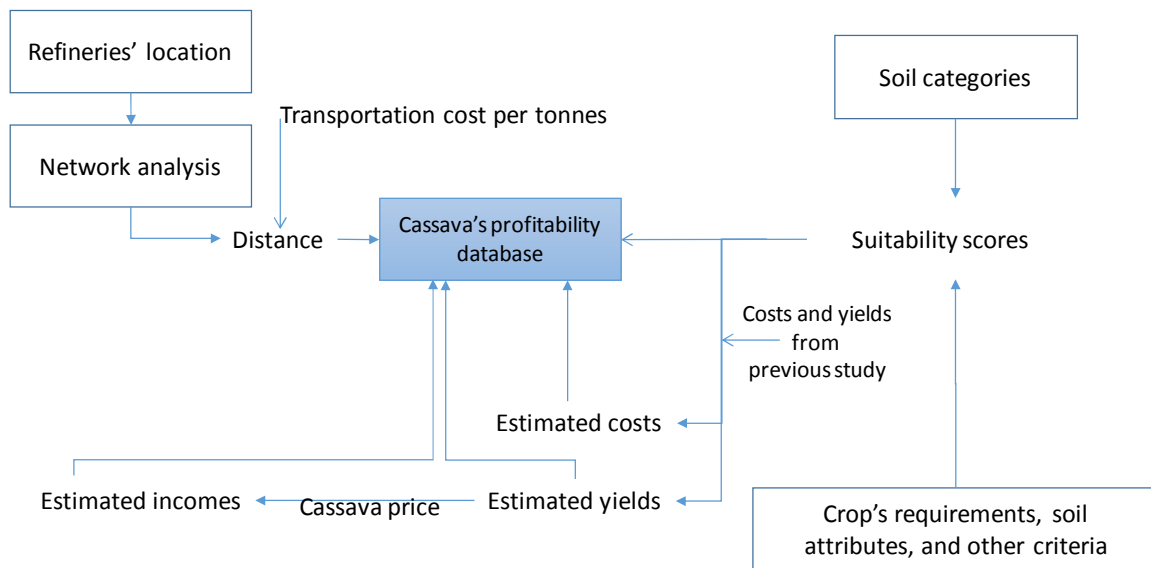


Figure 2.9 Considerations for ranking parcels by profitability of producing and transporting cassava for ethanol feedstock.

i. Reallocating cassava cultivation to meet ethanol demand for cassava feedstock as well as demand for food and feed uses

To reallocate land to cassava production, a sequence of three major steps were executed. First, those areas designated as suitable for cassava cultivation were separated into two main groups: land parcels already currently used for cassava and land parcels currently used for other crops, as illustrated in Figure 2.10. For the first group, very low profitability areas such as ridge lines, flood-prone parcels, parcels with steep slopes, parcels with soil types recommended only for paddy rice, and nonagricultural lands, were removed from the cassava cultivation in the reallocation.

For the second group, crop lands currently not being used for cassava, only the areas currently being used to grow crops with lower profitability on average than cassava, including

rice, corn, and fallow, were considered for reallocation to cassava cultivation. Other higher-value crops as well as permanent forests were excluded from the algorithm. Moreover, parcels over 400 km from a cassava ethanol biorefinery were also excluded from the calculation, as transportation costs would be prohibitive.

The demand deficit was added by supply by non-cassava areas. The potential areas were ranked by profit first. If there were the same profit in many parcels, the larger parcels were favored due to the impact of economics of scale. Now, the current and potential cassava areas completed the cassava demand. These areas were separated into nine regions based on biorefineries' location. In each region, the cassava areas were ordered by profit and size again. The higher profitable parcels were produced to meet ethanol feedstock demand first. After that the rest supply was served as food and animal feed because these demands were delivered to cassava collecting centers, always located nearby cassava growing areas. Based on this method, the current cassava areas were not switched to other crops even if they had low suitable cassava scores. Due to the fact that cassava can be produced in the marginal land which other crops could not be grown. If change these types of land to other crops, it cannot have a good production as well. Moreover, the most profitability areas were firstly considered to fulfill ethanol feedstock demand.

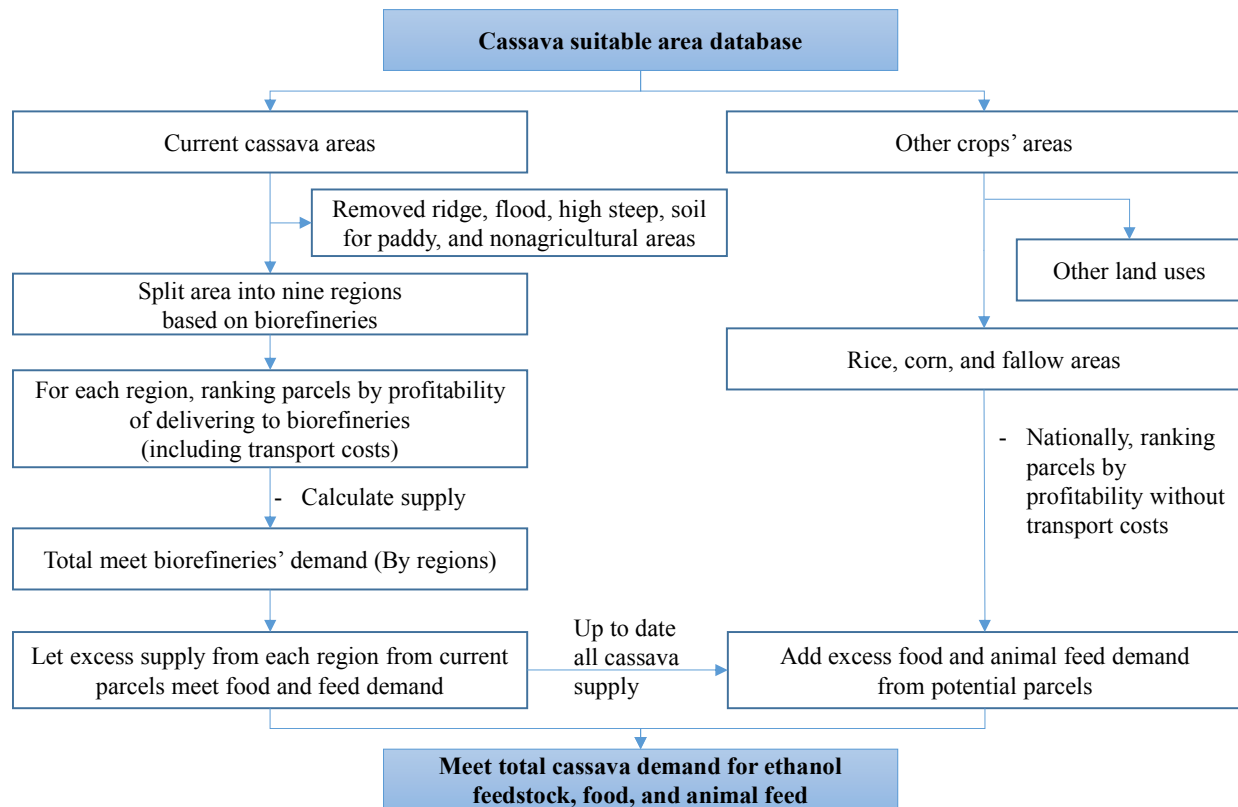


Figure 2.10 The diagram of assigned cassava area algorithm

2.4 Results

The new allocation of cultivation area for cassava increases cassava supply from 34.91 million tonnes to 41.39 million tonnes, to meet feedstock demand under the Thai government's ethanol target (Table 2.1). The cassava cultivation area, however, likely constant around 2.02 million hectares. Due to the fact that the cassava yields improved to 20.40 tonnes per hectare. Moreover, mean of cassava production costs decreased to 23,505 baht per hectare. The standard deviation of cassava yield was reduced.

Table 2.3 The statistic data of area, production, yield, cost, income, and distance comparing before and after reallocated area

		Cassava cultivated areas, before reallocation	Cassava cultivated areas, after reallocation
Production (million tonnes)		34,907,972	41,386,259
Area (hectares)		2,020,192	2,028,428
Yield (tonnes / hectare)		17.28	20.40
Cost (baht/ha)	Mean	29,903	23,505
	SD	13,229	4,048
Yield (tonnes/ha)	Mean	15.26	20.09
	SD	7.21	2.26
Income (baht/ha)	Mean	33,920	44,633
	SD	16,940	5,018

Data source: Authors' calculation

Figure 2.11 shows the distribution of cassava suitability scores for those areas cultivating cassava, nationally, before and after reallocation. Mean cassava suitability score in currently cultivate areas (before reallocation) is 57.60, whereas the mean cassava suitability score in newly allocated cultivation areas is projected to increase to 73.47. The score distribution's Probability Distribution Function (PDF) after reallocation displays greater kurtosis as well as an increase in mean. This indicates that the new areas added under the reallocation improve the scores by removing low score areas from cultivation. This is largely driven by the relocation of cassava

onto more suitable lands closer to the biorefineries. The score improvement directly impacts cassava yield. As a result, the average cassava yield, given reallocation, increases from 17.28 to 20.40 tonnes per hectare.

The projected yield after reallocation is slightly higher than average Thai cassava yield in 2012 reported by FAO (Figure 2.12). In the 1990s, the International Center for Tropical Agriculture (North Eastern Tapioca Trade Association) suggested that cassava yield could reach 23.3 tonnes per hectare with good soil management and improvement of drought resistant varieties (Howeler et al., 2013). Moreover, from the 1990s, the Thai government has promoted higher-yielding varieties of cassava; as a result, from 1990 to 2009, cassava yield increased about two-thirds and cultivation area decrease about 10 percent. A similar story has played out in the corn industry in the U.S., where corn production has dramatically increased since 1960, while corn cultivation areas were quite stable or even decreased. Corn yield improved from 60 to around 160 bushel per hectare since 1960, with a similar transformation, with increased mean and kurtosis, of the plot level yield distribution (Beddow, 2012).

