THE POTENTIAL OF PALM OIL AS A PATHWAY TOWARDS FOOD AND ENERGY SECURITY IN THAILAND

PRANEE NUTONGKAEW

A DISSERTATION SUBMITTED IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN
SUSTAINABLE DEVELOPMENT
THAKSIN UNIVERSITY
2017

DISSERTATION CERTIFICATION

THE DEGREE OF DOCTOR OF PHILOSOPHY IN SUSTAINABLE DEVELOPMENT

THAKSIN UNIVERSITY

Dissertation Title : The Potential of Palm Oil as a Pathway towards Food and Energy Security in Thailand

Student 's name : Miss Pranee Nutongkaew

DISSERTATION ADVISOR

(Prof. Dr. Yves Gagnon)
Major - Advisor

(Assoc. Prof. Dr. Jompob Waewsak)
Co – Advisor

DISSERTATION EXAMINER

(Prof. Dr. Lindsay Falvey)
Chair

(Prof. Dr. Carole Tranchant)
Examiner

(Prof. Dr. Joseph Khedari)
Examiner

Thaksin University approved This Dissertation in Partial Fulfillment of The Requirements for The Degree of Doctor of Philosophy in Sustainable Development

(Assoc. Prof. Kasem Asawatreratanakul)
Director of International Graduate Programs

2017

STATEMENT OF ORIGINALITY

I, Pranee Nutongkaew, certify that this thesis is my original work, except where clearly referenced to other sources.

Signed on 22 December 2019, in Songkhla, Thailand

Pranee Nutongkaew.

ACKNOWLEDGEMENTS

I am grateful for the support and assistance of a number of people in the completion of my doctoral research. My deep appreciation goes out to Assoc. Prof. Dr. Jompob Waewsak, thesis supervisor, Prof. Dr. Yves Gagnon, co-supervisor, as well as Asst. Prof. Dr. Tanate Chaichana, Asst. Prof. Dr. Warangkhana Riansut and Asst. Prof. Dr. Chuleerat Kungruang, co-authors on the research papers presented in this thesis. It has been a privilege to work with you and I am deeply grateful.

I am also very grateful to Assoc. Prof. Kasem Asawatreratanakul, Thaksin University (Thailand), Prof. Dr. Josef Khedari, Kasetsart University (Thailand) and Prof. Dr. Carole Tranchant, Université de Moncton (Canada), members of the Doctoral Examination Committee, for the constructive suggestions they offered on the work presented in this thesis.

I also thank the Agricultural Research Development Agency, Thailand, and Thaksin University for their financial support of this research, and Thaksin University Research Center in Energy and Environment for providing the research facilities.

Last but not least, I wish to thank my family and friends for their support and encouragements.

SUMMARY

Sustainability is a highly interdisciplinary topic and endeavour, requiring the consideration of various interacting and interdependent systems, both living and non-living. The research presented in this thesis considers the environmental, societal and economic aspects of sustainability in Thailand in relation to the production of palm oil for food and energy security. In Thailand, energy and food security are two key national policies that intend to contribute to sustainability. In 2015, the Ministry of Energy launched a revised Alternative Energy Development Plan (AEDP 2015), which replaces AEDP 2012, to gradually replace the usage of regular diesel with biodiesel, with the goal of producing 14 million liters of biodiesel per day by 2036. Annual targets for biodiesel production are set in the AEDP. Biodiesel, more specifically the B2, B5, and B10 diesels, have been authorized for sale in Thailand in 2008, 2011 and 2014, respectively, to replace diesel consumption in order to reduce the GHG emissions in the transportation sector as a way to mitigate climate change. In 2015, Thailand pledged a 20 to 25% reduction of its emissions of GHG by 2030. However, an increased demand for biodiesel could affect agricultural systems and jeopardize food security, especially edible cooking palm oil production, as palm oil is the single most important crop for biodiesel production in Thailand.

The main objectives of this research were (1) to assess whether the anticipated demand for crude palm oil (CPO) in Thailand, for edible cooking palm oil, biodiesel production and marginal uses, can be met using the agricultural land available for palm tree plantations in the country, and (2) to assess the emission of greenhouse gases (GHG) generated by the production of refuse derived fuel (RDF) from municipal wastes and palm kernels, a byproduct of CPO production. The thesis is comprised of three publications: two research papers assessing the production of CPO as a pathway towards food and energy security in the country, and one paper on the GHG emissions generated by the production RDF.

The first paper, submitted to *Renewable and Sustainable Energy Reviews* in 2017, analyzes the potential of palm oil production as a pathway to achieve food and energy security in Thailand within the planning period of AEDP 2015 (i.e., 2015 to 2036). The current (2016) and anticipated (2021 and 2036) demands for domestic edible cooking palm oil consumption were analyzed using three statistical models

(including the combined forecasting method, CFM) based on time-series analysis of historical patterns, along with two models based respectively on daily calorie intake and population. The statistical models used population, price of palm oil bottle, price of soybean oil bottle, and average revenue per capita. The forecasted demand for CPO was then transposed to surface areas that would be needed to produce the anticipated CPO for domestic edible consumption, biodiesel production, as well as marginal usages. Based on the total surface area needed across the country, site selection for palm tree plantations was analyzed using a multi-criteria decision making analysis based on ArcGIS Extension Spatial Analysis. The population-based model, with a quadratic regression between population and consumption of CPO for edible cooking palm oil, was found to be the most appropriate method for forecasting the demand for CPO for edible cooking palm oil (0.59 million tons in 2036). This results in a total demand for CPO in 2036 of 5.38 million tons for domestic consumption to supply the necessary amounts for the edible cooking palm oil production industry, the biodiesel production industry, and marginal usages of CPO. The total land currently cultivated for palm tree harvesting (6,765 km^2), along with the total surface area offering suitable and moderately suitable conditions for additional palm tree plantations (14,641 km^2), is greater than the forecasted area (17,803 km^2) needed to achieve food and energy security in 2036. Public policy measures would need to be implemented in order to achieve the most efficient and sustainable way of developing new palm tree plantations to satisfy the forecasted demand for CPO in 2036. The Government of Thailand should also provide guidelines, along with pro-active and supportive policies for mitigating worst case events (e.g., droughts, floods, economic crises), in order to reduce the negative impacts of biodiesel production for domestic demand and consumption of CPO.

The previous work on the demand and supply of CPO in Thailand, published in *Applied Mechanics and Materials* in 2016, used three statistical models and the demand for domestic edible cooking palm oil was forecasted within the planning period of AEDP 2012 (2012-2021). This study showed that the CFM was the most appropriate statistical model for forecasting CPO demand for edible palm oil (1.02 million tons in 2021). This study predicted a required palm oil plantation area of 11,152 km^2 in 2021 to supply the total demand for CPO (2.69 million tons in 2021), while GIS analyses indicated that the total area suitable for palm oil plantation was 14,639 km^2. Our most recent work (2017 paper), using AEDP 2015 as the planning period, established that the demand for edible palm oil is best forecasted using a population-based model. With this model, a 9.26% lower value of required palm oil plantation area (10,206 km^2) in 2021 was obtained. Indeed, CFM forecasting was found to overestimate the domestic demand for edible palm oil compared to the population-based and calorie-based methods.

The third paper, published in *Energy Procedia* in 2014, assessed the emission of GHG generated by the production of RDF-5 from municipal solid wastes (MSW) and palm kernels. Increasing volumes of wastes and diversity of materials comprising these wastes are a direct result of increases in population, changes in consumption patterns, economic development and urbanization. MSW cause serious environmental and health problems, but can also be used to generate energy via the production of RDF. RDF can be combusted directly or co-fired with other fuels; they can be produced by mixing dried combustible portions of MSW and some agricultural wastes. In Thailand, MSW and agricultural byproducts are becoming major sources for producing RDF. In southern Thailand, several CPO factories generate large amounts of palm kernels which can be used as fuel for combustion. Direct combustion of RDF can generate heat in an efficient way, thus contributing to energy security, but it can also contribute to global warming during its production and usage phases. My work used Life Cycle Assessment (LCA) to estimate the GHG emissions from RDF-5 produced from MSW alone or mixed with palm kernels. The corresponding GHG emissions were 1.423 kg CO_2 equivalent/kg of RDF-5 and 1.696 kg CO_2 equivalent/kg, respectively. In both cases, the production process entailed crushing, mixing and compression of waste materials. When palm kernels were included, they contributed $1/6^{th}$ of the total GHG emissions. The highest GHG emissions derived from plastics (1.228 kg CO_2 equivalent/kg), which represented 17% by weight of the material used to produce RDF-5, like palm kernels. GHG emissions from palm kernels, electricity consumption, waste paper and limestone were 4.5, 6.6, 136 and 400 times lower, respectively, compared to plastics.

In the short-term, the CPO production targets envisaged by AEDP 2015 seem achievable, but, as noted in papers 1 and 2, will likely require strong improvements in yields and productivity. The Government of Thailand could implement a management plan that aims to achieve long-term socioeconomic viability by enabling farmers to practices that will maintain or improve soil fertility to levels permitting optimal and sustainable yields. The required expansion of palm oil plantation area seems feasible, but should be carefully planned to avoid deforestation, biodiversity loss, water issues, expansion into areas affected by natural disasters, and excessive harmful crop changes. More studies are required to assess the impact of land use change resulting from palm oil expansion in Thailand.

It is noteworthy that increased production of CPO will go hand in hand with increased byproducts such as palm kernels. Our third paper showed that the use of palm kernels to produce RDF-5 contributes to GHG emissions. Future work is needed to determine which types of RDF and their optimal composition are best suited for Thailand to reduce its GHG emissions and help steer the country on the path of energy and food security as outlined in its national strategic plans. Future work should consider the emissions of GHG and of toxic heavy metals (e.g., lead) during RDF combustion, which can lead to serious environmental contaminations and health problems in addition to global warming.

TABLE OF CONTENTS

TABLE OF CONTENTS (Continued)

LIST OF FIGURES

LIST OF FIGURES (Continued)

LIST OF TABLES

LIST OF TABLES (Continued)

CHAPTER 1
GENERAL INTRODUCTION

According to the medium growth projection scenario of the United Nations, the global population will reach 9.5 billion by 2050 [1], which is the key driver to increase the demand for food and energy. Moreover, along with global climate change, the population growth, the loss of biodiversity, and resource depletion present significant challenges to addressing food security [2]. Food and energy security is a long-term concern for many countries. It has been estimated that there is a need to increase food production by 60% in order to feed the global anticipated population of the planet [3]. A recent World Energy Council (WEC) report found that without any change in our current practice, the world energy demand in 2020 would be 50–80% higher than 1990 levels [4].

The World Commission on Environment and Development presented a concept of sustainable development, which initially laid the groundwork for the convening of the 1992 Earth Summit and the adoption of Agenda 21, the Rio Declaration and the establishment of the Commission on Sustainable Development. The Brundtland report defined sustainable development as "development which meets the needs of current generations without compromising the ability of future generations to meet their own needs". Sustainable development includes the balancing of three critical, interconnected domains, namely the economic, social and environmental domains (Figure 1.1). The three keys of sustainability are a powerful tool for defining the complete sustainability problem and its corresponding solutions in every region and country as well as a global (international) scale. If one domain is weak then the system as a whole is unsustainable due to sustainable development connect together the resource of natural systems with the social and economic, which is the principle for human life on a finite resource. It means that human societies have to use resources for living without undermining the sustainability of natural systems and the environment, in order for future generations to also have their needs met.

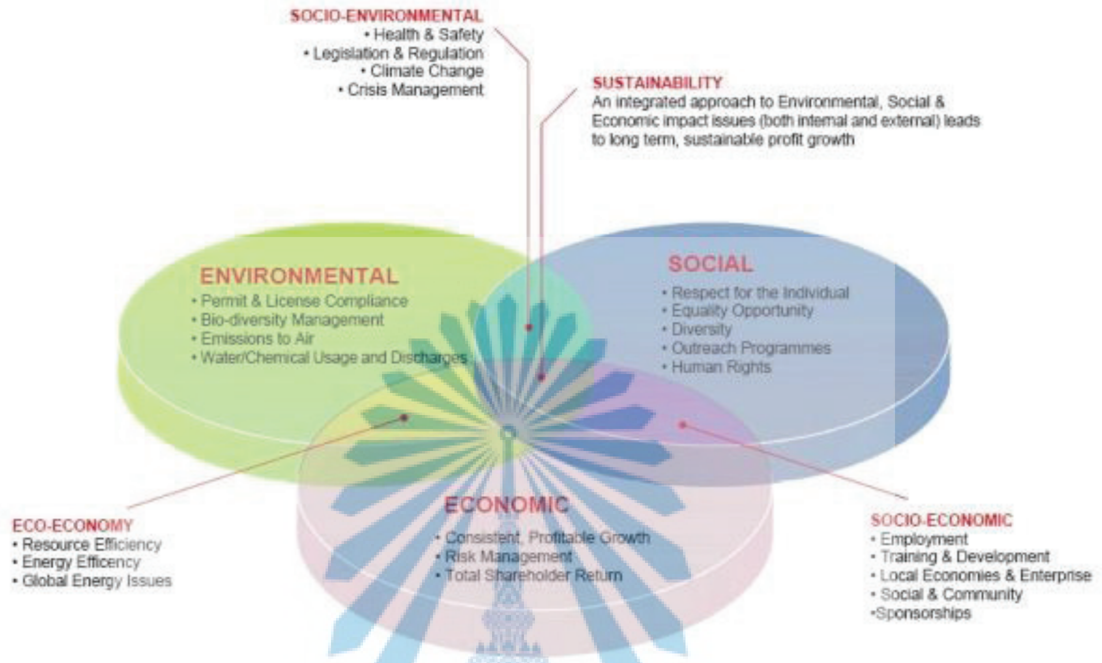

Figure 1.1 Path to sustainable development [5].

For the environmental part, global warming is a crucial problem in today's world and greenhouse gas (GHG) emission reduction is being prioritized by several countries. The global warming potential (GWP) of a GHG is measured relative to the same mass of CO_2 and evaluated for a specific time scale, it will have a large GWP on a 100 year scale but a small one on a 20 year scale. Carbon dioxide (CO_2) emissions are mainly contributed by the combustion of carbonaceous fuels such as coal, oil, and natural gas. CO_2 is a product of ideal, stoichiometric combustion of carbon, although few combustion processes are ideal, and burning coal, which also produces carbon monoxide [6]. Since 2000, fossil fuel related carbon emissions has equaled or exceeded the Intergovernmental Panel on Climate Change (IPCC)'s "A2 scenario", except for small dips during two global recessions [7-9]. Presently, Thailand (about 68.4 million people) contributes approximately 0.84% of the total GHG emissions worldwide, i.e., slightly less than similarly populated countries such as the United Kingdom, South Africa and France (1.21%, 1.13% and 0.97% of the global total GHG emissions, respectively) [10].

Thailand is a 513,120 km^2 country situated in Southeastern Asia. The country is comprised of 510,890 km^2 of land and 2,230 km^2 of water. Land use is 41.2% agricultural land, 37.2% forests, and 21.6% other uses [11]. It is an upper middle-income country (ranking 21 out of 229) in terms of gross domestic product (GDP) (purchasing power parity) [12] with relatively low rates of poverty. Thailand's economy is highly dependent on international trade, with exports accounting for two-third of the gross domestic product (GDP). Thailand's exports include electronics, agricultural commodities, automobiles and parts, and processed foods. The industry and service sectors produce about 90% of GDP. The agricultural sector (small-scale farms mainly) contributes only 10% of GDP but employs about one-third of the labor force [11].

Thailand has made great progress in improving food security and nutrition and, likewise, reducing poverty and promoting relatively inclusive economic growth. Achievements in this area from 1990/92 to 2014/16 are widely regarded as one of the best examples of a successful nutrition program and could provide important lessons for other countries facing malnutrition [13]. Over that period, the prevalence of undernourishment fell from 35% to 7% [14]. Still, recent data on nutrition and outcomes point to persistent challenges that must be addressed to eliminate hunger and undernutrition for all. Moreover, dietary and lifestyle shifts are driving increases in overweight and obesity, as well as increases in chronic diseases, which are further compounding the burden of malnutrition [15].

Food production and productivity have increased in Thailand, which is one of a few Southeast Asian countries that produce surplus agricultural food and non-food products for export [16]. Food crop production has grown from 2000 to 2010 (rice production grew by 26% and roots and tuber production (mostly cassava) grew by 57%). However, production of vegetables has diminished by 30% between 2000 and 2014. Yields have improved for nearly all crop groups [17]. Per capita supply of available food has increased in terms of overall dietary energy, carbohydrates, and proteins from 2005 to 2010. Availability of fats decreased during that period [16].

The consideration on sustainability and efficiency of energy generation and consumption is an issue which many countries worldwide are focusing on. The main reason is the need for new energy resources to replace the limited fossil-fuels and effective approaches for energy management to reduce fuel consumption and emissions of GHG which is the global major issue at present. A possible solution to this crisis is to use alternative energy. The Government of Thailand launched a first plan (AEDP 2012) to replace the usage of regular diesel with biodiesel, according to the initial 10-year Alternative Energy Development Plan (AEDP) for the period of 2012 to 2021, where the biodiesel production was targeted to be 6 million liters/day by 2021. In 2015, the Government of Thailand has launched a revised Alternative Energy Development Plan (AEDP 2015) which aims to achieve a 30% share of renewable energy in the total final energy consumption by 2036; in addition the Government adopted a waste management roadmap, which proposes a more efficient and sustainable waste management and promotion of power generation from waste to energy technology. This roadmap can greatly contribute environmental benefits in terms of GHG emissions and climate change.

Currently, there are many alternative energy sources that are being researched and developed in the world, namely solar, wind, biomass, hydro, geothermal and biofuels, notably from biomass such as sugarcane, corn, soybean, rapeseed and palm oil. The utilization of biofuels contributes to net zero carbon emissions, which can reduce the effect of global warming and decrease fossil fuel consumption. Generally, biofuels can be classified into biodiesel, bioethanol, biomethanol and biohydrogen. Biodiesel has been receiving a plenty of concentration because its characteristics are similar to those of diesel in terms of energy content and chemical structure. Biodiesel can be produced from many resource such as animal fat, soybean, rapeseed and palm oil.

The energy system plays an essential role in accounting of GHG emissions from waste management systems and waste technologies. Energy from waste for non-recyclable wastes is a suitable method of waste management and is important for renewable energy production [18]. The refuse-derived fuel (RDF) has emerged as one of the interesting alternatives to solve both global warming and municipal solid wastes (MSW) management problems. Thailand has a MSW generation average of 1.443 kg per capita per day (526 kg per person per year) [19]. In comparison, similarly populated countries such as the United Kingdom, Italy and France, have an annual, per capita MSW generation average, in 2000, of 560 kg, 500 kg and 510 kg, respectively [20]. RDF benefits are not only to improve world environmental quality, but also to reduce local economic losses [21]. Many research groups have studied the techniques to utilize refuse fuels, however, most investigations focused on direct combustion or thermal degradation [22-25]. MSW composition varies widely with different sources and seasons. Raw MSW has high moisture content, low calorific value, wide range of particle size distribution, and high ash content. RDF presents several advantages as a fuel over raw MSW. RDF are classified based on characteristics of waste fuels and combustion systems, according to ASTM standards

E856-83 (2006). These specify that RDF is a shredded fuel derived from MSW from which metal, glass and other inorganic materials have been removed; in terms of RDF particle size, 95 weight % passes through a 2-in square mesh screen. RDF can be classified into 7 categories as RDF-1 to RDF-7 as follows; [21].

- RDF-1: Wastes used in as discarded form.
- RDF-2: Wastes processed to coarse particle size with or without ferrous metal separation such that 95% by weight passes through a 6 in square mesh screen, namely Coarse RDF.
- RDF-3: Wastes processed to separate glass, metal and inorganic materials, shredded such that 95 % by weight passes 2 in square mesh screen, namely Fluff RDF.
- RDF-4: Combustible wastes processed into powder form, 95 weight % passes through a 10 mesh screen (0.035 in square), namely Powder RDF.
- RDF-5: Combustible wastes densified (compressed) into the form of pellets, slugs or briquettes, namely Densified RDF.
- RDF-6: Combustible wastes processed into liquid fuels, namely RDF slurry.
- RDF-7: Combustible wastes processed into gaseous fuels, namely RDF syngas.

Consequently, the Life Cycle Assessment (LCA) should be considered to estimate the GHG emissions from RDF at all stages of the production process, before combustion. Our research focused on the production of RDF-5, which are combustible wastes densified (compressed) into the form of briquettes.

Palm oil is one of the resource for both biofuel production and edible cooking palm oil production for domestic consumption. When utilizing palm oil as an alternative energy source, there are two main factors that are crucially important. First, there should be a plentiful supply to satisfy the current and future demands. Second, the price of palm oil should be stable in order to be affordable and thus adequately support the needs of the majority of the world population. Palm oil is indeed the largest edible oil in terms of volume share, just before soybean oil, and a sustainable feedstock for biodiesel production. As shown in Figure 1.2, 36% of the vegetable oil production worldwide is from palm oil and the plantation area of palm oil worldwide is around 5% of all oil crops. With the biofuel expansion, agricultural production is now being driven by a new set of economic incentives, while energy production is becoming dependent on climate change, growing global demand for food and feed, and other variables that affect agricultural output and prices [26, 27]. As the demand for biomass-based fuels increases, agricultural markets and energy markets will become more closely integrated and interdependent. There is recognition of the need to examine the impacts of biofuel policies on agricultural market [28] and on energy systems [29, 30]. Increase linkage between the agriculture and energy markets have competition for land, feedstock crops, and other agriculture resource [31, 32].

Presently, 13 biodiesel plants, 18 oil palm refineries and 137 oil palm crushing mills are in operation in Thailand, as illustrated in Figure 1.3. In 2016, the production of crude palm oil (CPO) reached 2,228,774 tonnes, of which 307,386 tonnes was exported. The Royal Thai Government, through the Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy, has revised the Alternative Energy Development Plan for 2015-2036 (AEDP 2015). The AEDP 2015 has reference to the oil palm and palm oil industries development strategy 2015-36. The government initiated a plan to increase biodiesel production from 5.6 to 14 million liters per day by the year 2036. The AEDP 2015 predictions for biodiesel production reach 7.1 million liters/day in 2019, 10 million liters/day in 2026, and 14 million liters/day in 2036 [33]. The long-term planning of energy policy of Thailand is shown in Table 1.1.

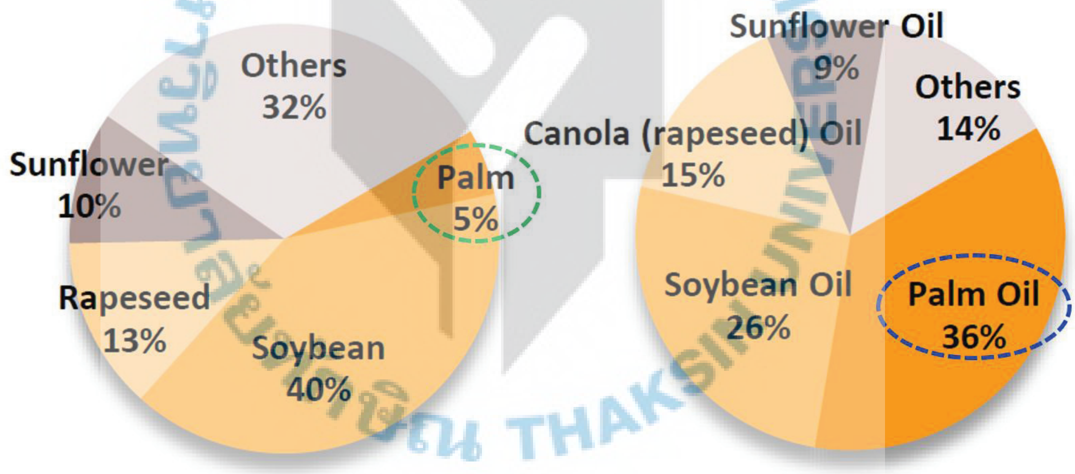

Figure 1.2 Proportions of world vegetable oil plantations (left)
and production (right) [34].

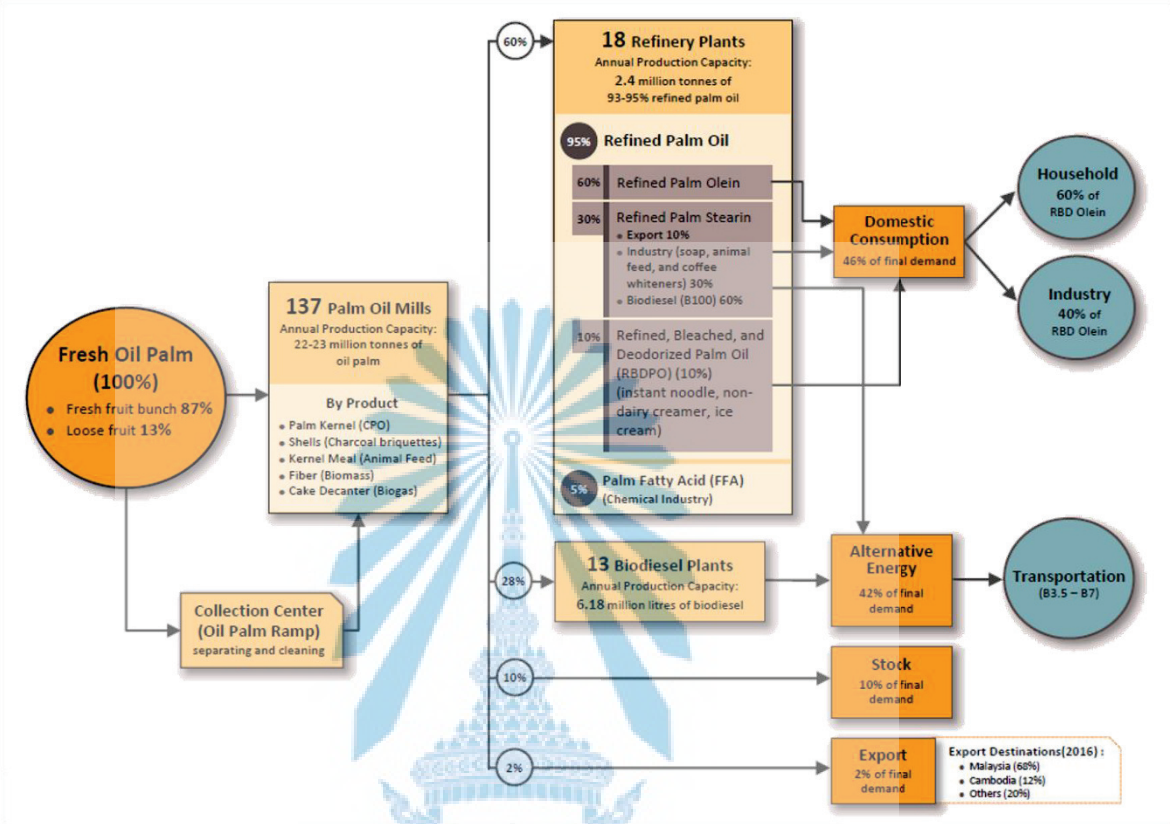

Figure 1.3 Structure of the Thailand palm oil industry [34].

