RENEWABLE ENERGY RESOURCE MANAGEMENT FOR A SUSTAINABLE ELECTRICITY SUPPLY FOR PATHUM THANI PROVINCE IN THAILAND

BY

TOBIAS KULLACK

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE
(ENGINEERING AND TECHNOLOGY)
SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY
THAMMASAT UNIVERSITY
ACADEMIC YEAR 2015

RENEWABLE ENERGY RESOURCE MANAGEMENT FOR A SUSTAINABLE ELECTRICITY SUPPLY FOR PATHUM THANI PROVINCE IN THAILAND

BY

TOBIAS KULLACK

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF
THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE
(ENGINEERING AND TECHNOLOGY)
SIRINDHORN INTERNATIONAL INSTITUTE OF TECHNOLOGY
THAMMASAT UNIVERSITY
ACADEMIC YEAR 2015

RENEWABLE ENERGY RESOURCE MANAGEMENT FOR A SUSTAINABLE ELECTRICITY SUPPLY FOR PATHUM THANI PROVINCE IN THAILAND

A Thesis Presented

By

TOBIAS KULLACK

Submitted to

Sirindhorn International Institute of Technology

Thammasat University

In partial fulfillment of the requirements for the degree of

Master of Science (Engineering and Technology)

Approved as to style and content by

Advisor and Chairperson of Thesis Committee ______________________

(Dr. Supachart Chungpaibulpatana)

Committee Member and
Chairperson of Examination Committee ______________________

(Dr. Bundit Limmeechokchai)

Committee Member ______________________

(Dr. Siriroj Sirisukprasert)

SEPTEMBER 2015

Acknowledgements

Firstly, I would like to express my sincere gratitude to my advisor Dr. Supachart Chungpaibulpatan for the continuous support of my Master of Science study and related research, for his patience, motivation, and immense knowledge. His guidance helped me in all the time of research and writing of this thesis. I could not have imagined having a better advisor and mentor for my study. Furthermore I would like to thank Dr. Supachart and SIIT to supporting my research with a full scholarship.

Besides my advisor, I would like to thank the rest of my thesis committee for their insightful comments and encouragement, but also for the hard question which incented me to widen my research from various perspectives.

Last but not the least, I would like to thank my family; My mother and my dad for being a great support in every possible way, to my brothers and sister for supporting me spiritually throughout study and especially my life in general. You are the greatest part and support of all. Thank you.

Abstract

RENEWABLE ENERGY RESOURCE MANAGEMENT FOR A SUSTAINABLE ELECTRICITY SUPPLY FOR PATHUM THANI PROVINCE IN THAILAND

by

Tobias Kullack

Bachelor of Engineering (Energy and Process Engineering)
Hochschule Ravensburg-Weingarten (2011)

Nowadays the renewable energy implementation and development is being widely discussed in Thailand with its 20-Year Energy Efficiency Development Plan (2011 - 2030) and additionally the 10-Year Alternative Energy Development Plan 2012 - 2021 (AEDP 2012 – 2021), which is targeting on increasing the share of renewable energy and alternative energy uses by 25 percent instead of fossil fuels within the next 10 years. To reach such an ambitious setting target, several measures must be established with data supports from relevant feasibility studies. In this Thesis, a province is being considered as a model to evaluate the renewable energy potential and a 100 % renewable electricity supply is employed in this province. It is proposed to be a feasibility study and Pathum Thani, a province in the vicinity of Bangkok, is selected as a case study. Different scenarios are discussed and analyzed for their possibilities in terms of technical, economic and environmental aspects.

This thesis strongly focus on the renewable energy potential of the Pathum Thani province in Thailand. A simulation model has been developed to simulate the hourly electricity potential of several renewable energy sources and their interaction while taking the actual electricity consumption of the province into account. Different scenarios to achieve a 100% renewable electricity production from renewable energies have been evaluated and verified with an hourly simulation, using the electricity consumption of the year 2012, solar radiation of the year 2012 and Biogas and Biomass feed stock of the year 2012. The hourly consumption and simulated production have

been found to be mismatched to show possible weak points and bottlenecks of different scenarios. Furthermore the total costs, including investment costs, operation, maintenance and reinvestment costs have been considered to calculate the final electricity costs for each system respectively. To limit the scope, not every site has been measured and evaluated separately, however with the information given by the Land Development Department Pathum Thani and the ArcGis software, a good overview can be made and possible sites can be evaluated. This methodology has been used to evaluate the rooftop area for the so called Small Solar installation. However as a case study the rooftop area of the major university bodies in Pathum Thani has been evaluated using Helioscope software and then been simulated. Furthermore the discussion about agricultural products used for Biogas or being used for food supply has not been regarded as this study will focus on the technical possibility and the general requirements to fulfill the 100% renewable electricity supply. Different available land areas have been evaluated and categorized according to size, actual use and soil conditions. For the solar energy simulation, the actual radiation data from the Meteorological Department of 2012 has been implemented into a 'PVsyst' simulation software, in which a standard plant is used as a reference. Several scenarios inclusive a Napier grass scenario are displayed to possibly cover 100% electricity supply by renewable energies. The most optimized system appears to be a system consisting on PV Solar Large scale installations on 1/25 covering the area of the soil condition number 11 and the rest of the respective area used as Biogas feedstock by converting the paddy rice fields to Napier grass fields. The system would require the less storage capacity and the price is optimized and the costs per produced kWh inclusive of necessary storage, considering a 25 years lifetime could be 0.126 USD/kWh.

The fact that the study does not consider the capacity of each individual substation but focus on the overall renewable energy potential would require a detailed and sustainable study on actual conditions and location of substations to more sustainable plan different scenarios and moreover allocate the potential and regions based on the transformer and free transformer capacity of each PEA substation

Table of Contents

List of Tables

Tables **Page**

List of Figures

Figures **Page**

Chapter 1

Introduction

1.1 Statement of Problem

Due to world wide price rises of electricity and the limitation of coal and oil, and due to the energy policy in Thailand, generating at least 20% of its electricity by 2020 by renewable energy technologies and implementing so called micro grids on islands to guarantee and provide a sufficient and reliable electricity supply to remote areas, the question of the total amount of renewable energy, which can be implemented by still guarantee a reliable electricity is raising. Further the limitation of natural resources and due to the time variance in the electricity generating from renewable energies, to guarantee a reliable and sufficient electricity supply, the resources needs to be evaluated, and displayed with the actual consumption. The actual consumption and possible production, as in several studies carried out, should not be only regarded as a daily or yearly average it has to be displayed as accurate as possible and the actual values of a possible renewable electricity supply has to match each other. This on the one hand needs a fast reacting grid for the future and on the other hand a good planned and working electricity infrastructure with a communication from weather forecast to electricity consumption forecast over to actual storage capacity and long term management.

1.2 Purpose of Study

The purpose of this study is to obtain the renewable energies which generally could be implemented. It will display the available renewable energy resources, simulate for possible systems the hourly electricity production from each resource and technology respectively. During the study a match between the consumption in 2012 and the actual resource data is being done and then used as a calculation basis for the actual electricity production. A program to evaluate different set ups with key points has been developed and is used to simulate and display different possible scenarios.

- 100 % renewable energy scenario
- Minimizing of the costs of different renewable energy scenarios

- Impact of solar rooftop systems
- Required storage technology and storage size

The overall outcome of this study are several system and set ups to theoretically supply a maximum amount, in the best case 100%, of electricity by renewable energies in Pathum Thani Province. Further as outcome of this study a cooperation between GIZ (Deutsche Gesellschaft für Internationale Zusammenarbeit - German International Cooperation), Fraunhofer Institute and KMUTT (King Mongkut's University of Technology Thonburi) has been started to conduct a similar study for 4 further provinces, named as Nan, Rayong, Phuket and Chonburi to display the potential of renewable energy sources in usage for electricity and further gas/heat supply and simulate a maximum share of each technology. This has been achieved through discussions with GIZ and Fraunhofer Institute in Germany while GIZ has realized the potential in this study and has seen is strong need for further provinces in Thailand. This study however, for Pathum Thani province will only display the benefits of each technology respectively, their benefits, advantages and disadvantages and will also calculate the price of electricity production especially the investment costs of each technology, feed costs and the reinvestment costs and the operation and maintenance costs as well.

A simulation will be carried out and a manual optimization calculation will be conducted with regards, investment costs, and operation and maintenance costs. An optimization program will be complex as there are several relations influencing each other's in a cross section such as, amount of planned photovoltaic, peak consumption and storage capacity as well as the longest off sun hour for a period. To ensure that the storage is huge enough and that the capacity to charge the storage is high enough the model is complex. Hence such an optimization model might be developed in a next stage.

Currently the study "Simulations of scenarios with 100% renewable electricity in the Australian National Electricity Market" by Ben Elliston, Mark Diesendorf, Iain MacGill, is in the process to develop and publish an open source program which is capable to be modified and be used with the mentioned parameters as input to solve for an optimum energy mix. As this was not yet ready to be used, cooperation in future might be achieved to adopt this program for Thailand as well.