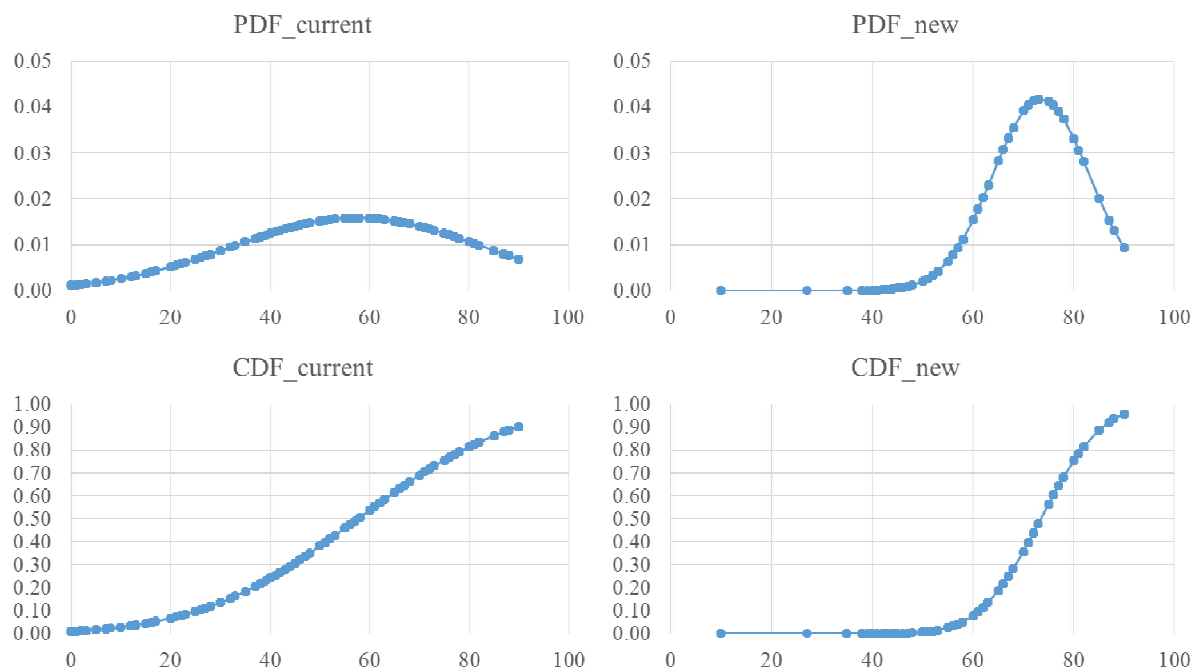
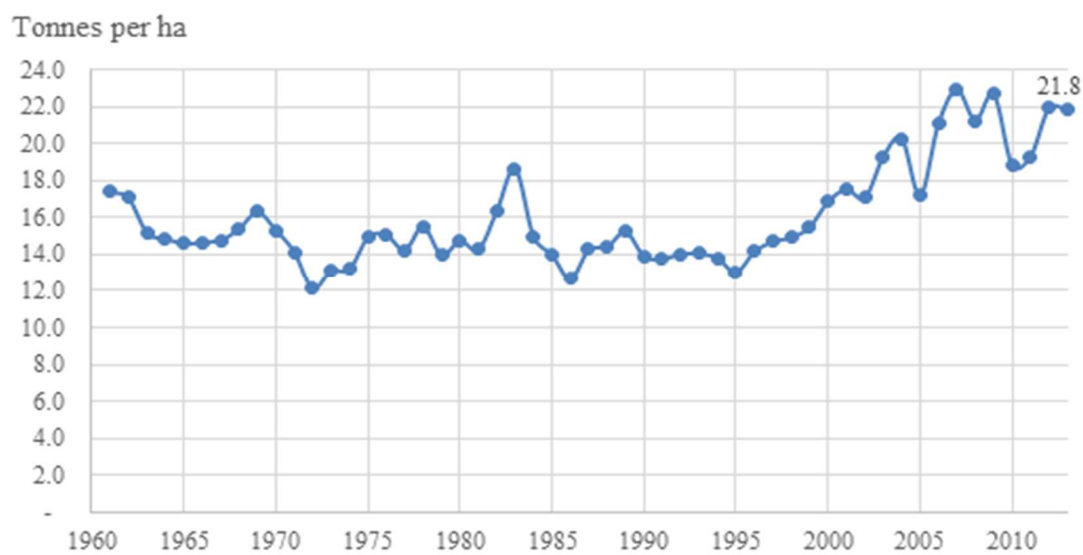


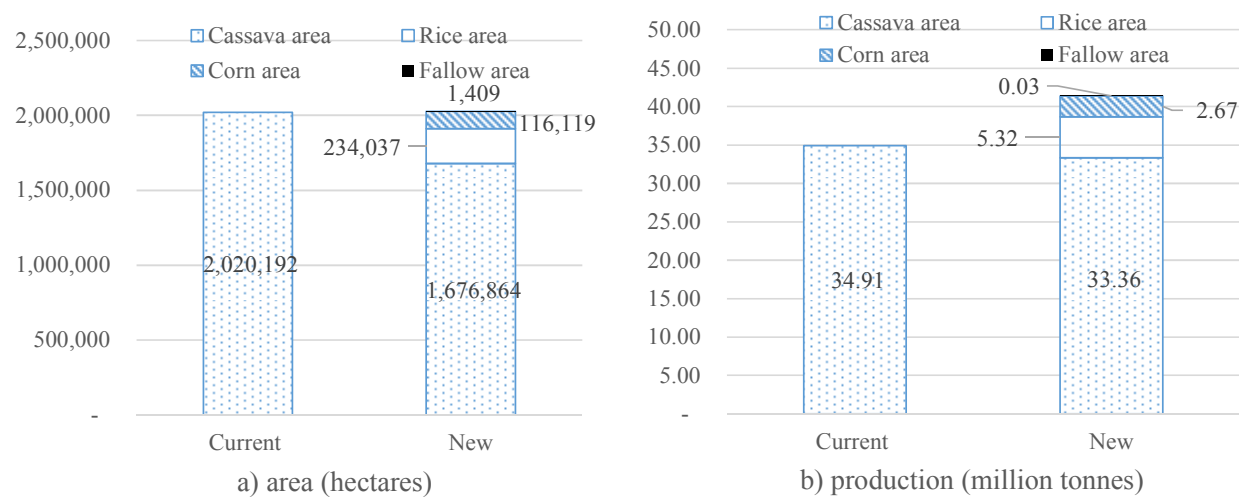
Figure 2.11 Distribution of suitability scores before and after reallocating cassava areas



Data source: FAOSTAT.

Figure 2.12 National average cassava yield in Thailand from 1960 to 2013

The projected cassava cultivation area in Thailand, due to reallocation, is decreased from 2.02 to 1.68 million hectares (Figure 2.13.a). At the same time, about 0.35 million hectares of other crops' areas are transferred to cassava cultivation. About 67 percent of the transferred areas came from rice, at 0.23 million hectares, accounting for an additional 5.32 million tonnes of additional cassava production (Figure 2.13.b).



Data source: Authors' calculation

Figure 2.13 Land from other major crops incorporated into new cassava cultivation area and production volumes.

The reallocation algorithm suggests that some areas of rice and corn cultivation may be reduced. Such a result could raise the specter of food security problems in Thailand due to this increased competition from biofuels. However, the decrease in rice area could be offset to some extent by the addition of new rice lands from those that had been deemed “highly unsuitable” and transferred out of cassava cultivation. The four groups of “highly unsuitable” soil types—ridge lines, high slope, flood prone, non-agricultural, and paddy lands—were taken out of cassava cultivation under the first step of the reallocation algorithm. The first four types were not suitable for any kind of crop; the last one, however, is suitable for paddy rice. Based on the

analysis of suitable areas for seasonal rice production, this soil type was in fact considered highly suitable for rice cultivation (Land Development Department, 2010). Moreover, most of these parcels were already surrounded by paddy rice cultivation. Thus, the paddy rice soil type parcels that were moved out of the cassava cultivation areas could be converted to produce paddy rice. Meanwhile, the other soil types were assumed to be converted fallow. In table 2.2, under the projected reallocation, 234,037 hectares of rice are transferred to cassava, while 193,638 hectares of cassava are converted to rice. As a result, rice cultivation area could actually decrease by only 40,339 hectares. As a result, net rice production would decrease by 0.15 million tonnes. On the one hand, corn production, typically used for animal feed, would decline by 0.70 million tonnes or about 14 percent of total domestic corn production. These amounts could be offset by other crops such as cassava that provides more feed production per unit area. Thus, reallocated areas to cassava due to the Thai government ethanol target do not necessarily induce the problem of food security, if some areas currently used (unproductively) for cassava are transferred to rice.

Table 2.4 Area and production of rice and corn, resulting from cassava area reallocation

Area reallocation		Rice	Corn
Acreage (hectares)	Cassava land to other crop	193,638	0
	Other crop land to cassava	234,037	116,119
	Net result	-40,399	- 116,119
Estimated production* (tonnes)	Cassava land to other crop	718,398	0
	Other crop land to cassava	868,277	702,517
	Net result	-149,879	-702,517

Data source: Authors' calculation

** Land Development Department 2010*

- Rice yield was 3.71 tonnes per hectare

- Corn yield was 6.05 tonnes per hectare.

Considering distance from cassava cultivation plots for ethanol feedstock to biorefineries, the mean distance travelled shrank from 89.46 to 59.38 km (Table 2.3). This result indicates that

the more profitable land parcels closer to biorefineries were assigned to fulfill demand for cassava as ethanol feedstock.

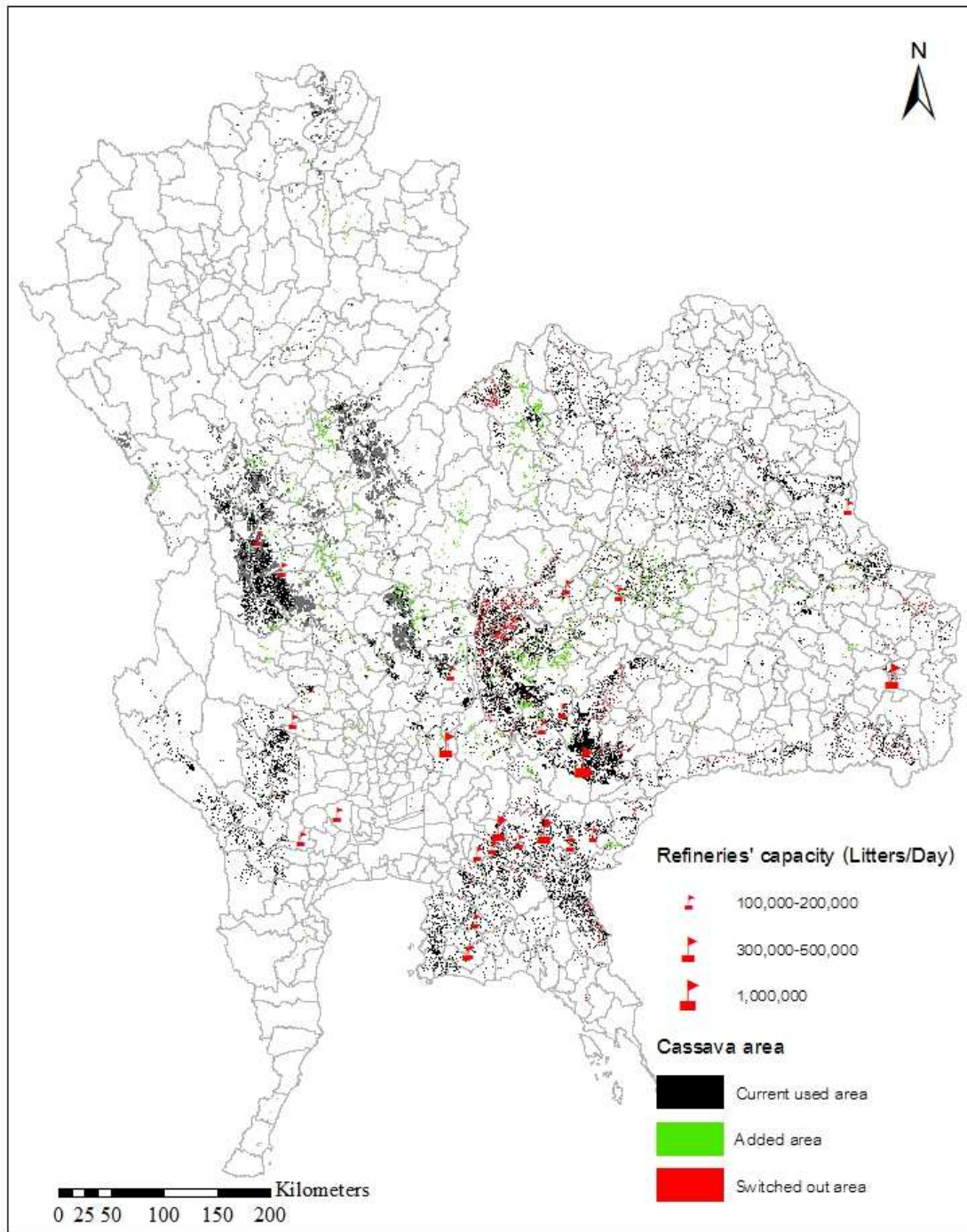
Table 2.5 The statistic of distance from parcels to biorefineries, in kilometers, comparing before and after reallocation

Distance to biorefineries	From current cassava locations, average for all parcels (km)	From new cassava locations, after reallocation	
		For ethanol (km)	For other uses (km)
Mean	89.46	59.38	99.43
SD	61.70	36.39	66.77

Data source: Authors' calculation

Finally, the reallocated area for cassava cultivation, nationally, is shown in Figure 2.14. The black parcels are those currently used for cassava which remained in cassava under the reallocation, while the green parcels are newly added cassava cultivation areas, switching into cassava from other crops. The red parcels are unsuitable areas switched out of cassava, either to paddy rice cultivation, as recommended by the paddy soil type, or to fallow.