Table 1.1 Long-term planning of the palm oil potential for biodiesel production.

Potential palm oil	2015[1/]	2017[1/]	2019[1/]	2026[1/]	2036[2/]
Targeted cultivation area (million rai)	4.5	5.0	5.5	7.5	10.2
Oil palm output (million tonnes per annum)	14.3	15.4	16.7	21.4	29.5
Crude palm oil (million tonnes per annum)	2.6	2.9	3.2	4.3	5.9
Crude palm oil balance (million tonnes per annum)[3/]	1.6	1.9	2.0	2.9	4.2
Maximum production of biodiesel (million liters/day)[4/]	5.6	6.5	7.1	10.0	14.0

Notes: 1/ Palm oil and palm oil industries development strategy 2015-2016
2/ Output extrapolation based on areas suitable for cultivation of palm tree nationwide
3/ Crude palm oil remaining balance before deducting export volume
4/ Estimates based on fatty acid methyl esters (FAME) diesel

With a biodiesel (B100) consumption target of 14.0 million liters/day by 2036, the plan focused on supply and demand analysis. For supply, the Government will promote the expansion of palm oil plantations, with a palm oil harvesting area of 10.2 million rai (16,320 km^2), an average yield target of 29.5 million tons of fresh fruit bunch (FFB), and a CPO production of 5.9 million tons by 2036.

The AEDP 2015 forecast for potential biodiesel production (Figure 1.4) sets a production target of 14 million liters of biodiesel per day by 2036. This forecast expects the biodiesel production to gradually grow over the years. Meeting these targets will require an increase of about 0.39 million liters/day each year between 2015 and 2036 (red dotted line in Figure 1.4). The current rate of production increase has been lower, however, reaching only 0.26 million liters/day per year based on actual production data between 2008 and 2016 (blue dotted line in Figure 1.4). Thus, biodiesel production rate in Thailand will have to increase by about 1.4 time from now on in order to meet the targets set by AEDP 2015.

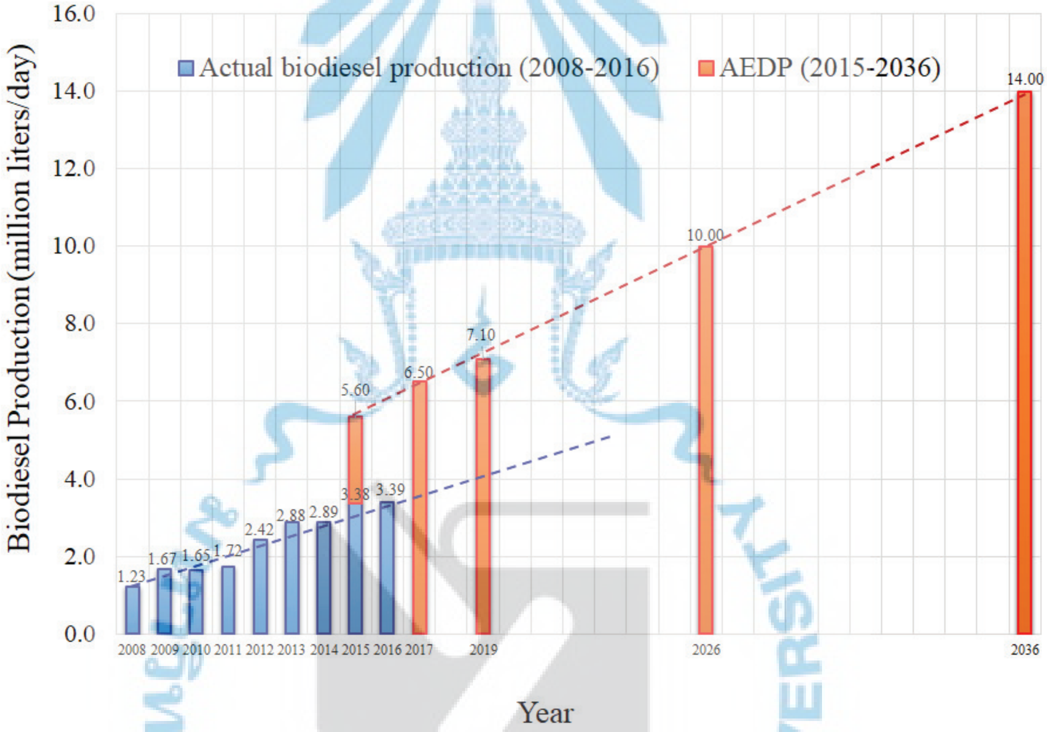

Figure 1.4 Thailand production of biodiesel (data from [34]).

For demand, the Government will balance required production of biodiesel with domestic CPO demand. The plan will start a pilot project for B10 or B20 for trucks and fishing boats. More specifically, the B2, B5 and B10 diesels have been authorized for sale in Thailand in 2008, 2011 and 2014, respectively, to replace diesel consumption. Biodiesel (B100) in Thailand is produced from CPO; Thailand does not import or export B100, but exports CPO. However, CPO can be processed and blended to produce a vast range of products with different characteristics. As illustrated in Figure 1.5, CPO is used in a wide variety of products, such as an alternative fuel source (biodiesel), food items (e.g., cooking oil, margarine, and sweets), and other commodities (e.g., cosmetics, soap, candles, textile, and plastics). The edible applications of CPO (cooking oil and derived manufactured foods) play an important role in food security in Thailand. Therefore, unless appropriate planning and measures are in place, the usage of CPO to produce biodiesel is expected to affect the supply of CPO in other industries, which could undermine food security in the country.

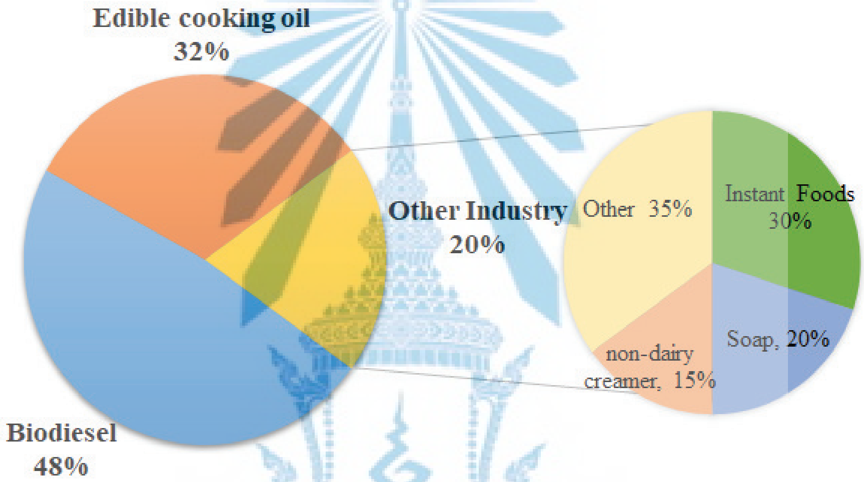

Figure 1.5 Domestic consumption of palm oil in Thailand (2016) (data from [34]).

Consequently, one of the main objectives of this research was to analyze the domestic demands of CPO for domestic edible cooking palm oil, biodiesel production as well as marginal usages in Thailand, in order to achieve the objectives of AEDP 2015 (specifically, the country-level goal of producing 14.0 million liters/day of biodiesel in 2036), without affecting other parts of the supply of palm oil for food uses and marginal uses. Ultimately, this approach seeks to preserve the delicate balance between increasing total demand for CPO and the ability to supply this demand with the limited land available, without jeopardizing food security in the country.

Increased demand and production of CPO will go hand in hand with increased by-products such as palm kernels which must be disposed of in the most ecological ways possible. Therefore, the second main objective of this research was to assess the GHG emissions generated by the production of RDF from municipal wastes and palm kernels. This study was conducted at one site in one of the 76 provinces of Thailand, the Phatthalung province, in southern Thailand, where there are several CPO factories currently in operation that produce large amounts of palm kernels.

References for Chapter 1

[1] Chen J, Shi H, Sivakumar B, Peart MR. Population, water, food, energy and dams. Renewable and Sustainable Energy Reviews 2016;56:18-28.

[2] Poulsen MN, McNab PR, Clayton ML, Neff RA. A systematic review of urban agriculture and food security impacts in low-income countries. Food Policy 2015;55:131-46.

[3] Dijk VM, Meijerink GW. A review of global food security scenario and assessment studies: Results, gaps and research priorities. Global Food Security 2014;3:227-38.

[4] World Energy Council (WEC). The world energy demand in 2020; 2009.

[5] Mann S. Sustainable lens: A visual guide. Dunedin: NewSplash; 2011.

[6] Lindeburgh MR. Mechanical engineering reference manual for the PE exam. Belmont, CA: Professional Publications, Inc; 2006.

[7] Intergovernmental Panel on Climate Change (IPCC). Special report on emissions scenarios: (data) IPCC SRES emissions scenarios, version 1.1. http://sres.ciesin.org/data/Version1.1/table/A2_ASF/A2_ASF_World.html; 2000 [accessed 25 June 2011].

[8] International Energy Agency. CO_2 Emissions from fuel combustion 2010 - Highlights, http://www.iea.org/co2highlights/CO2highlights.pdf; 2010 [accessed 2 May 2012].

[9] Harvey F. Worst ever carbon emissions leave climate on the brink. The Guardian, http://www.guardian.co.uk/environment/2011/may/29/carbon-emissions-nuclearpower; 2011 [accessed 25 June 2011].

[10] World Resources Institute. Climate analysis indicators tool (CAIT), version 2.0. Washington, DC, http://cait2.wri.org; 2014 [accessed 15 September 2017].

[11] World Factbook. East and Southeast Asia: Thailand. https://www.cia.gov/library/ publications/the-world-factbook/geos/th.html; 2017 [accessed 9 September 2017].

[12] World Factbook. Country comparison: GDP (purchasing power parity). https://www.cia.gov/library/publications/the-world-factbook/rankorder/2001rank.html#th; 2016 [accessed 9 September 2017].

[13] Gillespie S, Tontisirin K, Zseleczky L. Local to national: Thailand's integrated nutrition program. Chapter 10 in: Gillespie S, Hodge J, Yosef S, Pandya-Lorch R, editors. Nourishing millions: stories of change in nutrition, Washington, DC: International Food Policy Research Institute (IFPRI). http://dx.doi.org/10.2499/9780896295889_10; 2016, p. 91-8 [accessed 9 September 2017].

[14] Food and Agriculture Organization (FAO). FAOSTAT. http://faostat3.fao.org/download/Q/QC/E; 2017 [accessed 9 September 2017].

[15] Gillespie S, Hodge J, Yosef S, Pandya-Lorch R (editors). Nourishing millions: stories of change in nutrition. Washington, DC: International Food Policy Research Institute (IFPRI). http://dx.doi.org/10.2499/9780896295889; 2016 [accessed 9 September 2017].

[16] Tontisirin K, Chavasit V, Parinyasiri T, Ditmetharoj M, Photi J, Intaraluk P, Kittiprapas S. Country policy analysis. Nutrition impact of agriculture and food systems: Thailand, Geneva: UN System Standing Committee on Nutrition. https://www.unscn.org/files/Publications/Country_Case_Studies/Thailand_case_study_FINAL.pdf; 2013 [accessed 9 September 2017].

[17] Compact2025 Team. Thailand food security and nutrition case study. Successes and next steps. http://www.compact2025.org/files/2017/06/06.2017_Thailand-south-south-learning-draft-case-study.pdf; 2017 [accessed 9 September 2017].

[18] Ryu C. Potential of municipal solid waste for renewable energy production and reduction of greenhouse gas emissions in South Korea. Journal of the Air and Waste Management Association 2010;60:176-83.

[19] Troschinetz AM, Mihelcic JR. Sustainable recycling of municipal solid waste in developing countries. Waste Management 2009;29:915-23.

[20] NationMaster. Municipal waste generation: countries compared. http://www.nationmaster.com/country-info/stats/Environment/Municipal-waste-generation; 2017 [accessed 20 June 2017].

[21] Nithikul J. Potential of refuse derived fuel production from Bangkok municipal solid waste. Thesis, Master of Engineering in Environmental Engineering and Management, Asian Institute of Technology School of Environment, Resources and Development, Thailand; 2007.

[22] Miskolczi N, Borsodi N, Buyong F, Angyal A, Williams PT. Production of pyrolytic oils by catalytic pyrolysis of Malaysian refuse-derived fuels in continuously stirred batch reactor. Fuel Processing Technology 2011;92:925-32.

[23] Lee JM, Kim DW, Kim JS, Na JG, Lee SH. Co-combustion of refuse derived fuel with Korean anthracite in a commercial circulating fluidized bed boiler. Energy 2010;35:2814-18.

[24] Di Gregorio F, Zaccariello Lucio. Fluidized bed gasification of a packaging derived fuel: energetic, environmental and economic performances comparison for waste-to-energy plants. Energy 2012;42:331-41.

[25] Belgiorno V, De Feo G, Della Rocca C, Napoli RMA. Energy from gasification of solid wastes. Waste Management 2003;23:1-15.

[26] Schmidhuber J. Impact of an increased biomass use on agricultural markets, prices and food security: a longer-term perspective. In: Petersson B, Tornquist-Plewa B, editors. Energy security in Europe proceedings, CFE Conference Papers Series Number 2, Lund, Sweden: Center for European Studies Lund University; 2007, p. 133-69.

[27] Delzeit R, Britz W, Holm-Müller K. Modelling regional input markets with numerous processing plants: the case of green maize for biogas production in Germany. Environmental Modelling & Software 2012;32:74-84.

[28] Tokgoz S, Elobeid A, Fabiosa J, Hayes DJ, Babcock BA, Yu TH, Dong F, Hart CE. Bottlenecks, drought, and oil price spikes: impact on U.S. ethanol and agricultural sectors. Applied Economic Perspectives and Policy 2008;30:604-22.

[29] Thompson W, Whistance J, Meyer S. Effects of U.S. biofuel policies on U.S. and world petroleum product markets with consequences for greenhouse gas emissions. Energy Policy 2011;39:5509-18.

[30] Rajagopal D, Hochman G, Zilberman D. Indirect fuel use change (IFUC) and the lifecycle environmental impact of biofuel policies. Energy Policy 2011;39:228-33.

[31] Food and Agricultural Organization of the United Nations (FAO). The state of food and agriculture. Biofuels: prospects, risks and opportunities. http://www.fao.org/docrep/011/i0100e/i0100e00.htm; 2008 [accessed 13 July 2015].

[32] Ford Runge C, Senauer S. How biofuels could starve the poor. Foreign Affairs 2007;86:41-7.

[33] Department of Alternative Energy Development and Efficiency (DEDE). Alternative Energy Development Plan: AEDP. http://www.dede.go.th/download/files/AEDP2015_Final_version.pdf; 2015 [accessed 10 November 2016].

[34] Department of Alternative Energy Development and Efficiency. Local Press compiled by Krungsri Research; 2016.

CHAPTER 2

The Potential of Palm Oil Production as a Pathway to Food and Energy Security in Thailand

Pranee Nutongkaew, Jompob Waewsak, Warangkhana Riansut,
Chuleerat Kongruang and Yves Gagnon

Submitted to *Renewable & Sustainable Energy Reviews* in August 2017

Foreword

Besides being involved in defining the general methodology of the research work, the main contributions of the candidate to this paper were for data preparation, forecasting analyses (calorie- and population-based methods), interpretation of the results, and drafting the paper. For data preparation and analyses, the candidate was responsible for the data used for forecasting CPO demand for edible cooking palm oil using the calorie-based and population-based methods. In the first method, the daily average calories requirement for Thai people is used to forecast the demand. Thus, the annual demand for edible cooking palm oil is the product of daily calorie requirement per capita and total projected population. The second method assumes that the consumption profile of the population for edible cooking palm oil will not change significantly during the forecast period. Thus, regression between actual statistical CPO for edible cooking palm oil and population is performed.

This paper was submitted to *Renewable & Sustainable Energy Reviews* (Elsevier) for three main reasons. First, the scope of the work and the results presented are an excellent fit with the aim of the journal (see below). Second, this journal is an Open Access journal with a broad and diversified readership (research community, private sector, policy- and decision-makers), and, thirdly, it has a high impact factor (8.05 in 2016 according to Thomson Reuters Journal Citation Reports 2017). The aim of this journal is to share problems, solutions, novel ideas and technologies to support the transition to a low carbon future and achieve the global emissions targets established by the UN Framework Convention on Climate Change. It also aims to communicate the most interesting and relevant critical thinking in renewable and sustainable energy (from www.journals.elsevier.com/renewable-and-sustainable-energy-reviews).

The Potential of Palm Oil Production as a Pathway to Food and Energy Security in Thailand

Pranee Nutongkaew[a,b], Jompob Waewsak[b], Warangkhana Riansut[b],
Chuleerat Kongruang[c] and Yves Gagnon[d]

[a]Sustainable Development Program, International College, Thaksin University, Songkhla, Thailand
[b]Research Center in Energy and Environment
Thaksin University (Phatthalung Campus), Phatthalung, Thailand
[c]School of Management, Walailak University, Nakhon Si Thammarat, Thailand
[d]Université de Moncton, Edmundston (NB), Canada

Abstract

The global demand for palm oil is increasing due to its usage as the source for edible cooking palm oil, the production of biofuels and other marginal usages (cosmetics, animal food, aromatics and soap). The palm tree plantations in Thailand have increased continuously in response to the rising demand for palm oil, mainly for food and energy purposes. Currently, the palm tree harvested areas in Thailand cover 7,520 km^2 in 2016, and have an annual production of 11.2 million tonnes of oil palm for domestic edible cooking palm oil, biodiesel production and other marginal usages. This paper presents an analysis of the potential of palm oil production as a pathway to achieve the objectives of the Alternative Energy Development Plan (AEDP), and thus contribute to achieving food and energy security in Thailand. Initially, the current and anticipated demands for domestic edible cooking palm oil consumption in Thailand are analyzed using statistical forecasting techniques using three statistical models, based on three significant parameters: price of bottled palm oil, price of bottled soybean oil and gross domestic product per capita. The demand for domestic edible cooking palm oil is further analysed using calorie- and population-based models. For its part, the palm oil needed to achieve the palm oil-based biodiesel production targets are set in the AEDP. Finally, the demand for other marginal usages of palm oil is estimated based on the constant proportion of 62.5% of the total edible cooking palm oil consumed in the country. Three scenarios are studied in order to

analyze the sensitivity of the predictions, i.e. base case, and along with 10% variations with respect to the base case, thus assessing the sensitivity of the variables on the forecasting. The anticipated demand for palm oil is then transposed to surface areas that would be needed to produce the anticipated palm oil for domestic edible consumption, biodiesel production and other marginal usages. Based on the total surface area needed throughout the country, the site selection for palm tree plantations is analyzed using a multi-criteria decision making analysis based on the ArcGIS Extension Spatial Analysis tool. The three major characteristics for the selection of sites for palm tree plantations consist of topography (slope; elevation above mean sea level), climate (annual mean temperature, rainfall and sunshine hours; orientation), and soil characteristics (presence of clay loam and clay; depth of soil layer). The maps of suitable sites for potential palm tree plantations are overlaid with the maps of current land use, on which prohibited and constrained zones are specifically excluded. Assuming average yields of 17%, results show that a total area of 17,803 km^2, would be necessary for the production of the palm oil needed to achieve the 2036 AEDP energy objectives, while continuing to supply the necessary edible cooking palm oil and supplying the marginal usages.

Keywords: Palm Oil, Edible Cooking Palm Oil, Food and Energy Security, Biodiesel.

2.1 Introduction

As a fundamental and overarching objective of countries, the goal of achieving sustainable development leads to the transition and the transformation of several sectors, notably in food and energy security (see for example [1-8]).

With the increase of the global population, food security is a long-term concern for many countries, notably in developing countries. It has been estimated that there is a need to increase food production by 60% in order to feed the global anticipated population of the planet [9]. During the last decade, scenario analyses have been applied as a tool for dealing with the complexities and uncertainties of interrelated issues associated with climate change, land use, and food and energy security. According to the medium growth projection scenario of the United Nations, the global population will reach 9.5 billion by 2050 [10], which is the key driver to increase the demand for water, food and energy. Moreover, it is anticipated that, in the future, climate change will affect food production [11]. Finally, along with global climate change, global population growth, the loss of biodiversity, and resource depletion present significant challenges to addressing food security [12].

Food and energy security are important issues that are being considered together with economic development and environmental sustainability. Food security, the link between resource consumption and agricultural activities analyzed, where the sudden changes in resource supply can affect agricultural production and, as an extension, national food security. Food and energy security are indeed interconnected such that integrated policy responses will be required if these issues are to be tackled effectively [13]. Apart from that, the water-energy-food nexus is currently being promoted as a conceptual tool for achieving sustainable development [14, 15]. These show the complexity and interactions in scenario analyses towards food and energy security under several constraints and objectives, such that energy security has gained increasing prominence in political agenda and policy making frameworks [16, 17].

To address the issue of oil depletion, the insecurity of supply, the volatility in prices, along with the environmental constraints on social and economic development, biofuel is now considered as part of the solution in the transportation sector [18-24]. For their part, Huang et al. [25] assessed the future impacts of biofuel production on regional agriculture and related sectors in developing nations.

With the growing interest for expanding the production of biofuels on a global scale, the need to establish sustainability and certification criteria have been identified [26] through eight dimensions of sustainable development, including social, cultural, ecological, environmental, territorial, economic, and political on both national and international levels. Renewable energy, biofuel in particular, is sometimes depicted in the policy sphere as a means to reduce greenhouse gas (GHG) emissions and simultaneously increase energy security, especially in the transport sector, which is dependent on oil products [27, 28]. Nevertheless, Mitchell [29], Rosegrant [30], FAO [31], Tokgoz et al. [32], and the National Research Council [33] have examined how biofuels can impact the agricultural commodity markets. Likewise, some research show that an increased biofuel production affects the fuel costs and increases the greenhouse gas emissions from field crops [34-37].

Biofuels are a new generation of fuels. Biodiesel is one of the most attractive biofuel since it can be obtained from vegetable or animal oils, and it has properties similar to conventional diesel [38]. It can be produced by a chemical reaction of a vegetable oil with an alcohol through transesterification using either methanol or ethanol, resulting in methyl or ethyl ester. It can be used in blends with diesel oil to fuel trucks and public transportation buses [39]. In Thailand, biodiesel is mainly produced from palm oil. Although jatropha is considered as one of the other promising energy crops for biodiesel production, it produces much lower yields of oil than palm trees [40].

Biodiesel, more specifically the B2, B5, and B10 diesels, have been authorized for sale in Thailand in 2008, 2011, and 2014, respectively, to replace diesel consumption in order to reduce the greenhouse gas emissions in the transportation sector as a way to mitigate climate change.

Along with being used to produce biodiesel, palm oil is currently the most consumed edible oil in the world. In addition, edible oils are used in the production of soap, washing powders and personal care products. Two edible oils, soybean oil and palm oil, account for roughly 61% of the total world production [41]. Palm oil has a high oil content and the highest potential of yield per unit area when compared to other oil crops [42-44]. In terms of global palm oil supply, in 2015, Indonesia was the world's market leader with an annual production of 33 million metric tonnes, followed by Malaysia with a production of 20.5 million metric tonnes, while Thailand 2.4 million metric tonnes [45].

For Thailand, the palm oil industry is one of the most significant economic driver due to its multiple usages, in particular for the production of domestic edible oil and biodiesel. Crude palm oil (CPO) is used in a wide variety of products such as food items (cooking oil, margarine, and sweets), an alternative fuel source (biodiesel), and commodities (cosmetics, soap, candles, textile, and plastics). CPO is produced from fresh fruit bunch (FFB) through the palm oil mill industry. In Thailand, the palm tree harvested areas are essentially distributed in every region; however, most of the oil palm production outputs are from the Southern provinces as they have favorable geophysical conditions for palm trees to grow. In Southern Thailand, palm oil is the second most important crop, after rubber (latex), and is a primary source of income and employment in rural areas. The provinces with highest harvested areas and highest production output levels are in the Southern region, including Surat Thani, Krabi and Chumphon. Based on the 2016 data provided by the Thai Department of Internal Trade, Ministry of Commerce (2016), there were 137 crushing mills to serve the CPO production, while 100 of these mills were situated in Southern Thailand, with a maximum production capacity of nearly 5,000 tonnes CPO/day.

The Government of Thailand launched a first plan to replace the usage of regular diesel with biodiesel; which created an expansion of palm oil production. According to the initial 10-year Alternative Energy Development Plan [46, 47] for the period of 2012 to 2021, the Thai Government targeted a biodiesel production of 6 million liters/day by 2021. However, an increased demand of biodiesel will affect agricultural systems; it could also negatively affect food security, especially edible cooking palm oil production, if appropriate measures are not taken.

The main objective of the AEDP is to reduce oil imports, which Thailand imported more than 60% of energy used commercially, including 80% of total domestic oil usage [46, 47]. In this plan, the target ratio for alternative energy consumption would increase from 7,431 ktoe (kilo tonne of oil equivalent) in 2012 to 25,000 ktoe in 2021, corresponding to 25% of the total energy consumption, while biodiesel productions of 3.6 million liters/day and 6.0 million liters/day were targeted for 2016 and 2021, respectively.

The Government of Thailand has recently launched a revised AEDP [48], which sets the target for alternative energy usage at 30% of total energy consumption in 2036. The target for biodiesel production has been amended to 14.0 million liters/day by 2036, which will require a total surface area of 14,631 km^2 of palm tree plantations.

According to the Office of Agricultural Economics [49], the current palm tree harvested areas in Thailand cover 6,765 km^2, generating approximately 2.4 million tonnes of CPO annually. This CPO is used for domestic consumption (approximately 2.08 million tonnes; 86.6% of the total CPO production), for stock management (approximately 0.25 million tonnes; 10.7% of the total CPO production) and for export (approximately 0.07 million tonnes; 2.6% of the total CPO production).