1.3 Significance of Study

This study will display the renewable energy potential as a case study for Pathum Thani province. It will indicate the total amount of each resource and its respective electrical potential and further clearly outlines the renewable energy mix to achieve a 100% share of electricity by renewable energies. Further, the developed system will have the feature to easily define limits on maximum share of each technology as they might be given by the grid operator to ensure a stable and reliable energy supply. Such limits can be defined and the electricity generated by such a system over 1 year – here in case for Pathum Thani – can be simulated and compared to the actual consumption – here for the year 2012. Nowadays the limitation of the implementation is given by the grid capability to handle the different power sources and or the available resources. A so called Smart Grid which is the future planning in Thailand will increase the efficiency and through its smart communication the total amount of implemented renewable energies.

The beneficiary on the one hand is Sirindhorn International Institute of Technology which can follow this study and apply it on other provinces, regions or even the whole country; on the other hand it will be GIZ together with Frauenhofer and Ministry of Energy in Thailand as a similar study based on this study will be carried out in 4 Provinces in Thailand to display the potential and define further goals and objectives. And at least, authorities such as PEA (Provincial Electricity Authority in Thailand) who are currently interested in a smart grid and the deployment of renewable energy technologies. A great beneficiary could also be the private sector especially IPP's (Independent Power Producer), SPP's (Small Power Producer) and VSPP's (Very Small Power Producer)[1], as the renewable energies are highly subsidies and hence an investment with an approximately 4-5 years return is a good investment opportunity.

---

[1] IPPs= Independent Power Producers (Cap. sold to EGAT ≥ 90 MW)

SPPs=Small Power Producers (Cap. sold to EGAT < 90 MW)

VSPPs=Very Small Power Producers (Cap. sold to MEA/PEA < 10 MW)

Chapter 2

Literature Review

The literature review is in a first case based on different topics, the topics are structured accordingly to renewable energy technologies and storage technologies, affecting policies and further grid development in Thailand, land use and cost and reliability analysis of the electricity sources respectively.

2.1 Similar Studies Conducted

Similar studies have been recently done for Germany. The document "100 % Erneuerbare Energieen fuer Strom und Waerme in Deutschland" [11] shows the simulation results for a 100% renewable electricity and heat supply in Germany. This document will generally be used as a guideline through this study. The study shows only results and hence the methodology needs to be developed for Thailand again as this is considered as a unique know-how.

Similar studies have recently been conducted for other countries or states such as Australia [22], and national scenarios for Australia (Wright and Hearps, 2010), Ireland [23], New Zealand (Mason et al., 2010), Portugal [24], Japan [25], the United Kingdom (Kemp and Wexler, 2010), Germany (German Advisory Council on the Environment, 2011) and Denmark [26]. More broadly, a regional study has been produced for northern Europe (Sorensen, 2008) and several studies of the global situation have been produced including by Sorensen and Meibom (2000) and Delucchi and Jacobson [27]. Several optimizations have been carried out, but the optimization program is not available thus the open source programs are limited even to purchase a program was not possible in this stage. Nevertheless, currently the study "Simulations of scenarios with 100% renewable electricity in the Australian National Electricity Market" by Ben Elliston, Mark Diesendorf, Iain MacGill, is in the process to develop and publish an open source program which is being able to be modified and using the mentioned parameters as input to solve for an optimum energy mix.

2.2 Similar Studies in Thailand

- Several Studies about Renewable Energy Potential for Thailand and CO_2 Mitigation have been carried out
- Mostly focused on total capacity installed and peak consumption no study has been found focusing on hourly values
- Ongoing "Green Islands" Projects by DEDE
- 4 Islands: Koh Jik, Koh Samui, Koh Paluay and Koh Raya

The green island Project as proposed by DEDE is pointing on the basic objectives: [28]

1) Overall Objective
    - To improve energy supply management in the targeted islands
    - To achieve lower costs of delivered electricity with less environmental impact
    - To reduce carbon footprint

2) Specific Objective
    - Increased energy conservation, reduced energy consumption and greenhouse gas (GHG) emissions through extensive use of green technologies and sustained tourists demand for eco-friendly hotels and resorts.

2.3 Energy Planning and Energy Forecasting Simulation Models

Energy planning and forecasting has been considered in several studies, the energy planning, simulation models and energy forecasting can be conducted as seen in [29] and the electricity forecast consumption provided by PEA. In this document the electricity peak consumption of several regions can be forecasted in case of different scenarios.

2.4 Technology and Potential Review

2.4.1 Solar

For the set-up of a Solar Plant (PV Power Plant) a guideline for typical designs and specification is given in in several studies for instance "Solar Energy; Fundamentals and Applications" [30]. This literature describes deeply the plant set up, and gives details for the calculation of the power output as well as constrains influencing the plant. The calculations are also applicable for the so called "Solar Home System" but the adjustments of those will be done according to the description in [31]

Prices and reliability for the solar plant can either be found in [11] or in the respectively sources as given respectively.

As the price in Thailand will be slightly changing due to different import prices but due to lower labor costs, the price will be considered as equal.

The CO_2 mitigation of a solar power plant in Thailand was estimated in [14] Thailand grid emission 2010 report.

2.4.2 Biogas and Biomass

The process and typical technologies and application as used for Biogas and Biomass were evaluated and can be found in the German literature “Nachwachsende Rohstoffe” from the Federal Ministry for Food, Agriculture and Consumer Protection, Germany [18]. For Thailand the study [7] “Overall Analyses of Using Rice Straw Residues for Power Generation in Thailand- Project Feasibility and Environmental GHG Impacts Assessment provides a detailed analysis.

2.4.3 Storage

If the amount of resources is greater than the electricity consumption, different storage conditions as described in 100 % Erneuerbare Energieen für Strom und Wärme in Deutschland [11], will be applied, otherwise the amount of external generated electricity will be displayed.

2.4.5 Cost of Electricity Generation, Maintenance Costs, Reliability and Lifetime

The values for the installation costs, maintenance costs, reliability and lifetime of each technology have been concluded in the report [11] “100 % Erneuerbare Energieen für Strom und Wärme in Deutschland” and hence those values are going to be the basics and may be adjusted if necessary.

2.5 Thailand Electricity Consumption and General Grid Situation

2.5.1 Actual Renewable Energy Situation in Thailand in 2012

According to the statistic published by the DEDE (Department of Alternative Energy Development and Efficiency, Thailand) [37], the actual share of alternatives renewable energies were at 9.9 % share of the total energy consumption with a total of 2,786 MW in electricity, 4,886 ktoe in heat and 3.5 ml./day in Biofuels.

“In 2012, the installed capacity of renewable energy was 2,786 MW, accounting for 7.6% of total power capacity in Thailand” [36] while the installed capacity, generating electricity by the end of 2021 should be 9,201 MW.

2.5.2 Load Factor (Capacity Factor net)

The load factor is defined to be “the ratio of the net electricity generated, for the time considered, to the energy that could have been generated at continuous full-power operation during the same period” [34].

And hence it’s the percentage of the actual generation to the installed capacity.

$$\text{CFN} = \frac{\text{Actaual Production [GW]}}{\text{Installed Capacity [GW]}}$$

Typical values for Thailand are around 70 – 85 % for the last few years and hence a strong growth in electricity consumption will use those reserves and new installations have to be done.

2.5.3 Electric Power Transmission and Distribution Losses in Thailand

The Electric power transmission and distribution losses are an important factor in the planning of an electricity production, during the last years, the losses (% of output) in Thailand was 5.91 in 2009, according to a World Bank report, published in 2010. Electric power transmission and distribution losses include losses in transmission between sources of supply and points of distribution and in the distribution to consumers.

Chapter 3

Methodology

3.1 Information Gathering

To conduct this study general information on available resources on the one hand as well as possible technologies on the other hand must be collected and defined. For the purpose of this study, unless otherwise defined, the "Best Available Technologies" (BAT) in the year 2012 have been assumed to simulate potentials of different resources.

3.1.1 Land Overview Pathum Thani

The land overview of Pathum Thani province gives a general overview of Pathum Thani and shows the elevation of the land, the usage of the land and its respective area. The information in this chapter is provided by the Department of Land Development – Pathum Thani. The land overview information are required to determine on the one hand available land for installations such as Solar and Biogas, to further define limits of resources for each technology and also to define the soil condition of Pathum Thani, province and its respective water body which plays a major role in the rice growing capacity.

3.1.1.1 General information

Pathum Thani is a central province of Thailand with a direct border to Ayutthaya, Saraburi, Nakhon Nayok, Chachoengsao, Bangkok and Nonthaburi.