Most biorefineries were located around high density cassava cultivation areas, especially in the eastern Thailand. In these areas, current cassava parcels served to meet ethanol feedstock first (given the relative inelasticity of feedstock demand from the biorefineries). The rest of existing cassava parcels in these areas were then allocated by the algorithm for food and animal feed uses. Finally, new cassava cultivation areas were added on lands deemed most profitable for cassava cultivation, but without regard for distance to biorefineries, to meet the remaining demand for food and animal feed uses.

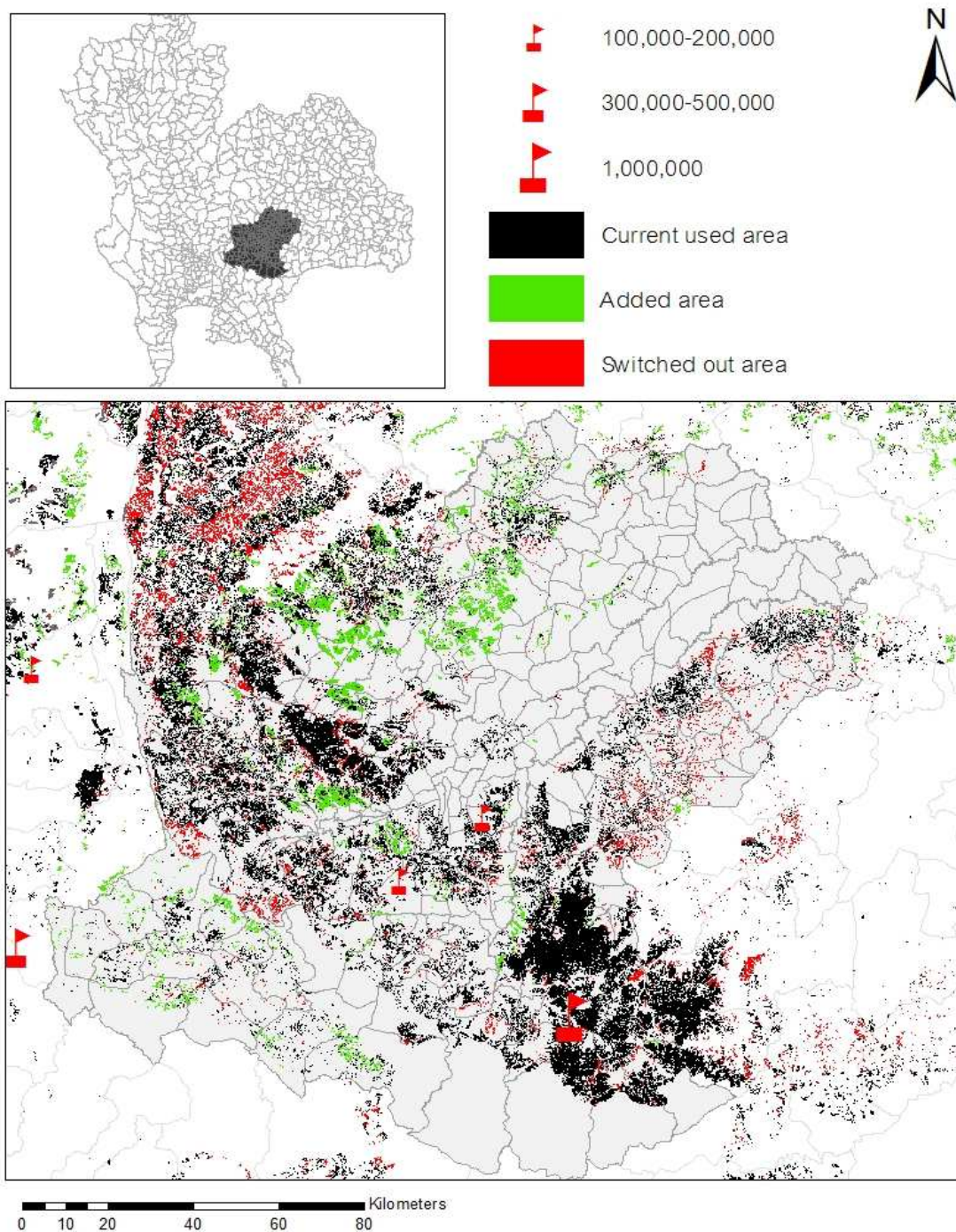


Data source: (Department of Alternative Energy Development and Efficiency; Department of Industrial Works; Land Development Department)

Figure 2.14 Reallocation of land into and out of cassava cultivation and cassava-based ethanol refineries' location.

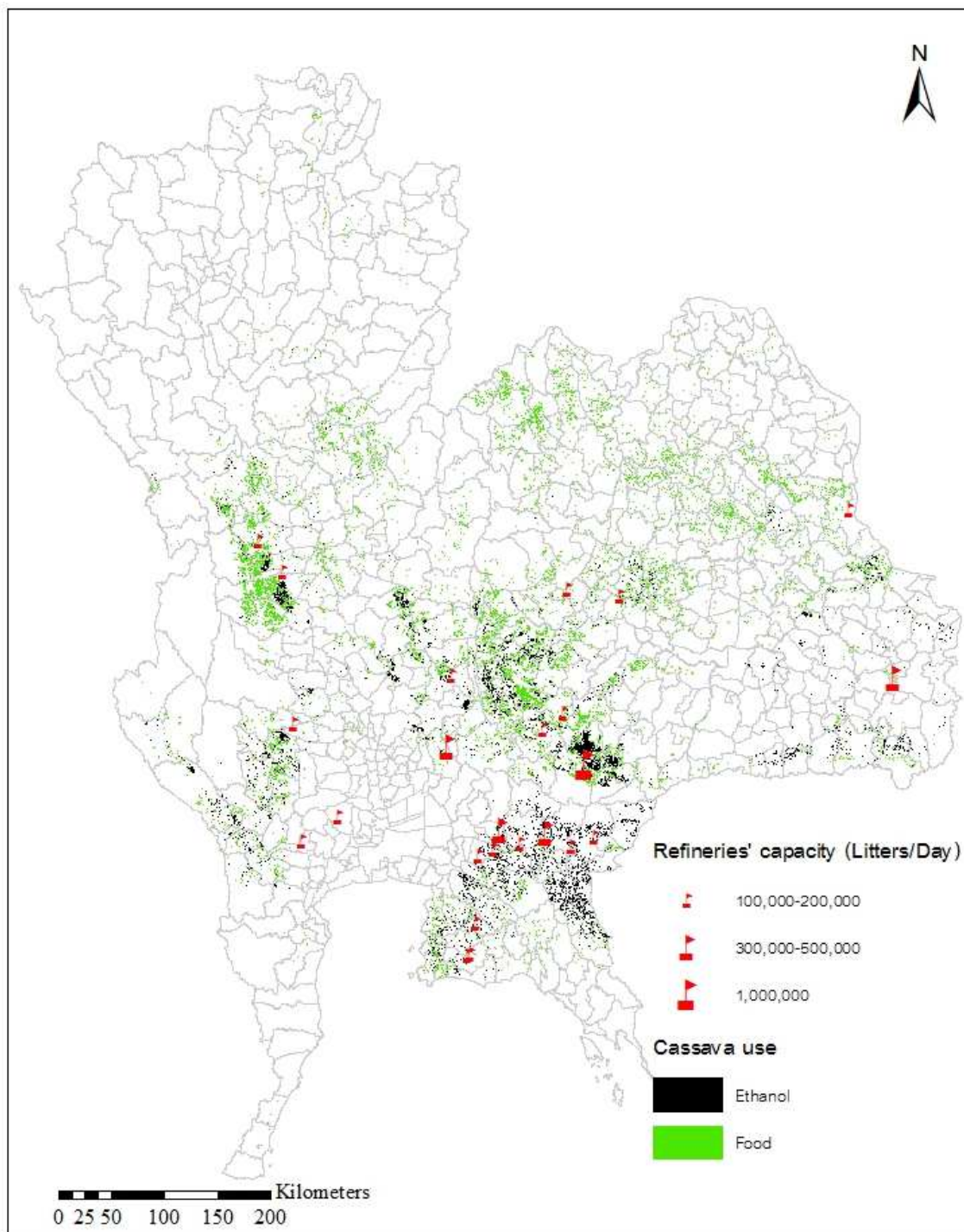
Figure 2.15 shows a sample of these calculations for one regional area, in Nakornratsema province. There were three refineries, one of them was the biggest refinery in the country, located in the heart of the main cassava area in Thailand. Most of these areas already served as cassava cultivation, especially around the biggest biorefinery.

Nationally, Figure 2.16 shows in greater detail projected cassava uses after reallocation. Based on the algorithm, most of the cassava cultivation destined for ethanol feedstock, black parcels, were clustered around the biorefineries' locations. The added cassava areas, which are largely projected to provide for food and animal feed, were assigned in the best (e.g. most profitable) soils but might be far from biorefineries.



Data source: (Department of Alternative Energy Development and Efficiency; Department of Industrial Works; Land Development Department)

Figure 2.15 Reallocation of land-use from major crops' cultivation and cassava-based ethanol refineries' location in Nakornratsema province.



Data source: (Department of Alternative Energy Development and Efficiency; Department of Industrial Works; Land Development Department)

Figure 2.16 Area of cassava use for ethanol and food, and biorefineries' locations.

2.5 Conclusion and discussion

The results of this analysis show the potential impact of increasing cassava demand from meeting the Thai government's ethanol production target on cropping and land use patterns nationally across Thailand. The estimated cassava suitability scores, based on biophysical factors, range from 0 to 90 with a mean and standard deviation around 44 and 25 respectively, across all potentially suitable lands for cassava cultivation nationally. The cost of production and yield are estimated from these cassava suitability scores based upon enterprise accounting data from previous studies of cassava farms in southeast Asia. The most unsuitable areas are removed from cassava cultivation. From the reallocation algorithm, based on cassava suitability score and distance, cassava production is increased by 6.48 million tonnes but overall cassava acreage is quite constant around 2.02 million hectares. Due to the fact that more suitable soils were being cultivated average cassava yield improved by 3.12 tonnes per hectare. The new cassava cultivation areas mostly came from converting current rice and corn areas. Finally, the results are driven by allocating the most profitable parcels nearest to biorefineries to providing cassava for ethanol feedstock.

These cropping and land-use pattern changes are of concern both for the potential effects on food security and food prices and for the potential impacts on the environment, including those that result from crop switching, yield improvement, and agricultural intensification. The results show that if more suitable areas for cassava are used, yields are improved, and cassava acreages are constant. These results show a slight decrease in the magnitude of pressures placed on the balance between energy crops and food security under such a scenario of cassava intensification. Not only could such an outcome benefit the Thai economy, but it could also reduce anxiety over potential deforestation.

However, it was not possible to assess the extent that increases in food prices might be caused by energy crop demand, due to indirect land use change, deforestation, and decreases in biodiversity. Nevertheless, the results of this analysis show that if an increase in cassava cultivation replaces unsuitable rice cultivation areas, this cassava expansion would be less likely to harm food security or raise food prices. Indeed, (Wianwiwat and Asafu-Adjaye, 2013) argue that food prices in Thailand would not be significantly impacted by the Thai biofuel policy in the foreseeable future.

Furthermore, the Thai government has played an important role in major agricultural markets such rice, cassava, and corn via subsidy programs. In 2012, the Knowledge Network Institute of Thailand (KNIT) estimated that the Thai government subsidized 377 billion baht, or about 17 percent of the government's budget, for the national rice subsidy program. Moreover, it is estimated that the program accounted for the loss of about 146 billion baht in that year. The burden of the rice subsidy program on the Thai government's budget was especially high in 2012 and 2013 (Thaipublica, 2013). Thus, the Thai government has reduced its budget for the rice subsidy program by limitations place on the subsidy area and price. Moreover, due to the drought, off-season rice production was discouraged as well.

The Thai government also financed about 26 billion baht for a cassava subsidy program in 2011. This program was targeted to support about 30 percent of all cassava production with a minimum price of 2,750 baht per tonnes (Department of Internal Trade). This provides farmers with a price incentive to cultivate cassava, supported by the Thai government. In term of political support, rice farming households number around 3.7 million, while cassava growing households are only about 0.54 million. Even if the numbers of cassava growers are lower than rice farmers' number, the government budget per household spent to support cassava are much lower and

more effective than that for rice farmers. Moreover, the Thai government's rice subsidy policy has exacerbated a significant overproduction, and contributed to the deficit budget. Thus, encouraging farmers to replace unsuitable areas devoted currently to rice with cassava or sugarcane could support both the rice and ethanol sectors in Thailand.