For the domestic consumption of 2.08 tonnes, the CPO is used for the production of cooking vegetable oil (0.66 million tonnes; 32%), for the production of an alternative fuel source (biodiesel) (1 million tonnes; 48%), and for other usages (0.42 million tonnes; 20%). The distribution of palm oil transformation in Thailand, for the year 2013, is shown in Figure 2.1 [50].

In order to assure food and energy security in the country, the share of CPO usage for the production of biodiesel, without any impact of the production of edible cooking palm oil and other marginal usages, is the main issue to be considered in order to meet the total domestic demand of palm oil in Thailand.

In this context, the objective of this paper is to present an analysis to achieve the goal of producing 14.0 million liters/day of biodiesel by 2036, without affecting any other parts of the supply chain for CPO, including the growth of the demand for edible cooking oil and for the marginal usages of palm oil. The analysis is based on achieving a balance between the areas available for palm tree plantations and the increasing demand of palm oil to achieve food and energy security.

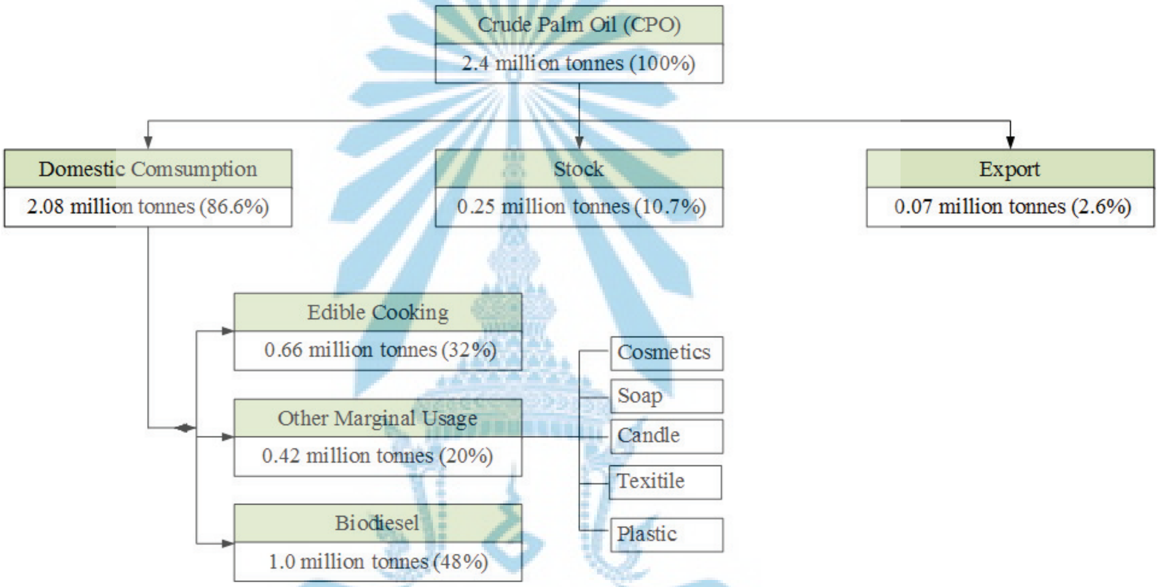

Figure 2.1 Distribution of palm oil transformation in Thailand (2015) [50].

2.2 Methodology

The Kingdom of Thailand is a country at the center of the Indochinese peninsula in Southeast Asia. With a total area of approximately 513,120 km^2, Thailand is the world's 51st largest country. It is the 20th most populous country in the world, with 68.86 million people in 2016. With a GDP of US$406.84 billion in 2016, Thailand is an emerging economy and is considered a newly industrialized country [51].

In order to drive the economic and social development of the country, and considering the annual increases in the population, the demand and supply of palm oil for food and energy should be analyzed for the short to long-terms. In this section, the demand for CPO is analyzed up to 2036, followed by an analysis of the supply of CPO to fulfill the anticipated demand for palm oil-based biodiesel to achieve Thailand's AEDP, while continuing to supply the growing demand for edible cooking palm oil and other marginal usages.

2.2.1 Demand of Edible Cooking Palm Oil

In the case of food security, the domestic edible cooking palm oil demand is forecasted using statistical models based on time-series analysis of the historical patterns in the data, along with forecasting models based on daily calorie intake and population.

In this work, the statistical models include multiple regression analysis, Holt's Exponential Smoothing Method (ESM), and a Combined Forecasting Method (CFM), in order to identify the most appropriate technique for forecasting the demand of domestic edible cooking palm oil. The main inputs in the modeling include the population in the country, as predicted by the National Statistical Office [52]; the price of bottled palm oil (PPO) and the price of bottled soybean oil (PSOY), obtained from the Thai Department of Internal Trade, Ministry of Commerce [53]; and the gross domestic product per capita (GDP per capita: PERCAP), obtained from the World Bank [51]. For the forecasting, the time series data used are on a yearly basis for the period 1985-2012. However, when analyzing the variables of population, the results showed that the independent variable and regression coefficients of the population had a high variance inflation factor (VIF). Thus, the population and GDP cause a multicollinearity problem for the forecasting of the CPO needed. Further analysis showed that it was better to remove the population from the model, rather than GDP, due to the VIF criteria.

(1) Multiple Regression Analysis

A multiple regression analysis is conducted to generate a forecast of the edible cooking palm oil consumption in Thailand. Using SPSS (Statistical Package for Social Sciences) version 17 [54] and the SAS (Statistical Analysis System) version 9 [55], the independent variable used in this analysis is a time series of the annual consumption of edible cooking palm oil, with the multiple regression analysis in the form of Eq. (2.1) [56]:

$$Q = \beta_0 + \beta_1 PPO + \beta_2 PSOY + \beta_3 PERCAP \quad (2.1)$$

where Q is the annual consumption of edible cooking palm oil (tonnes)

PPO is the price of bottled palm oil (Thai Baht)

PSOY is the price of bottled soybean oil (Thai Baht)

PERCAP is the GDP per capita (Thai Baht)

β_0 is the level of the time series

β_i are the regression coefficients from the least square method with expected signs $\beta_1 < 0, \quad \beta_2 > 0, \quad \beta_3 > 0$

(2) Holt's Exponential Smoothing Method (ESM)

Exponential smoothing assigns exponentially decreasing weights on the previous observations. In other words, recent observations are given relatively more weight in forecasting than the previous observations. The Holt's ESM is shown in Eq. (2.2) [57], while the forecasting model obtained is shown in Eq. (2.3) [54]:

$$Y_t = \beta_0 + \beta_1 t \tag{2.2}$$

$$\hat{Y}_{t+m} = a_t + b_t(m) \tag{2.3}$$

where Y_t is the time series consumption for bottled palm oil at time t

$\hat{Y}_{t+m}$ is the forecast demand for bottled palm oil at time t+m, where m is the amount of time forward

β_0 and β_1 are the parameters for the intercept and the slope, respectively

t is the time, t =1 to n

a_t and b_t are the estimates of parameter at time t

This method is effectively used when the data exhibit a trend, where exponential smoothing works better than simple smoothing. The level is a smoothed estimate of the value of the data at the end of each period, while the trend is a smoothed estimate of the average growth at the end of each period. The specific formula for simple exponential smoothing is:

$$a_t = \alpha Y_t + (1-\alpha)(a_{t-1} + b_{t-1})$$

$$b_t = \gamma(a_t - a_{t-1}) + (1-\gamma) b_{t-1}$$

where α and γ are smoothing factors, with $0 < \alpha < 1$ and $0 < \gamma < 1$.

(3) Combined Forecasting Method (CFM)

There are many forecasting models used in time series forecasting. However, model selection is often unstable and may cause an unnecessary high variability in the final prediction. The CFM are used for risk minimization as they reduce the variance of the final forecast. Combining techniques is also used to improve forecast accuracy under certain circumstances. An alternative viewpoint is that random errors are more significant for short-range forecasts, because these errors are off-setting and a combined forecast should reduce the errors [58, 59]. In this paper, the CFM from the multiple regression analysis and Holt's ESM are combined, and displayed in Eq. (2.4):

$$\hat{Y}_t = b_0 + b_1\hat{Y}_{1t} + b_2\hat{Y}_{2t} \quad (2.4)$$

where $\hat{Y}_t$ is the forecast demand for bottled palm oil at time t

$\hat{Y}_{1t}$ and $\hat{Y}_{2t}$ are the single forecasts from multiple regression analysis and Holt's Exponential Smoothing Method, respectively

b_0 , b_1 and b_2 are the weights from the least square method

(4) Calorie- and Population-Based Forecasting

The forecasted demand of CPO for edible cooking palm oil is also predicted using calorie- and population-based methods. In the calorie-based method, a calorie constraint of 600 kcal/day per capita, recommended as the daily average calories requirement for Thai people [60], is used to forecast the demand of edible cooking palm oil. Thus, the annual demand of edible cooking palm oil, based on the calorie-based analysis, is the product of the daily calorie requirement per capita and the total projected population. The population-based method assumes that the consumption profile for edible cooking palm oil of the Thai population will not change significantly in the period of this analysis. Thus, a simple regression between actual statistical CPO and population based on linear and quadratic regressions is also done.

(5) Forecast Performance Measures

This study considered three indicators to assess the performance of the forecasting, as follow: mean absolute percentage error (MAPE), root mean square error (RMSE) and coefficient of determination (R^2).

The MAPE can be computed using Eq. (2.5).

$$\text{MAPE} = \frac{100}{n}\sum_{t=1}^{n}\left|\frac{e_t}{Y_t}\right| \quad (2.5)$$

while the RMSE can be computed using Eq. (2.6).

$$\text{RMSE} = \sqrt{\frac{1}{n}\sum_{t=1}^{n}e_t^2} \quad (2.6)$$

where $e_t = Y_t - \hat{Y}_t$

n is the number of data point in the time series

Y_t is the time series LQN at t time, where LQN is the forecasting (log base) of the demand for edible cooking palm oil

$\hat{Y}_t$ is the predicted time series LQN at time t

These measures are used to compare the performance of the forecast values obtained from the multiple regression analysis, the Holt's ESM and the CFM.

2.2.2 Demand of Biodiesel from Palm Oil

In the case of energy security, the demand of biodiesel production is predicted to be 3.6 million liters/day in 2016, 6.0 million liters/day in 2021 and 14.0 million liters/day in 2036, as identified by the Ministry of Energy of the Government of Thailand [48].

2.2.3 Demand of Palm Oil by other Industries

Other industries in Thailand consume palm oil in the production of products. These include the cosmetics industry, animal food production, the production of creams and margarine, aromatics, detergent and soap for domestic consumption purpose only. The total demand of CPO for these industries are forecasted to be a constant proportion of 62.5% of the total edible cooking palm oil consumed in the country.

2.2.4 Analysis of the Supply of CPO

In order to analyze the supply of CPO in Thailand, some assumptions are applied as follows: the yield of oil palm FFB is 1,750 tonnes/ km^2, the CPO yield is 17% (meaning that one tonne of FFB yields 0.17 tonne of CPO) and the conversion factor of CPO to bottled edible cooking palm oil is 1 tonne of CPO produces 0.95 tonne of refined palm oil and 1 tonne of refined palm oil produces 0.60 tonne of bottled palm oil. Regarding the transformation of CPO to biodiesel, the conversion factor is 0.95, thus 1 tonne of CPO produces 0.95 tonne of biodiesel [61].

In the supply and demand analysis, the area needed for new palm tree plantations is transposed based on the above assumptions. However, new palm tree plantations should be prioritized on areas satisfying criteria that will produce the optimum yield of palm oil. The suitable topography, soil type and properties, as well as suitable climate for palm tree plantations are as follows [62]: the slope of the terrain is between 0 and 4%, the elevation is less than 100 m above mean sea level, the annual mean temperature is in the range of 29 to 32^{o}C, the annual average rainfall amount is in the range of 2,700 to 3,000 mm distributed throughout the year, the amount of sunshine hours is in the range of 5 to 6 hours per day, the orientation is South, the soil type is presence of clay loam and clay, and depth soil layer is over 0.75 m.

The suitable area for new palm oil plantation promotion is analyzed using the land availability with the exclusion of current national economic plantation areas, i.e., rice, rubber, sugarcane, cassava and several fruits (rambutan, durian, mangosteen, banana, and longan) plantations.

The area for palm tree plantations needed to satisfy the forecasted demand of edible cooking palm oil, biodiesel consumption and other marginal usages in Thailand is analyzed based on the business as usual (BAU) scenario. Further, in order to assess the risk in these forecasts, other scenarios as a function of the BAU scenario are analyzed: low (10% decrease) and high (10% increase) demand scenarios; and low (10% decrease) and high (10% increase) supply scenarios.

The site selection of areas for new palm tree plantations in Thailand is performed using ArcGIS version 10.2 Extension Spatial Analyst [63], along with several spatial GIS database. The characteristics, and respective weighting, used for the analysis, are classified into three main classes, as shown in Tables 2.1 and 2.2 the characteristics used to identify the biophysical suitability for the plantation of palm trees include [62]: topography, climate and soil that are suitable for palm tree crops. In the areas where all these characteristics are satisfactory, palm tree crops can be considered to be suitable for agricultural production.

Table 2.1 Characteristics used for the analysis of potential sites for the expansion of palm tree plantations in Thailand.

Characteristics	Weighting
Topography - Slope of the terrain - Elevation above mean sea level	30%
Climate - Annual mean rainfall - Annual mean temperature - Annual sunshine hours - Orientation (Direction)	35%
Soil - Presence of clay loam and clay - Depth of soil layer over 0.75 m	35%

Table 2.2 The scoring for the variable data.

Data	Variable	Quantity	Suitability	Scoring (0-10)
Topography	Slope of the terrain (Degree)	0.0 - 4.0	Most Suitable	10
		4.1 - 8.0	Moderately Suitable	5
		8.1 - 12.0	Less Suitable	1
	Elevation above mean sea level (m)	0 - 100	Most Suitable	10
		101 - 200	Moderately Suitable	5
		201 - 300	Less Suitable	1
Climate	Annual mean rainfall (mm)	2,701 - 3,000	Most Suitable	10
		2,401 - 2,700	Moderately Suitable	5
		2,200 - 2,401	Less Suitable	1
	Annual mean temperature (^{o}C)	29.1 - 32.0	Most Suitable	10
		25.1 - 29.0	Moderately Suitable	5
		22.0 - 25.0	Less Suitable	1
	Annual sunshine hours (hr)	5.0 - 6.0	Most Suitable	10
		6.1 - 7.0	Moderately Suitable	5
		7.1 - 8.0	Less Suitable	1
	Orientation (Direction)	S	Most Suitable	10
		SE, SW, E, W	Moderately Suitable	5
		N, NE, NW	Less Suitable	1
Soil	Type of soil	Presence of clay loam and clay (C)		10
	Depth of soil layer	more than 0.75 m		10

The slope, elevation above mean sea level and depth of soil layer are analyzed using Digital Elevation Model (DEM) based on GDEM with 30 m resolution. Figure 2.2 shows the spatial distribution of the slope of the terrain throughout Thailand. The data related to the climate of the country are obtained from the Thai Department of Meteorology and Climatology [64] over the 10-year period of 2001-10. Annual mean temperature, rainfall, and sunshine hours (Figures 2.3 to 2.5), obtained from 119 met stations throughout the territory of Thailand, are used to generate the spatial digital database based on the Inverse Distance Weight (IDW) interpolation technique in ArcGIS 10.2. Data related to the soil resources of Thailand, obtained from the Office of Soil and Land Use Planning, a commercial product of Thai Land Development Department [65], are shown in Figure 2.6 in the form of the spatial distribution of the suitable soil type (combinations of clay).

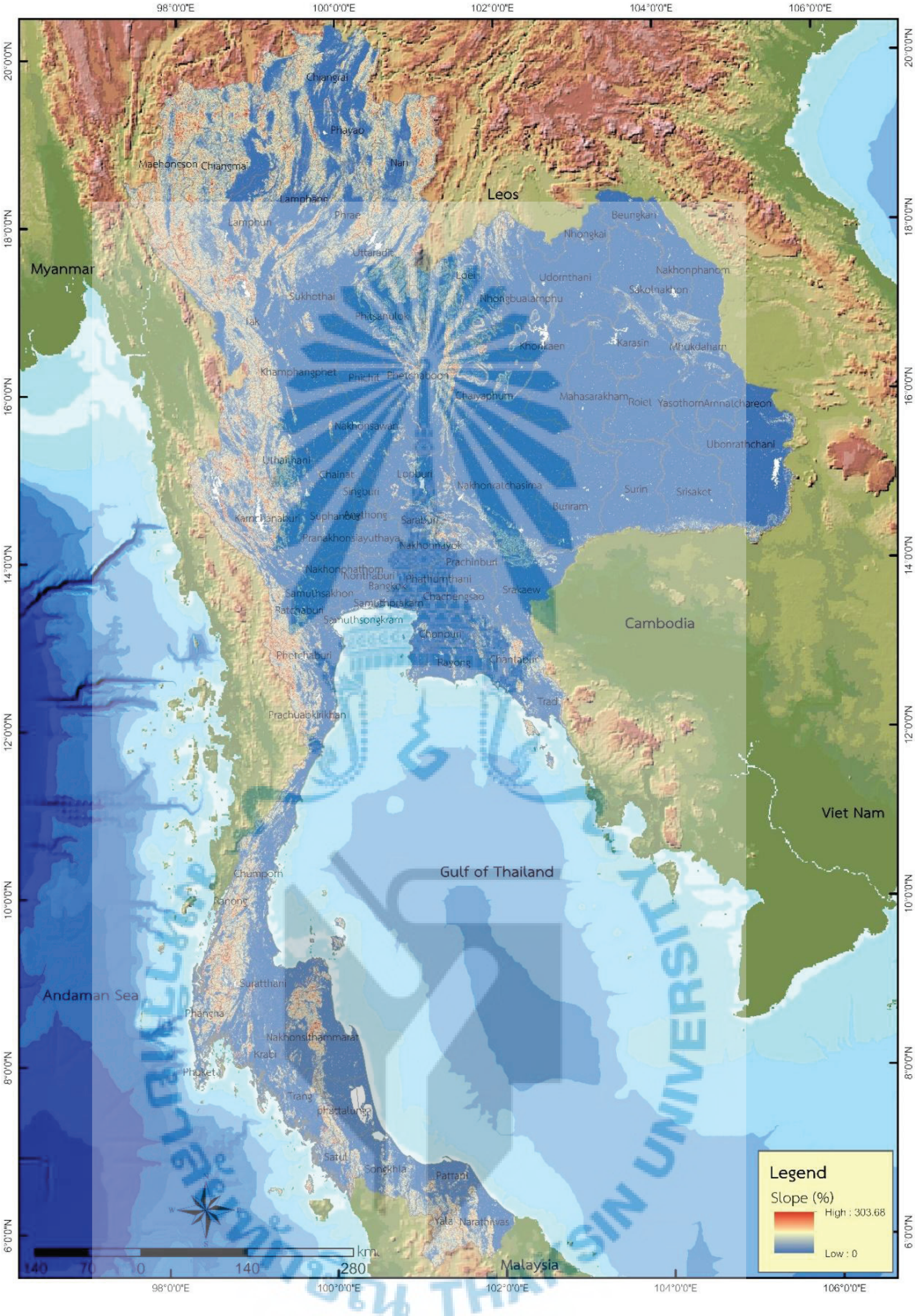

Figure 2.2 Spatial distribution of the slope of the terrain in Thailand.

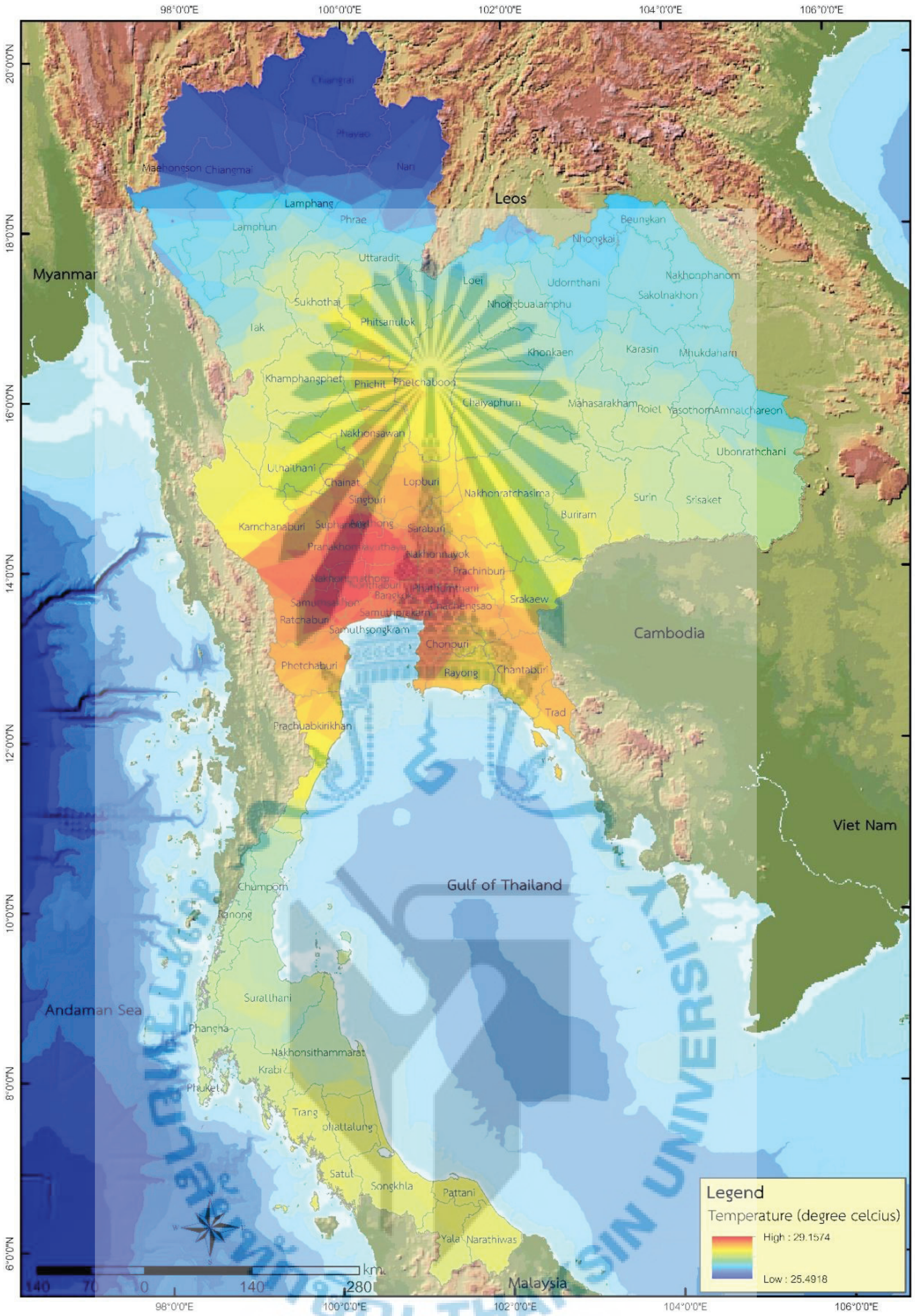

Figure 2.3 Spatial distribution of the annual mean temperature in Thailand.

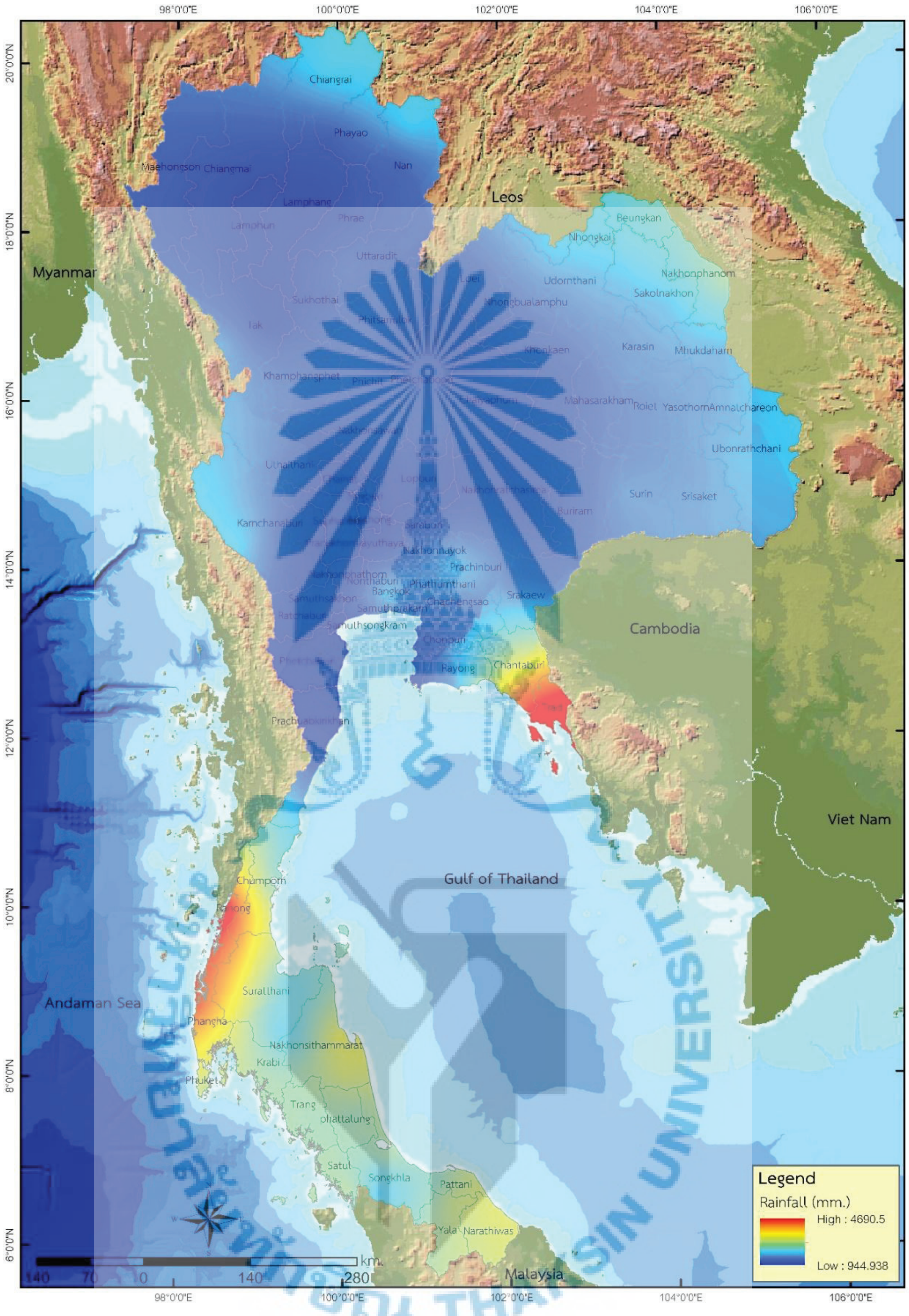

Figure 2.4 Spatial distribution of the annual rainfall in Thailand.