The province is north of Bangkok and is part of the Bangkok metropolis. Pathum Thani is located in the low flats of the Chao Phraya River, which also flows through Bangkok. Many canals (khlongs) cross the province and feed the rice paddies. (Details in chapter 3.1.2)

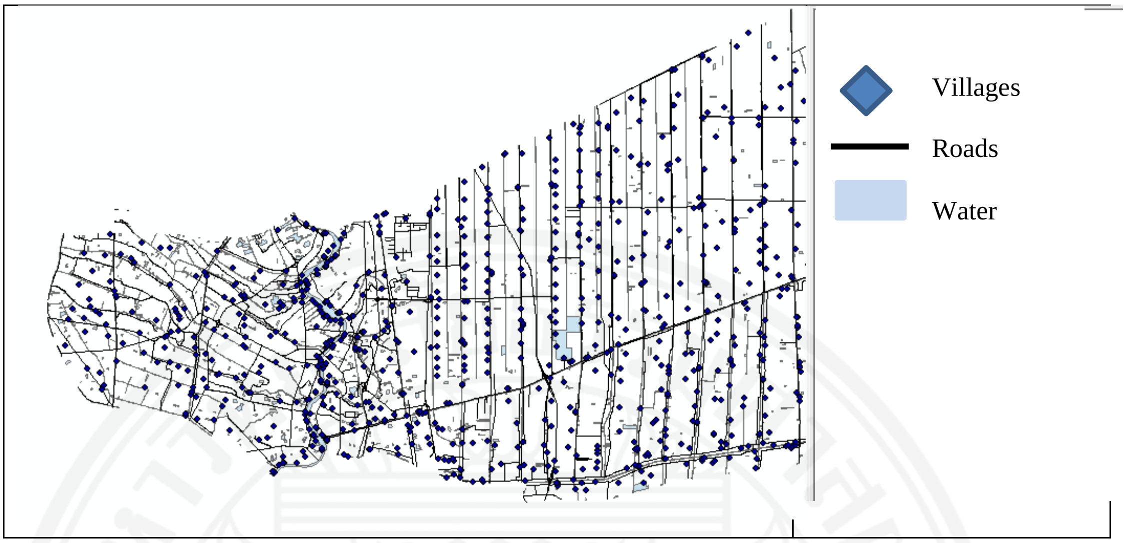

Figure 1: Overview Map - Pathum Thani

The map in Figure 1 shows the shape of Pathum Thani, the location of the villages, roads and the water body. It clearly gives an overview that only minor areas are covered with villages and the water body is around 3%. The total area is 1,525.9 km^2 with a population (2011) of 1,010,898 people and hence the density is 660/km^2.

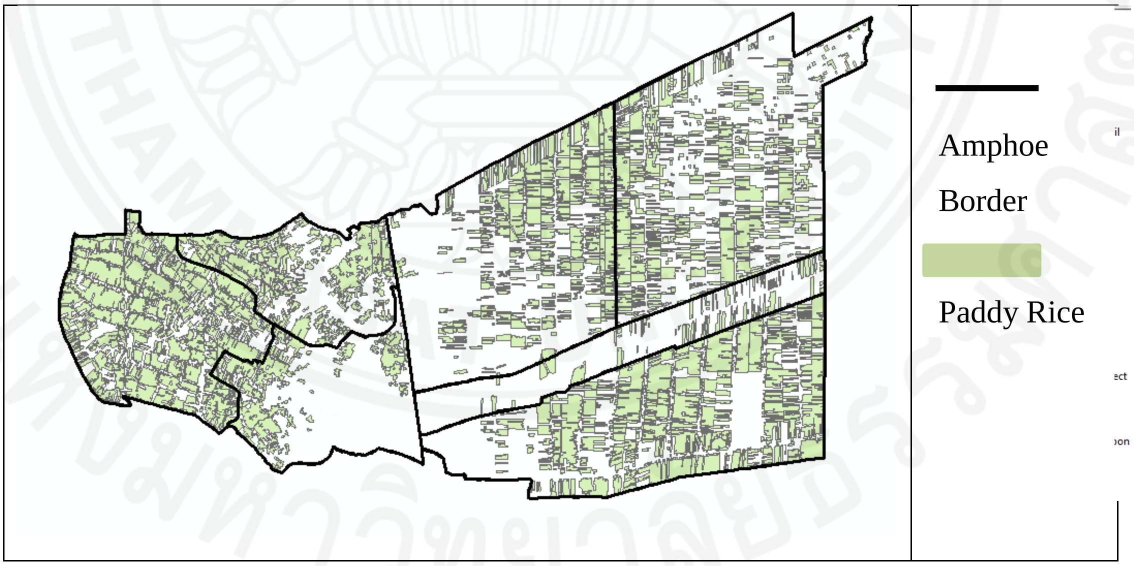

Figure 2: Amphoe in Pathum Thani

Pathum Thani is separated in 7 districts, which can be seen in Figure 2. The so called amphoe which are [1], [12]:

1. Mueang Pathum Thani
2. Khlong Luang

3. Thanyaburi
4. Nong Suea
5. Lat Lum Kaeo
6. Lam Luk Ka
7. Sam Khok

3.1.1.2 ArcGIS Software

The ArcGis software, a "Mapping & Analysis for Understanding Our World - A platform for designing and managing solutions through the application of geographic knowledge" [2] is a software used by the land development department in Pathum Thani to evaluate the land usage and land development in Pathum Thani. The software can be used for several analyses and the data provided by the Land Development Department consists of different layers with different information, such as:

- Land Usage and its respective size
- Soil condition
- "Amphoe " (Major of a Province District)
- "Tamphol" (District of a Amphoe)
- Boarders of each district (Ampohe and Tamphol)
- Size of each field and categorization

3.1.2 Agricultural Usage and its Respective Area

The agricultural usage of the land in Pathum Thani province has been evaluated with the ArgCIS software. In Table 1 it can be seen that the major agriculture product is Paddy Rice and is covering more than 38% of the total area in Pathum Thani. The water body with its 3 % of the total area is important for the paddy rice growth. The water body enables a biyearly growth of the rice in this area. According to the Office of Agricultural Economics, Thailand, [4] this are the so called:

- Major Rice : Rice were cultivated during 1 May - 31 October
- Second Rice : Rice were cultivated during 1 December - 30 April

Thus, the total rice harvested in one year is almost of double the size than in provinces, with only yearly harvesting rate. The total amount of paddy fields, separated to soil condition as seen in Table 3, shows that a majority is on soil category 11 and soil category 2. This is due to the fact that soil of the category 2 and 11 have the major coverage in Pathum Thani as seen in Figure 3.

Table 1: Pathum Thani - Agricultural Usage - Land Size and Percentage of Total Area [3]

	Rai	*m^2*	*%*
Total Area:	955,063	1,528,101,052	100
Rice Paddy:	363,924	582,278,400	38
Water Body	28,651	45,843,024	3
Other Agricultural	12,749	20,398,400	1.3

Table 2: Other Agricultural Products - Pathum Thani [5]

Agricultural Product	*Area Planted Rai*	*Area Harvested Rai*	*Tones*	*Yield kg/Rai*
Oil Palm	9,602	3,282	9,850	3,001
Coconuts	706	706	606	858
Tangerine	1,138	453	130	287
Guava	1,054	961	1,846	1,921
Orchid	249	249	471	1,892

Table 3: Paddy Rice Area According to Soil Conditions and Land > 10 Rai [3]

	Summary	*Land >10 Rai*	*Unit*	*Summary*	*Land >10 Rai*	*Unit*
All	363,924	361,531	Rai	582,278,400	578,449,381	m^2
Only Soil 2	114,820	114,040	Rai	183,713,031	182,465,430	m^2
Only Soil 3	85,600	84,872	Rai	136,960,964	135,795,776	m^2
Only Soil 10	7,131	7,125	Rai	11,410,984	11,400,840	m^2
Only Soil 11	150,404	149,551	Rai	240,647,500	239,281,985	m^2

3.1.2.1 Soil Condition

The different soil condition classification according to Land Development Department Pathum Thani can be seen in Figure 3 and Table 4. The soil has been tested by the Land Development Department, Pathum Thani and the data have been implemented into the ArgCIS software. The basic information is that the more acid the land the harder to grow any agricultural products and hence the land is not as useful as the less acid land. The numbering shows already the status of acidity. While category 2 and 3 is only light acid, category no 10 – 11 becomes more acid.

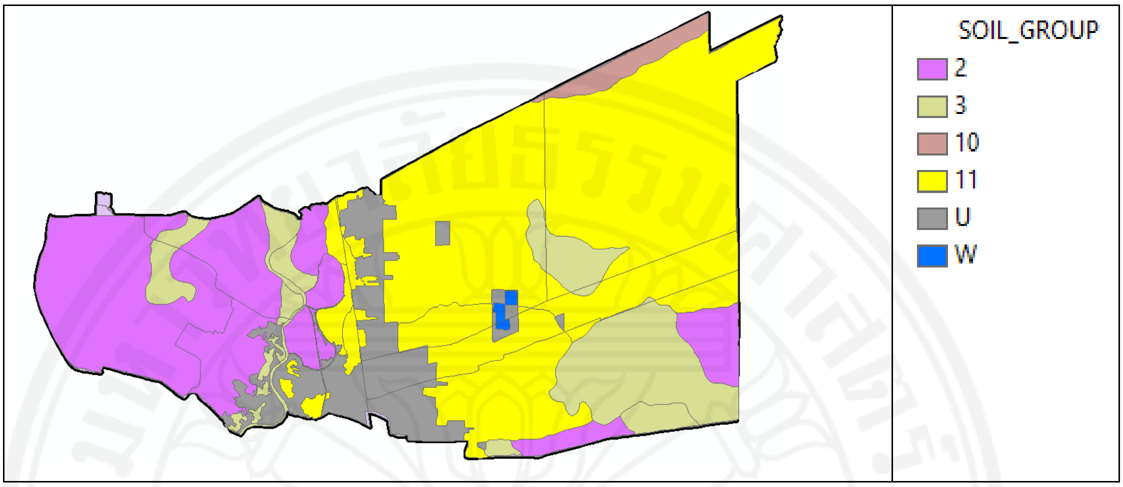

Figure 3: Graphical Soil Group Overview - Pathum Thani

Table 4: Numerical Soil Group Overview Pathum Thani [3] (Free Translated)