Nonetheless, this study has some important limitations in source of database and crops' price interaction.

First, even though the algorithm is concerned with the concept of farmers' profitability derived from output, production cost, and transportation costs from land parcels to ethanol refineries, the location of other important cassava markets, such as cassava collecting centers for food uses, such as starch mills, are ignored due to lack of spatial data. Such cassava collection centers, however, are typically located nearby cassava growing areas.

Second, the GIS-based cassava area data used in this study indicate a much higher area and level of production than do the official cassava acreage and production statistics from OAE. This, however, is the best GIS data available of cassava cultivation areas in Thailand. Using regional scale spatial analysis, based on both biophysical and economic data, to investigate results of switching cassava cultivation area due to ethanol feedstock demand was very useful. Nonetheless, the results are significantly sensitive to the choice of data, so more reliable spatial data will give the more consistent result.

This model is derived from a simple individual profit maximization rule, instead of an economy-wide model, like CGE. Thus, the changes in crop prices from adjustments in demand or supply will not be considered by this model. Also, the model does not integrate the impact of indirect land use change or other secondary effects from area expansion based on the pressures of growing energy feedstock demand. The results, however, indicate a reduction in cassava

acreages, and some food crop areas are replaced by cassava. Thus, the impact of indirect land use is this projected scenario would not likely be enormous. Finally, only switching among major crops were considered, while an extension of the model might concern all crops—including minor crop—cultivated in the study areas.

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Chapter 3 Projected environmental impacts resulting from land-use and cropping changes under the Thai ethanol policy

3.1 Introduction

The growth of population, the increase in energy and food demand, and the decline in environmental quality and natural resources are among the most important problems in the twenty-first century. The challenges in the near future will be to increase global energy and food supply within the bounds of environmental sustainability (Foley et al., 2011; Godfray et al., 2010). To this end, bioenergy derived from renewable resources has been promoted for the purpose of energy security, economic development, and reduction of greenhouse gas (GHG) emissions (Phalan, 2009; Zhou and Thomson, 2009). Global bioenergy production has increased from 16 billion liters in 2000 to more than 100 billion liters, largely due to increased ethanol production (IEA).

Aligned with these goals, the Thai government has enacted an ethanol production target of 9 million liters per day by 2022. While the policy is economically and politically feasible (see Chapter 1), land use change due to the demand for feedstock resulting from the dramatic increase in ethanol production could negatively affect environmental impacts such GHG emissions, deforestation and biodiversity, soil quality, and water resource (Field et al., 2008; Phalan, 2009; Scarlat and Dallemand, 2011; Searchinger et al., 2008).

Some studies have utilized life-cycle analysis (Lapola et al.) as a method for investigating impacts of biofuel production in terms of net energy output and GHG emissions (Cherubini et al., 2009; Davis et al., 2009; Liska and Cassman, 2008). The significant factors considered in LCA are energy crop cultivation, conversion processes, transport distance, heat and power

sources, utilization of co-products, as well as various sources of uncertainty. The uncertainty of impacts on soil processes, soil carbon emission, and nitrous oxide emission have played an important role in LCA results (Whitaker et al., 2010). Moreover, bioenergy crop cultivation directly and indirectly changes land use that is significantly implicated in GHG emissions. Indirect land use change (ILUC) has normally fallen outside of the assessment boundaries of life cycle analysis (Liska and Cassman, 2008). On the one hand, the land use change was determined by some to be the biggest source of environmental impact and pushed a net positive value of GHG emissions from corn and switchgrass ethanol in the U.S. (Searchinger et al. 2008).

Moreover, biodiversity loss from (direct and indirect) land use change due to biofuel policy has been of great concern. Biodiversity plays an important role in natural landscapes and ecosystem services for human beings, including, for example, such factors as soil erosion, watershed protection, carbon sequestration, pollination, and pest regulation (Chappell and LaValle, 2011; Hooper et al., 2005). A dramatic increase in biofuel crop cultivation, it is feared, would drive biodiversity loss from direct and indirect land use change, as well as putting pressure on food crop area expansion, especially in biodiversity hotspots such Southeast Asia (Edenhofer et al., 2011; Phalan, 2009; Sodhi et al., 2010).

Not only is natural biodiversity a concern, but also biological diversity in agricultural areas including the variety and ability of plants, animals, and microorganisms to thrive in term of richness, evenness, and ecosystem functions (Jarvis et al., 2013). In addition to biodiversity loss from deforestation, the biodiversity in agricultural ecosystem, addressing sustainable agricultural production systems and ecosystem services, should be considered as well.

The Thai government's ethanol production target for 2022 is expected to push up cassava demand, and cultivation area, in a manner that causes land use change. This study aims to

investigate the impact that cassava area movements resulting from the projected land use change associated with increase in ethanol production in Thailand will have on environmental factors, especially soil carbon sequestration. Moreover, the influence of this land use change on other GHGs emission and biodiversity will be assessed and discussed.

In the next section, a background of the study's approach will be provided. Then, in the following section, methods and data will be considered. After that, results from the simulation model of soil carbon sequestration, other GHGs emission, and biodiversity will be presented. The last section will provide discussion and conclusions.

3.2 Background

Many countries have promoted bioenergy production because of its impact on energy security, its reduction of government expenditure, its supporting of major agricultural products and its positive environmental impacts, especially in Asia (Zhou and Thomson, 2009). There has been little doubt that bioenergy supports domestic economic development. Its impact on the environment, however, is still quite controversial. Numerous life cycle analysis (Lapola et al.) studies show bioenergy products provided positive net energy and environmental impacts via reductions in GHGs emission. On the other hand, some studies have found a negative impact, especially when considering indirect land-use change (Bureau et al., 2010; De Souza et al., 2010; Farrell et al., 2006; Hill et al., 2006; Larson, 2006; Searchinger et al., 2008; Shapouri et al., 2002).

Direct and indirect land-use change (DLUC and ILUC) determine the environmental cost of ethanol production. While DLUC is easier to investigate using methods of LCA, ILUC has been more difficult and needs, in principle, to be considered on a global scale, given international

trade and global climate factors. ILUC might be considered a “leakage” or displacement effect, as local agriculture, economics, and environmental conditions change in response to global conditions. Especially, environmental changes such soil quality, land quality, and water availability directly affect ecosystem productivity and resilience (Van Stappen et al., 2011).

The impacts of DLUC from the Brazilian biofuel mandate on sugarcane and soybean production on soil carbon payback time were analyzed over 4-year and 35-year periods respectively. The carbon payback times were found to increase by 62 and 301 years when considering ILUC due to deforestation (Lapola et al., 2010). Moreover, due to the impact of ILUC, (Melillo et al., 2009) suggest that increase of intensive cultivation was preferred to land use expansion when considering GHG emissions from cellulosic feedstock cultivation.

However, the concept of ILUC could lead to double counting of GHG emissions due to uncertainty. While ILUC should be included in sensitivity analysis, the impact of DLUC should normally be included in LCA (Pawelzik et al., 2013; Zilberman et al., 2011).

Biofuel policy has driven environmental impact. For example, ethanol targets in the U.S. has pushed the expansion of corn cultivation and increased nitrogen use as source of GHG emission (Khanna et al., 2010). In Thailand, our scenarios (calculated in Chapters 1 and 2) show that the Thai government’s ethanol target make cassava cultivation area change by adding cassava from existing rice and corn areas. Previous studies have also stated that in Thailand cassava cultivation would increase by replacing sugarcane areas (Silalertruksa et al., 2009; Ubolsook, 2010). The soil organic carbon (North Eastern Tapioca Trade Association) loss under cassava cultivation could significantly contribute to net GHGs emission. Moreover, increase in fertilizer use may also induce GHGs emission via greater nitrous oxide emissions due to higher fertilization rates and runoffs (Bureau et al., 2010; Hill et al., 2006; Melillo et al., 2009).

In Brazil, the shifting cultivation land in semi-arid area for six years reduced soil organic matters (Vongkasem et al.) by 10 tC per ha or 30 percent (Tiessen et al., 1992). In the eastern Thailand, the SOC loss due to conversion from dry evergreen forest to corn cultivation decreased $6.97 \text{ Mg C ha}^{-1} \text{ y}^{-1}$ within 12 years (Jaiarree et al., 2011). Converting previous crops to cassava also alter and release SOC to harvested crop biomass or the atmosphere. The cassava cultivation in Thailand consumed a lot of potassium, but less of nitrogen and phosphorus; soil erosion, causing of SOM loss, however, was the important effect from cassava cultivation. The continuously productive cassava yield would be stable only if added enough fertilizers and having soil erosion control (Howeler, 1991; Putthacharoen et al., 1998). Moreover, a paper showed that SOC change from cassava cultivation also depends on management practices and harvest manner. The tilling practice for cassava cultivation by ploughing elimination could reduce soil erosion impact and SOC loss, but maintains fresh root production (Ohiri and Ezumah, 1990).

There are many models that estimate SOM depending on different datasets and with different final results. (Smith et al., 1997) compare nine soil organic matter models using twelve datasets, seven long-term experiments within three land-use types, and three different treatments in each plot. The study show that RothC and CENTURY model, sharing the same basic idea, data, and results, were the popular models to investigate plant growth and SOM in agricultural crop area, forest, and grassland. The study of comparison among CENTURY, RothC, and combining RothC and Century model in UK, Hungary, and Sweden showed that the RothC model was better than CENTURY based on only datasets and regions in this study (Falloon and Smith, 2002). These two models still needed to improve in net C input and SOM decomposition sub model. However, there were many papers applied these two models to evaluate SOM change

due to biofuel crop expansion. (Shirato et al., 2005) applied RothC with long-term data (28 years) to investigate SOM of maize and cassava cultivation in the Northeastern Thailand. The result was overestimate in tropical soils with large added organic matter. On the other hand, CENTURY model, estimating SOC of jute, rice, and wheat in semi-arid and dry region in India, was better in semi-arid region, but it was overestimate in humid site (Bhattacharyya et al., 2007). CENTURY model was also used to evaluate SOC of sugarcane cultivation among different management and harvest and duration practices in Brazil and South Africa (Galdos et al., 2009).

3.2 Method and study data

CENTURY Model

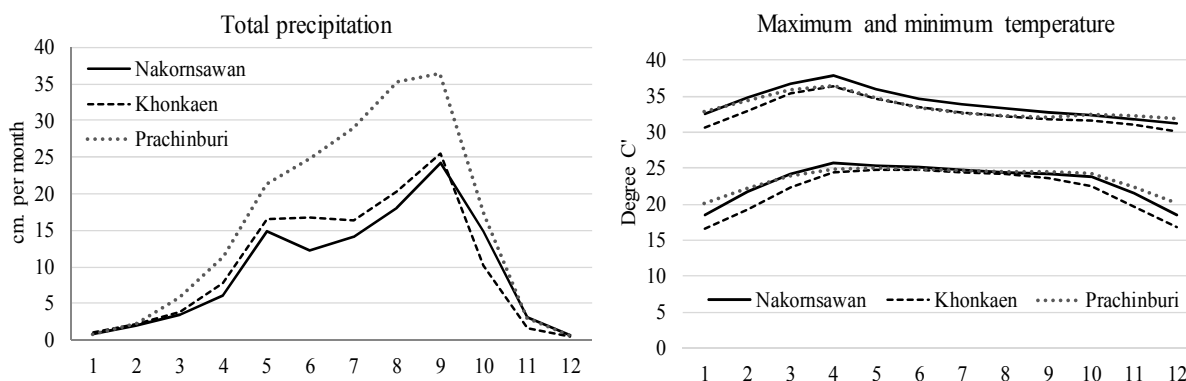
The CENTURY model was first developed at Colorado State University by (Parton et al., 1987), to simulate SOM, especially soil carbon emissions and removals in the Great Plains grasslands of the U.S. (Denef et al., 2011). The model basically requires monthly weather data, such as average, maximum, and minimum temperatures and precipitation. Additionally, it also needs data on soil textures and plant attributes, such as lignin content, C:N ratio, and plant productivity (Metherell et al., 1993). The CENTURY model works with a number of sub-models, for example, of crop parameters, cultivation practices, fertilizer use, harvest methods, irrigation applications, soil quality, fire events, grazing pressure, and weather history. The CENTURY command file provides options of land-use patterns in different types of ecosystems (crops, grasslands, forest, and savannas), and cultivation managements. The mainly results of ecosystem change covered SOC in the top 20 cm. of soil, water balance, and other nutrients' flux related with N, P, and S (Denef et al., 2011). The SOC was transferred to CO₂ release as the key GHGs emission, but N₂O and CH₄ cannot be obtained from this model unfortunately. Moreover,

parameters and the model had been calibrated with several long-term experiment (generally over 10 years) sites in the U.S. Canada and others, many soil textures, different crops, and climate conditions.