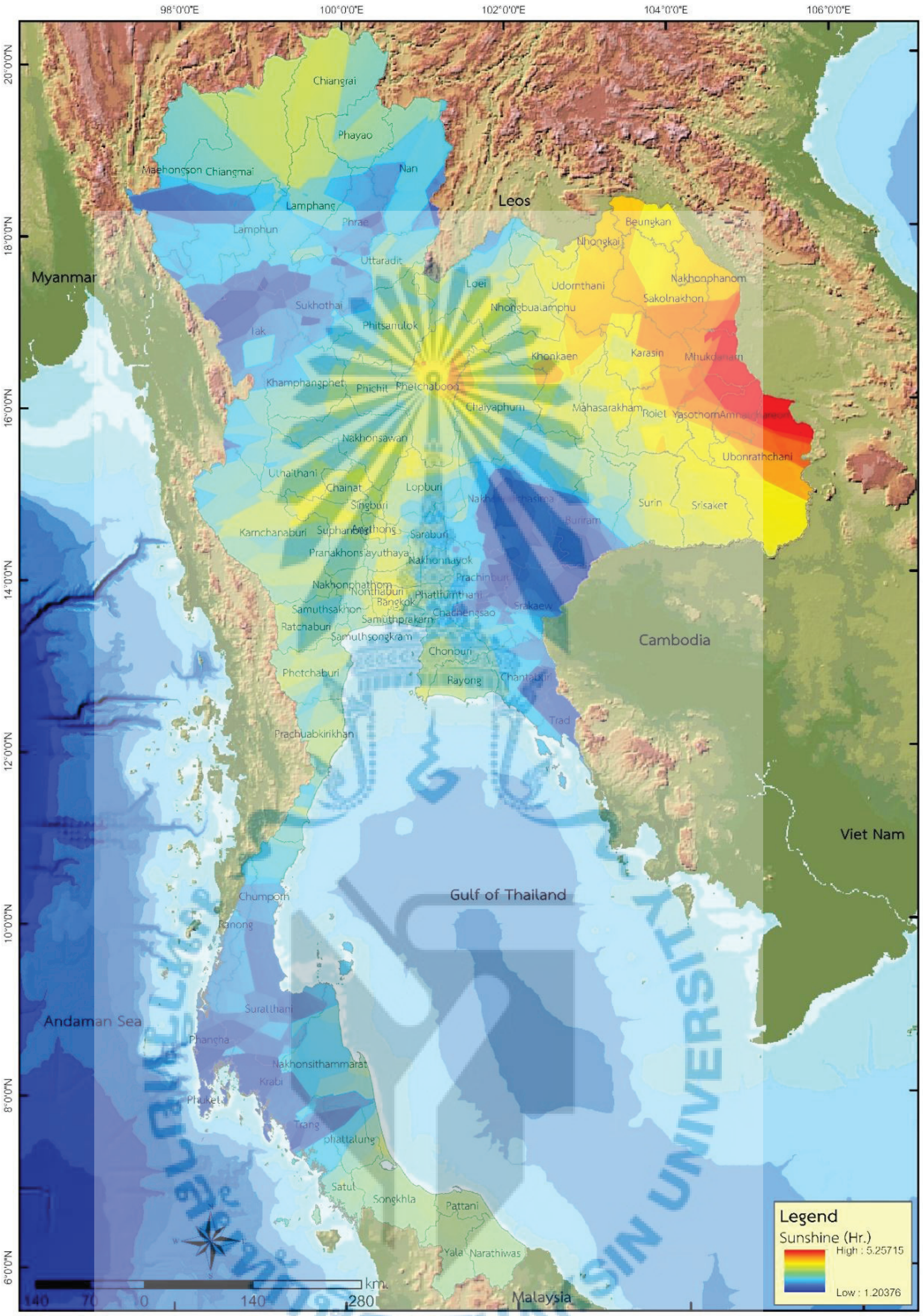

Figure 2.5 Spatial distribution of the annual sunshine hours in Thailand.

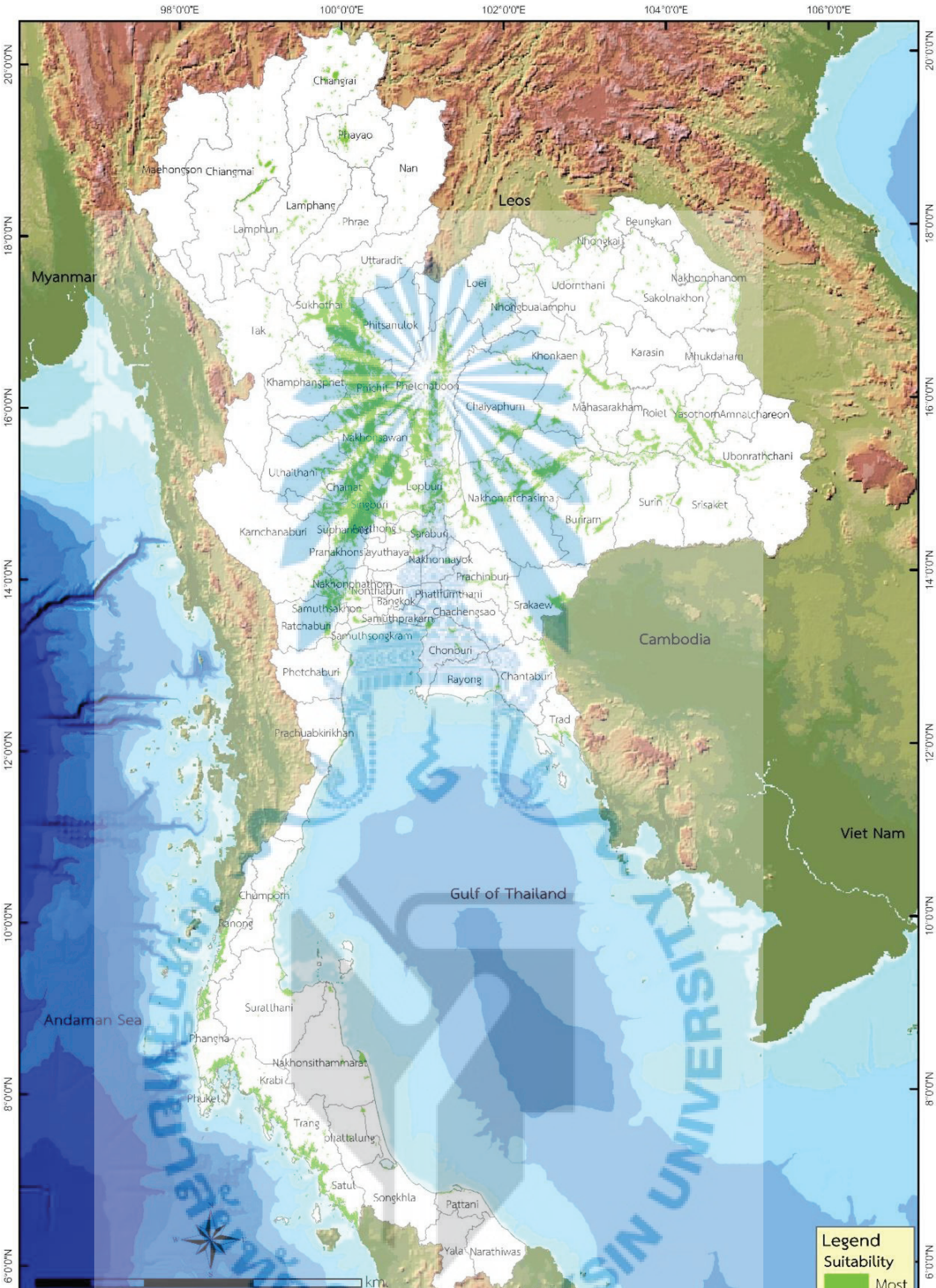

Figure 2.6 Spatial distribution of the suitable soil type (combinations of clay) for palm tree plantations in Thailand.

In terms of land-use suitability, the identification of all prohibited and constrained zones, i.e., urban areas, industrial zones, forests, sanctuaries, national parks, military zones, environmental protection areas, along with the areas for the main commercial agriculture activities of Thailand, i.e., rice, cassava, rubber, existing palm tree plantations, and sugar cane, are excluded from possible areas of development. In the end, Figure 2.7 shows the possible areas for palm tree plantations in Thailand.

The suitability of the areas for palm tree plantations is assessed on the basis of a scale with three levels, namely:

- Score 8-10: Suitable area
- Score 4-7: Moderately suitable area
- Score 0-3: Less suitable area

The results of this investigation will identify the suitable areas, the moderately suitable areas and the less suitable areas where it would be possible to have new palm tree plantations in Thailand.

2.3 Analyses

Figure 2.8 shows that the historical demand of CPO for edible cooking palm oil follows a smooth trend, with a small increase in 2012-2014. Further, in 2016, the Thai oil industry had to face the negative consequences of the extended severe drought which ran from 2015 into the first half 2016; the oil palm output for 2016 was down 12.3% from the previous year.

The performance of each forecasting statistical model for the demand of edible cooking palm oil is shown in Table 2.3. It can be seen that the R^2 obtained from the multiple regression analysis is the most appropriate; however, the MAPE and RMSE is higher than that of Holt's ESM. On the other hand, it is found that the MAPE and RMSE obtained from the CFM have decreased to 1.3463 and 0.0416, respectively. However, the R2 for the CFM has increased slightly (0.930) compared to the Holt's ESM (0.924), but is lower than that of the multiple regression analysis (0.956). Therefore, based on the statistical method, the CFM appears to be the most appropriate to forecast the demand of edible cooking palm oil; the results are shown in Figure 2.8.

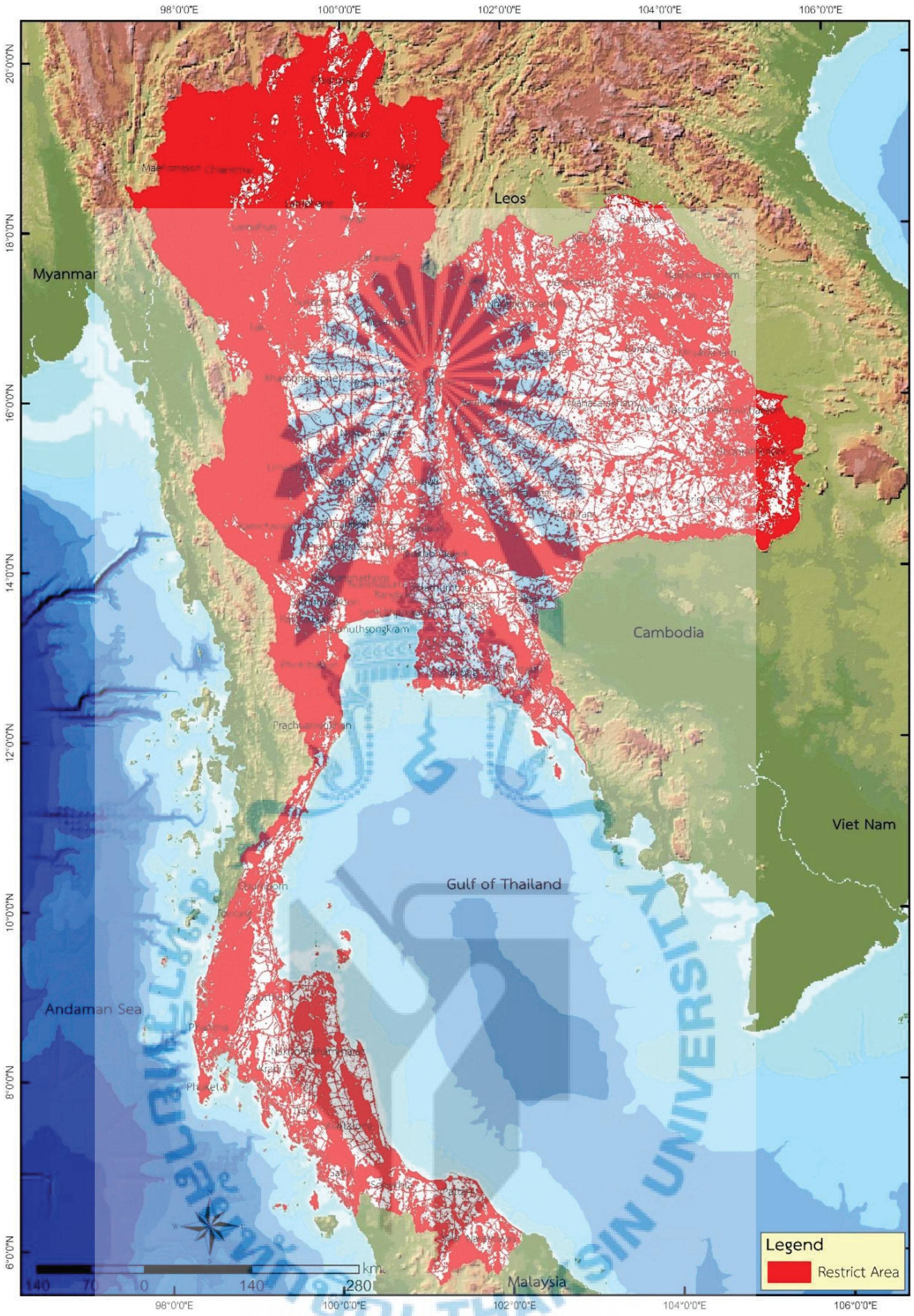

Figure 2.7 Restricted (red) and possible (white) areas for palm tree plantations in Thailand.

Table 2.3 Performance of each forecasting statistical model for the demand of edible cooking palm oil.

Model	Model Selection Criteria		
	MAPE	RMSE	R^2
Multiple Regression Analysis	1.9149	0.0605	0.956
Holt's Exponential Smoothing	1.4008	0.0435	0.924
Combined Forecasting Method	1.3463	0.0416	0.930

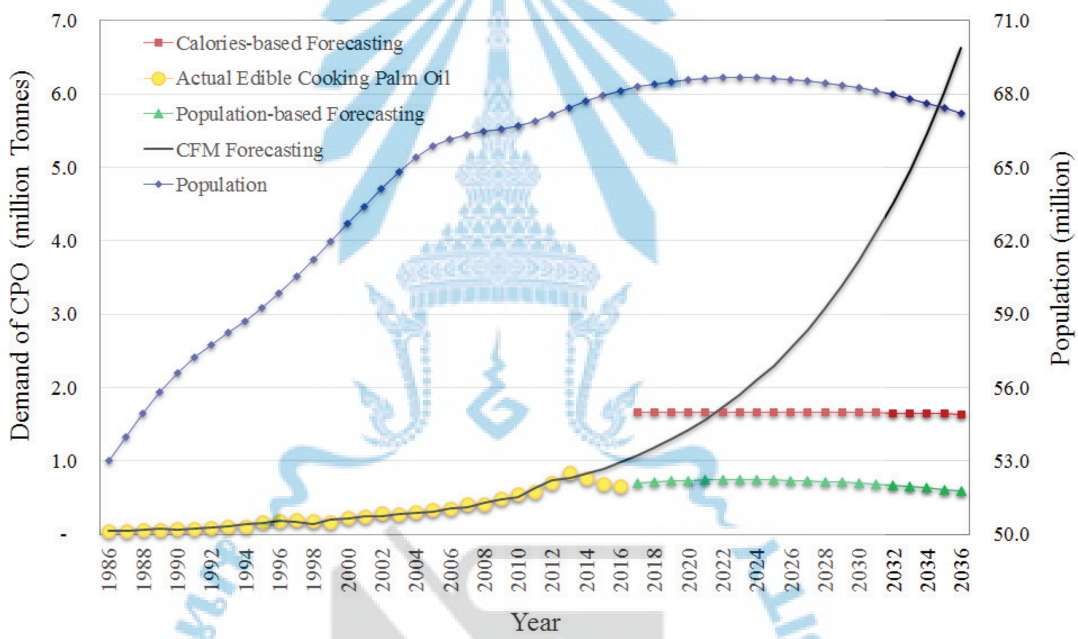

Figure 2.8 Forecasted total demand of CPO for edible cooking palm oil based on the statistical method along with calorie- and population-based (with a quadratic regression) methods.

The forecasted demand of edible cooking palm oil is compared with the calorie-based analysis and the population-based regression between the past consumption of CPO and population. The projections of the total demand of edible cooking palm oil based of the calorie-and population-based analyses, along with the projection of population until 2036, are also shown in Figure 2.8.

It can be observed that the projections based on statistical forecasting do not provide realistic results. This could be explained by the fact that, in the first trials, the statistical forecasting using GDP, population, amount of bottled palm oil, price of bottled palm oil, and price of bottled soybean oil revealed that there was a multicollinearity between GDP and population, notably because of the rising trend of GDP. For this reason, the population had to be eliminated for the statistical forecasting due to the VIF criteria. For its part, the calorie-based analysis provides values that do not correspond to the current, and past, consumption of edible cooking palm oil, meaning that the Thai population consume their daily energy intake from diversified sources, not only from palm oil. Finally, the population-based forecast analyzed simple and quadratic regressions between the statistical consumption of CPO and population, with 0.886 R^2 (Figure 2.9). Since this method, using a quadratic regression, appears to provide the most realistic projections, the forecasted demand of CPO for edible cooking palm oil, until 2036, is obtained using a population-based forecast with a quadratic regression between consumption of CPO and population.

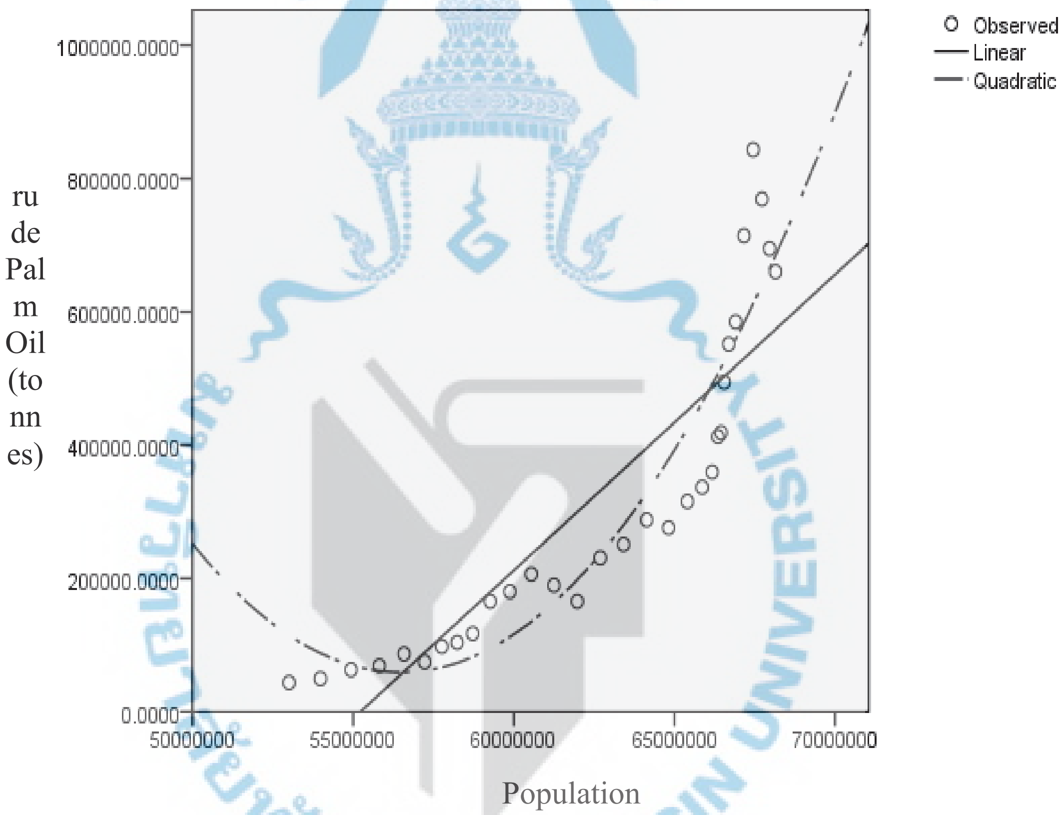

Figure 2.9 The best-fit based on simple linear and quadratic regressions between past and current consumption CPO for edible cooking palm oil and population.

The forecasted demand of CPO needed to satisfy the demand of edible cooking palm oil for domestic consumption in Thailand, based on the BAU scenario and a population-based forecast, is found to be 0.66 million tonnes in 2016, 0.74 million tonnes in 2021 and 0.59 million tonnes in 2036. The 10% increase (high scenario) and 10% decrease (low scenario) of forecasted demand of CPO is shown in Figure 2.10, where the data up to the year 2016 correspond to the real consumption of edible cooking palm oil in Thailand.

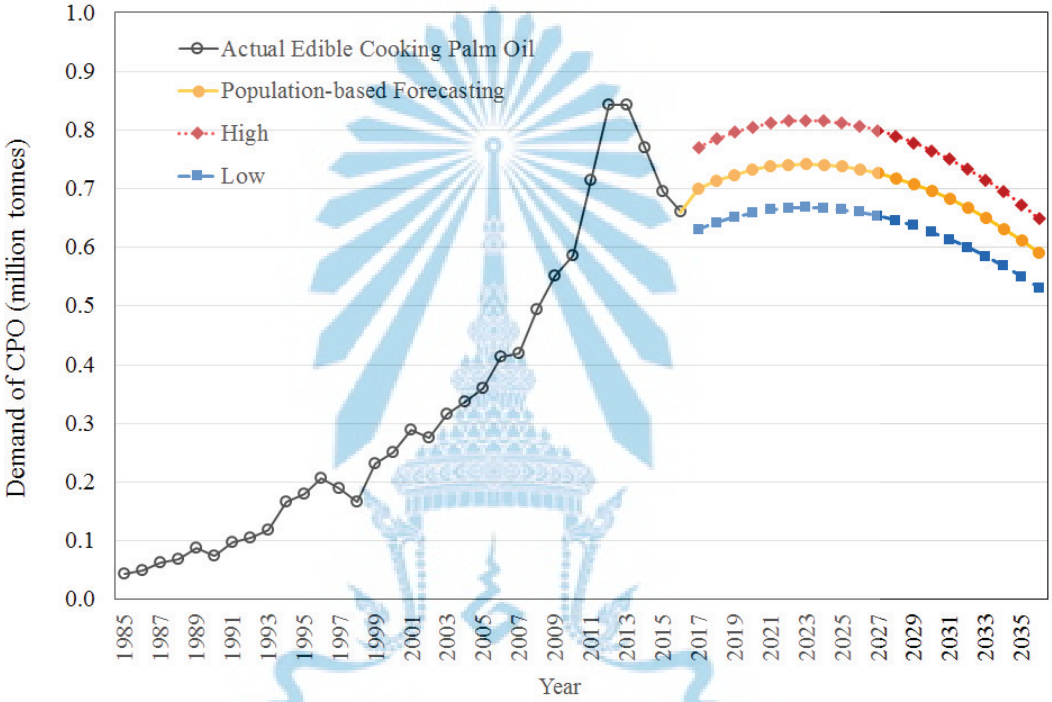

Figure 2.10 Actual (up to 2012) and forecasted demand of CPO for edible cooking palm oil for domestic consumption in Thailand.

Based on the revised AEDP 2015-2036 [48], the biodiesel consumption in Thailand is forecasted at 6.0 million liters per day in 2016 and 14.0 million liters per day in 2036. In order to achieve the AEDP 2015 targets, the demand of CPO for biodiesel production is estimated to be 1.15 million tonnes per year in 2016, 1.89 million tonnes per year in 2021 and 4.42 million tonnes per year in 2036. These estimates are based on the following assumptions: oil palm yield following AEDP plan and crushing rate of crude palm (oil yield) of 17%. The forecasted demand of CPO for the production of biodiesel in Thailand is shown in Figure 2.11.

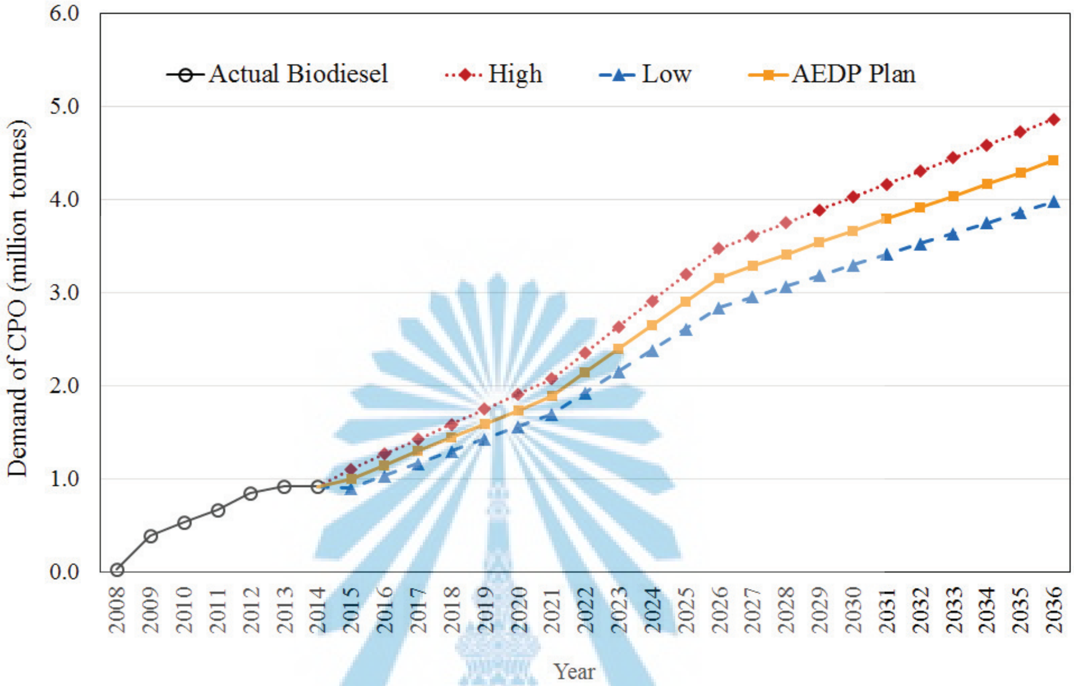

Figure 2.11 Actual (up to 2012) and forecasted demand of CPO for the production of biodiesel in Thailand.