Land Unit	*Quality*		*Drainage*	*Soil Fertility*	*Slope ratio*	*PH*		*Depth cm*	*Clay Thickness cm*
	Up	Down							
2	Clay	Clay	bad	medium	0-2	6.0-7.0	4.5-5	>150	>150
3	Clay	Clay	bad	medium	0-2	6.0-7.0	7.0-8.0	>153	>100
10	Clay	Clay	bad	medium	0-2	4.5-50	4.0-4.5	>152	>100
11	Clay	Clay	bad	medium	0-2	4.5-50	4.0-4.5	>151	>100

3.1.3 Water Body, Rice Potential and Biyearly Harvesting

The total paddy area of 648,171 [5] Rai has been used to grow paddy rice in 2012 as Table 5 indicates. However the total area of paddy fields used to grow rice in 2012 according to [5] is maximum 324,359 Rai. The explanation is the biyearly planting and harvesting capacity of Pathum Thani due to its 3% water body. However the ArcGis simulation has shown that 363,924 Rai are potential and available rice paddy fields.

In consideration of a biyearly usage of each field, a total potential of 727,848 Rai would be available to grow and harvest rice.

Table 5: Actual Rice Planted and Harvested - Pathum Thani 2012 [5]

Rice Yield and Harvest Rice						
	Planted Rai	Planted m^2	Harvested Rai	Harvested m^2	Harvested t	Yield t/sqkm
Major Rice	319,959	511,934,400	302,149	483,438,400	201,574	416.96
Second Rice	328,758	526,012,800	325,813.	521,300,800	245,637	471.20
Sum	648,717	1,037,947,200	627,962	1,004,739,200	447,211	888.16
Average	324,359	518,973,600	313,981	502,369,600	223,606	444

Table 5 also indicates the total harvested amount in tons. This amount is only the average rice yield of rice grains including husk but without the straw. The straw is usually harvested in a later stage and then burnt. To calculate the total amount of rice straw, the SGR (Straw – to – Grain – Ratio) ratio will be applied. According to [6], the SGR ratio varies from region to region and from season to season. “However values between 0.75 and 0.45 have been reported.” For the central plain in Pathum Thani, and in this study, an average SGR ratio of 0.6 is used to estimate the straw yield and as a consequence the Grain to Straw Ratio is supposed to be 0.4 (GSR). The amount given in the agricultural statistic of 2012, 447,211.00 tons (Major and Second Rice) are only grain with Husk and hence the available straw can be calculated to:

$$\text{Straw Amount [t]} = \frac{\text{Grain Amount [t]*SGR}}{\text{GSR}} = \frac{447{,}211\ \text{t*0.6}}{0.4} = 670815\ \text{t.}$$

3.2 Hourly Electricity Consumption – EGAT Sai Noi

The approach to use the hourly electricity distribution in Pathum Thani from its respective 23 substations cannot be done as the several monitoring failures did not allow PEA (Provincial Electricity Authority) to carry out an accurate monitoring. While some substations provide a monthly average load, some substations do have hourly or daily values while others are hardly recorded. Therefore the hourly values of the EGAT (Electricity Generating Authority of Thailand) substation Sai Noi, which delivers all of its capacity to Pathum Thani will be used and seen as a sample of Pathum Thani province. The hourly consumption is provided by PEA statistical center. Instead of using exact values of substations in Pathum Thani, the values from the EGAT Substation Sai Noi are being used. The advantages implicates that the values exists and all electricity passing this substation is only used in Pathum Thani province. According to PEA the actual consumption of Pathum Thani is around 80 – 100 % from Sai Noi substation, however, a few more substations may provide electricity to Pathum Thani province but this cannot be displayed and therefore the load profile of Sai Noi will be used to reflect the Pathum Thani province in this study. The received load profile has also shown some errors in monitoring but in discussion with PAE the values missing were averaged of the hours before and after the missing values which seemed to be logically matching in the system. The yearly load of 2012 shows the peak and off peak clearly it also points out that the base load (purple line) is around 110,000 kW to 120,000 kW. This base load in a general system is provided by constant and reliable source – for instance nuclear or coal power plant. The peaks and maximum is usually provided by fast running, but yet, expansive equipment or expansive fuel such as gas turbines. The major goal is to cover the base load with renewable energies to ensure the base load in a 100% renewable energy system. In a mixed system, renewable energies are basically used to cover the peak consumptions and base load is still provided conventional. [21]

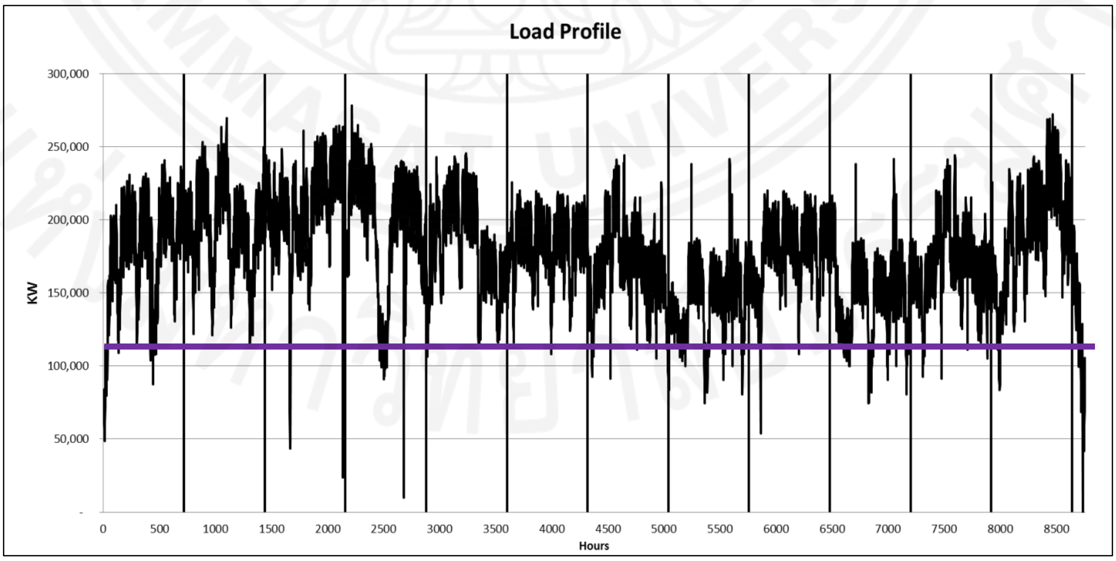

Figure 4: Yearly Load – Sai Noi and Assumed Base Load in 2012

3.3 Set Up and Simulation of the Potential of Each Technology

3.3.1 Biomass and Biogas Potential

In principle, any material of organic origin counts as biomass. Biomass can be used in a direct and indirect way to produce energy – it can be directly burnt in a power station to produce heat (direct way) or fermented in a anaerobic digester to make biogas and then electricity and heat (indirect way), or converted into a synthetic gas and fuel by thermochemical gasification (indirect way).

In a first instance the difference between Biogas and Biomass and its respective sources needs to be clarified. During this study the assumption as see in Figure 5a below will be followed, meaning all dry residues are for the combustion, hence Biomass assumption while all wet residues such as animal manure are for the biogas combustion. The potential of landfills and human waste has not yet been considered as non-valid data has been found during this study but the potential might be enormous and should be implemented.

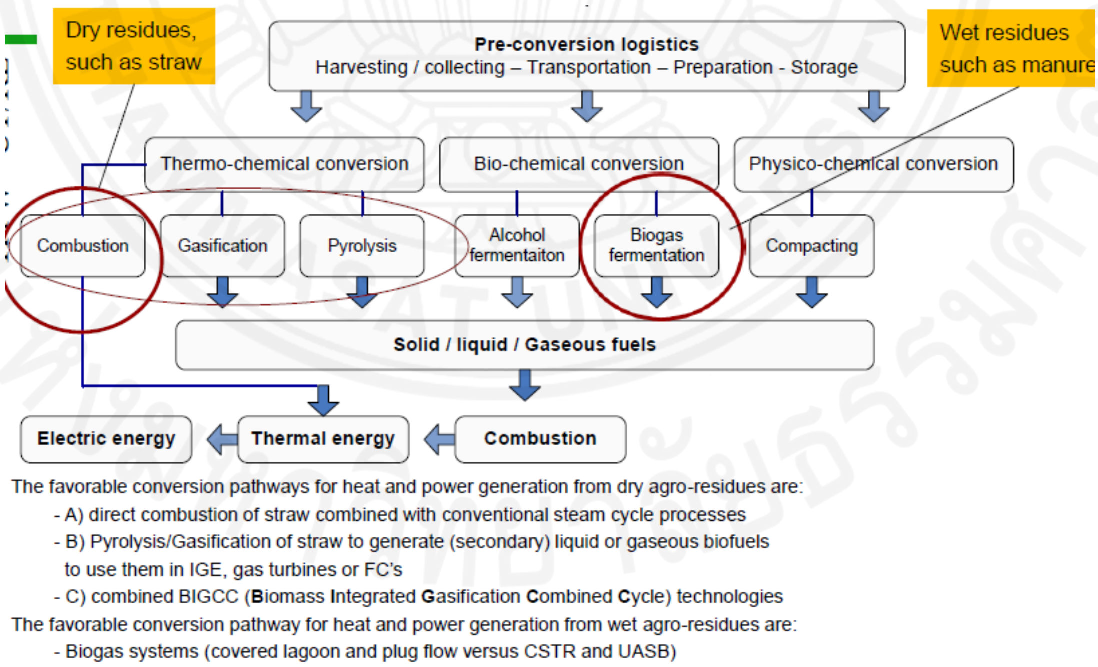

Figure 5a: Biogas and Biomass [36]

3.3.2 Biomass Potential

The Overall Analyses of Using Rice Straw Residues for Power Generation in Thailand has been analyzed in several studies, two major studies are the "Overall Analyses of Using Rice Straw Residues for Power Generation in Thailand- Project Feasibility and Environmental GHG Impacts Assessment" [7] and "Logistics cost analysis of rice straw for biomass power generation in Thailand" [6]

The explanation and usage of the equation can be seen in both references.