Study data

The study area covers land-use change from cassava, rice, corn, and grassland area reallocation based on the suitable cassava areas and cassava demand resulting from the Thai government's ethanol target for 2022, located within the range of 10.9688 to 20.4644 latitude and 97.3554 to 105.6211 longitude. Previous study (Chapter 2) has found that, under the Thai government's policy, current cassava would be switched out of 343,278 hectares, to be replaced by 114,272, 67,353 and 612 hectares of rice, corn, and fallow, respectively. It is estimated that significant shares of abandoned cassava area could be used for rice cultivation. In this study, the major changes of area, from cassava to rice and from grassland as well as from rice and corn to cassava, were investigated.

The monthly weather data (1961 to 2012) were obtained from the Thai (National Climatic Data Center (NCDC)). There are about 30 weather stations located within the study area. During the earlier years of the study's timeframe, three stations, Prachinburi, Nakornsawan and Khonkaen, represented the major separate weather zones in the study area. However, the average monthly weather data from 1961 to 2012 in the north and northeast area, represented by Nakornsawan and Khonkaen station correspondingly, are quite similar, as showed in Figure 3.1. Thus, only two stations, Prachinburi and Khonkaen, were chosen to represent east and the rest of Thailand respectively.



Data source: (National Climatic Data Center (NCDC))

Figure 3.1 The average of monthly total precipitation (a), monthly maximum and minimum temperature (b) in Nakornsawan, Khonkaen, and Prachinburi station from 1961-2012.

Based on soil attribute data from the (Land Development Department, 2010), there are 62 soil types across the study area in Thailand. These soil types were grouped into four main soil texture classes--clayey, sandy, silty, and loamy--as shown in Table 3.1. The percent of soil elements or particle-size distribution was approximated by USDA soil class system. The bulk density values were calculated from percent of soil texture value.

Table 3.1 Soil texture classes and bulk density

Soil	% of sand	% of silt	% of clay	Bulk density
Clayey	25%	23%	52%	1.13895
Loamy	35%	35%	30%	1.23094
Silty	22%	65%	13%	1.32094
Sandy	70%	23%	7%	1.48943

Source: (Land Development Department, 2010; National Climatic Data Center (NCDC)) based on USDA

The cassava, rice, corn, and soybean cultivation systems were reviewed from previous studies in Thailand. For the cassava, the planting season is around April-May. Fertilizer is applied at the planting process, and the product will be harvested in January-February normally

(Howeler and Hershey, 2002; Tongglum et al., 2000). The corn is planted around the same time with cassava, but it takes about only four month for harvesting (Ekasingh et al., 2004). After the corn, soybean could be cultivated. The soybean from planting to harvesting takes only about 2 months (Department of Agricultural Extension). Meanwhile, the seasonal rice is grown around June, with two fertilizers applications, and harvested in November to December as showed in figure 3.2.

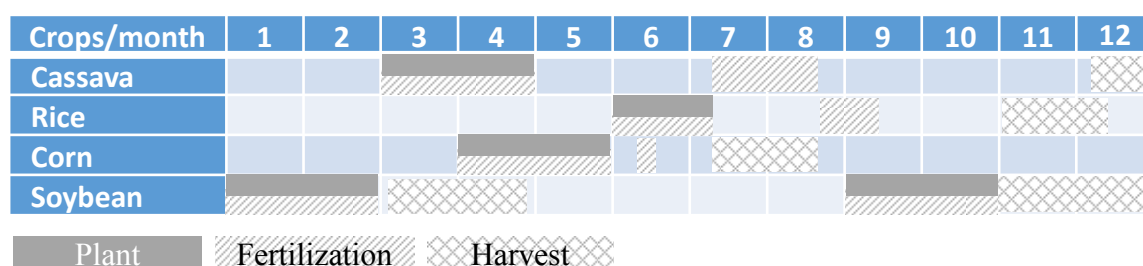


Figure 3.2 Schedule of cassava, rice, corn, and soybean cultivated pattern in Thailand.

Normally, the cassava in Thailand is cultivated in the nutrient poor areas, because of the crop's lower nutrient and water requirements compared to other major crops. However, to produce cassava in a high yield situation, the cassava crop extracts a large amount of nutrient from the soil. Moreover, it also causes severe soil erosion, a significant impact on soil degradation (Howeler, 1991; Putthacharoen et al., 1998). When investigating SOM change from cassava cultivation, the magnitude of soil erosion should be considered.

A number of studies investigate soil erosion from cassava grown in Thailand and Asia, as shown in Table 3.2. The high soil loss from erosion in China and Vietnam was from high rainfall during the beginning of cassava growing season (Howeler et al., 2001). In case of Thailand, soil loss ranged from 18 to 75 tonnes/ha/year, within different locations and experiments. In this study, we used the average value of 41.75 tonnes/ha/year to represent soil erosion in Thailand.

Table 3.2 The soil loss from cassava cultivation in Thailand and other countries in Asia.

Experiment conditions	Location	Soil loss (t/ha/year)	Precipitation (mm/year)
7% slope in sandy loam soil *	Thailand	75	1,209
5% slope (no specific soil) **	Thailand	53	NA.
5% slope in sandy loam soil ***	Thailand	21	1,400
8% slope in sandy loam soil***	Thailand	18	1,300
5% slope in sandy clay loam soil***	Vietnam	23	2,100
10% slope in sandy clay loam soil***	Vietnam	39	2,100
15% slope in sandy clay loam soil***	Vietnam	105	2,100
12% slope in clay soil***	China	16	1,405
15% slope in clay soil***	China	128	1,800
5% slope in clay soil***	Indonesia	47	2,180
8% slope in clay soil***	Indonesia	42	2,052

Data sources: * (Putthacharoen et al., 1998); ** (Tongglum et al., 2000); *** (Howeler et al., 2001)

Current and historical data of land-use is needed for estimating nutrient movement. In this simulation, current land-use was from GIS land-use database provided by the Thai (Land Development Department). We assume that relevant areas had been tropical forest until 1977, in the lead-up period. In this study, we run the simulation model for 10,000 years to set up an equilibrium of soil nutrients with and without land use changes implemented as a result of the Thai government's ethanol policy. After that starting phase, the forest was assumed to have been clear cut and has transformed to the current crops observed as of 2012. After 2013 and up to 2022, a new land use pattern will have been reallocated as according to our scenario. The experiments assumed that some areas of cassava were transferred to rice and grassland, while some areas of rice and corn were transferred to cassava. Mixing each land-use change with the weather conditions and the four soil types, SOC is estimated. Moreover, we assumed that rice and corn are cultivated for only one rotation per year, after that soybean is grown. The results show estimated SOC alterations after reallocating land for the long run.

3.3 Result

Based on the scenario of land use change due to the Thai government's ethanol target, the major direct land use changes were conversion of rice and corn to cassava area. At the same time, some lower yielding cassava land was switched out to rice and grassland. The results in this section presented SOC change due to this scenario using CENTURY model within four soil types and two weather patterns. The history of land use was separated into three periods, including initial forest, current crops, and the subsequent experience following the land use changes due to cassava intensification. The first period was assumed to be a tropical forest until 1977. After that, current crops, including cassava, rice, and corn, were introduced. Then, the land use change, as the primary experiment, was started from 2012. The SOC change was investigated over different time frames, ranging from 2013 to 2112, and was transferred to a unit of CO₂ equivalence as GHG emission.

Moreover, the impact on nitrous oxide (N₂O) and methane (CH₄) emissions, as well as on biodiversity, all due to the land use change scenario are also discussed.

SOC sequestration

According to the land use change scenario from the algorithm in Chapter 2 areas transferred to cassava were mostly from clay, silt, and sandy soils characterized by the weather data from the Khonkaen station (Table 3.3). Meanwhile, the areas were switched out of cassava were mostly sandy and clay soil types. The areas switched out of cassava cultivation were mostly unsuitable for cassava cultivation. They were assumed to be converted to rice paddy, as recommended by their soil types based on LDD database. Meanwhile, the rest of the areas were assumed to be converted to grasslands, since they were designated by the LDD as high slope, flood prone, ridge line, and non-agricultural area.

The results from the CENTURY model show that transferring rice to cassava caused the greatest loss of SOC in the long run, 30 years after the land was reallocated (Table 3.4). (More details from the CENTURY analysis are shown in appendix 2. In particular, greater SOC change was realized, the longer the time-period considered.) On the other hand, SOC is only slightly changed when corn is reallocated to cassava area. Switching out area from cassava to rice and grassland provides significant SOC sequestration.

Table 3.3 The modelled scenario of land use reallocations in Thailand, based on weather and soil types.

Weather station	Soil textures	Reallocated area (ha)			
		Corn to cassava	Rice to cassava	Cassava to rice	Cassava to grassland
Khonkaen	Clayey	82,722	57,986	33,709	11,155
	Loamy	527	275	5,417	123
	Silty	21,419	72,918	3,959	23
	Sandy	11,247	99,569	112,385	131,234
Prachinburi	Clayey	150	3,205	14,928	26
	Loamy	32	39	5	0
	Silty	8	21	2,362	1,520
	Sandy	13	24	20,874	5,608
Total		116,118	234,036	193,638	149,689

Table 3.4 SOC loss or gain for each regional climate and soil types over the long run (30 years), given different coping changes

Weather station	Soil textures	Reallocated area (ha)			
		Corn to cassava	Rice to cassava	Cassava to rice	Cassava to grassland
Khonkaen	Clayey	-0.138	-0.624	1.330	6.065
	Loamy	0.220	-0.768	1.247	5.101
	Silty	0.280	-1.919	2.307	5.491
	Sandy	0.834	0.495	-0.463	3.374
Prachinburi	Clayey	-0.113	-0.948	1.716	5.572
	Loamy	0.346	-1.721	2.216	4.278
	Silty	0.399	-2.267	2.717	4.727
	Sandy	0.734	-1.022	1.073	2.316

In table 3.5, since one tonne of carbon equal to 3.67 tonne CO₂, the SOC and land use change together were conducted to CO₂ emission. The reallocated land for cassava due to Thai ethanol target, out to 2043, could accumulatively decrease CO₂ emissions about 4 million tonne. In this time period, transferring rice to cassava area increased CO₂ emission about 90,220 tonnes CO₂, but switching to cassava from corn decreased CO₂ emissions. Moreover, the area converted from corn to cassava was just about a half of that converted from rice to cassava. The increase in CO₂ emission from rice was simply offset by CO₂ reduction from corn. On the one hand, replacing cassava with rice area create CO₂ reduction. Most of CO₂ reduction in this

scenario was from switching of cassava to grassland, about 3 million tonnes of CO₂. Thus, it could be implied that the cassava yield improvement based on using best suitable land making cultivation area shrink was a significant solution to reduce CO₂ emission in cassava production.

Table 3.5 The SOC loss or gain in term of CO₂ emission from reallocated area over long run (tonne CO₂)

From\To	Cassava	Rice	Grassland	Total
Cassava	-	17,217	144,957	162,175
Rice	-35,513	-	-	-35,513
Corn	1,114	-	-	1,114
Total	-34,399	17,217	144,957	127,775

Nevertheless, in agricultural sector, the significant GHGs emission is not only CO₂, but also N₂O and CH₄. Following IPCC, values of GHG emission as global warming potential (GWP) at 100 years from N₂O and CH₄ are much higher than that from CO₂, about 298 and 25 times in the order (Solomon, 2007).