The total demand of CPO for marginal usages, based on the constant proportion of 62.5% of the total edible cooking palm oil consumed in the country, is forecasted to be 0.41 million tonnes in 2016, 0.46 million tonnes in 2021 and 0.37 million tonnes in 2036.

The total demand of CPO production for edible cooking palm oil, biodiesel production and other marginal usages is estimated to be 2.22 million tonnes per year in 2016, 3.08 million tonnes per year in 2021 and 5.38 million tonnes per year in 2036 to achieve food and energy security in the BAU scenario. For the worst-case scenario, the total demand of CPO production is estimated to be 2.44 million tonnes per year in 2016, 3.39 million tonnes per year in 2021 and 5.92 million tonnes per year in 2036, as illustrated in Figure 2.12.

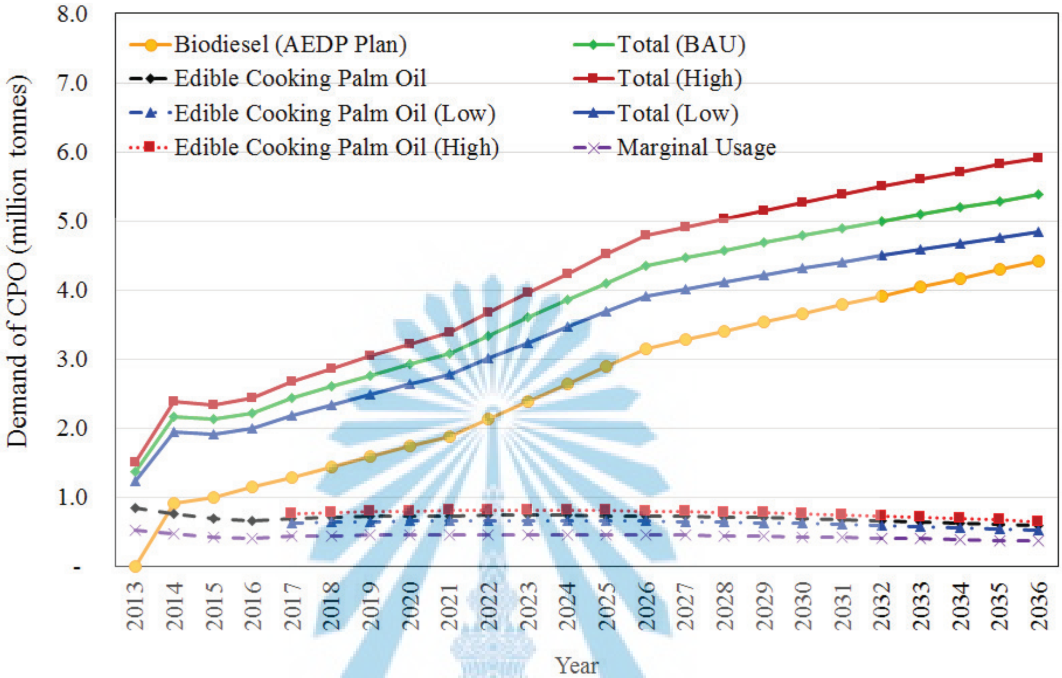

Figure 2.12 Forecasted total demand of CPO for edible cooking palm oil, biodiesel production and marginal usages in Thailand.

2.4 Results and Discussion

Results from the reveal that, for an oil yield of 17%, the production of 2.22, 3.08 and 5.38 million tonnes of CPO production (under the BAU scenario) would require total areas for palm tree plantations to reach 7,353 km^2 in 2016, 10,206 km^2 in 2021 and 17,803 km^2 in 2036, respectively. For the worst-case scenario, the palm harvesting area needed is 8,334 km^2 in 2016, 11,567 km^2 in 2021 and 20,176 km^2 in 2036. For the BAU scenario, but assuming different oil yields, results show that average oil yields of 15% and 19% would require 20,176 km^2 and 15,929 km^2, respectively, of palm tree plantations, in 2036.

To identify the suitable areas for new palm tree plantations, a multi-criteria decision making analysis is applied. The suitable areas for palm tree plantations in Thailand are distributed in every region, as shown in Figure 2.13.

Results from the analysis show that the most suitable areas for new palm tree plantations in Thailand have a total surface area of 9,666 km^2, while the moderately suitable areas have a total surface area of 4,975 km^2. Therefore, the total suitable area for new palm tree plantations in Thailand is 14,641 km^2. The existing oil palm harvested areas in 2014 covers 6,765 km^2 in Thailand. Thus, the surface area of current land available for palm tree plantations, along with the total surface area offering suitable or marginally suitable conditions for palm tree plantations provide a total surface area of 21,406 km^2. Thus, it is over the required area of 17,803 km^2 for palm tree plantation in 2036.

Since the surface area needed for palm tree plantations to satisfy the demand of CPO in 2036 is in the same range as the available land for palm tree plantations, it will be important to initially establish palm tree plantations in the most suitable areas (9,666 km^2), followed by development in moderately suitable areas (4,975 km^2). Therefore, government agencies should assure that appropriate planning and public policies are implemented to optimize the development of the palm oil industry, and thus contribute food and energy security 2036.

However, the analysis is done based on the assumption that the palm oil yield is 17%. If the palm oil yield increases to 19%, the required surface area would be 15,929 km^2, meaning that the new palm tree plantations needed (9,164 km^2) could all be developed in the most suitable areas. This analysis shows that the palm oil yield is another key success factor for oil palm plantation implementation in Thailand to achieve food and energy security in 2036.

Thailand has several suitable areas for palm tree plantations, spreading in the South, the North, the East, the West, the Northwest and the Central regions. The Central region has the highest number of suitable areas. The details of existing and new suitable areas for palm tree plantations in each region of Thailand are given in Table 2.4. It can be seen that the potential new areas for palm tree plantations could be achieved in the Central, Northeast and Northern parts of the country, thus increasing the distribution of palm tree plantations in different regions of the country.

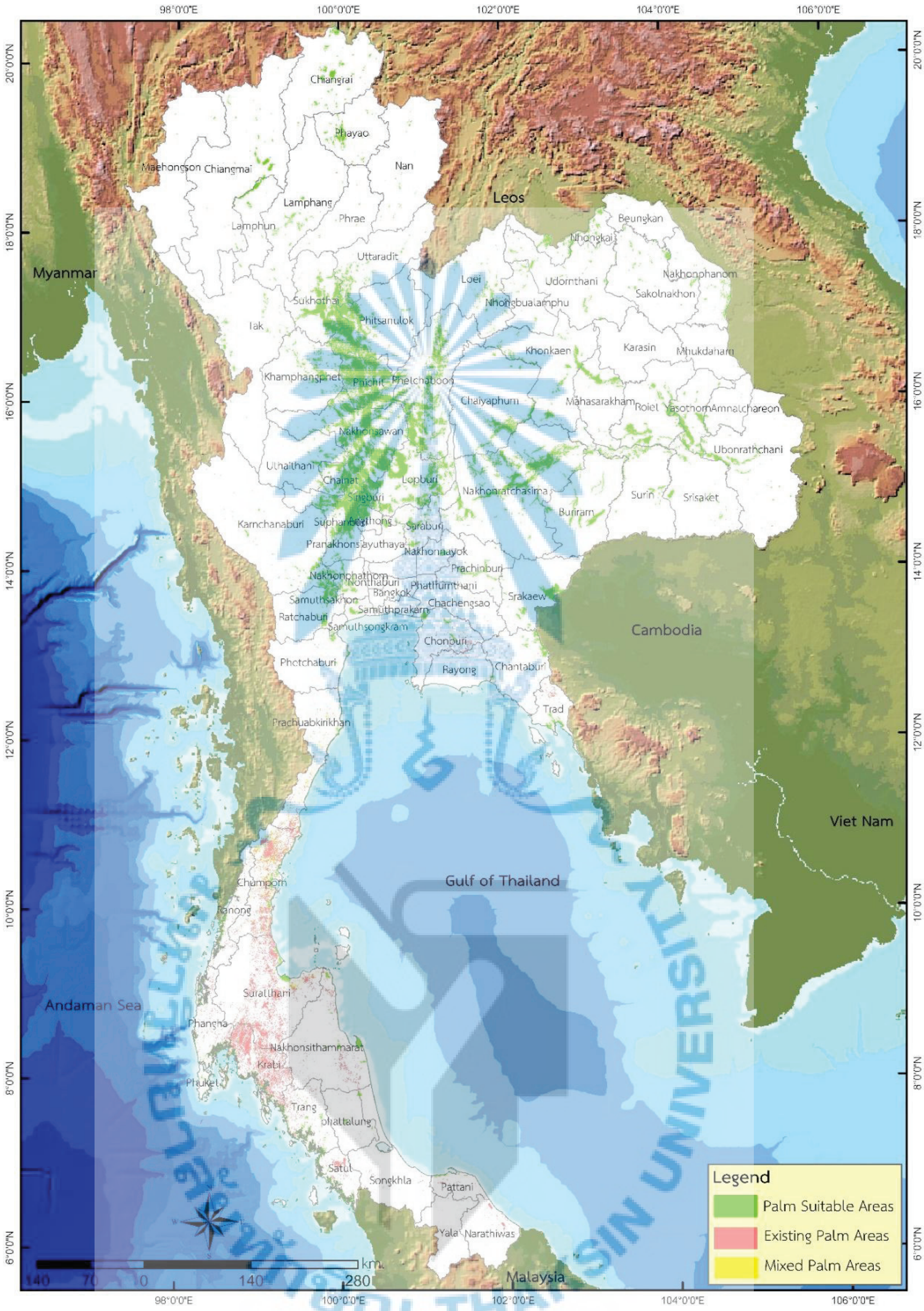

Figure 2.13 The suitable areas for palm tree plantations in Thailand.

Table 2.4 Existing and new suitable areas for palm tree plantations (PTP) in Thailand, classified by region.

Area (km^2)	North	Northeast	Central	East	West	South	Total
Existing PTP	4	30	12	257	272	6,190	6,765
Suitable for PTP	410	2,425	6,363	212	204	52	9,666
Moderately Suitable for PTP	222	1,357	3,124	124	110	38	4,975
Total for PTP	636	3,812	9,499	593	586	6,280	21,406

As mentioned above, the total palm tree plantation area is estimated based on several assumptions. Among those assumptions, the yield seems to be the most important parameter that affects the productivity of a plantation area. In this work, the calculation is done based on the oil yield ratio of 17% for all productions. In order to minimize the risk in assessment, the yield for each type of production is varied to 21%, leading to the plantation area variations shown in Tables 2.5 to 2.7 for edible cooking palm oil production industry, biodiesel production industry and other marginal usages, respectively. Tables 2.8 to 2.10 the summary of the domestic demand of CPO in 2036 (in million tonnes), the summary of the domestic demand of FFB in Thailand in 2036, and the summary of the palm tree plantation areas in Thailand in 2036, respectively.

Table 2.5 Variation of the plantation area of palm trees due to varied % yield for edible cooking palm oil production industry.

% Oil yield	Area (km^2)		
	2016	2021	2036
15%	2,475	2,767	2,212
16%	2,321	2,594	2,074
17%	2,184	2,441	1,952
18%	2,063	2,306	1,843
19%	1,954	2,184	1,746
20%	1,857	2,075	1,659
21%	1,768	2,075	1,659

Table 2.6 Variation of the plantation area of palm trees due to varied % yield for biodiesel production industry.

% Oil yield	Area (km^2)		
	2016	2021	2036
15%	4,311	7,071	16,582
16%	4,042	6,629	15,545
17%	3,804	6,239	14,631
18%	3,593	5,892	13,818
19%	3,404	5,582	13,091
20%	3,233	5,303	12,436
21%	3,233	5,303	12,436

Table 2.7 Variation of the plantation area of palm trees due to varied % yield for other marginal usage.

% Oil yield	Area (km^2)		
	2016	2021	2036
15%	1,547	1,729	1,383
16%	1,450	1,621	1,296
17%	1,365	1,526	1,220
18%	1,289	1,441	1,152
19%	1,221	1,365	1,091
20%	1,160	1,297	1,037
21%	1,160	1,297	1,037

Table 2.8 Summary of the domestic demand of CPO in 2036 (million tonnes).

Type of Demand	2016	2021	2036
Edible Cooking Palm Oil Production	0.66	0.74	0.59
Biodiesel Production	1.15	1.89	4.42
Other Marginal Usage e.g., Cosmetic, Animal Food, Aromatic, and Soap	0.41	0.46	0.37
Total	2.22	3.08	5.38

Table 2.9 Summary of the domestic demand of fresh fruit bunches (FFB) in Thailand in 2036 (million tonnes).

Type of Demand	2016	2021	2036
Edible Cooking Palm Oil Production	3.88	4.34	3.47
Biodiesel Production	6.76	11.09	26.01
Other Marginal Usage e.g., Cosmetic, Animal Food, Aromatic, Soap	2.43	2.71	2.17
Total	13.07	18.14	31.64

Table 2.10 Summary of the palm tree plantation areas needs to achieve food and energy security in Thailand in 2036 (km^2).

Type of Demand	2016	2021	2036
Edible	2,184	2,441	1,952
Biodiesel	3,804	6,239	14,631
Marginal	1,365	1,526	1,220
Total	7,353	10,206	17,803

In order to achieve the AEDP target of 2036, the government organizations in the Ministry of Agriculture and Cooperative and the Ministry of Industry should work with all stakeholders of the palm oil industry, from upstream to downstream, i.e., farmers, collection centers (ramps), and palm oil mills, to collaborate in increasing and assuring that the palm oil yield reaches 17-19%. This is possible since the palm oil yield in 2015 has already reached 21% and over in Indonesia (23.2%) and in Malaysia (20.9%) [66]. Even though the contexts of the palm oil industry in Indonesia and Malaysia are relatively different from Thailand, some good and best practices from those two main producer and exporter countries could be adapted and deployed for Thailand, e.g., high yield palm oil seed breeding, integrated farm management, cultivation behavior of farmers, and high and advanced technology production process replacement for the palm oil mills. Ultimately, a national Act of Oil Palm should be enacted to assure an efficient long-term management of the palm oil industry in Thailand.

2.5 Conclusion

In this work, the total demand of CPO for edible cooking palm oil production, biodiesel production, and marginal usages estimated to achieve the food and energy security up to 2036 in Thailand. The supply of CPO analyzed using palm tree plantations in suitable areas, oil palm FFB yield, and % yield of CPO from CPO mill. Along with the BAU scenario, high and low scenarios are studied to assess the sensitivity of the variables on the forecasts.

Results show that the total annual demand of CPO in the BAU scenario is 2.22, 3.08 and 5.38 million tonnes in 2016, 2021 and 2036, respectively, corresponding to total oil palm plantation areas of 7,353 km^2, 10,206 km^2 and 17,803 km^2 in 2016, 2021 and 2036, respectively. The results from the analysis show that the total suitable area for palm tree plantations in Thailand is 9,666 km^2 while the total moderate suitable area is 4,975 km^2. Including the land currently available for palm tree harvesting, along with the total surface area offering suitable or moderately suitable conditions for palm tree plantations provide a total surface area of 21,406 km^2, which is more than the 17,803 km^2 forecasted to achieve food and energy security in 2036. Public policy measures would need to be implemented to achieve the most efficient way of developing new palm tree plantations to satisfy the forecasted demand for palm oil in 2036.

In summary, some mechanisms would also be required to assure that the industry has the appropriate infrastructure and public policy measures for the palm oil industry to be sustainable. Public policy measures could include zoning, distribution of the palm tree plantations in all the regions of the country. Infrastructure could include central points for oil palm collection, logistics for the transportation of the raw material, crushing mills. Increasing the yield of palm oil in the domestic industry could have a significant impact in bridging the gap between the supply and demand of palm oil in 2036; this would also help in expanding the oil palm industry in the neighboring the Association of Southeast Asian Nations (ASEAN) countries of Cambodia, Burma and Laos.

2.6 Acknowledgements

The authors thank the Agricultural Research Development Agency (Public Organization) of Thailand for the research funding of this project.

2.7 References for Chapter 2

[1] Halsnes K, Markandya A, Shukla P. Introduction: sustainable development, energy, and climate change. World Development 2011;39:983-86.

[2] Esseghir A, Khouni LH. Economic growth, energy consumption and sustainable development: the case of the union for the Mediterranean countries. Energy 2014;71:218-25.

[3] Gaigalis V, Skema R. Analysis of fuel and energy transition in Lithuanian households sector and its sustainable development in compliance with the EU policy. Renewable and Sustainable Energy Reviews 2014;37:273-87.

[4] Gaigalis V, Skema R. Analysis of the fuel and energy transition in Lithuanian industry and its sustainable development in 2005–2013 in compliance with the EU policy and strategy. Renewable and Sustainable Energy Reviews 2015;52:265-79.

[5] Emodi NV, Boo K-J. Sustainable energy development in Nigeria: Current status and policy options. Renewable and Sustainable Energy Reviews 2015;51:356-81.

[6] Ozturk M, Yuksel YE. Energy structure of Turkey for sustainable development. Renewable and Sustainable Energy Reviews 2016;53:1259-72.

[7] Andriosopoulos MK. Energy security in East Asia under climate mitigation scenarios in the 21st century. Omega 2016;59:60-71.

[8] Lam HL, Varbanov PS, Klemes JJ, Yan J. Green applied energy for sustainable development. Applied Energy 2016;161:601-04.

[9] Dijk VM, Meijerink GW. A review of global food security scenario and assessment studies: results, gaps and research priorities. Global Food Security 2014;3:227-238.

[10] Chen J, Shi H, Sivakumar B, Peart MR. Population, water, food, energy and dams. Renewable and Sustainable Energy Reviews 2016;56:18-28.

[11] Ferranti P. Food sustainability, security, and effects of global change. Reference module in food science. http://dx.doi.org/10.1016/B978-0-08-100596-5.03332-1; 2016 [accessed 5 January 2017].

[12] Poulsen MN, McNab PR, Clayton ML, Neff RA. A systematic review of urban agriculture and food security impacts in low-income countries. Food Policy 2015;55:131-146.

[13] Gasparatos A. Resource consumption in Japanese agriculture and its link to food security. Energy Policy 2011;39:1101-12.

[14] Biggs EM, Bruce E, Boruff B, Duncan JMA, Horsley J, Pauli N, McNeill K, Neff A, Ogtrop FV, Curnow J, Haworth B, Duce S, Imanari Y. Sustainable development and the water–energy–food nexus: a perspective on livelihoods. Environmental Science and Policy 2015;54:389-97.

[15] Lele U, Klousia-Marquis M, Goswami S. Good governance for food, water and energy security. Aquatic Procedia 2013;1:44-63.

[16] Jonsson DK, Johansson B, Mansson A, Nilsson LJ, Nilsson M, Sonnsjo H. Energy security matters in the EU energy roadmap. Energy Strategy Reviews 2015;6:48-56.

[17] Cherp A, Jewell J. The concept of energy security: Beyond the four As. Energy Policy 2014;75:415-21.

[18] Mansson A, Pereira AS, Hermann S. Biofuels for road transport: Analysing evolving supply chains in Sweden from an energy security perspective. Applied Energy 2014;123:349-57.

[19] Gunatilake H, Holst DR, Sugiyarto G. Energy security for India: biofuels, energy efficiency and food productivity. Energy Policy 2014;65:761-67.

[20] Koizumi T. Biofuel and food security in China and Japan. Renewable and Sustainable Energy Reviews 2013;21:102-09.

[21] Koizumi T. Biofuels and food security. Renewable and Sustainable Energy Reviews 2015;52:829-41.

[22] Negash M, Swinnen JFM. Biofuels and food security: micro-evidence from Ethiopia. Energy Policy 2013;61:963-76.

[23] Maltsoglou I, Kojakovic A, Rincón LE, Felix E, Branca G, Valle S, Gianvenuti A, Rossi A, Thulstrup A, Thofern H. Combining bioenergy and food security: an approach and rapid appraisal to guide bioenergy policy formulation. Biomass and Bioenergy 2015;79:80-95.

[24] Modi AT. A Simple model to evaluate integrated vegetable production for food security in KwaZulu-Natal, South Africa. Food Research International 2015;76:946-952.

[25] Huang J, Yang J, Msangi S, Rozelle S, Weersink A. Biofuels and the poor: global impact pathways of biofuels on agricultural markets. Food Policy 2012;37:439-51.

[26] Garcez C, Souza V JN. Brazilian biodiesel policy: social and environmental considerations of sustainability. Energy 2009;34:645-54.

[27] European Union. The European Parliament and of the Council on the promotion of the use of biofuels or other renewable fuels for transport. Official Journal of the European Union 2003.

[28] Viju C, Kerr WA. Taking an option on the future: subsidizing biofuels for energy security or reducing global warming. Energy Policy 2013;56:543-8.

[29] Mitchell D. A note on rising food prices. Policy Research Working Paper No. 4682. http://econ.worldbank.org; 2008 [accessed 15 January 2017].

[30] Rosegrant MW. Biofuels and grain prices: impacts and policy responses. Testimony for the U.S. Senate Committee on Homeland Security and Governmental Affairs. http://www.ifpri.org/publication/biofuels-and-grain-prices; 2008 [accessed 15 January 2017].

[31] Food and Agricultural Organization of the United Nations (FAO). The state of food and agriculture. Biofuels: prospects, risks and opportunities. http://www.fao.org/ docrep/011/i0100e/i0100e00.htm; 2008 [accessed 13 July 2015].

[32] Tokgoz S, Elobeid A, Fabiosa J, Hayes DJ, Babcock BA, Yu TH, Dong F, Hart CE, Beghin C. Emerging biofuels: outlook of effects on U.S. grain, oilseed, and livestock markets. Staff Report 07-SR 101. http://www.card.iastate.edu/ publications/dbs/pdffiles/ 07sr101.pdf; 2007.

[33] National Research Council. Renewable fuel standard: potential economic and environmental effects of U.S. biofuel policy. Washington, DC: The National Academies Press; 2011.

[34] Kochaphum C, Gheewala SH, Vinitnantharat S. Does biodiesel demand affect palm oil prices in Thailand? Energy for Sustainable Development 2013;17:658-70.

[35] Kochaphum C, Gheewala SH, Vinitnantharat S. Does palm biodiesel driven land use change worsen greenhouse gas emissions? An environmental and socio-economic assessment. Energy for Sustainable Development 2015;29:100-11.

[36] Amigun B, Müller F, Blottnitz H. Predicting the costs of biodiesel production in Africa: learning from Germany. Energy for Sustainable Development 2008;12:5-21.

[37] Dyer JA, Vergé XPC, Desjardins RL, Worth DE, McConkey BG. The impact of increased biodiesel production on the greenhouse gas emissions from field crops in Canada. Energy for Sustainable Development 2010;14:73-82.

[38] Siangjaeo S, Gheewala SH, Unnanon K, Chidthaisong A. Implications of land use change on the life cycle greenhouse gas emissions from palm biodiesel production in Thailand. Energy for Sustainable Development 2011;15:1-7.

[39] Rovere ELL, Pereira AS, Simoes AF. Biofuels and sustainable energy development in Brazil. World Development 2011;39:1026-36.

[40] Prueksakorn K, Gheewala SH, Malakul P, Bonnet S. Energy analysis of Jatropha plantation systems for biodiesel production in Thailand. Energy for Sustainable Development 2010;14:1-5.

[41] CME Group. Agricultural products: an overview of the edible oil markets: crude palm oil vs soybean oil; 2010.

[42] Salunkhe DK, Chavan JK, Adsule RN, Kadam SS. World oilseeds: Chemistry, technology, and utilization. New York: Van Nostrand Reinhold; 1992.

[43] Mattsson B, Cederberg C, Blix L. Agricultural land use in life cycle assessment (LCA): case studies of three vegetable oil crops. Journal of Cleaner Production 2010;8:283-92.

[44] Corley RHV, Tinker PB. The palm oil. 4th edition. Massachusetts: Blackwell Publishing; 2003.

[45] United States Department of Agriculture. Foreign Agricultural Service, Oilseeds: World markets and trade; 2016.

[46] Department of Alternative Energy Development and Efficiency (DEDE). The 10-year Alternative Energy Development Plan. http://weben.dede.go.th/webmax/content/10-year-alternative-energy-development-plan; 2012 [accessed 9 February 2016].

[47] Sutabutr T. Alternative Energy Development Plan: AEDP 2012-2021. International Journal of Renewable Energy 2012;7:1-10.

[48] Department of Alternative Energy Development and Efficiency (DEDE). Alternative Energy Development Plan: AEDP. http://www.dede.go.th/

download/files/AEDP2015_Final_version.pdf; 2015 [accessed 10 November 2016].

[49] Office of Agricultural Economics. Oil palm harvested areas. http://www.oae.go.th/download/document_tendency/journalofecon2558.pdf; 2016 [accessed 10 June 2017].

[50] Center for International Trade Studies. Distribution of palm oil transformation in Thailand. http://www.thaifta.com/trade/study/imtgt_chap5-3.pdf; 2013 [accessed 9 February 2016].

[51] World Bank. GDP at market prices (current US$) and total population in 2016. http://www.worldbank.org/en/country/thailand; 2016a [accessed 14 August 2017].

[52] National Statistical Office of Thailand. The population in Thailand. http://service.nso.go.th/nso/web/statseries/statseries01.html; 2015 [accessed 10 March 2015].

[53] Thai Department of Internal Trade, Ministry of Commerce. The price of bottled palm oil and price of bottled soybean oil. http://www.dit.go.th/pricelist/showannual.asp; 2015 [accessed 17 March 2015].

[54] IBM Corporation. IBM SPSS Statistics Information Center, http://publib.boulder.ibm.com/infocenter/spssstat/v20r0m0/index.jsp; 2013 [accessed 9 February 2015].

[55] SAS Institute Inc. SAS (Statistical Analysis System) version 9; 2015. http://www.sas.com/ en_th/software/university-edition.html.

[56] Montgomery DC, Peck EA, Vining GG. Introduction to linear regression analysis. 4th edition, New York: Wiley; 2006.

[57] Holt C.C. Forecasting trends and seasonal by exponentially weighted averages. International Journal of Forecasting 2004;20:5-10.