Equation 1: Annual Biomass Demand

$$Annual\ Biomass\ Demand = 1.11 * 1.10 * \frac{Electrical\ Output * 3.6 * Plant\ Factor}{El.\ Efficency * LHV\ Fuel\ Value}$$

Equation 2: Area Required Providing Annual Biomass Demand

$$Area\ (sqkm) = \frac{Annual\ Demand\ Of\ Rice\ Straw\ (t)}{Straw\ Yield\ \left(\frac{t}{sqkm}\right) * Collection\ Efficency * Land\ Efficency * Farm\ Land}$$

It is required to add the moisture content (11%) and the organic loss portion (10%) to the annual demand of the rice. According to [7], the SGR is selected to be 0.6.

Equation 3: Biomass - Electrical Output in Kwh/h

$$El\ Output\ (\frac{kwh}{h}) = \frac{Catch\ Area\ (sqkm) * Av\ Prod\ Yield\ (\frac{t}{sqkm}) * SGR * EL\ Efficency * LHV\ Fuel}{1.11 * 1.10 * 3.6 * 8760\ \left(\frac{h}{yr}\right)}$$

Equation 4: Installed Capacity

$$Installed\ Capacity\ (KW) = \frac{El\ Output\ \left(\frac{Kwh}{h}\right) * hours\ of\ year}{Average\ PLant\ Operation\ hours\ per\ Year}$$

Calculation of the total Biomass Potential:

There are 2 possible Biomass feedstocks.

1. The paddy straw which is leftover in the fields
2. The Husk which is harvest among with the grain and needs to be separated.

Values for Rice Straw: [7]

- Assumed parameters for estimating the annual rice straw demand:
- Annual operation hours 6,000 h
- Foreseen overall efficiency of the plant based on LHV 23%
- Low heating value (LHV) of rice straw 12.39 MJ/kg
- Moisture content (MC) assumed on dry basis 11%
- Loss of rice straw during handling and storage 10%

Values for Rice Husk:

Assumed parameters for estimating the annual rice Husk demand.

- Annual operation hours 6,000 h [7]
- Foreseen overall efficiency of the plant based on LHV 23% [7]
- The HTG ratio is around 0.22 [8]
- The LHV of Rice Husk: Rice husk 12.56 MJ/kg [8]

The total potential of Biomass is the calculated with the area of 582,278,400 m^2 (582.278 km^2) to:

Table 6: Biomass Potential from Rice Straw - Pathum Thani 2012

Area Rice [sqm]	*[sqkm]*	*Av. Prod. grain [t/sqkm]*	*Straw to Grain Ratio*	*Av. Prod Straw [t/sqkm]*	*LHV rice straw [MJ/kg]*	*El efficiency [%]*	*El Capacity [MW]*
582,278,400.00	*582.28*	*888*	*0.60*	*1,332.19*	*12.39*	*0.23*	*57.41*

Table 7: Biomass Potential from Rice Husk - Pathum Thani 2012

Area Rice [sqm]	*[sqkm]*	*Av. Prod. grain [t/sqkm]*	*Husk to Grain Ratio*	*Av. Prod Husk [t/sqkm]*	*LHV rice straw [MJ/kg]*	*El efficiency [%]*	*El Capacity [MW]*
582,278,400.00	582.28	888	0.22	195.39	12.56	0.23	9.39

Total installed capacity:

The total installed capacity for each technology is calculated respectively, in assumption of 6000 operational hours/year

Equation 5: Biomass Capacity

$$Min. Installed\ Capacity_{Rice\ Straw\ 100\%}\ (KW) = \frac{El\ Output\ \left(\frac{Kwh}{h}\right) * hours\ of\ year}{Average\ PLant\ Operation\ hours\ per\ Year}$$

$$= \frac{57410\ \left(\frac{Kwh}{h}\right) * 8760h}{6000h} = 83{,}819\ KW$$

$$Min. Installed\ Capacity_{Rice\ Husk\ 100\%}\ (KW) = \frac{El\ Output\ \left(\frac{Kwh}{h}\right) * hours\ of\ year}{Average\ PLant\ Operation\ hours\ per\ Year}$$

$$= \frac{9390\ \left(\frac{Kwh}{h}\right) * 8760h}{6000h} = 13{,}710\ KW$$

3.3.3 Biogas Potential

3.3.3.1 Farm Residues

A resource for the Biogas plant are the farm wastes, farm wastes are high potential and reliable. The agricultural livestock in Pathum Thani can be seen in Table 8.

Biogas is the result of the microbial degradation of organic products under humid, anaerobic conditions. Farm waste such as manure, industrial waste and municipal solid waste is regarded as Biogas resource and hence it will be stored under anaerobic conditions, the yield of CH_4 is specific for each resource. The amount of CH_4 which is collectable can be calculated and with an electrical efficiency of 35% out of the total CH_4 amount the electrical output will be calculated as seen in Equation 6. [37]

Equation 6: Biogas Potential of Farm Waste

$$Potential\ \left[\frac{KWh}{yr}\right] = Available\ Amount\ \left[\frac{kg}{yr}\right] * Collectibe\ Ratio * VS\ [\%] * Biogas\ Content\ \left[\frac{m^3}{kgVS}\right] * Amount\ of\ CH4\ Content * \eta_{el}$$

Table 8: Livestock Pathum Thani [9]

กรมปศุสัตว์
รายงานข้อมูลสัตว์ระดับจังหวัด
พ.ศ.2556
จังหวัดปทุมธานี

	โคเนื้อ Beef		โคนม Dairy cattle		กระบือ Buffalo		สุกร Pig		ไก่ Chicken		เป็ด Duck		แพะ Goat		แกะ Sheep	
อำเภอ	จำนวน - number	เกษตรกร farmers	จำนวน	เกษตรกร	จำนวน	เกษตรกร	จำนวน	เกษตรกร	จำนวน	เกษตรกร	จำนวน	เกษตรกร	จำนวน	เกษตรกร	จำนวน	เกษตรกร
	(ตัว)	(ครัวเรือน)	(ตัว)	(ครัวเรือน)	(ตัว)	(ครัวเรือน)	(ตัว)	(ครัวเรือน)	(ตัว)	(ครัวเรือน)	(ตัว)	(ครัวเรือน)	(ตัว)	(ครัวเรือน)	(ตัว)	(ครัวเรือน)
เมืองปทุมธานี Mueang Pathum Thani District	39	9	0	0	0	0	421	5	8,738	309	2,207	73	55	6	0	0
คลองหลวง Klong Luang	1,543	28	0	0	18	1	4,877	28	41,260	417	91,612	37	253	7	0	0
ธัญบุรี Thunyaburi	311	13	34	1	32	3	30	1	19,988	349	2,718	68	240	4	0	0
หนองเสือ Nong Suea District	473	17	0	0	42	4	34	7	139,046	427	16,645	163	203	5	0	0
ลาดหลุมแก้ว Lat Lum Kaeo	321	23	0	0	46	8	420	12	130,082	919	147,162	134	493	9	459	3
ลำลูกกา Lam Luk Ka	341	41	0	0	34	7	20	1	11,090	446	38,649	90	202	18	0	0
สามโคก Sam Khok	282	10	0	0	55	7	267	10	12,404	275	2,443	86	51	1	0	0
รวม	**3,310**	**141**	**34**	**1**	**227**	**30**	**6,069**	**64**	**362,608**	**3,142**	**301,436**	**651**	**1,497**	**50**	**459**	**3**

ที่มา : สำนักงานปศุสัตว์อำเภอ (ประมวลผลข้อมูล ณ วันที่ 6 สิงหาคม 2556)

Table 9: Biogas Potential from Agricultural Waste - Pathum Thani [10]