N₂O emission

In the U.S., GHGs emission from crop cultivation was about 53 percent of all emission in agricultural sector; moreover, N₂O and CH₄ shared about 80 and 15 percent of total cropland GHG emission (U.S. Department of Agriculture, 2008). The N₂O was significantly from nitrogen input in the fertilizer. The sources of N₂O was uncertainty due the complexity of soil processes, moisture soil microbes, fertilization, etc. (Nakicenovic and Swart, 2000). However, the IPCC suggested the default value of N₂O loss at 0.03 percent (range from 0 to 0.6 percent) and 1 percent (range from 0.03 to 3 percent) nitrogen (N) fertilizer application per year for paddy rice and other crops respectively (Eggleston et al., 2006). The study of direct N₂O emission from agricultural land, mostly in the U.S. and Europe, showed that the 43 out of 87 experiments were

closed to default value of 1 percent on N fertilizer application (Bouwman, 1996). Thus, this study applied the N₂O default factor from IPCC to measure N₂O emission. The N₂O emission dramatically decreased from switching out corn area due to the huge area change (Table 3.6). However, N₂O emission slightly increased from added cassava cultivation. Moreover, the N fertilizer application in cultivated corn was about twice in cassava. It could be implied that the corn areas released more N₂O than cassava area for the same area.

Table 3.6 The N₂O emission or (reduction) from cassava, corn, and rice cultivation based on the scenario (tonne N₂O per year)

Crop change	N use (kg/ha/year)	Removed areas		Added areas		Total
		Area	Estimated N ₂ O	Area	Estimated N ₂ O	
Cassava	8	343,328	(27.82)	350,155	28.37	0.55
Corn	16	116,118	(18.00)	-	-	(18.00)
Rice	14	234,037	(10.15)	193,639	8.40	(1.75)
Total N₂O emission or (reduction)		(55.97)		36.77		(19.20)

Moreover, the more moisture climate and more SOM condition, as in clay or peat soil, as well as higher temperature trended to produce more N₂O (Lesschen et al., 2011). Thailand, where was wet and hot climate condition, could induce more N₂O emission than the default value. In addition, the crops' yield improvement, usually responding to fertilizer use, also increased N₂O emission; some papers, however, mentioned that the fertilizer use likely decreased in 1990's and N₂O emission rate would not increase in the agricultural sector (Nakicenovic and Swart, 2000)

CH₄ emission

The only real source of estimated CH₄ emissions in this study are rice paddies. Methane is released by bubbling from decomposition of submerged soil organic matter and diffusion losses from the water surface (U.S. Department of Agriculture, 2008). Generally CH₄ emissions are smaller in the U.S. due to a small share of rice paddies; in Thailand, on the other hand, rice paddies cover a major share of the agricultural land area.

CH₄ emissions are driven by many uncertain factors, such as climate, farm practices, fertilizing, added organic matter, and harvest conditions. A number of studies investigate CH₄ emission from rice paddies, both in the U.S. and Asia, and especially in Thailand (Table 3.7). The estimated CH₄ emission from primary rice cultivation in the U.S. was about 210 (ranging from 22 to 479) kg of CH₄ per hectare per year, while the second crop was higher, about 780 (range from 481 to 1490) kg of CH₄ per hectare per year (U.S. Department of Agriculture, 2008). In India where fertilizer was applied as in this scenario, the CH₄ emission was 96 to 101 kg of CH₄ per ha (Pathak et al., 2005). In China, the average CH₄ emission from local crop management without organic matter added was about 136 (ranging from 53 to 239) kg of CH₄ ha (Lu et al., 2000). These values differed from water management, seasonal, cultivars, and fertilizer use.

Table 3.7 The CH₄ emission or (reduction) from cassava, corn, and rice cultivation based on the modelled land use change scenario (tonnes of CH₄ per year)

Experiment conditions	Location	CH ₄ emission (kg/ha/season)	References
Irrigation experiment*	Louisiana	285	(Banker et al., 1995)
120-180 kg per ha of N fertilizer	India	96-101	(Pathak et al., 2005)
Local management (no organic matter)	China	136	(Lu et al., 2000)
Globally modelling estimation in Thailand	Global	164-444	(Cao et al., 1996)
Rained rice in acid sulfate field	Thailand	8	(Jermasawatdipong et al., 1994)
Rained rice in alluvial field	Thailand	135	(Jermasawatdipong et al., 1994)
Rained rice in low humid field	Thailand	467	(Jermasawatdipong et al., 1994)
Rainy seasonal rice	Thailand	72.75	(Yagi et al., 1994)
Rained rice	Thailand	105	(Chareonsilp et al., 2000)

* Estimated at 94 flood days per season (Yagi et al., 1994)

Meanwhile, in Thailand, emissions varied from 8 to 467 kg of CH₄ per ha. (Cao et al., 1996; Chareonsilp et al., 2000; Jermasawatdipong et al., 1994; Yagi et al., 1994). The lowest emissions level was in acid soil which normally releases a low rate of CH₄. Meanwhile, most studies found emissions to be higher than 100 kg CH₄ per ha. Comparing to the default value of CH₄ emission from IPCC was about 1.30 (range from 0.80 to 2.20) kg CH₄ per ha per flooding day (Intergovernmental Panel on Climate Change (IPCC), 2006) and the average flooding day of rice cultivation at 94 days (Yagi et al., 1994), the default value of CH₄ emissions was calibrated at 122 (range from 75 to 207) kg CH₄ per ha.

The calculation of CH₄ emission from reallocated rice area is shown in Table 3.8. The CH₄ emission could increase 9,903 (ranging from 6,094 to 16,759) tonnes of CH₄ per year due to increase in rice cultivation area.

Table 3.8 The CH₄ emissions increase or reduction from rice cultivation area based on the modelled land use change scenario (tonne CH₄ per year)

Emission factor (kg/ha/day)	Flooding days per year	Removed rice area		Added rice areas		Total
		Area (ha)	CH ₄ (reduction)	Area (ha)	CH ₄ emission	
0.80	94*	234,037	(17,600)	193,639	14,562	(3,038)
1.30	94*		(28,599)		23,663	(4,937)
2.20	94*		(48,399)		40,045	(8,354)

* Average flooding day in Thailand (Yagi et al., 1994)

However, CH₄ emissions depend on many factors. For example, water management with continuous flooding in early season and long flooding period and organic matter add significantly to CH₄ emissions (Dowling and Fischer, 1998). The spatial value of CH₄ emission in Thailand could be higher or lower than the default value due to the cultivation management.

Total GHGs emission

Due to the fact that the different GHGs provided varied impact on global warming, the GWP was introduced to compare different sources of GHGs. Based on IPCC, GWP at 100 years from N₂O, and CH₄ were 298 and 25 times of that from CO₂, in the order. Table 3.9 shows the net GHGs emission from different estimated GHGs based on the completion of land-use change over 10, 30, and 50 years from 2013 respectively. The results highlighted that all GHG emissions are mostly reduced because of switching out area from cassava to grassland and eliminating N fertilizer application. In the same way, CH₄ emission decreased due to the absolute decrease in rice area. When considered to cassava-based ethanol production at 5.68 million liters a day, the land reallocation reduced GHGs emission about 0.063 to 0.067 kg CO₂ eq. per liter of cassava ethanol in different time-period. The GHGs emission per ethanol liter more decrease in longer time-period due to the impact of CH₄ reduction, from rice cultivation area decrease.

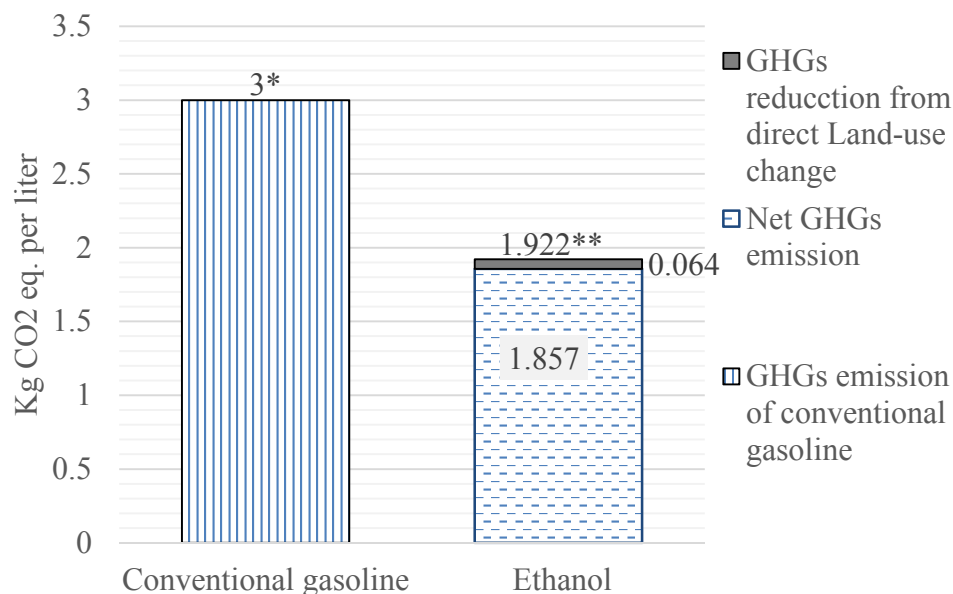
Table 3.9 Accumulated net GHGs emission increase or (reduction) based on the direct land use change in term of GWP (tonne CO₂ eq.) in 10, 30, and 50 years from 2013

GHGs Emission	10 years	30 years	50 years
CO₂	(101,870)	(127,775)	(122,117)
N₂O	(57,210)	(171,629)	(286,049)
CH₄*	(1,234,159)	(3,702,477)	(6,170,782)
Net total	(1,393,238)	(4,001,882)	(6,578,961)
kg CO₂ eq / liter of ethanol**	(0.067)	(0.064)	(0.063)

* CH₄ was estimated at 1.3 kg CH₄/ha/day

** Estimated from 5.68 million liter a day of cassava-based ethanol

GHGs emission from conventional gasoline in Thailand was reported at 3.00 kg CO₂ eq. per liter (Nguyen and Gheewala, 2008). Meanwhile, the emission from sole cassava-based ethanol processes was about 1.922 kg CO₂ eq. per liter (Silalertruksa and Gheewala, 2009). The impact of direct land use change on GHGs reduction from reallocated suitable area was about 0.064 kg CO₂ eq. per liter, figure 3.3. Combining both ethanol processes and direct land use change, the GHGs emissions from cassava-based ethanol were about 62 percent of that from conventional gasoline. Thus, this study showed that the ethanol introduction of 9 million liter a day from the Thai government's target, mainly increase in cassava feedstock, was probably still friendly with environment in term of GHGs emission.



Data source : * (Nguyen and Gheewala, 2008)
 ** (Silalertruksa and Gheewala, 2009)

Figure 3.3 GHGs emission from cassava-based ethanol relative to that from conventional gasoline in Thailand.

This result showed GHGs emission from direct land use change due to the introduction of cassava-based ethanol in Thailand. However, the consequential impact of indirect land-use change on GHGs emission could not be ignorable (Khanna et al., 2011; Lapola et al., 2010; Searchinger et al., 2008). The impact of indirect land-use was investigated by deforestation from food cultivation area that replacing by energy crops. However, this land reallocation scenario based on most suitable cassava area stated that the cassava plantation area could raise 8 thousand ha, as well as rice cultivation area could shrink only 40 thousand ha. Thus, the competition between energy crop and food security might not be strongly observed. The impact of indirect land-use change on GHGs emission in Thailand could reasonably be not huge. Instead of GHGs emission, biodiversity loss due to the indirect land use change form energy crops was one of the concern on sustainability (Fargione et al., 2010).