[58] Box GE, Jenkins GM, Reinsel GC. Time series analysis. Wiley Series in Probability and Statistics. Forecasting and Control. 4th edition. Hoboken, NJ: John Wiley & Sons Inc.; 2008.

[59] Goodwin P, Lawton R. On the asymmetry of the symmetric MAPE. International Journal of Forecasting 1999;15:405-08.

[60] MedThai The amount of calories that should be received each day. https://medthai.com/Calorie; 2017 [accessed 10 June 2017].

[61] Nutongkaew P. Life cycle assessment of palm oil biodiesel production. Thesis, Master of Engineering, Chiang Mai University, Thailand; 2008.

[62] Office of Soil Resources Survey and Research, Land Development Department. The land use for oil palm crops. Technical Paper No. 171/12/52; 2009.
[63] ESRI. ArcGIS 10.2 and spatial analysis extension; 2015.
[64] Thai Department of Meteorology and Climatology. Mean annual rainfall in Thailand, annual mean temperature in Thailand. http://www.tmd.go.th/climate/climate.php? FileID=7; 2015 [accessed 8 April 2015].
[65] Land Development Department. Geographic information system soil and landuse. http://www.ldd.go.th/gisweb/index.html; 2015 [accessed 10 February 2015].
[66] IJM Plantatios Berhad. Nurturing sustainability. Annual report, http://www.ijm.com/web/ijmplt/download/agm_presentation_150821.pdf; 2015 [accessed 10 February 2017].

CHAPTER 3

Demand and Supply of Crude Palm Oil for Biodiesel Production Towards Food and Energy Security

Pranee Nutongkaew, Jompob Waewsak, Warangkhana Kiratiwibool
and Yves Gagnon

Published in *Applied Mechanics and Materials*
Vol. 839, pp. 151-158, 2016

Foreword

For this paper, besides being involved in defining the general methodology of the research work, the main contributions of the candidate to this paper were for data preparation used for forecasting the demand of CPO for edible cooking palm oil, interpreting the results, and drafting the paper. The main inputs in the modeling include the population in the country, as predicted by the National Statistical Office; the price of bottled palm oil and the price of bottled soybean oil, obtained from the Thai Department of Internal Trade, Ministry of Commerce; as well as the gross domestic product per capita, from the World Bank.

The paper was published in *Applied Mechanics and Materials* (Trans Tech Publications Inc.), a peer-reviewed journal which covers various aspects of theoretical and practical research in the field of mechanical engineering and material sciences. This journal was chosen in part because it specializes in the rapid publication of complete volumes on given topics, proceedings and complete special topic volumes (from the journal's website: https://www.scientific.net/AMM/Details).

This paper was published as part of a special volume on the theme "World Future Alternatives" (June 2016), following the International Conference on Energy, held at Naresuan University, Thailand.

Demand and Supply of Crude Palm Oil for Biodiesel Production Towards Food and Energy Security

Pranee Nutongkaew[a], Jompob Waewsak[a], Warangkhana Kiratiwibool[b] and Yves Gagnon[c]

[a]Research Center in Energy and Environment
Department of Physics, Faculty of Science, Thaksin University, Thailand
[b]Department of Mathematics and Statistics, Faculty of Science,
Thaksin University, Thailand
[c]Université de Moncton, Edmundston (NB), Canada

Abstract

Energy and food security are two key national policies and agenda of Thailand. The Department of Alternative Energy Development and Efficiency (DEDE), Ministry of Energy has modified a 15-year (2008-2021) Alternative Energy Development Plan (AEDP). According to the modified AEDP, the share of renewable and alternative energy consumption should increase to 25% by 2021. The latest policy aims to promote the biodiesel consumption and production by 5.97 million liters/day within 2021, up from its previous plan of 4.50 million liters/day while nowadays production capacity is 1.62 million liters/day. The current and anticipated production of biodiesel require raw materials, notably crude palm oil (CPO) from oil palm plantations. This paper presents a feasibility study, with respect to the AEDP plan, for biodiesel production by using domestic fresh fruit oil palm as a raw material. Demand and supply are analyzed based on statistical modeling and forecasting techniques, as well as GIS spatial analysis. The results show that the domestic CPO consumption for cooking palm oil will be 1.02 million tons/year, while biodiesel production will be 1.67 million tons/year in 2021. This corresponds to an oil palm plantation area of 11,152 km^2 in 2021. Based on GIS spatial analysis along with land-use database and other relevant databases, it was found that the suitable area for palm oil plantation in Thailand is 14,639 km^2, which is sufficient for domestic demand and consumption. The suitable area consists of 9,664 km^2 for quite suitable and 4,975 km^2 for medium suitable. However, the government should provide the guidelines, along with pro-active and supportive policies for worst case scenarios, e.g., drought and flood leading

to the insufficient raw material, in order to reduce the negative impacts of biodiesel production for domestic demand and consumption.

Keywords: Oil Palm, Biodiesel, Supply, Demand, Crude Palm Oil.

3.1 Introduction

Palm oil has been grown commercially since the 1960s [1]. Growth of commercial plantations in Southeast Asia and recent expansions in West Africa and Latin America have led to a growing call for the sustainable production of palm oil [2]. In Thailand, the current surface area covered by oil palm plantations is 7,175 km^2, mainly in the southern and central parts of the country, with 6,194 km^2 and 708 km^2, respectively.

Oil palm has high oil content and the highest potential of yield per unit area when compared to other oil crops [3]. Global demand for palm oil is increasing to fulfil worldwide needs for cooking oil, food ingredients, cosmetics, chemical products and biodiesel [4, 5]. Palm oil is also a major source of sustainable and renewable raw material for food and for energy.

In recent years, in Thailand, many research work have been done on palm oil sustainability in regards to land use and land use change, biodiversity, environment and economics. [6-10]. While using palm oil as a source of energy may lead to both positive and negative socio-economic impacts, the impacts of palm oil biodiesel demand in Thailand has a minimal effect on palm oil price [11].

The Royal Thai Government, through the Department of Alternative Energy Development and Efficiency (DEDE), has launched the 15-year Alternative Energy Development Plan (AEDP 2012) [12]. The Plan aims to increase the share of renewable and alternative energy consumption to 25% by 2021. The main objective of the AEDP is to reduce oil imports, which account for approximately 80% of the total oil consumption in the country.

According to AEDP 2012, the target ratio of alternative energy consumption will increase from 7,431 ktoe in 2012 to 25,000 ktoe in 2021, corresponding to 25% of the total energy consumption, while biodiesel productions of 3.64 million liters/day and 5.97 million liters/day were targeted for 2016 and 2021, respectively. From the current oil palm plantation of 7,200 km^2, the oil palm fruit harvesting was impacted by flooding in 2011 due to severe and unpredictable tropical storms, which lead to the shortage of edible cooking palm oil and biodiesel in Thailand to achieve the AEDP planning towards food and energy security. In this context, the main objective of this research is to devise a strategy to manage and to achieve the goal of producing 5.97 million litres/day of biodiesel by 2021, without affecting any other parts of the supply chain for crude palm oil, including for the production of various types of food. The strategy adopted will need to achieve a balance between the plantation area available for harvesting and the increasing demand of palm oil to produce biodiesel.

3.2 Methodology

The plantation and cultivation area of oil palm in Thailand was analyzed using Arc GIS version 10.2 with respect to domestic edible cooking palm oil demand and biodiesel consumption demand in the AEDP planning within 2021, with an objective of identifying new oil palm plantation areas in Thailand. The domestic edible cooking palm oil demand was forecasted based on three statistical models using population, price of palm oil bottle (PPO), price of soybean oil bottle (PSOY) and average revenue per capita (GDP per Capita: PERCAP). The total area for palm oil plantation response to the forecasted demand of edible cooking palm oil and biodiesel consumption demand in Thailand was analyzed.

Modeling Prediction

Various databases from the Government of Thailand are used to access data needed for the modeling, notably data on the climate, soil resources, water resources, forest resources and land use are used in this study.

(1) Multiple Regression Analysis

This study is conducted to generate a forecast of cooking palm oil bottle (PPO) consumption in Thailand. Using SPSS (Statistical Package for Social Sciences) version 17 and the SAS (Statistical Analysis System) version 9, the data used in this study are a time series of monthly cooking PPO consumption.

The dependent variable is the total demand for cooking palm oil and the independent variables are population, Gross Domestic Product per capita and household income. Time series data, with 28 observations per year, from 1985 to 2012, are used to construct the multiple regression analysis [13].

(2) Holt's Exponential Smoothing Method

The Holt's exponential smoothing method is also used in this study [14].

(3) Combined Forecasting Method

A combined forecasting method between multiple regression analysis and Holt's exponent smoothing method is used to reduce the error from the forecast.

Forecast Performance Measure

Two criterions, i.e., the mean absolute percentage error (MAPE) and the root mean square error (RMSE), are used to compare the performance of the forecast values obtained from the multiple regression analysis, the Holt's exponential smoothing method and the combined forecasting method.

To identify the suitable areas for new oil palm plantations, a multi-criteria decision making analysis is applied. The criteria used to identify the biophysical suitability of production stems from the scientific literature on oil palm and include:

- Topography that is suitable for the target crop
- Climate that is suitable for the target crop
- Soil that is suitable for the target crop

Areas where all these principles are satisfied can be considered suitable for the sustainable agricultural production, to which are added indicators related to rainfall, slope, elevation, drainage and soil texture.

A GIS-based approach, using Arc GIS version 10.2 Extension Spatial Analyst, is used for the site selection. The criteria used for the analysis are classified in three main classes, as shown in Table 3.1.

The data related to the climate of the country are from the Thai Department of Meteorology and Climatology over the 10-year period of 2001-2010. Data related to the soil resources of Thailand are obtained from the Office of Soil and Land Use Planning, Thai Land Development Department, with a map scale of 1: 50,000.

Suitable oil palm plantation areas are assessed on the basis of a scale with three levels, namely:

- Score 8-10: Suitable area
- Score 4-7: Moderately suitable area
- Score 0-3: Less suitable area

Table 3.1 Criteria used for the analysis of potential sites for the expansion of oil palm plantation and production in Thailand.

Criteria	Weighting
Topography - Slope - Elevation above mean sea level	30%
Climate - Monthly mean rainfall - Monthly mean temperature - Monthly sunshine hours - Orientation	35%
Soil - Clay loam (CL) and clay (C) - Depth of soil layer over 75 cm	35%

3.3 Analyses

The demand for cooking palm oil has been steadily increasing in Thailand over the period of 1985-2012. Using a multiple regression analysis, the smoothing with an exponential curve of Holt and the Combined Forecasting Method (CFM), the model predictions are shown Table 3.2. The MAPE and RMSE criteria for the CFM are less than for the other methods, thus indicating that it is the most accurate in forecasting.

Results show that the most appropriate model is the Combined Forecasting Method, namely,

$$\hat{Y}_3 = L\hat{Q}N(\text{Combined}) = -0.247239 + 0.407325\hat{Y}_1 + 0.694065\hat{Y}_2 \qquad (3.1)$$

$L\hat{Q}N$ is Forecasting (log base) of the demand for cooking palm oil

$\hat{Y}_1$ and $\hat{Y}_2$ is Single forecasts from multiple regression analysis and Holt's exponential smoothing method, respectively

Table 3.2 Accuracy of the different forecasting technics.

Year	Demand for cooking palm oil (ton)	LQN	Forecasting (LQN)		
			Multiple regression	Holt	Combined
1985	25,007	3.7304	3.8215		
1986	28,366	2.1232	2.1398	2.1677	2.1289
1987	35,946	2.1971	2.1826	2.1864	2.1593
1988	39,410	2.1826	2.2278	2.2065	2.1916
1989	49,570	2.2610	2.2601	2.2257	2.2181
1990	42,597	2.1424	2.2907	2.2464	2.2450
1991	55,860	2.2950	2.3130	2.2636	2.2660
1992	59,334	2.2588	2.3304	2.2842	2.2874
1993	67,001	2.2977	2.3558	2.3034	2.3110
1994	94,499	2.4191	2.3854	2.3231	2.3367
1995	102,779	2.3765	2.4178	2.3454	2.3655
1996	117,750	2.4162	2.4231	2.3660	2.3819
1997	108,227	2.3483	2.4092	2.3872	2.3910
1998	94,469	2.3087	2.3912	2.4060	2.3967
1999	131,721	2.4843	2.3986	2.4233	2.4117
2000	143,123	2.4439	2.4238	2.4447	2.4368
2001	164,148	2.4843	2.4264	2.4645	2.4516
2002	157,433	2.4347	2.4419	2.4849	2.4720
2003	179,904	2.5022	2.4648	2.5034	2.4942
2004	192,048	2.4999	2.4957	2.5232	2.5206
2005	205,012	2.5132	2.5063	2.5424	2.5382
2006	235,226	2.5579	2.5294	2.5615	2.5609
2007	238,694	2.5327	2.5436	2.5812	2.5804
2008	281,937	2.6016	2.5500	2.5998	2.5959
2009	314,496	2.6108	2.5333	2.6197	2.6028
2010	333,484	2.6111	2.5827	2.6393	2.6366
2011	407,060	2.6842	2.5736	2.6584	2.6462
2012	480,636	2.7105	2.5997	2.6789	2.6710
R^2			**0.999**	0.924	0.930
MAPE			1.9149	1.4008	**1.3463**
RMSE			0.0605	0.0435	**0.0416**

The combined forecasting method is thus used to forecast the demand for cooking palm oil (Q) during the period 2013-2021. The demand for cooking palm oil (Q), in tons, follows the following regression:

$$\hat{Y}_t = \text{Log } Y_t - 0.529683 \text{Log } Y_{t-1}$$

$$Y_t = 10^{\hat{Y}_t + 0.529683 \text{Log } Y_{t-1}} \quad (3.2)$$

Y_t is Time series LQN at time t,

Therefore, the forecast demand for cooking palm oil can be calculated by the following equation:

$$\hat{Y}_t = 10^{\hat{Y}_{t,3} + 0.529683 \text{Log } \hat{Y}_{t-1,3}} \quad (3.3)$$

Finally, the demand for cooking palm oil in Thailand is forecasted to be 1.02 million tons per year in 2021. The forecasting results from the Combined Forecasting Method are shown in Table 3.3.

Table 3.3 Forecasting of the demand for cooking palm oil in Thailand for the period 2013-2021 using the Combined Forecasting Method.

Year	Demand of cooking palm oil in Thailand (million tons)
2013	0.50
2014	0.54
2015	0.58
2016	0.64
2017	0.70
2018	0.77
2019	0.84
2020	0.93
2021	1.02

3.4 Results and Discussion

The total oil palm plantation areas in Thailand, for edible cooking palm oil, other industries and biodiesel production are shown in Tables 3.4 to 3.6.

Table 3.4 Plantation area of oil palm for cooking palm oil and other industries.

Year	Area (km^2)		
	Refined Palm Oil	Other industries	Total
2013	2,485	1,139	3,624
2014	2,581	1,232	3,813
2015	2,707	1,315	4,022
2016	2,856	1,392	4,246
2017	3,037	1,464	4,501
2018	3,224	1,526	4,750
2019	3,437	1,587	5,024
2020	3,674	1,648	5,322
2021	3,925	1,712	5,627

Table 3.5 Plantation area of oil palm for biodiesel production.

Year	CPO for Biodiesel Production (million tons)	Yield (tons/rai)	% Oil	Area (km^2)
2008	0.27	2,844	0.17	896
2009	0.38	2,844	0.17	1,264
2010	0.38	2,844	0.17	1,264
2011	0.37	2,844	0.17	1,232
2012	0.63	2,844	0.17	2,080
2013	0.68	2,844	0.17	2,256
2014	1.08	2,844	0.17	3,568
2015	1.09	2,844	0.17	3,600
2016	1.12	2,844	0.17	3,712
2017	1.52	2,844	0.17	5,024
2018	1.55	2,844	0.17	5,136
2019	1.59	2,844	0.17	5,264
2020	1.63	2,844	0.17	5,392
2021	1.67	2,844	0.17	5,520

Table 3.6 Total oil palm plantation area in Thailand.

Year	Area (km^2)			
	Refined Palm Oil	other industries	Biodiesel	Total
2016	2,848	1,392	3,712	7,952
2021	3,920	1,712	5,520	11,152

The forecasting results found Thailand's demand for edible cooking palm oil to be 1.02 million tons per year of crude palm oil, and for biodiesel production of 1.67 million tons per year. The projection of the plantation area needed for the cultivation of oil palm in Thailand to satisfy the demand for the consumption and biodiesel production according to the national goals in 2021 is 11,152 km^2.

Based on GIS analysis, the potential areas for new oil palm plantations are identified. These potential areas are overlaid with the existing economic crops, i.e., cassava, sugar cane, oil palm, etc., in order to assess the added-value that would be achieved with the transformation of the land usage.

Results show that the suitable area for palm oil plantation in Thailand is 14,639 km^2, which is sufficient for the domestic demand and consumption. The suitable area consists of 9,664 km^2 of quite suitable and 4,975 km^2 of medium suitable areas, which is enough to meet the targets of the Alternative Energy Development Plan by 2021. These findings suggest that Thailand has sufficient land areas for the production of oil palm to meet the domestic demand, and thus for achieving its national goals towards food and energy security. The classification of the suitable areas in each region of the country shown in Table 3.7. The spatial distribution of suitable areas for new oil palm plantation in Thailand is shown in Figure 3.1.

Table 3.7 Classification of the suitable areas of Thailand for the expansion of oil palm plantations, by region.

Region	Suitable (km^2)	Moderately Suitable (km^2)
Central	6,362.51	3,124.29
North	409.82	222.38
South	51.47	38.14
East	212.33	124.03
West	203.78	109.9
Northeast	2,424.9	1,356.55
Total	9,664.81	4,975.29

However, the government should provide the guidelines, along with pro-active and supportive policies for worst case scenarios, e.g. drought and flood leading to the insufficient raw material, in order to reduce the negative impacts of biodiesel production for domestic demand and consumption.

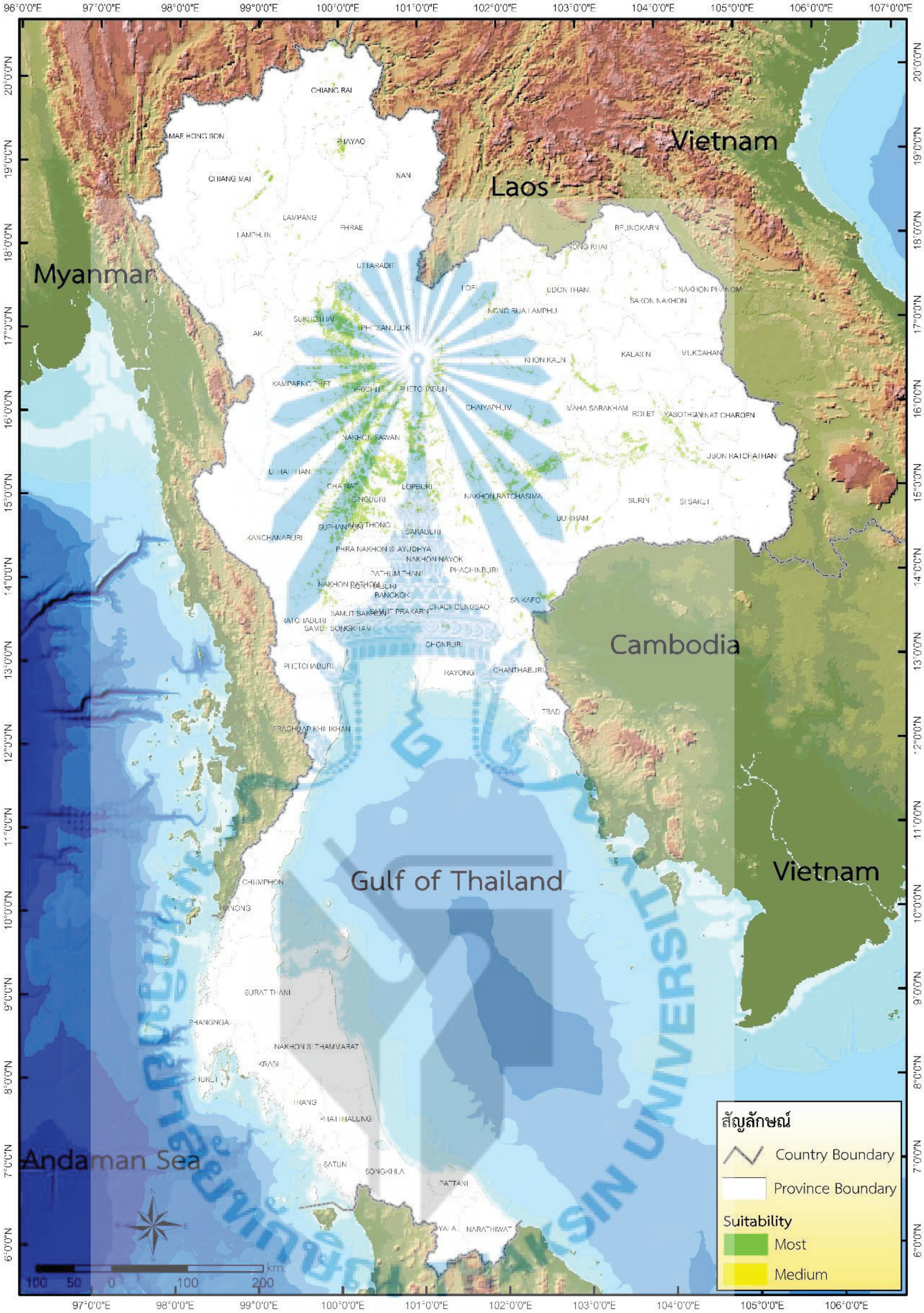

Figure 3.1 Plantation areas for oil palm plantations in Thailand.

3.5 Conclusion

Results from this investigation show that the available and suitable areas for oil palm plantation in Thailand is sufficient to achieve food and energy security. However, the promotion of new oil palm plantation in other parts of Thailand requires the guidance, recommendation, and know-how like the suitable area, high yield seeds, and cultivation and farm management. To achieve those targets, a specific zoning for new oil palm plantation is recommended.

In addition, in order to have guidelines for palm oil production having the least effect on energy security, the AEDP should be revised and updated with respect to the current social and economic development. To achieve this, the current demand-supply and potential of domestic palm oil production in Thailand should be taken into consideration. However, if the AEDP continues to be promoted by the Ministry of Energy, then the Ministry of Agriculture and Cooperatives should cooperate in order to put much effort on oil palm to achieve the national agenda and also to enact the Oil Palm Act, similar to the Sugar and Bagasse Act or the Rubber Act.

3.6 Acknowledgements

The authors thank the Agricultural Research Development (Public Organization) for the financial support and the Research Center in Energy and Environment of Thaksin University for providing the research facilities.

3.7 References for Chapter 3

[1] McCarthy JF, Cramb RA. Policy narratives, landholder engagement, and oil palm expansion on the Malaysian and Indonesian frontiers. Geographical Journal 2009;175:112-23.

[2] Sune B.H, Rory P, Khadijah S, Stephanie E, Zuriati Z, Sharifah M. Trends in global palm oil sustainability research. Journal of Cleaner Production 2015;100:140-9.

[3] Mattsson B, Cederberg C, and Blix L. Agricultural land use in life cycle assessment (LCA): case studies of three vegetable oil crops. Journal of Cleaner Production 2000;8:283-92.

[4] Oosterveer P. Promoting sustainable palm oil: viewed from a global networks and flows perspective. Journal of Cleaner Production 2015;107:146-53.

[5] Thoenes P. Biofuels and commodity markets palm oil focus. Rome: FAO; 2006.

[6] Mukherjee I, Benjamin K. Sovacool. Palm oil-based biofuels and sustainability in Southeast Asia: a review of Indonesia, Malaysia, and Thailand. Renewable and Sustainable Energy Reviews 2014;37:1–12.

[7] Saswattecha K, Kroeze C, Jawjit W, Hein L. Assessing the environmental impact of palm oil produced in Thailand. Journal of Cleaner Production 2015;100:150-69.

[8] Permpool N, Bonnet S,Gheewala SH. Greenhouse gas emissions from land use change due to oil palm expansion in Thailand for biodiesel production. Journal of Cleaner Production 2016;134:532-8.

[9] Dallinger J. Oil palm development in Thailand: economic, social and environmental considerations. In: Oil palm expansion in South East Asia: trends and implications for local communities and indigenous peoples; Forest Peoples Programme and Sawit Watch, England; 2011.

[10] Silalertruksa T, Gheewala SH. Environmental sustainability assessment of palm biodiesel production in Thailand. Energy 2012;43:306-14.

[11] Kochaphum C, Gheewala SH, Vinitnantharat S. Does biodiesel demand affect palm oil prices in Thailand? Energy for Sustainable Development 2013;17:658-70.

[12] Department of Alternative Energy Development and Efficiency. Alternative Energy Development Plan (AEDP). Government of Thailand; 2012.

[13] Montgomery DC, Peck EA, Vining GG. Introduction to linear regression analysis. 4th edition, New York: Wiley; 2016.

[14] IBM Corporation. IBM SPSS Statistics Information Center. http://publib.boulder.ibm.com/infocenter/spssstat/v20r0m0/index.jsp; 2013 [accessed 2 May 2016].

CHAPTER 4

Greenhouse Gas Emissions of Refuse Derived Fuel-5 Production from Municipal Waste and Palm Kernels

Pranee Nutongkaew, Jompob Waewsak, Tanate Chaichana and Yves Gagnon

Published in *Energy Procedia* (Refereed Proceedings, Elsevier)
Vol. 52, pp. 362-370, 2014

Foreword

The purpose of this work was to evaluate the GHG emissions generated by RDF-5 production from municipal solid wastes (MSW) and palm kernels. The methodology developed in this study is based on life cycle assessment (LCA). In this research and paper, besides being involved in defining the general methodology of the research work, the main contributions of the candidate were for data and materials preparation, analyses, interpreting the results, and drafting the paper. For preparation and analyses, the candidate collected the data by direct measurements and literature review. Actual data corresponding to the production process at Thaksin University, Phatthalung campus, were collected. Data analyses included materials, energy and chemicals and other inputs (MSW, palm kernels, limestone and electricity consumption). Material preparation for producing RDF-5 was by mixing shredded paper, plastics, palm kernels and limestone. The evaluation of GHG emissions was conducted using the damage-oriented approach.