Pathum Thani

Animal	Number Heads	Manure [kg/head/d]	Collectible Ratio	VS [%]	Biogas [m^3/kg VS]	Biogas [m^3/yr]	Potential Energy [MJ/yr]	El efficency 35 %	Electrical Output [KWh/year]	Electrical Output [KWh/hour]	Substrate Biogas yield (m3/t fresh mass) CH4 content (Vol.-%)
Cattle Beef	3,310	5	0.5	13.37%	0.31	123974	2604496	35%	253215	29	Cattle slurry 20 – 30 60
Diary - Cow	34	15	0.8	13.37%	0.307	6113	128415	35%	12485	1	Pig slurry 20 – 35 60 – 70
Buffalo	227	8	0.5	13.64%	0.286	12929	271614	35%	26407	3	Cattle manure 40 – 50 60
Swine - Sow	-	2	0.8	24.84%	0.217	0	0	35%	0	0	Pig manure 55 – 65 60
Swine - Boar	6,069	2	0.8	324.84%	0.217	2498384	52487062	35%	5102909	583	Chicken manure 70 – 90 60
Swine - Piglet	-	0.5	0.8	24.84%	0.217	0	0	35%	0	0	Maize silage 170 – 200 50 – 55
Swine - Fattering	-	1.2	0.8	24.84%	0.217	0	0	35%	0	0	Rye whole-crop silage 170 – 220
Swine - Native	-	1.2	0.8	24.84%	0.217	0	0	35%	0	0	Organic waste 80 – 120 58 – 65
Chicken	3,142	0.03	0.8	22.34%	0.242	1488	31261	35%	3039	0	Grass cuttings 150 – 200 55 – 65
Duck	301,436	0.03	0.8	17.44%	0.31	142760	2999166	35%	291586	33	
Elephant	-	40	0.5	6.81%	0.241	0	0	35%	0	0	
						2785647.87	58522014.1		5689640.256	649.5	

Table 10: Oil Palm and Coconut Potential Pathum Thani [10], [11]

Crop	*Production 2003 (ktons)*	*Residue*	*RPR*	*Surplus Availability Factor*	*Calorific Value (MJ/Kg)*	*Fuel Value (kwh/kg)*	*El. Efficiency %*	*Potential from Surplus (kWh/h)*
Oil Palm	10	Empty bunches	0.428	0.584	16.44	2.0	35%	0.46
		Fiber	0.147	0.134	16.19	2.0	35%	0.01
		Shell	0.049	0.037	17	2.0	35%	0.00

		Frond	0.2604	1	7.97	2.0	35%	0.40
		Male bunches	0.233	1	14.86	2.0	35%	0.67
Coconut	1	Husk	0.362	0.595	14.27	4.0	35%	0
		Shell	0.16	0.378	10.24	2.8	35%	0
		Empty Bunches	0.049	0.843	14.27	4.0	35%	0
		Frond	0.225	0.809	10.24	2.8	35%	0

The potential of Oil Palm and Coconut is too small and will not be considered.

3.3.3.2 Napier Grass

Napier Grass has a yield of 36-60 tons per crop per hectare. And can be furthermore harvested around 8 times a year with 45 days duration of growing. [19]

Therefore the yield harvested on 1 hectare over 1 year is around 288 to 400 tons.

Due to its high methane yield (190 – 270 m^3 per ton) only around 112 – 167 tons of fresh Napier grass per day are required to operate a 1 MW plant. With an assumed load factor of 0.9 the output would be 21,600 kWh / day. [19]

For the 112-167 tons of Napier grass per day an area of 85 - 211 hectares are approximately required. Therefore it is assumed that around 150 hectares (approximately 1,000 Rai) will be used for the 1 MW plant.

3.3.4 PV Power Plants

A PV Power Plant is a Power plant which is using the energy from the sun to produce electricity. The usage of the Photovoltaic Cells will transmit the sun energy into electricity. With a setup of modules in strings, connected as arrays and finally plugged in to an inverter to generate alternate current (AC).

The setup of such a Power plan can vary by type and location and also will vary due to factors such as costs (investment and operation costs), environment, and equipment.

3.3.4.1 Site Are and Land Use

The required are for a PV solar installation depends on

1. Module Type
2. Module Efficiency
3. Location

(Fixed tilt solar arrays using typical modules of about 15% efficiency on horizontal sites, need about 1 hectare/MW.)

To prevent shadowing and a frequent crass cutting, Solar Modules are installed around 1 m above the ground on a mounting system.

3.3.4.2 Typical Set UP of a PV Power Plant

3.3.4.2.1 Fixed or Tracking Mounting System

The Solar Modules are mounted on a mounting system and pointed into the direction with the calculated maximum power output. Which is supposing south on the northern hemisphere. A fixed or tracking mounting System can be installed. A fixed mounted inclination is calculated to provide the optimum annual output profile. A variant on this design is the use of arrays, whose tilt angle can be adjusted seasonally to optimize output in summer and winter or during day times. This design therefore requires the angle to be mechanically adjusted. In this study on fixed mounting systems are regarded.

3.3.4.2.2 String Connection

The solar panels are connected in a string of typical 15 – 25 modules this is done to increase the Voltage. In this study 20 modules have been selected.

3.3.4.2.3 Array Connection

Several Strings are connected together as one array to increase the current; this value strongly depends on the Inverters and is influenced by the PID[1] effect and the Maximum Power Point tracking capability of an inverter.

[1] PID = potential induced degradation [http://www.en.csp.fraunhofer.de/aktuelles/details/id/51]

3.3.4.2.4 Power conversion

Solar panels produce direct current (DC) electricity; hence an Inverter to convert from DC to alternating current (AC) is required.

There are two alternatives to do so, on the one hand centralized inverters and on the other hand and string inverters.

3.3.4.2.5 Centralized Inverters

Centralized inverters are central installed inverters with a high capacity as usually several arrays are connected into one centralized inverter.

3.3.4.2.6 String Inverters

String inverters are substantially lower in capacity String inverters can enhance the efficiency of solar parks, where different parts of the array are experiencing different levels of insolation, for example where arranged at different orientations, or closely packed to minimize site area and also provide higher reliability in terms of failures as if one inverter fails only a lower percentage of the plant is offline for the duration.

3.3.4.2.7 Transformers

The system inverters typically provide power output at voltages of the order of 1000 V AC. Electricity grids operate at much higher voltages of the order of tens or hundreds of thousands of volts, so transformers are incorporated to deliver the required output to the grid.

3.3.4.3 System Performance

The performance of a solar park strongly depends on the climatic conditions, the equipment used and the system configuration. The primary energy input is the global light irradiance. A key determinant of the output of the system is the conversion efficiency of the solar modules, which will depend in particular on the type of solar cell used.

There will be losses between the DC output of the solar modules and the AC power delivered to the grid, due to a wide range of factors such as light absorption losses, mismatch, cable voltage drop, conversion efficiencies, and other parasitic losses.

The performance ratio has been developed to evaluate the total value of these losses. The performance ratio gives a measure of the output AC power delivered as a proportion of the total DC power which the solar modules should be able to deliver under the ambient climatic conditions. Typical and good developed PV Power Plants are showing values for a Performance Ratio (PR) up to 80-85%.

3.3.4.4 CO_2 Mitigation

The CO_2 mitigation for a PV Power plant and a PV – Home system is divided into 3 parts. On the one hand the already installed capacity is regarded, as well as the planned capacity and a mix value of both. As this study will only concentrate and calculate a value as a scenario as if the sources are installed already, the CO_2 mitigation for the installed capacity will be used.

Table 11: CO2 Mitigation as applicable in Thailand - Year 2011 [14]

Project type	Emission Factor (tCO_2/MWh)		
	$EF_{grid, OM}$	$EF_{grid, BM}$	$EF_{grid, CM}$
General Project	0.5996	0.4231	0.5113
Wind and solar power generation project	0.5996	0.4231	0.5554

3.3.4.5 PVsyst

PVsyst is a Microsoft Windows software application for developing energy production estimates for photovoltaic power systems. It was developed by André Mermoud at the University of Geneva. The company PVsyst SA was created to maintain and sell the application. [15]

PVsyst is using metrological data of several years in an hourly basis, together with the latest technology developments to estimate and simulate the efficiency and approximate power output of the Solar System set up. The software is applicable for Grid Connected Power Plants, for Off Grid Systems and for Grid Connected Home Systems.

PVsyst includes the meteor database management, it also includes a database of around 330 sites in the world. The component database holds over 1750 PV modules, 650 inverters, nearly 100 solar pumps and dozens of batteries or regulator models.

However the meteonorm hourly values are not measured, but synthetic data constructed in the same way as the synthetic hourly values in PVsyst from monthly values. Constructing hourly data in Meteonorm instead of PVsyst may give slightly more realistic results as the models (especially for temperature) have been slightly improved, and wind velocities are also generated. [16]

Sources of Meteo data in monthly values

Meteonorm monthly irradiance data are available for about 1'200 "stations", as averages of 1960-1991 (and also 1981- 2000 in version 6.0). All "stations" (i.e. with irradiance measurements) of the main European countries are referenced in the PVsyst database. Data for any other site may be obtained by interpolation (usually between the 3 nearest "stations"). [16]

3.3.4.6 HelioScope

HelioScope is a program developed by Folsom Labs and is “an advanced PV system design tool that integrates system layout and performance modeling to simplify the process of engineering and selling solar projects.” [18]. The program enhances a direct size measuring from a satellite image of a location and further analysis the maximum potential of the selected area while inputting the solar module and inverter type and brand. Further a full electrical wiring can be planned a system performance analysis can be done, however for this study it was enough to measure respective sites, especially the rooftop areas, and use the values of possible installable capacity to simulate the output with PVsyst.