Biodiversity

Biodiversity loss due to the indirect land use change from bioenergy crops introduction has been a significant concern, especially in tropical areas such Malaysia and Brazil. Direct land use change from sugarcane cultivation in Brazil only lightly impacted biodiversity due to the fact that it mostly just replaced already existing food or pasture areas. Indirect land use change, however, could be considered to play an important role in biodiversity loss (Svensson, 2011). In the U.S., a meta-analysis of biodiversity change in energy crop areas showed that land use change from natural habitat to corn cultivation caused negative impact on vertebrate diversity (Fletcher Jr et al., 2010).

Meanwhile, the Indo-Burma region, including Thailand, containing 2.3 percent and 1.9 percent of global plant and vertebrate species, respectively, is one of the most biodiverse hotspots in the world (Myers et al., 2000). Moreover, a high proportion of plant and vertebrate species are threatened due to deforestation (Sodhi et al., 2010). The prediction of biodiversity loss from the northern Thailand by 2050 mainly was from high habitat loss due to deforestation and development of transportation or roads (Trisurat et al., 2011). Land fragmentation was a plausible cause of biodiversity loss in Brazil as well (Svensson, 2011).

The results in this study suggest that the cassava cultivation area was slightly increased due to yield improvements from reallocation of cassava cultivation onto better quality lands. Thus, the impact of direct land use change on deforestation and biodiversity loss would not be consistent with this scenario. Meanwhile, some rice and corn areas were transferred to cassava areas that could raise the probability of deforestation from indirect land use change; however, some areas of cassava were also shifted to rice at the same time. The results showed a slightly

net decrease in rice cultivation area. Thus, the impact of indirect land use change due to the food area replacement could be insignificant.

Historically, during the 1970s to 1980s, cassava expansion had been the major case of biodiversity loss by deforestation, especially in northeastern Thailand, due to the fact that the Thai government encouraged agricultural area expansion to defend against communist invasion (Howeler et al., 2001). However, forest area is quite stable, or even gradually increased, nowadays.

It should be noted that this land use scenario does not enhance deforestation. So, any biodiversity issue that is raised here would result from change of agricultural biodiversity based on differences between cultivated crops. In term of agricultural ecosystem, rice fields are one of the most rich in terms of biodiversity within the cultivation area, both of fauna and flora (Bambaradeniya and Amarasinghe, 2004). A number of studies report species richness from rice paddies in Sri Lanka (Bambaradeniya et al., 2004), Thailand (Choosai et al., 2009), and Indonesia, Philippines and Laos (Halwart et al., 2007). Not only does the biodiversity richness in paddy field provide ecosystem services, but also it provides local sources of protein from fish and animals living in the paddy fields (Halwart et al., 2007; Jarvis et al., 2013). This scenario suggests increased cassava area, but somewhat net decrease in rice area. Thus, it could be implied that agricultural biodiversity could be degraded from this scenario. However, one study suggested that the bioenergy crops could be beneficial to biodiversity if they were placed on suitable area and improved climate change mitigation, while the main negative impact of bioenergy crops on biodiversity was due to pollution from fertilizer use (Chappell and LaValle, 2011).

3.4 Conclusion and discussion

The Thai government enacted the national ethanol target at 9 million liters per day in 2022 to support rural economic development, promote national energy security, and improve environmental sustainability. Our previous analyses argues that meeting the target could be economically and politically feasible. Consequently, the cassava demand, ethanol feedstock, as well as cassava cultivation area could be significantly increased. The impact of this policy on environment was however obscured. This study shows that based on a method of reallocating suitable lands for cassava cultivation, increases in cassava demand for meeting the Thai ethanol target does not put unreasonable impacts on the environment in terms of overall GHGs emission as well as biodiversity.

Based on this scenario, the SOC change was determined by the CENTURY model. The results show that SOC is increased by about 0.13 million tonne CO₂ eq. over the long run, 30 years from 2013. Due to the fact that the most unsuitable area for cassava and other crops is likely to be switched to grassland, which dramatically increased carbon sequestration. As well, the net N₂O from land-use reallocation, estimated by IPCC's default value, declined about 19 tonnes N₂O per year because reduction of N fertilizer use from crops pattern change and cultivation area falloff. However, the CH₄, deducted from IPCC's default value and solely in rice paddies, declined by 4,937 tonnes CH₄ per year as a result of net decrease in rice cultivation area. The overall GHGs reduction in term of GWP during 30 years from this land use change was about 4 million tonnes CO₂ eq. that shrined GHGs emission 0.064 kg CO₂ eq. per liter of cassava-based ethanol in Thailand. Summarily, including both ethanol production processes and direct land use change, the GHGs emission from cassava-based ethanol production was lower than that from sole conventional gasoline about 38 percent. Finally, the biodiversity was

probably not loss based on the scenario because there was not induced direct deforestation. Moreover, the grassland area, being mostly advantageous to biodiversity than cassava plots, were increased. However, the somewhat decrease in rice could not induced a pressure of food security. The biodiversity loss due to both direct and indirect land use change from cassava-based ethanol promotion in this scenario was sensibly not a significant anxiety.

Nevertheless, the GHGs emission from crops' cultivation was highly sensitive to farm management practices, climate conditions, and other interacting factors. These GHGs emission results represent reasonably approximate guidelines, not actual expected values. More concrete estimates could be conducted by calibrating the model's results with field experiments. Unfortunately, there are few studies of SOC change in crops' cultivation areas in Thailand.

The impact of indirect land use change on GHGs emission and biodiversity was a significant concern, especially in tropical areas such as Brazil. The indirect land use change was not measurable from direct investigation without interaction among economics activities, international trade, and policy assumptions (Khanna and Crago, 2012). The land reallocation assumption in this study missed interaction of dynamic food and energy crops' price in the future. However, with the oversupply of domestic rice production in Thailand currently, this result could be the reasonable to investigate environmental impact of ethanol expansion. Moreover, the increase in population and consumption could raise a pressure on deforestation, sourcing of GHGs emission and biodiversity loss. To still maintain GHGs reduction and sustainable biodiversity, as well as energy and food security, the other solutions, such increase in efficiency of agricultural production and consumption, should be simultaneously considered (Foley et al., 2011).

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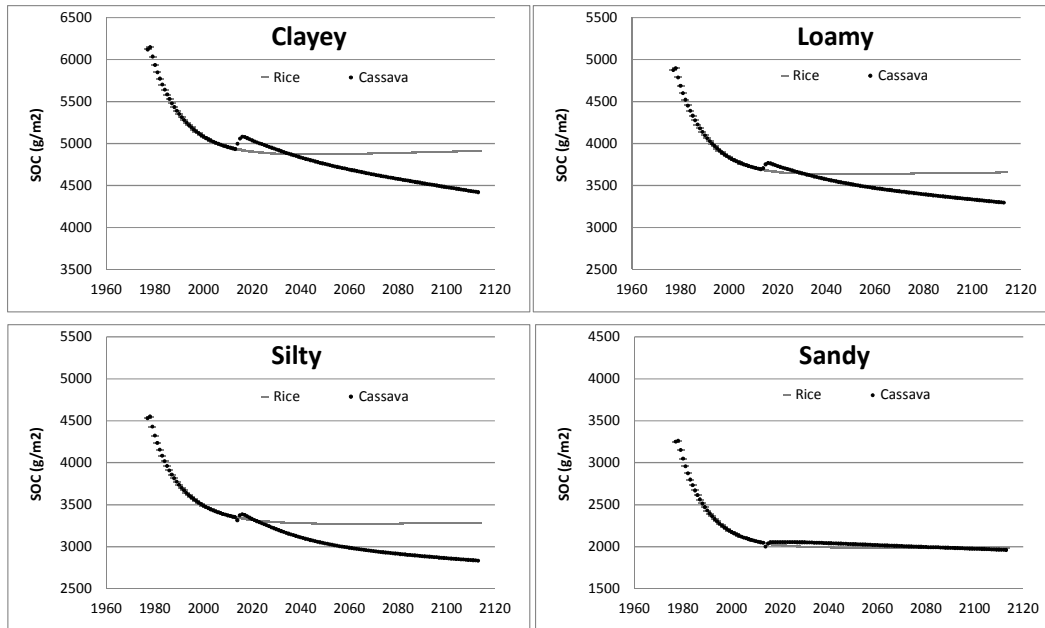
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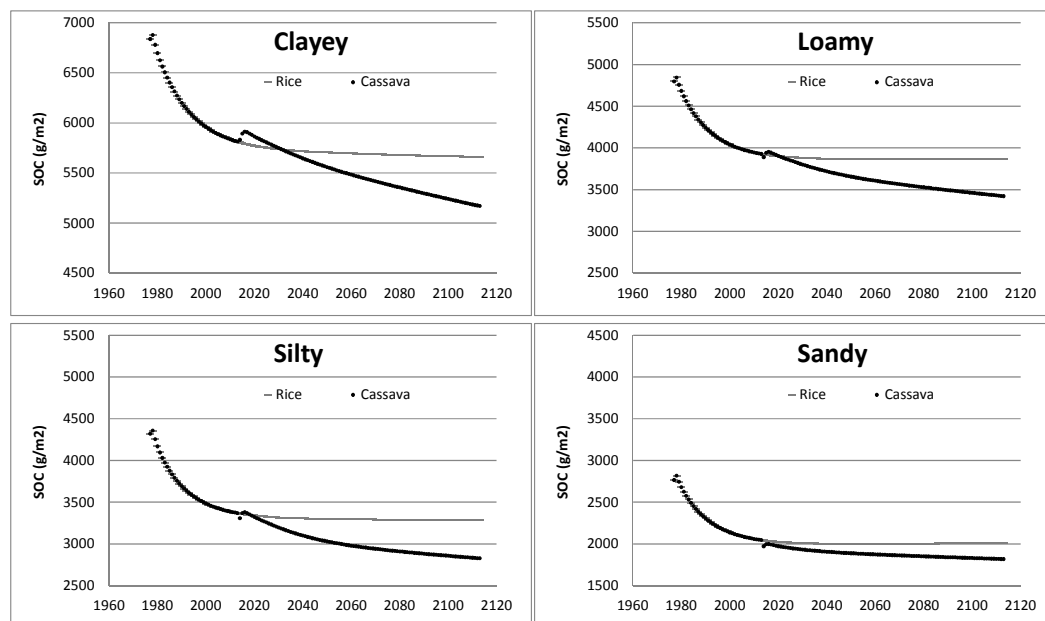
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Appendix