Energy Procedia (Elsevier) was chosen to publish the results as this is an Open Access publication focussing on publishing high-quality conference proceedings across the energy field. This journal enables the fast dissemination of conference papers in dedicated online proceedings volumes made freely available on ScienceDirect, accessible to millions of researchers worldwide. The proceedings series is indexed in Scopus, the largest abstract and citation database of peer-reviewed literature (from the journal’s website: https://www.journals.elsevier.com/energy-procedia). This paper was selected and peer-reviewed under the responsibility of the Organizing Committee of the 2013 International Conference on Alternative Energy in

Developing Countries and Emerging Economies (AEDCEE), held in Bangkok, Thailand, in 2013.

Greenhouse Gas Emissions of Refuse Derived Fuel-5 Production from Municipal Waste and Palm Kernels

Pranee Nutongkaew[a,b], Jompob Waewsak[b], Tanate Chaichana[c], and Yves Gagnon[d]

[a]Sustainable Development Program, International College, Thaksin University, Thailand
[b]Research Center in Energy and Environment Thaksin University (Phatthalung Campus), Phatthalung, Thailand
[c]School of Renewable Energy, Maejo University, Thailand
[d]Université de Moncton, Edmundston (NB), Canada

Abstract

This paper presents greenhouse gas (GHG) emissions of refuse-derived fuel-5 (RDF-5) production from municipal waste and palm kernels. Two cases were considered. In case I, RDF-5 was produced from municipal waste mixed with palm kernels, while in case II, RDF-5 was produced from municipal waste only, without mixing with palm kernels. Life cycle inventory (LCI) of both types of RDFs production was analyzed. Results showed that the production of 1 kg of the RDF-5 contributed GHG emissions of 1.696 kg CO_2 equivalent in case I, and 1.423 kg CO_2 equivalent in case II. In both cases, the highest GHG emissions derived from plastics, which was one of the major material components.

Keywords: Greenhouse Gas Emissions, Palm Kernels, RDF-5, Life Cycle Assessment.

4.1 Introduction

Global warming is a crucial problem in today's world and reduction in greenhouse gas emissions is being prioritized by several countries. Greenhouse gases (GHG) are gases in the atmosphere that absorb and emit radiation within the thermal infrared range contributing to global warming. The global warming potential (GWP) is measured relative to the same mass of CO_2 and evaluated for a specific time scale, it could have a large GWP on a 100 year scale, but a small one on a 20 year scale. More details are presented in Table 4.1. Carbon dioxide (CO_2) emissions are mainly contributed by combustion of carbonaceous fuels such as coal, oil, and natural gas. CO_2 is a product of ideal, stoichiometric combustion of carbon, although few combustion processes are ideal, and burning coal, which also produces carbon monoxide [1]. Since 2000, fossil fuel related carbon emissions has equaled or exceeded the IPCC's "A2 scenario", except for small dips during two global recessions [2-4].

Table 4.1 Atmospheric lifetime and global warming potentials (GWP) relative to CO_2 at difference time horizons for various greenhouse gases.

Greenhouse Gases	Global Warming Potential (GWP) for Given Time Horizon		
	20-year	100-year	500-year
Carbon dioxide	1	1	1
Methane	72	25	7.6
Nitrous oxide	289	298	153
CFC-12	11,000	10,900	5,200
HCFC-22	5,160	1,810	549
Tetrafluoromethane	5,210	7,390	11,200
Hexafluoroethane	8,630	12,200	18,200
Sulphur hexafluoride	16,300	22,800	32,600
Nitrogen trifluoride	12,300	17,200	20,700

The use of CFC-12 (except some essential uses) has been phased out due to its ozone depleting properties [5]. The phasing-out of less active HCFC-compounds be completed 2030 [6].

The energy system plays an essential role in accounting of GHG emissions from waste management systems and waste technologies. Energy from waste for non-recyclable wastes is a suitable method of waste management and is important for renewable energy production [7].

The refuse-derived fuel (RDF) becomes one of the interesting alternatives to solve both global warming and municipal solid waste management problems. Its benefits are not only to improve world environmental quality, but also reduce local economic losses [8]. Many research groups have studied the techniques to utilize refuse fuels; however, most investigations focused on direct combustion or thermal degradation [9-12].

At present, municipal waste and agricultural waste are major sources for RDF production. RDF could be produced by mixing dried combustible portions of municipal waste and some agricultural waste.

In southern Thailand, there are several crude palm oil factories that generate a large amount of palm kernels which has high heating value and could be used as fuel in combustion. Furthermore, RDF can be combusted directly or co-fired with other fuels. Even though direct combustion of RDF may generate heat in very efficient way, however, it may also contribute to global warming during production and usage phases. Consequently, a Life Cycle Assessment (LCA) should be considered in order to estimate the GHG emissions from RDF-5 production. LCA is an internationally standardized method that is able to account for upstream and downstream inputs and emissions related to the life cycle of a product or a service.

The amounts of municipal solid wastes (MSW) generated in Thailand during 2008-2012 are shown in Figure 4.1 [13]. In 2012, the volume of MSW was estimated to be about 24.73 million tons, thus an average of 67,577 tons per day, and the amount of waste left in the bin to community residents was about 15.90 million tons.

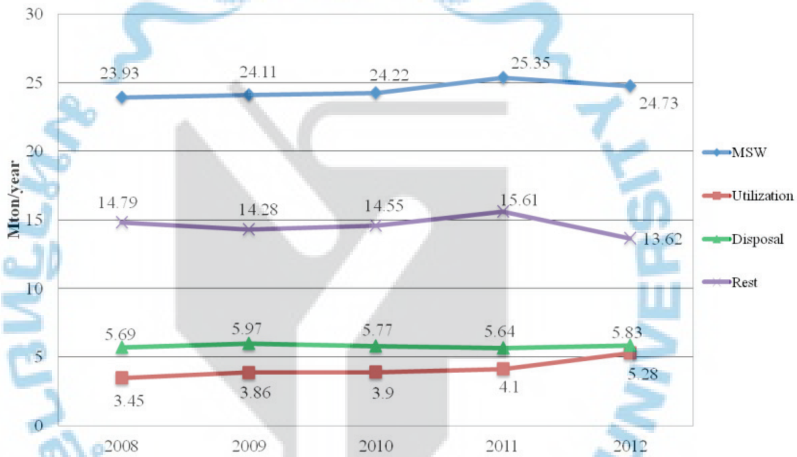

Figure 4.1 The amount of waste, utilization, and disposal in 2008-2012 in Thailand [13].

Of the 11.90 million tons that local authorities can carry, about 5.83 million tons are disposed in landfills, while approximately 5.28 million tons can be utilized. The rest, consisting of approximately 13.62 million tons of MSW, were not disposed appropriately. The Pollution Control Department has reported that there is a large quantity of MSW, about 82%, that was not exploited, as shown in Figure 4.2. The composition of MSW, as shown in Figure 4.3, consists of organic waste (64%), plastics (16.9%), paper (8.3%), glasses (3.5%), metals (2.1%), clothes (1.4%), rubber (0.5%), wood (0.1%) and the rest of miscellaneous products (3.2%) [13].

The purpose of the present study was to evaluate the GHG emissions from RDF-5 production from MSW and palm kernels. Specifically, the aim was to quantify and compare the GHG emissions of two cases of RDF-5 production: one case in which RDF-5 was produced from MSW alone, and one case in which RDF-5 was produced by mixing MSW with palm kernels, a byproduct from palm oil production.

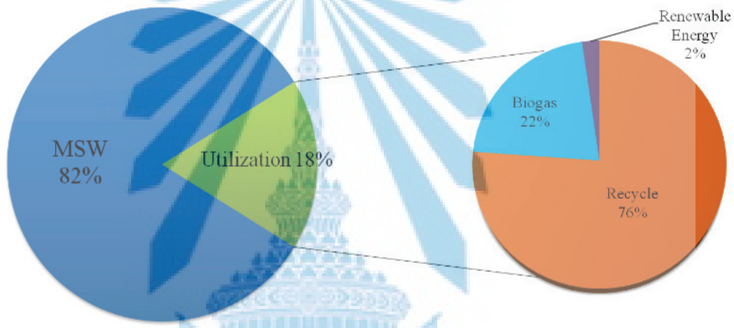

Figure 4.2 Proportion of the municipal solid waste utilization [13].

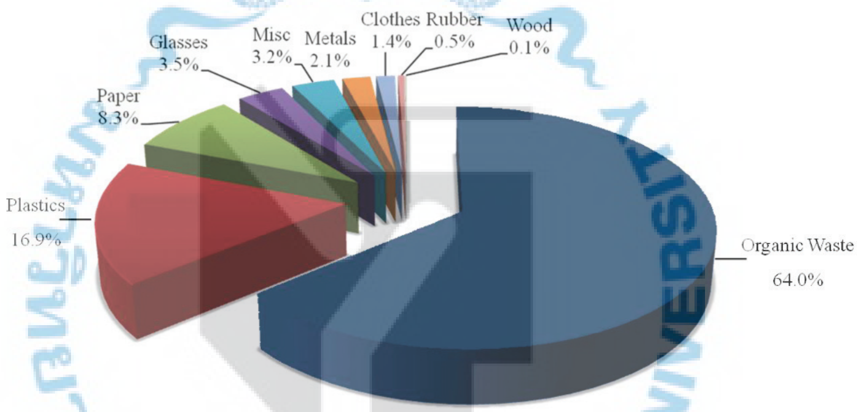

Figure 4.3 Waste composition in Thailand [14].

4.2 Methodology

The International Organization for Standardization (ISO) has developed international standards that describe how to conduct an LCA (ISO 14040 series) [1]. LCA considers the potential environmental impacts (e.g., use of resources and the environmental consequences of releases) throughout a product life cycle, from raw material through production, usage, end of life treatment, recycling and final disposal of the product (i.e., cradle to grave). LCA has been extensively used over the past several decades by a wide array of organizations for many applications, including strategic planning, priority setting, product or process design or redesign, the selection and tracking of relevant indicators of environmental performance, marketing, eco-labeling, etc. The methodology developed in this study is based on the LCA. This methodology consists of four major steps, as shown in Figure 4.4.

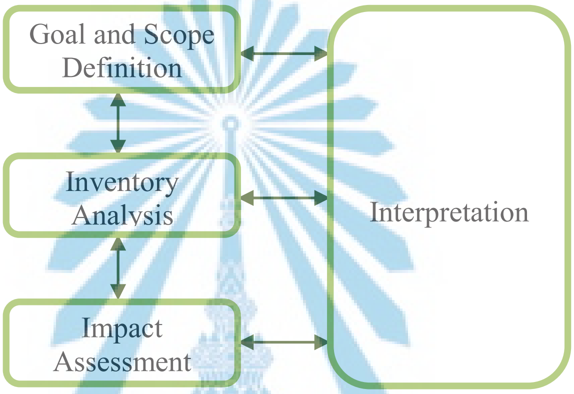

Figure 4.4 Phases of a life cycle assessment (LCA).

4.2.1 Goal definition

The first step in an LCA is the definition of the goal and scope. It includes the definition of a reference unit: all the inputs and outputs are related to this reference, which is called the "functional unit". The goal and scope should address the overall approach used to establish the system boundaries. The system boundaries determine which unit processes are included in the LCA, and must reflect the goal of the study. This provides a clear, full and definitive description of the product or service being investigated, and also enables subsequent results to be interpreted correctly. In this study, the functional unit is 1 kg of RDF-5.

4.2.2 Life cycle inventory

The second step in an LCA is an inventory analysis. This is based primarily on systems analysis, treating the process chain as a sequence of subsystems that exchange inputs and outputs. Hence, in a life cycle inventory or assessment (LCI or LCA), the product system is defined, which includes setting the system boundaries, designing the flow diagrams with unit processes, collecting the data for each of these processes, and ascertaining which emissions will occur.

The inventory involves data collection and modeling of the RDF-5 production, as well as description and verification of data. This encompasses all data related to environmental (e.g., CO_2) and technical development. Examples of inputs and outputs quantities include inputs of materials, energy, chemicals and other, while examples of outputs include air emissions, water emissions or solid waste. Usually, life cycle inventories and modeling are carried out using dedicated software packages. Depending on the software package used, it is possible to model life cycle social impacts in parallel with environmental life cycle. The data must be related to the functional unit defined in the goal and scope definition. Data can be presented in tables and some interpretations can already be made at this stage. Results from the LCI provide information about all inputs and outputs in the form of elementary flow from the environment from all the unit processes involved in the study.

4.2.3 Life cycle impact assessment

The last step in an LCA is the life cycle impact assessment. It is aimed at evaluating the contributions to impact categories such as global warming, acidification, etc., including the impacts in terms of emissions and raw material depletion. The first step is the characterization, where impact potentials are calculated based on the LCI results. The next step is normalization, which provides a basis for comparing different types of environmental impact categories (all impacts get the same unit). In the weighting step, a weighting factor to each impact category is assigned depending on the relative importance. This step is necessary to create a single indicator, i.e., kg CO_2 equivalent.

Climate change is represented based on the International Panel on Climate Change (IPCC) 100-year weightings of the global warming potential of various substances. Substances known to contribute to global warming are weighted based on an identified global warming potential expressed in kilograms of CO_2 equivalent. In this paper, the damage approach was applied using SimaPro software based on the IPCC GWP 100a Method and the Ecoinvent Database.

4.3 Results and Discussion

A life cycle approach has been used to calculate the GHG emissions from the RDF-5 production, as presented below.

4.3.1 Goal and scope definition

The purpose of this study was to evaluate the GHG emissions from RDF-5 production from MSW and palm kernels. The study considered the amount of carbon dioxide equivalent (kg CO_2-eq) per 1 kg of RDF-5. The specific aim was to quantify and compare the GHG emissions of two cases of RDF-5 production. In case I, RDF-5 was produced from MSW mixed with palm kernels. In case II, RDF-5 was produced from municipal waste only or without mixing with palm kernels. The scope of this LCA study is divided into three phases ("gate to gate") as shown in Figure 4.5.

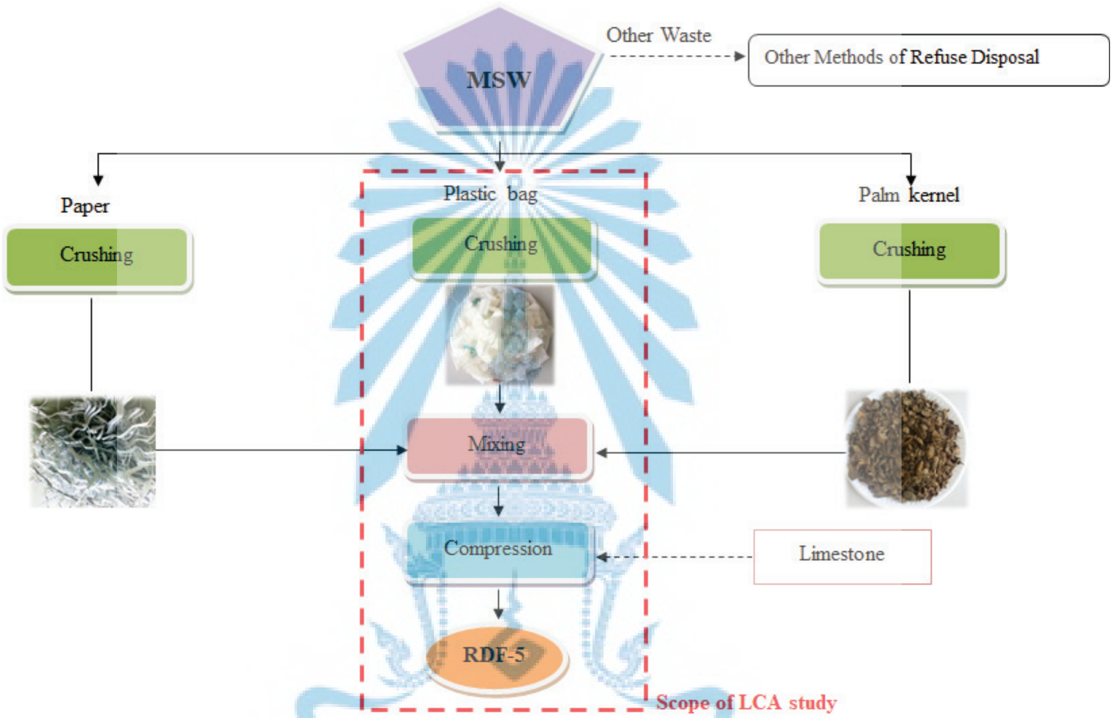

Figure 4.5 The scope of the LCA study.

The data were collected by direct measurements and from a literature review. The data analysis includes materials and energy inputs as well as outputs of each stage as follows. The RDF-5 production is located in Thaksin University, Phatthalung province, Thailand. For materials and energy, the input data were municipal waste, palm kernels and electricity consumption.

4.3.2 Life cycle inventory

In the life cycle inventory analysis, the actual data in the production process at Thaksin University (Phatthalung campus) were collected. The formation of RDF-5 production was done by mixing shredded paper, plastics and palm kernels, as illustrated in Figure 4.6. The result of the inventory and the ratio of the material used for RDF-5 production are shown in Table 4.2 and Figure 4.7.

Figure 4.6 The materials used in the RDF-5 preparation: plastics (left), paper (middle) and palm kernels (right).

Table 4.2 Life cycle inventory.

Process	Inventory	
Crushing	$Input_1$	Paper 585.37 kg Plastics 195.12 kg
	$Output_1$	Paper 585.37 kg Plastics 195.12 kg
Mixing	$Input_2$	Paper 585.37 kg Plastics 195.12 kg Palm kernels 195.12 kg Limestone 195.12 kg
	$Output_2$	Mixed Materials 1,170.73 kg
Compression	$Input_3$	Mixed Materials 1,170.73 kg Electricity 230.31 kWh
	$Output_3$	RDF-5 1,000 kg

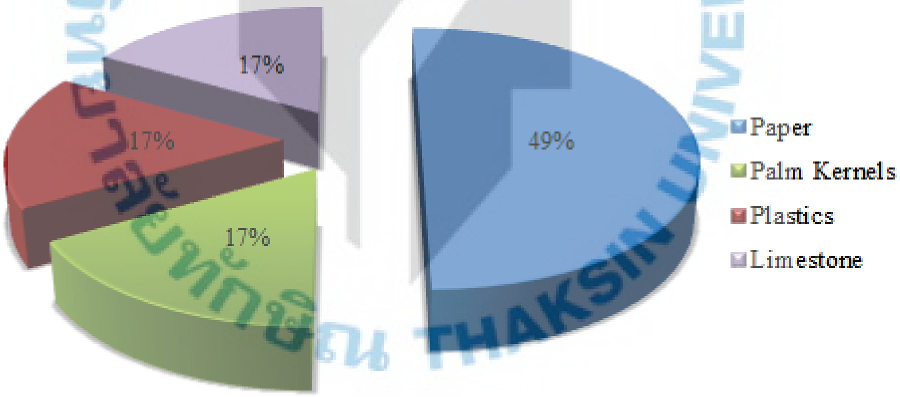

Figure 4.7 The ratio of the materials used for the RDF-5 production.

4.3.3 Life cycle impact assessment

The GHG emissions were assessed based on the IPCC method. The results from this method represent the CO_2 equivalent (kg CO_2-eq). The global warming potential of carbon dioxide equivalent emissions for each type is shown in Table 4.3. The methods consistent with the guidance from the Intergovernmental Panel on Climate Change (IPCC) was applied in this study. The results from this method provided the carbon dioxide equivalent (kg CO_2-eq). The global warming potential of CO_2 equivalent emissions for each material is shown in Table 4.4.

Table 4.3 Direct global warming potentials (GWP) relative to CO_2.

Greenhouse Gases	Global Warming Potentials (100 years)
Carbon dioxide (CO_2)	1
Methane (CH_4)	23
Nitrous oxide (N_2O)	296
Hydrofluorocarbons (HFC)	12 - 12,000
Perfluorocarbons (PCF)	5,700 - 11,900
Sulfurhexafluoride (SF_6)	22,200

Source: IPCC Report Climate Change (The scientific basis) [15]

Table 4.4 The greenhouse gas emissions.

Materials	GWP (kg CO_2 eq)	
	Case I	Case II
Waste paper	0.009	0.009
Plastics	1.228	1.228
Palm kernels	0.272	-
Limestone	0.003	0.003
Electricity	0.184	0.184
Total	1.696	1.423

The results have shown the GHG emissions of the RDF-5 production from municipal solid wastes and palm kernels by means of the life cycle assessment approach. It involves three main processes: (1) crushing, (2) mixing and (3) compression. The results obtained in this study are based on 1 kg of RDF-5. Case I and case II correspond to GHG emissions of 1.696 kg CO_2-eq and 1.423 kg CO_2-eq, respectively.

4.4 Conclusion

An analytical comparison between two cases of RDF-5 production from municipal waste and palm kernels, were assessed by the internationally standardized method of LCA. This study thus represents GHG emissions in terms of kg CO_2-eq/kg of RDF-5. The production of 1 kg of the RDF-5 contributed the GHG emissions of 1.696 kg of CO_2-eq for case I, and 1.423 kg of CO_2-eq for case II. In both cases, the highest GHG emissions are derived from plastics, which constitute one of the major material components. It is noteworthy that the results from this study are dependent on the actual data in the Phattalung province. The results of the GHG emission evaluation in other areas might be different due to material characteristics, technology, and related information and characteristics.

4.5 Acknowledgements

The authors would like to thank Thaksin University for financial support of the project. The authors also thank the Research Center in Energy and Environment for providing the research facilities and financial support.

4.6 References for Chapter 4

[1] Lindeburgh, MR. Mechanical engineering reference manual for the PE exam. Belmont, CA: Professional Publications, Inc.; 2006.

[2] IPCC. Special report on emissions scenarios: (data) IPCC SRES emissions scenarios - version 1.1. http://sres.ciesin.org/data/Version1.1/table/A2_ASF/A2_ASF_World.html; 2002 [accessed 25 June 2011].

[3] International Energy Agency. CO_2 emissions from fuel combustion 2010 - highlights. http://www.iea. org/co2highlights/CO_2highlights.pdf; 2010 [accessed 25 June 2011].

[4] Fiona H. Worst ever carbon emissions leave climate on the brink. The Guardian. http://www.guardian.co.uk/environment/2011/may/29/carbon-emissions-nuclear power; 2011 [accessed 25 June 2011].

[5] TemaNord. Use of ozone depleting substances in laboratories. 2003;516.

[6] Montreal Protocol. http://ozone.unep.org/publication/MP_Handbook/Section _1.1_ The_Montreal_Protocol, United Nations Environmental Programme (UNEP); 1999 [accessed 2 January 2014].

[7] Changkook Ryu. Potential of municipal solid waste for renewable energy production and reduction of greenhouse gas emissions in South Korea. Journal of Air and Waste Management Association 2010;60:176-83.

[8] Nithikul J. Potential of refuse derived fuel production from Bangkok municipal solid waste. Thesis, Master of Engineering in Environmental Engineering and Management, Asian Institute of Technology School of Environment, Resources and Development, Thailand; 2007.

[9] Miskolczi N, Borsodi N, Buyong F, Angyal A, Williams PT. Production of pyrolytic oils by catalytic pyrolysis of Malaysian refuse-derived fuels in continuously stirred batch reactor. Fuel Processing Technology 2011;92:925-32.

[10] Jong-Min L, Down-Won K, Jae-Sung K, Jeong-Geol N, See-Hoon L. Co-combustion of refuse derived fuel with Korean anthracite in a commercial circulating fluidized bed boiler. Energy 2010;35:2814-8.

[11] Di Gregorio F, Lucio Z. Fluidized bed gasification of a packaging derived fuel: energetic, environmental and economic performances comparison for waste-to-energy plants. Energy 2012;42:331-41.

[12] Belgiorno, V, De Feo G, Della RC, Napoli R.M.A. Energy from gasification of solid wastes. Waste Management 2003;23:1-15.

[13] Pollution Control Department. Reports of pollution in Thailand in 2012. http://infofile.pcd.go.th/mgt/DraftPolReport2555_25560214.pdf?CFID=13119758& CFTOKEN=22373626; 2013 [accessed 1 April 2013].

[14] Pollution Control Department. Thailand - Partnership for development (waste management: realization of waste-to-energy and beyond. http://infofile.pcd.go.th/waste/waste2energy49.pdf?CFID=12912988&CFTOKE N=42888764; 2006 [accessed 1 April 2013].

[15] Intergovernmental Panel on Climate Change (IPCC). IPCC Guidelines for national Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp; 2006 [accessed 1 March 2016].

CHAPTER 5
CONCLUSION AND RECOMMENDATIONS

The research presented in this thesis covered a variety of topics from the environmental, social and economic aspects of sustainability in Thailand. The objectives of this research was firstly to assess whether the anticipated demand for CPO in Thailand, for edible cooking palm oil, biodiesel production and marginal uses, can be met using the agricultural land available in the country, and, secondly, to assess the GHG emissions generated by the production of RDF from municipal wastes and palm kernels, a byproduct of CPO production. The thesis is comprised of three publications: two papers assessing the production of CPO as a pathway towards food and energy security in the country, and one paper on the GHG emissions generated by the production of RDF-5 from municipal waste and palm kernels.

The first paper, submitted to *Renewable and Sustainable Energy Reviews* in 2017, analyzes the potential of palm oil production as a pathway to achieve food and energy security in Thailand within the planning period of AEDP 2015 (2015-2036). The current (2016) and anticipated (2021 and 2036) demands for domestic edible cooking palm oil consumption were analyzed using three statistical models (including the combined forecasting method, CFM) based on time-series analysis of historical patterns, along with two models based respectively on daily calorie intake and population. The statistical models used population, price of palm oil bottle, price of soybean oil bottle, and average revenue per capita. The forecasted demand for CPO was then transposed to surface areas that would be needed to produce the anticipated CPO for domestic edible cooking palm oil consumption, biodiesel production, as well as marginal usages. Based on the total surface area needed across the country, site selection for palm tree plantations was analyzed using a multi-criteria decision making analysis based on ArcGIS Extension Spatial Analysis. The supply of CPO was analyzed using palm tree plantations in suitable areas, oil palm FFB yield, and % yield of CPO from CPO mill. Along with the business as usual (BAU) scenario, high and low scenarios were studied to assess the sensitivity of the forecasts.