3.3.4.7 Home Systems and Small Scale Systems

The so called “Solar Home Systems” or PV Home – Systems” or Small Scale Systems are Systems installed around a house, on car parks, around highways or in general on the roof to produce electricity from the sun. The electricity is either directly fed in as an off grid system, and hence the components are not connected to the grid or it is used as an On-Grid system, which in general, if more electricity is produced as consumed, can fed back to the grid. In case of such an ON-Grid system, the required Power from the Grid can be calculated as seen in Equation 5.

Equation 7: Grid Connected Home Systems

$$\mathbf{P}_{\mathbf{Grid}} = \boldsymbol{P}_{consumption} - \boldsymbol{P}_{Home\ System}$$

For the further discussion and calculation only "On Grid Systems"2 are regarded as the "Off-Grid Systems"3 don't contribute directly to the electricity consumption generated by the grid are in generally used to supply electricity to "Stand-Alone Systems" and hence don't influence the total electricity consumption used in this statistics. The Home – Systems can be build up as Solar Systems, Wind Systems and a combination and even as Hybrid with Battery Backup. In this study all systems less which are not on a field and or ground mounted will be considered as small scale (less than 0.5 MWp installed capacity) or as rooftop large scale systems (larger 0.5 MWp) . A PV Power Plant is used to generate electricity in a typical range of 0.5 to several Mega Watts and is only applicable for ground mounted systems.

3.3.4.8 PVsyst Calculation for the Year 2012

The PVsyst simulation for Thammasat University with the coordinates of, 14°4′16.7″N 100°36′33.2″E, and the following set up of the plant:

- Fixed Mounting Structure, 15 degree tilt angle
- REC 250PE Modules (Efficiency 15.5 %)
- 23 Modules / String
- 174 Strings of 23 Modules
- SMA Sunny Tripower 15000 TL inverter

Will provide an overall efficiency of 77.7%.

The assumption of a 1.0 MWp (6700 m^2 Module Area) plant set up will be done. With the actual radiation data from the Thai Metrological Department, with the coordinates

[2] As "On Grid System" Photovoltaic systems which fed into the grid are regarded and not being used for the own consumption.

[3] As "Off Grid System" photovoltaic systems, which are not connected to the grid and powering a single system, are regarded.

Lat: 13 40' N, Long: 100 37' E, the following calculations, to calculate the possible power output for the year 2012 can be done.

Equation 8: Performance Ratio [PR] [20]

$$PR = \frac{Output\ of\ the\ Plant\ [kWh]}{Theoretical\ Maximum\ Output\ of\ the\ Plant\ after\ Modular\ Efficency\ [kWh]}$$

3.3.3.9 Radiation implemented into PVsyst

The solar radiation of 2012 has been implemented into PVsyst. As PVsyst requires an ASCII format, all values have been transferred into an ASCII format and then implemented into PVsyst. The hourly values for the year 2012 have been exported from PVsyst. As those values are for 1 MWp, it is set for this study that 1 MWp requires 20,000 sqm. Hence it’s a simple relation area and total installed capacities.

3.3.4.9 Probability Analysis - P50/75/90/95

The probability analysis as integrated into the software PVsyst is a tool to evaluate and interpret simulation results over years. As several values are variable and further the meteorically data from Meteonom are average data over a specific period, a probability to achieve a certain value and vice versa a value for achieved within a specific probability can be calculated. Generally, using a Gauss distribution curve. The software itself requires as an input the variability of each parameter as: [16]

- The annual variability (sigma value) will be dominated by the meteor year-to-year variability.
- PV modules model and parameters (the main uncertainty after Meteo)
- Inverter efficiency (negligible)
- Soiling and module quality loss (highly depending on the site conditions)
- Long term degradation
- Custom other contributions,

and is then calculating the respective “PXX” values, while P50 is assumed as a standard.

Extract from the software's description:

"Probability law- This approach supposes that over several years of operation, the distribution of the annual yields will follow a statistical law, which is assumed to be the Gaussian (or "normal") distribution. P50-P90 represents different yield levels, for which the probability that the production of a particular year is over this value is 50%, resp. 90%. The problem is now to establish the 2 parameters of this Gaussian distribution, i.e. the Mean value and the Variance (named sigma or RMS).

The main contribution to those parameters will be the uncertainty and variability of the meteor data. But other uncertainties in the simulation process and parameters should be taken into account."

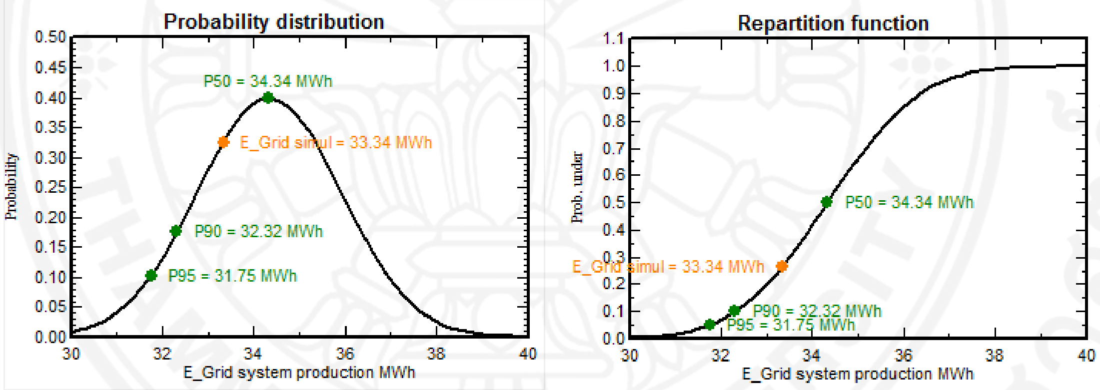

Figure 5: Example of a PVsyst P50/P90 determination [16]

3.3.5 Wind and Wind Potential

The data from a wind met mast installed at Thammasat University have displayed an average wind speed of 3.8 m/s for the period of March – November 2012. Generally to implement a wind power generation facility it is confirmed that wind speeds starting with 4-5 m/s are considered. Therefore the wind potential in Pathum Thani Province is not considered further in this study. However the simulation software is in a stage to be updated for possible wind sources.

3.4 Storage Technologies and Applications

Several Storage technologies has been described in [11] while there are storage technologies to cover the daily hourly and short time fluctuations caused on the one hand by increased load over a day and or by unavailability of resources caused by factors such as clouds or no existing wind, batteries and pump storage can be used here. On the other hand there are storage technologies to store electricity offer a certain period of time to ensure to equalize the yearly differences on both sides, load consumption and also on generation. However as solar and wind is almost evenly over a year in Thailand this does not need to be considered, unless the load profile shows great discrepancies over a year and thus only short time storage solutions will be considered.

3.5 Cost Analysis

The costs for each system should be included to determine the economics of a potential system. Therefore the costs as described in the [11] will be applied here as well. The costs for Biogas systems for Napier Grass have been analyzed by Department of Alternative Energy Development and Efficiency (DEDE) Thailand and can be seen in Figure 6 and 7.