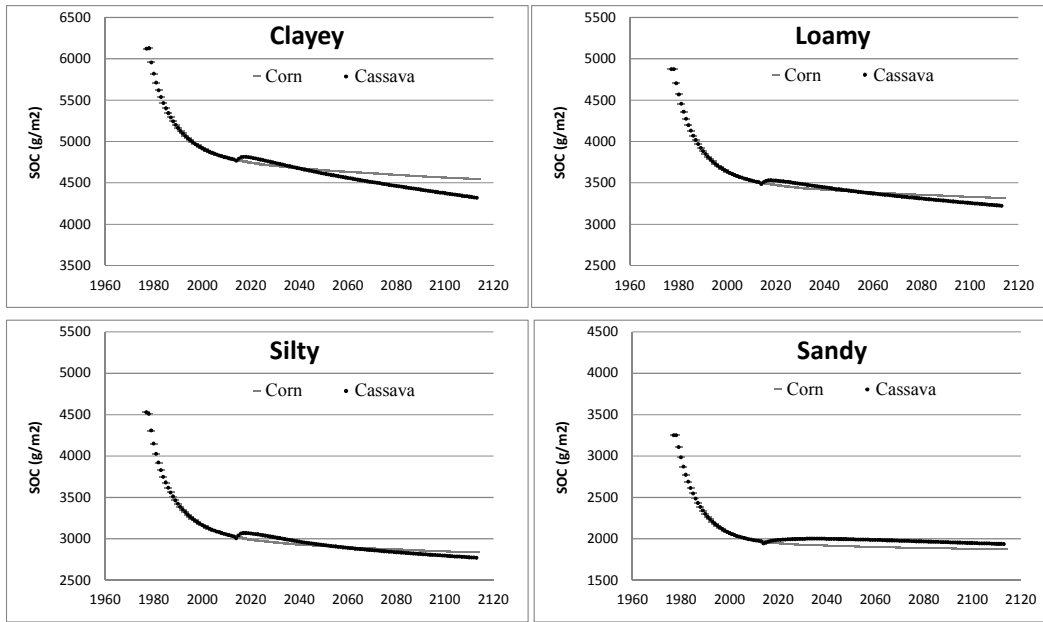


Climate station in Khonkaen

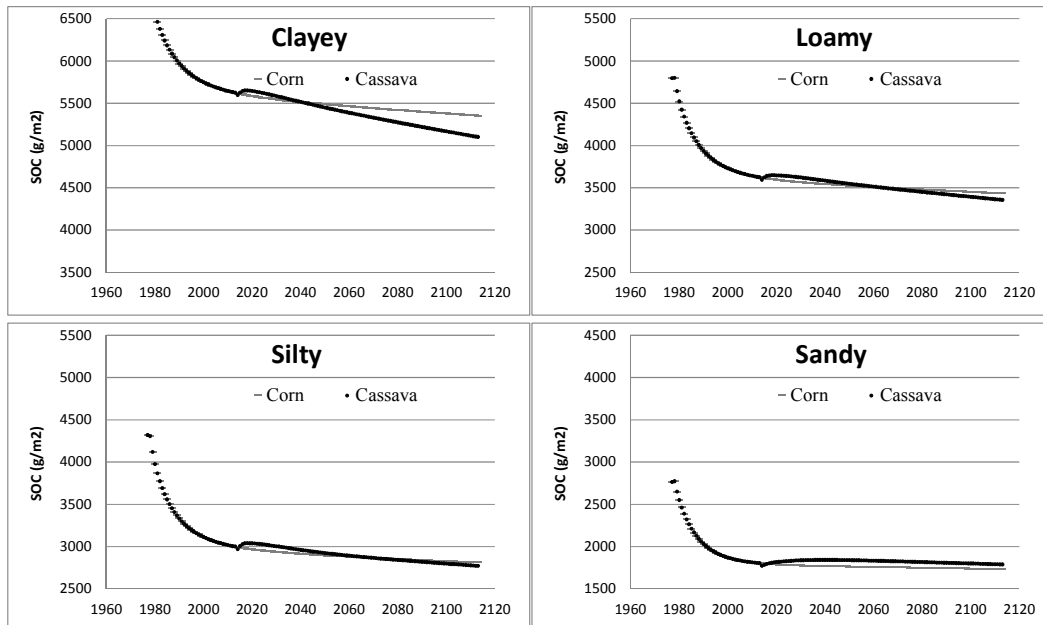


Climate station in Prachinburi

Figure A.1 SOC change from introduction of cassava into rice area, from 1977 to 2113.

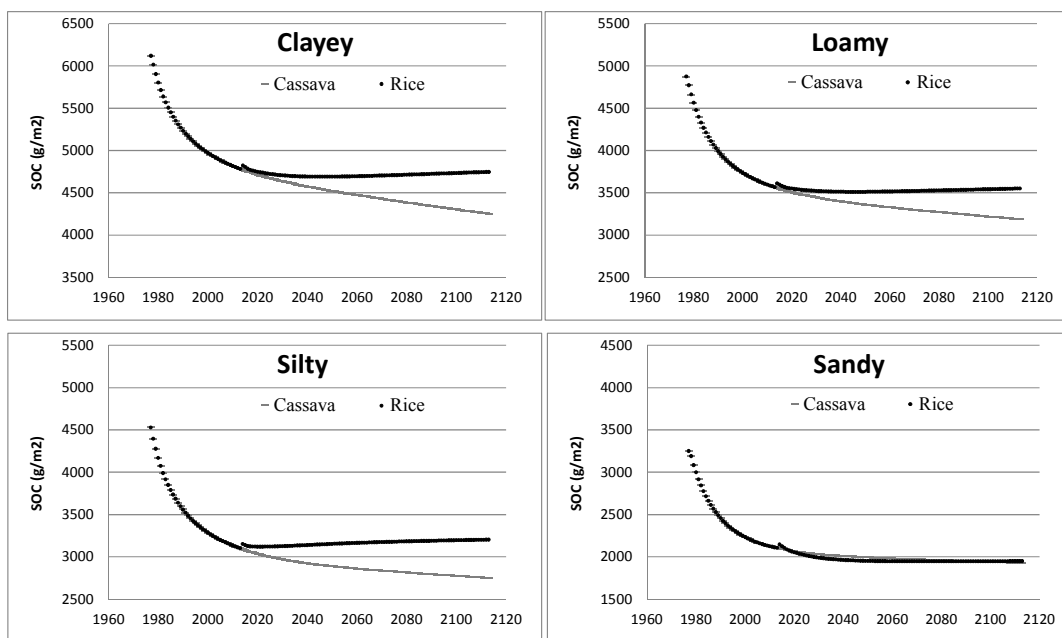


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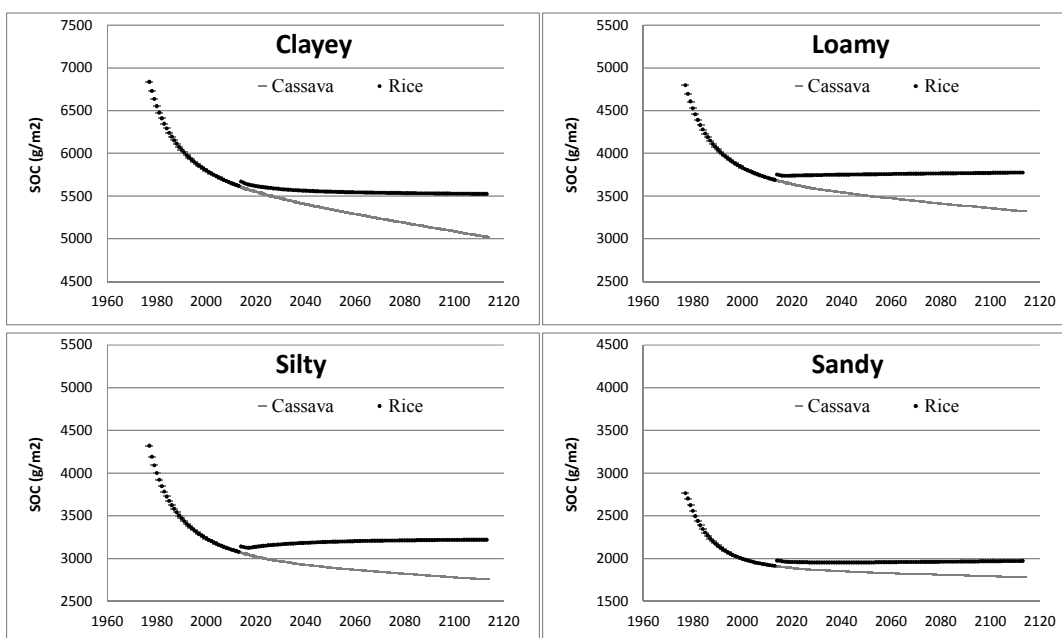


Climate station in Prachinburi

Figure A.2 SOC change from introduction of cassava into corn area, from 1977 to 2113.

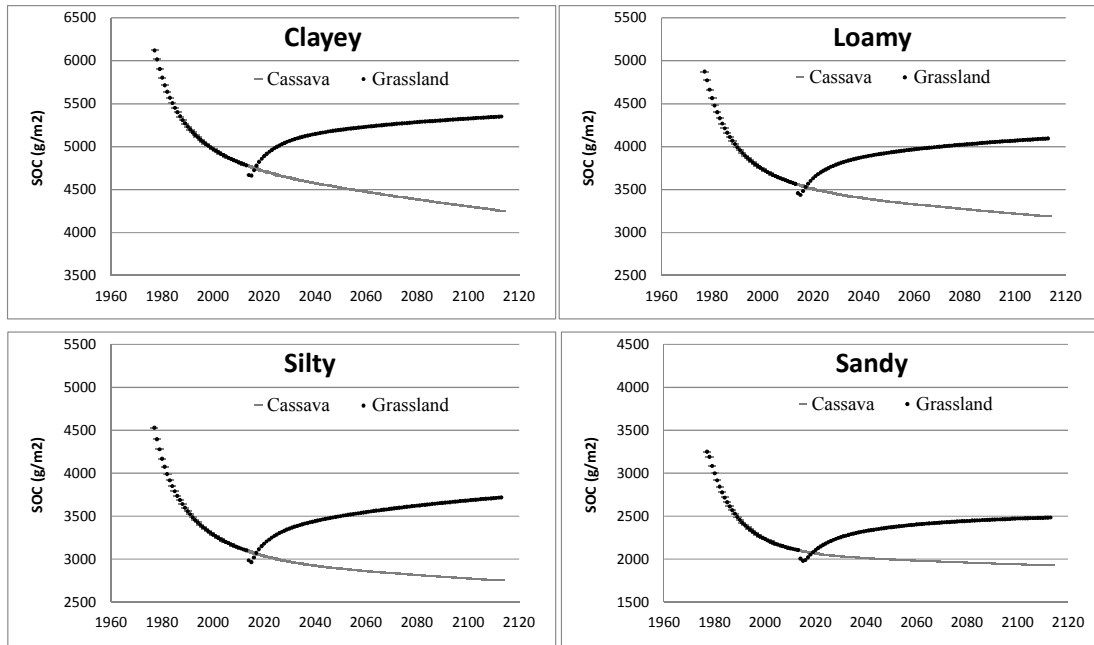


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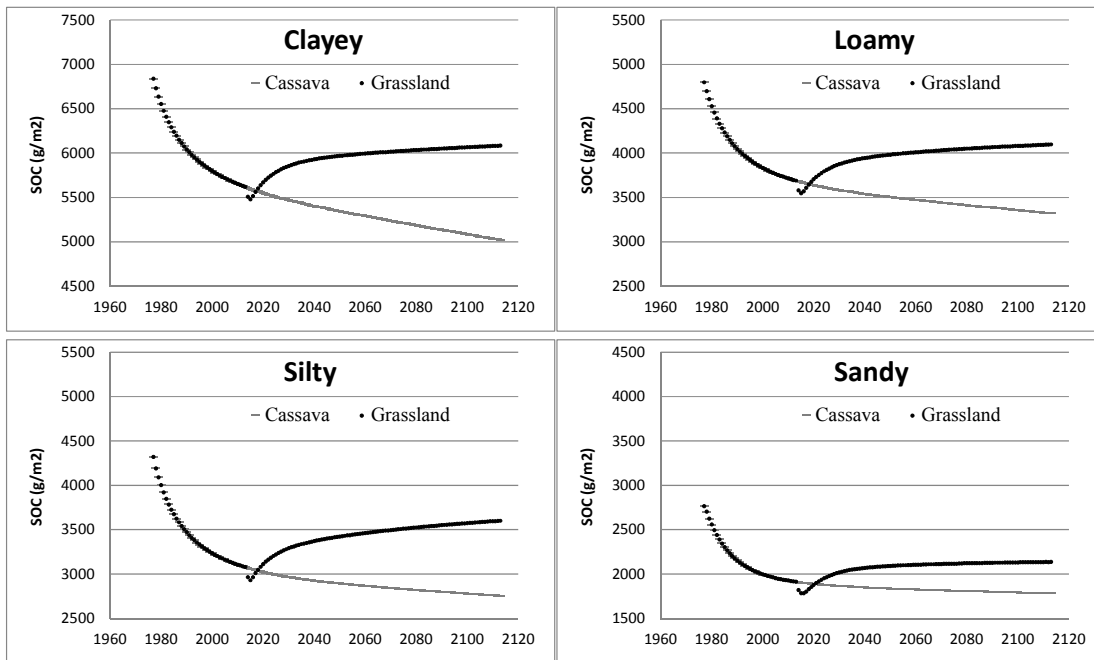


Climate station in Prachinburi

Figure A.3 SOC change from introduction of rice into cassava area, from 1977 to 2113.



Climate station in Khonkaen



Climate station in Prachinburi

Figure A.4 SOC change from switching out of cassava to grassland, from 1977 to 2113.