The population-based model, with a quadratic regression between population and consumption of CPO for edible cooking palm oil, was found to be the most appropriate method for forecasting the demand for CPO for edible cooking palm oil (0.59 million tons in 2036). This results in a total annual demand for CPO in the

BAU scenario of 2.22, 3.08 and 5.38 million tons in 2016, 2021 and 2036, respectively, for domestic consumption to supply the necessary amounts for the edible cooking palm oil production industry, the biodiesel production industry, and marginal usages of CPO. This correspond to total oil palm plantation areas of 7,353 km^2, 10,206 km^2 and 17,803 km^2 in 2016, 2022 and 2036, respectively. The total land currently available for palm tree harvesting (21,406 km^2), which is comprised of 6,765 km^2 currently cultivated for palm tree harvesting and 14,641 km^2 offering suitable conditions for additional palm tree plantations, was found to be greater than the forecasted area (17,803 km^2) required to achieve food and energy security in 2036. The total area offering suitable conditions for additional palm tree plantations (14,641 km^2) was found to be comprised of 9,666 km^2 of suitable area and 4,975 km^2 of moderately suitable area. These findings should not underscore the need for public policies and measures to be implemented in order to achieve the most efficient and sustainable way of developing new palm tree plantations to satisfy the forecasted demand for CPO in 2036.

The previous work on the demand and supply of CPO in Thailand, published in *Applied Mechanics and Materials* in 2016, used three statistical models and the demand for domestic edible cooking palm oil was forecasted within the planning period of AEDP 2012 (2012-2021). This study showed that the CFM was the most appropriate statistical model for forecasting CPO demand for edible cooking palm oil in 2021. The results showed that the predictions required a palm tree plantation area of 11,152 km^2 in 2021 to supply the total demand for CPO (2.69 million tons in 2021), while GIS analyses indicated that the total area suitable for palm oil plantation was 14,639 km^2. Our most recent work (2017 paper), using AEDP 2015 as the planning period, established that the demand for edible cooking palm oil is best forecasted using a population-based model. With this model, a 9.26% lower value of required palm oil plantation area (10,206 km^2) in 2021 was obtained. Indeed, CFM forecasting was found to overestimate the domestic demand for edible cooking palm oil compared to the population-based and calorie-based methods.

In terms of GHG emissions, LCA is a tool for the systematic evaluation of potential environmental impacts associated with a product, process or activity, from the production of raw materials through to its final disposal. Our third paper, published in *Energy Procedia* (Elsevier) in 2014, assessed the emission of GHG generated by the production of RDF-5 from MSW and palm kernels. Increasing volumes of wastes and diversity of materials comprising these wastes are a direct result of increases in population, changes in consumption patterns, economic development and urbanization. MSW cause serious environmental and health problems, but can also be used to generate energy, notably via the production of RDF. RDF can be combusted directly or co-fired with other fuels; they can be produced by mixing dried combustible portions of MSW and some agricultural wastes. In Thailand, MSW and agricultural byproducts are becoming major sources for producing RDF. In southern Thailand, several CPO factories generate large amounts of palm kernels that can be used as fuel. Direct combustion of RDF can generate heat in an efficient way, thus contributing to energy security, but it can also contribute to global warming during its production and usage phases. Our work used Life Cycle Assessment (LCA) to estimate the GHG emissions from RDF-5 produced from MSW alone or mixed with palm kernels. The aim was the quantification and the comparison of the GHG emissions of two cases for RDF-5 production. In case I, RDF-5 was produced from MSW mixed with palm kernels, while in case II, RDF-5 was produced from MSW only without mixing with palm kernels. The scope of this LCA study was divided into three phases ("gate to gate"). The results showed that the corresponding GHG emissions were 1.423 kg CO_2 equivalent/kg of RDF-5 and 1.696 kg CO_2 equivalent/kg, respectively. In both cases, the production process entailed crushing, mixing and compression of waste materials. When palm kernels were included, it contributed $1/6^{th}$ of the total GHG emissions. The highest GHG emissions derived from plastics (1.228 kg CO_2 equivalent/kg), which represented 17% of the material used to produce RDF-5, like palm kernels. GHG emissions from palm kernels, electricity consumption, waste paper and limestone were 4.5, 6.6, 136 and 400 times lower, respectively, compared to plastics. These results depend on the actual data in the Phattalung province where both cases were located. Thus, the results of the GHG emission evaluation in other areas might be different due to material characteristics, technology, as well as related information.

Many countries have prioritized the development of renewable energy on their agenda. In Thailand, with a rapidly developing biofuels sector, energy security is an important issue in the development of national policies. The Ministry of Energy has launched the Alternative Energy Development Plan (AEDP 2015) to replace the usage of regular diesel with biodiesel, where palm oil is the single most important crop for the production of biodiesel in Thailand. This policy presents new opportunities for

Thai farmers who have high potential to produce palm oil. However, serious concerns are rising about the effect of biodiesel production on food security, notably because palm oil is one of the most significant economic driver in Thailand, due to the production of domestic edible cooking palm oil and biodiesel, along with marginal usages.

In the short-term, the CPO production targets envisaged by the AEDP 2015 seem achievable, but, as noted in papers 1 and 2, will require strong improvements in yields and productivity. Indeed, we showed in chapter 1 (Figure 1.2) that the current rate of biodiesel production increase in Thailand (0.26 million liters/day per year, based on actual production data between 2008 and 2016) is insufficient to meet the targets set by AEDP 2015 within the planning period 2015-2036, which necessitate that the national production of biodiesel grows at a rate of about 0.39 million liters/day per year. To address this challenge, the Government of Thailand could implement a management plan that aims to achieve long-term socioeconomic viability by enabling farmers to practices that will maintain or improve soil fertility to levels permitting optimal and sustainable yields. The required expansion of palm oil plantation area seems feasible, but should be carefully planned to avoid deforestation, biodiversity loss, water issues, expansion into areas affected by natural disasters, and excessive harmful crop changes.

More studies are required to thoroughly assess the impact of land use change resulting from palm oil expansion in the country. It is particularly important that future studies seek to better understand the interdependencies among energy/bioenergy, land, water, food, as well as population health in the context of Thailand. Such interactions need to be taken into account in the development of the country's policies. Likewise, the development of integrated approaches that will enhance the cohesion of policies is strongly recommended.

It is noteworthy that increased production of CPO will go hand in hand with increased amounts of byproducts such as palm kernels that will need to be disposed of. Our third paper showed that the use of palm kernels and MSW to produce RDF-5 contributes to GHG emissions. Future work is needed to determine which types of RDF and their optimal composition are best suited for Thailand to reduce its GHG emissions and help steer the country on the path of energy and food security as outlined in its national strategic plans. Additional work is also needed to assess the emissions of GHG and of toxic heavy metals (e.g., cadmium, lead and nickel) during

RDF combustion, which can lead to serious contaminations and health problems in addition to global warming. One of the best strategies for managing wastes ("Reduce, Reuse and Recycle") should be implemented in every sector of the Thai society and economy, and accompanied by effective measures to reduce the production of wastes at the source, which is the best strategy of all.

REFERENCES FOR THE THESIS

Agricultural Research Development (Public Organization). Product of palm oil. http://www.arda.or.th/kasetinfo/south/palm/used/index.php; 2015 [accessed 19 September 2015]

Amigun B, Müller F, Blottnitz H. Predicting the costs of biodiesel production in Africa: learning from Germany. Energy for Sustainable Development 2008;12:5-21.

Andriosopoulos MK. Energy security in East Asia under climate mitigation scenarios in the 21st century. Omega 2016;59:60-71.

Belgiorno V, De Feo G, Della RC, Napoli RMA. Energy from gasification of solid wastes. Waste Management 2003;23:1-15.

Biggs EM, Bruce E, Boruff B, Duncan JMA, Horsley J, Pauli N, McNeill K, Neff A, Ogtrop FV, Curnow J, Haworth B, Duce S, Imanari Y. Sustainable development and the water–energy–food nexus: a perspective on livelihoods. Environmental Science and Policy 2015;54:389-97.

Box GE, Jenkins GM, Reinsel GC. Time series analysis. Wiley Series in Probability and Statistics. Forecasting and Control. 4th edition. Hoboken, NJ: John Wiley & Sons Inc.; 2008.

Changkook R. Potential of municipal solid waste for renewable energy production and reduction of greenhouse gas emissions in South Korea. Journal of Air and Waste Management Association 2010;60:176-83.

Chen J, Shi H, Sivakumar B, Peart MR. Population, water, food, energy and dams. Renewable and Sustainable Energy Reviews 2016;56:18-28.

Cherp A, Jewell J. The concept of energy security: beyond the four As. Energy Policy 2014;75:415-21.

CME Group. Agricultural products: an overview of the edible oil markets: crude palm oil vs soybean oil; 2010.

Compact 2025 Team. Thailand food security and nutrition case study. Successes and next steps. http://www.compact2025.org/files/2017/06/06.2017_Thailand-south-south-learning-draft-case-study.pdf; 2017 [accessed 9 September 2017].

Corley RHV, Tinker PB. The palm oil. 4th edition. Massachusetts: Blackwell Publishing; 2003.

Dallinger J. Oil palm development in Thailand: economic, social and environmental considerations. In: Oil palm expansion in South East Asia: trends and implications for local communities and indigenous peoples. Forest Peoples Programme and Sawit Watch, England; 2011.

Delzeit R, Britz W, Holm-Müller K. Modelling regional input markets with numerous processing plants: the case of green maize for biogas production in Germany. Environmental Modelling and Software 2012;32:74-84.

Department of Alternative Energy Development and Efficiency (DEDE). The 10-year Alternative Energy Development Plan. http://weben.dede.go.th/webmax/content/10-year-alternative-energy-development-plan; 2012 [accessed 9 February 2016]

Department of Alternative Energy Development and Efficiency (DEDE). Alternative Energy Development Plan: AEDP 2015. http://www.dede.go.th/download/files/AEDP2015_Final_version.pdf; 2015 [accessed 10 November 2016].

Department of Alternative Energy Development and Efficiency. Local press compiled by Krungsri Research; 2016.

Di Gregorio F, Lucio Z. Fluidized bed gasification of a packaging derived fuel: energetic, environmental and economic performances comparison for waste-to-energy plants. Energy 2012;42:331-41.

Dijk VM, Meijerink GW. A review of global food security scenario and assessment studies: Results, gaps and research priorities. Global Food Security 2014;3:227-38.

Dyer JA, Vergé XPC, Desjardins RL, Worth DE, McConkey BG. The impact of increased biodiesel production on the greenhouse gas emissions from field crops in Canada. Energy for Sustainable Development 2010;14:73-82.

Emodi NV, Boo KJ. Sustainable energy development in Nigeria: current status and policy options. Renewable and Sustainable Energy Reviews 2015;51:356-81.

Esri. ArcGIS 10.2 and spatial analysis extension; 2015.

Esseghir A, Khouni LH. Economic growth, energy consumption and sustainable development: the case of the union for the Mediterranean countries. Energy 2014;71:218-25.

European Union. The European Parliament and of the Council on the promotion of the use of biofuels or other renewable fuels for transport. Official Journal of the European Union; 2003.

Ferranti P. Food sustainability, security, and effects of global change. Reference module in food science. http://dx.doi.org/10.1016/B978-0-08-100596-5.03332-1; 2016.

Fiona H. Worst ever carbon emissions leave climate on the brink. The Guardian. http://www.guardian.co.uk/environment/2011/may/29/carbon-emissions-nuclear power; 2011 [accessed 25 Jun 2011].

Food and Agriculural Organization of the United Nations (FAO). The state of food and agriculture. Biofuels: prospects, risks and opportunities. http://www.fao.org/ docrep/011/i0100e/i0100e00.htm; 2008 [accessed 13 July 2015]

Food and Agriculture Organization (FAO). FAOSTAT. http://faostat3.fao.org/download/ Q/QC/E; 2017 [accessed 9 September 2017].

Gaigalis V, Skema R. Analysis of fuel and energy transition in Lithuanian households sector and its sustainable development in compliance with the EU policy. Renewable and Sustainable Energy Reviews 2014;37:273-87.

Gaigalis V, Skema R. Analysis of the fuel and energy transition in Lithuanian industry and its sustainable development in 2005-2013 in compliance with the EU policy and strategy. Renewable and Sustainable Energy Reviews 2015;52:265-79.

Garcez CAG, Souza Vianna JN. Brazilian biodiesel policy: social and environmental considerations of sustainability. Energy 2009;34:645-54.

Gasparatos A. Resource consumption in Japanese agriculture and its link to food security. Energy Policy 2011;39:1101-12.

Gillespie S, Tontisirin K, Zseleczky L. Local to national: Thailand's integrated nutrition program. Chapter 10 in: Gillespie S, Hodge J, Yosef S, Pandya-Lorch R, editors. Nourishing millions: stories of change in nutrition, Washington, DC: International Food Policy Research Institute (IFPRI). http://dx.doi.org/10.2499/9780896295889_10; 2016, p. 91-8 [accessed 9 September 2017].

Gillespie S, Hodge J, Yosef S, Pandya-Lorch R (editors). Nourishing millions: stories of change in nutrition. Washington, DC: International Food Policy Research Institute (IFPRI). http://dx.doi.org/10.2499/9780896295889; 2016 [accessed 9 September 2017].

Goodwin P, Lawton R. On the asymmetry of the symmetric MAPE. International Journal of Forecasting 1999;15:405-08.

Gunatilake H, Holst DR, Sugiyarto G. Energy security for India: biofuels, energy efficiency and food productivity. Energy Policy 2014;65:761-67.

Halsnes K, Markandya A, Shukla P. Introduction: sustainable development, energy, and climate change. World Development 2011;39:983-86.

Holt CC. Forecasting trends and seasonal by exponentially weighted averages. International Journal of Forecasting 2004;20:5-10.

Huang J, Yang J, Msangi S, Rozelle S, Weersink A. Biofuels and the poor: global impact pathways of biofuels on agricultural markets. Food Policy 2012;37:439-51.

IBM Corporation. IBM SPSS Statistics Information Center. http://publib.boulder.ibm.com/infocenter/spssstat/v20r0m0/index.jsp; 2013 [accessed 9 February 2015]

Intergovernmental Panel on Climate Change (IPCC). IPCC Guidelines for national greenhouse gas inventories. http://www.ipcc-nggip.iges.or.jp; 2016 [accessed 9 December 2016].

Intergovernmental Panel on Climate Change (IPCC). Special report on emissions scenarios (SRES): (data) IPCC SRES emissions scenarios - Version 1.1. http://sres.ciesin.org/data/Version1.1/table/A2_ASF/ A2_ASF_ World.html; 2000 [accessed 25 June 2011].

International Energy Agency. CO_2 emissions from fuel combustion 2010 - Highlights. http://www.iea. org/co2highlights/CO_2highlights.pdf; 2010.

Jonsson DK, Johansson B, Mansson A, Nilsson LJ, Nilsson M, Sonnsjo H. Energy security matters in the EU energy roadmap. Energy Strategy Reviews 2015;6:48-56.

Jong-Min L, Down-Won K, Jae-Sung K, Jeong-Geol N, See-Hoon L. Co-combustion of refuse derived fuel with Korean anthracite in a commercial circulating fluidized bed boiler. Energy 2010;35:2814-8.

Kochaphum C., Gheewala H.S., Vinitnantharat S. Does biodiesel demand affect palm oil prices in Thailand? Energy for Sustainable Development 2013;17:658-70.

Kochaphum C, Gheewala SH, Vinitnantharat S. Does palm biodiesel driven land use change worsen greenhouse gas emissions? An environmental and socio-economic assessment. Energy for Sustainable Development 2015;29:100-11.

Koizumi T. Biofuel and food security in China and Japan. Renewable and Sustainable Energy Reviews 2013;21:102-09.

Koizumi T. Biofuels and food security. Renewable and Sustainable Energy Reviews 2015;52:829-41.

Lam HL, Varbanov PS, Klemes JJ, Yan J. Green applied energy for sustainable development. Applied Energy 2016;161:601-04.

Land Development Department. Geographic Information System Soil and Landuse; 2015. http://www.ldd.go.th/gisweb/index.html; [accessed 10 February 2015]

Lele U, Klousia-Marquis M, Goswami S. Good governance for food, water and energy security. Aquatic Procedia 2013;1:44-63.

Lindeburgh MR. Mechanical Engineering Reference Manual for the PE Exam. Belmont, CA: Professional Publications, Inc.; 2006.

Maltsoglou I, Kojakovic A, Rincón LE, Felix E, Branca G, Valle S, Gianvenuti A, Rossi A, Thulstrup A, Thofern H. Combining bioenergy and food security: an approach and rapid appraisal to guide bioenergy policy formulation. Biomass and Bioenergy 2015;79:80-95.

Mansson A, Pereira AS, Hermann S. Biofuels for road transport: analysing evolving supply chains in Sweden from an energy security perspective. Applied Energy 2015;123:349-57.

Mattsson B, Cederberg C, Blix L. Agricultural land use in life cycle assessment (LCA): Case studies of three vegetable oil crops. Journal of Cleaner Production 2010;8:283-92.

McCarthy JF, Cramb RA. Policy narratives, landholder engagement, and oil palm expansion on the Malaysian and Indonesian frontiers. The Geographical Journal 2009;175:112-23.

MedThai The amount of calories that should be received each day. https://medthai.com/Calorie; 2017 [accessed 10 June 2017].

Mitchell D. A note on rising food prices. Policy Research Working Paper No. 4682. http://econ.worldbank.org; 2008 [accessed 15 January 2017].

Miskolczi N, Borsodi N, Buyong F, Angyal A, Williams PT. Production of pyrolytic oils by catalytic pyrolysis of Malaysian refuse-derived fuels in continuously stirred batch reactor. Fuel Processing Technology 2011;92:925-32.

Modi AT. A Simple model to evaluate integrated vegetable production for food security in KwaZulu-Natal, South Africa. Food Research International 2015;76:946-52.

Montgomery DC, Peck EA, Vining GG. Introduction to linear regression analysis. 4th edition. New York: Wiley; 2006.

Montreal Protocol. http://ozone.unep.org/publication/MP_Handbook/Section_1.1_The_Montreal_Protocol, United Nations Environmental Programme (UNEP); 1999 [accessed 2 January 2014].

Mukherjee I, Sovacool BK. Palm oil-based biofuels and sustainability in Southeast Asia: a review of Indonesia, Malaysia, and Thailand Renewable and Sustainable Energy Reviews 2014;37:1-12.

National Statistical Office of Thailand. The population in Thailand. http://service.nso.go.th/nso/web/statseries/statseries01.html; 2015 [accessed 10 March 2015]

National Research Council. Renewable fuel standard: potential economic and environmental effects of U.S. biofuel policy. Washington, DC: The National Academies Press; 2011.

NationMaster, Municipal waste generation: countries compared, http://www.nationmaster.com/country-info/stats/Environment/Municipal-waste-generation; 2017.

Negash M, Swinnen JFM. Biofuels and food security: micro-evidence from Ethiopia. Energy Policy 2013;61:963-76.

Nithikul J. Potential of refuse derived fuel production from Bangkok municipal solid waste. Thesis, Master of Engineering in Environmental Engineering and Management, Asian Institute of Technology School of Environment, Resources and Development, Thailand; 2007.

Nutongkaew P. Life cycle assessment of palm oil biodiesel production. Thesis, Master of Engineering, Chiang Mai University, Thailand; 2008.

Nutongkaew P, Waewsak J, Chaichana T, Gagnon Y. Greenhouse gases emission of refuse derived fuel-5 production from municipal waste and palm kernel. Energy Procedia 2014;52:362-370.

Nutongkaew P, Waewsak J, Kiratiwibool W, Gagnon Y. Demand and supply of crude palm oil for biodiesel production towards food and energy security. Applied Mechanics and Materials 2016;839:151-58.

Nutongkaew P, Waewsak J, Kiratiwibool W, Gagnon Y. The potential of palm oil production as a pathway to food and energy security in Thailand. Submitted to Renewable & Sustainable Energy Reviews in August 2017.

Office of Agricultural Economics. Oil palm harvested areas. http://www.oae.go.th/download/document_tendency/journalofecon2558.pdf, 2015 [accessed 10 June 2015]

Office of Soil Resources Survey and Research, Land Development Department. The land use for oil palm crops. Technical Paper No. 171/12/52; 2009.

Oosterveer P. Promoting sustainable palm oil: viewed from a global networks and flows perspective. Journal of Cleaner Production 2015;107:146-53.

Ozturk M, Yuksel YE. Energy structure of Turkey for sustainable development. Renewable and Sustainable Energy Reviews 2016;53:1259-72.

Permpool N, Bonnet S, Gheewala SH. Greenhouse gas emissions from land use change due to oil palm expansion in Thailand for biodiesel production. Journal of Cleaner Production 2016;134:532-8.

Pollution Control Department. Thailand - Partnership for development: waste management: realization of waste-to-Energy and beyond 2006. http://infofile.pcd.go.th/waste/waste2energy49.pdf?CFID=12912988&CFTOKEN=42888764; 2006 [accessed 1 April 2013].

Pollution Control Department. Reports of pollution in Thailand in 2012. http://infofile.pcd.go.th/mgt/DraftPolReport2555_25560214.pdf?CFID=13119758&CFTOKEN=2237362; 2012 [accessed 1 April 2013].

Poulsen MN, McNab PR, Clayton ML, Neff RA. A systematic review of urban agriculture and food security impacts in low-income countries. Food Policy 2015;55:131-46.

Prueksakorn K, Gheewala SH, Malakul P, Bonnet S. Energy analysis of Jatropha plantation systems for biodiesel production in Thailand. Energy for Sustainable Development 2010;14:1-5.

Rajagopal, D., Hochman, G., Zilberman, D. Indirect fuel use change (IFUC) and the lifecycle environmental impact of biofuel policies. Energy Policy 2011;39:228-33.

Rosegrant MW. Biofuels and grain prices: Impacts and policy responses. Testimony for the U.S. Senate Committee on Homeland Security and Governmental Affairs; 2008. http://www.ifpri.org/publication/biofuels-and-grain-prices.

Rovere ELL, Pereira AS, Simoes AF. Biofuels and sustainable energy development in Brazil. World Development 2011;39:1026-36.

Runge CF, Senauer B. How biofuels could Starve the poor. Foreign Affairs 2007;86:41-7.

Salunkhe DK, Chavan JK, Adsule RN, Kadam SS. World oilseeds: Chemistry, technology, and utilization. New York: Van Nostrand Reinhold 1992.

SAS Institute Inc. SAS (Statistical Analysis System) version 9. http://www.sas.com/en_th/software/university-edition.html; 2015.

Saswattecha K, Kroeze C, Jawjit W, Hein L. Assessing the environmental impact of palm oil produced in Thailand. Journal of Cleaner Production 2015;100:150-69.

Schmidhuber J. Impact of an increased biomass use on agricultural markets, prices and food security: a longer-term perspective. In: Petersson B, Tornquist-Plewa B, editors. Energy security in Europe proceedings, CFE Conference Papers Series Number 2. Center for European Studies Lund University, Lund, Sweden; 2007, p. 133-69.

Siangjaeo S, Gheewala SH, Unnanon K, Chidthaisong A. Implications of land use change on the life cycle greenhouse gas emissions from palm biodiesel production in Thailand. Energy for Sustainable Development 2011;15:1-7.

Silalertruksa T, Gheewala SH. Environmental sustainability assessment of palm biodiesel production in Thailand. Energy 2012;43:306-14.

Sune BH, Rory P, Khadijah S, Stephanie E, Zuriati Z, Sharifah M. Trends in global palm oil sustainability research. Journal of Cleaner Production 2015;100:140-9.

Sutabutr T. Alternative Energy Development Plan: AEDP 2012-2021. International Journal of Renewable Energy 2012;7:1-10.

TemaNord. Use of ozone depleting substances in laboratories. 2003:516.

Thai Department of Meteorology and Climatology. Mean annual rainfall in Thailand, annual mean temperature in Thailand. http://www.tmd.go.th/climate/climate.php? FileID=7; 2015 [accessed 8 April 2015].

Thai Department of Internal Trade, Ministry of Commerce. The price of bottled palm oil and price of bottled soybean oil. http://www.dit.go.th/pricelist/showannual.asp; 2015 [accessed 17 March 2015].

Thoenes P. Biofuels and commodity markets: palm oil focus. Rome: FAO; 2006.

Thompson W, Whistance J, Meyer S. Effects of U.S. biofuel policies on U.S. and world petroleum product markets with consequences for greenhouse gas emissions. Energy Policy 2011;39:5509-18.

Tokgoz S, Elobeid A, Fabiosa J, Hayes DJ, Babcock BA, Yu TH, Dong F, Hart CE. Bottlenecks, drought, and oil price spikes: impact on U.S. ethanol and agricultural sectors. Applied Economic Perspectives and Policy 2008;30:604-22.

Tokgoz S, Elobeid A, Fabiosa J, Hayes DJ, Babcock BA, Yu TH, Dong F, Hart CE, Beghin C. Emerging biofuels: outlook of effects on U.S. grain, oilseed, and livestock markets. Staff Report 07-SR 101. http://www.card.iastate.edu/publications/dbs/pdffiles/07sr101.pdf; 2007.

Tontisirin K, Chavasit V, Parinyasiri T, Ditmetharoj M, Photi J, Intaraluk P, Kittiprapas S. Country policy analysis. Nutrition impact of agriculture and food systems: Thailand, Geneva: UN System Standing Committee on Nutrition. https://www.unscn.org/files/Publications/Country_Case_Studies/Thailand_case_study_FINAL.pdf; 2013 [accessed 9 September 2017].

Troschinetz AM, Mihelcic JR. Sustainable recycling of municipal solid waste in developing countries. Waste Management 2009;29;915-523.

United States Department of Agriculture. Foreign Agricultural Service, Oilseeds: world markets and trade; 2016.

Viju C, Kerr WA. Taking an option on the future: Subsidizing biofuels for energy security or reducing global warming. Energy Policy 2013;56:543-8.

World Bank. GDP at market prices (current US$) and total population in 2014. http://www.worldbank.org/en/country/thailand; 2015a [accessed 19 October 2015].

World Bank. Gross domestic product per capita. http://data.worldbank.org/country/thailand#cp_fin; 2015b [accessed 10 March 2015]

World Factbook. East and Southeast Asia: Thailand. https://www.cia.gov/library/publications/the-world-factbook/geos/th.html; 2017 [accessed 9 September 2017].

World Factbook. Country comparison: GDP (purchasing power parity). https://www.cia.gov/library/publications/the-world-factbook/rankorder/2001rank. html#th; 2016 [accessed 9 September 2017].

World Resources Institute. Climate analysis indicators tool (CAIT), version 2.0. Washington, DC. http://cait2.wri.org; 2014 [accessed 15 September 2017].