Technologie	Beschreibung	Werte aus Quelle	verwendeter Wert	Quelle
BHKW	spezifische Kosten	2344 €/kW (20kWel)	1400 €/kW	ASUE (2011), IEA (2010)
	Wirkungsgrad el	26-40	33%	IEA (2010)
	Wirkungsgrad tot	80-90	85%	IEA (2010)
	Lebensdauer	20-25a	25	IEA (2010)
	Wartungskosten	-	3%	
Wärmepumpe, el.	spezifische Kosten	1050€/kWth	1050 €/kWth	UBA (2009)
	Wirkungsgrad	-	3.5-4.5	Interne Studien
	Lebensdauer	20	20	ECO (2011)
	Wartungskosten	-	3%	Interne Studien
Wärmepumpe Gas	spezifische Kosten	-	800 €/kWth	Interne Befragung
	Wirkungsgrad	-	1.5-2.1	Interne Befragung
	Lebensdauer	-	20	Interne Befragung
	Wartungskosten	-	1.5%	Interne Befragung
Kessel, zentr.	spezifische Kosten	90 (200kWth)	90 €/kWth	BMVBS (2012)
	Wirkungsgrad	98%	98%	Schramek (2007)
	Lebensdauer	20	20	Schramek (2007)
	Wartungskosten		1%	
Kessel, dez.	spezifische Kosten	669 €/kWth	660 €/kWth	TUB
	Wirkungsgrad	96%	96%	Schramek (2007)
	Lebensdauer	20a	20	Schramek (2007)
	Wartungskosten		1%	
Pumpspeicher	Instal. Kapazität	6.6 GW (aktuell)	10 GW	dena (2010b)
	Speichervermögen	40 GWh (aktuell)	60 GWh	
	Wirkungsgrad	80%	80%	SRU (2011)
	spezifische Kosten	1600 €/kW	1600	SRU (2011)
	Lebensdauer	60a	60a	SRU (2011)
	Wartungskosten	1%	1%	SRU (2011)
Batteriespeicher	spezifische Kosten	300€/kW	300 €/kWh	BCG (2010)
	Wirkungsgrad	90-95	95%	BMWi (2009b)
	Lebensdauer	3000 Zyklen	15a	BMWi (2009b)
	Wartungskosten	-	1%	geschätzt
Gas Speicher	Wirkungsgrad	99%	99%	DB Research (2012)
	Volumen	15+20 Mrd m³		DB Research (2012)
Wärmespeicher, zentr.	spezifische Kosten	20 €/m³	20 €/m³	Nielsen (2011)
	Lebensdauer	40a	40a	Nielsen (2011)
Wärmenetz	spez. Kosten	562 (200-500 kW)	400 €/kW	BMU (2011)
	Lebenszeit	40-80a	50a	TGA (2011)
Biomasse	Kosten	60 €/MWh	50 €/MWh	DVGW (2011)
Wind offshore	spezifische Kosten	2100-2600 USD/kWel	1800 €/kW	IEA (2010)
	Lebensdauer	25a	25a	ECO (2011) und EWEA
	Wartungskosten	68 USD	2.90%	IEA (2010)
	Vollaststunden	3500	3500	EEX wind
Wind onshore	spezifische Kosten	1200-2600 USD	1080 €/kW	IEA (2010)
	Lebensdauer	20a	20a	EWEA
	Wartungskosten	39 USD	2.80%	IEA (2010)
	Vollaststunden	1800	1800	EEX wind
PV	spezifische Kosten	1000-1600 USD	1000 €/kW	IEA (2010)
	Lebensdauer	25a	25a	ECO (2011)
	Wartungskosten	13 USD	1.00%	IEA (2010)
	Vollaststunden	975	975	EEX solar
Wasserkraft	spezifische Kosten	2000 (big)-3000 (small)	1600 €/kW	IEA (2010)
	Lebensdauer	50a	50a	ECO (2011)
	Wartungskosten	2.00%	2.00%	IEA (2010)
	Vollaststunden	4500	4500	EEX hydro
	installierte Kap.	4700 MW	4700 MW	BMU (2010)
Solarthermie, dez.	spezifische Kosten	450-550 USD/kWth	380 €/kWth	IEA (2010)
	Lebensdauer	20a	20a	ECO (2011)
	Wartungskosten	1.30%	1.30%	ECO (2011)
Solarthermie, zentr.	spezifische Kosten	225-275 USD/kWth	190 €/kWth	IEA (2010)
	Lebensdauer	20a	20a	ECO (2011)
	Wartungskosten	1.40%	1.40%	ECO (2011)
P2G	spezifische Kosten	1000-2000 €/kW	1500 €/kWth	Sterner (2009)
	Lebensdauer	15-20a	20a	Sterner (2009)
	Wartungskosten	3%	3%	Sterner (2009)
GuD	spezifische Kosten	640 €/kW	640 €/kW	BMWi (2009a)
	Wirkungsgrad	65%	65%	BMWI (2009b)
	Lebensdauer	30a	30a	dena (2005)
	Wartungskosten	2.70%	3.00%	dena (2005)
GuD-KWK	spezifische Kosten	650 €/kW	650 €/kW	BMWi (2009a)
	Wirkungsgrad el	55%	55%	Siemens (2012)
	Wirkungsgrad th	35%	35%	Siemens (2012)
	Lebensdauer	24a	24	IEA (2010)
	Wartungskosten	-	3%	

Fraunhofer ISE 100 % EE für Strom und Wärme

Figure 6: Typical Installation and Maintenance Cost

Land Unit	*Installation Costs*		*Lifetime*		*Maintenance Costs*	*Fuel Costs*	
Napier Grass	3,125,000	USD/MWe	30	Years	25%	12	USD/ton
Biomass	2,000,000	USD/MWe	30	Years	25%	20	USD/ton
Solar	1,300	USD/kWe	25	Years	10%		
Storage	500	USD / kW	25	Years	1%		

Financial Brief[1] : Napier Biogas Power Plant in Thailand

Component	1 MW e	Note
Initial Investment	2.25 M € (100.0 M THB)	12,000 m3 DV CSTR digester + generator NOT including land
Feedstock Cost (per ton fresh)	6.75 – 11.25 € (300 - 500 THB)	Including logistic cost within vicinity
Feedstock / day	112 – 167 ton fresh	Based on 20 – 30 %DM
Electricity price (FIT)	0.101 € / kW.h (4.50 THB / kW.h)	Special rate for Napier Demonstration
Electricity production kW.h / day	*21,600 kW.h/day* *7.128 M kW.h/year*	Load factor 0.9 330 days / year

€ 1.00 = 44.5 THB (Jan 2014)

[1] DEDE, Thailand MoE publication on Napier Grass Power Plant

Figure 7: Napier Grass Costs and Potential [19]

3.6 Resource Limitation and Simulation Constrains

The available area for solar installation and Biogas installation will have the following constraints.

Solar on a Large Scale Installation

- Only on land which is greater than 10 Rai (this will on the one hand limit the maximum land available and also make the study more realistic, besides this, the small land will only be sufficient for minor installations)
- Only on existing paddy fields

Solar Small Scale and Rooftop Installations (Such as rooftops of educational buildings, residential and smaller installation)

- Limited to major Universities
- Limited to around 0.5% of the total area available as total potential excluding the universities

Biogas/ Biomass:

- Resources from paddy rice fields
- Biogas/ Biomass plant will not use any paddy field resource
- Minor potential from coconuts, farm residues as constant value

General:

- Area used for solar cannot be used for biogas/ biomass feedstock
- Biogas/ Biomass feedstock areas cannot be used for solar installation

Chapter 4

Simulation Software

To combine and simulate various technologies in regards to usage of size, required storage capacity for load shifting and cost analysis a Microsoft excel based simulation software has been developed during this study. The inputs for the system are as following:

1. Area for large scale solar system
2. Area for Biogas / Biomass system and type of resource
3. Storage size
4. Wind speeds and potential

The software has as a background already the load profile of Sai Noi substation however those values can be adjusted if needed. The outcome of the simulation as following:

- Hourly comparison between total consumption and production
- Evaluation of storage size and hourly storage status
- Hourly, Monthly and Yearly comparison between production and consumption
- Cost simulation
- Flow direction of electricity such as amount into grid or storage technologies or exported amount
- Load shifting
- Storage capacity

The software, a excel based simulation, is available and attached to this dissertation in form of a CD.

Chapter 5

Simulation and Results

With all the parameters and given values, different scenarios have been simulated. TO conduct the simulation, a excel based template has been created which can be modified in future studies and can be used to enhance the system and would allow it to be expanded by an optimization model. The current model however requires only the area of solar installation and respective area used for Biomass and Biogas and further requires some basic information such as:

- Agricultural resources usage for Biogas/Biomass or not.
- Small System Solar used or not and area available for it.

The first scenario is a 100% large scale solar simulation. When talking about 100% large scale solar installation 2 aspects have to be taken into consideration for a better understanding:

1. 100% large scale solar can be understood as 100% of the available paddy field area will be used to install solar facilities and generate electricity from it and compare the total generation to the total consumption over 1 year
2. 100% large scale solar can be understood as the amount of solar energy to be installed as a minimum to cover 100% of the consumption and is the subject to determine the required minimum storage capacities over 1 year.

In this research only the first case has been regarded to show the potential of solar in Pathum Thani as the scenario 2 is unrealistic and not reasonable to happen. Before going into further details, some explanation to understand the simulation results:

Explanation:

1. Consumption total: Actual sum of hourly consumption of Pathum Thani Province – Values from Sai Noi EGAT substation
2. Consumption max: maximum peak in the specific period
3. Solar Production – sum of hourly values of electricity produced by solar in specific period
4. Solar maximum – peak production of solar systems in specific period

5. Total Biogas / Biomass – sum of hourly values of Biogas (or respective Biomass) in specific period
6. Total: Sum of hourly difference between productions and consumption
7. Mean: Mean in hourly values of the difference production – consumption
8. If not further explained or explicitly mentioned, the electricity generated with solar is equal to the P50 value.

5.1 100 % Large Scale Solar Scenario

The 1st scenario assumed that 100% of paddy rice fields, greater than 10 Rai have been used for a solar installation.

With the total area of 578,449,381 sqm, a total capacity of 28,922 MWp could be installed. The simulation has been done with this value.

5.1.1 Simulation Results

It can be seen that the yearly production from this scenario is around 40,900,836 MWh which is approximately 2,615% higher than the yearly total consumption. However, a look in the hourly production and consumption shows clearly the problems, while at daytime a production up to 27,009 MWh while at night time the production is 0 MWh. Such a system requires a great storage of a minimum of 3,626,220 MWp to ensure enough electricity could be supplied. This assumption does not take into consideration the fact of the enormous electricity supplied and generated at day time. This chapter is a demonstration of the solar potential and not a simulation of grid impact and evacuation studies. However only this minor and short simulation displays the enormous potential and also problems solar power does have.

Furthermore this system would struggle in case of several rain days. Nevertheless the production summed over the year 2012 is around 2,615 % higher than the consumption and hence the enormous potential of the solar is clear.

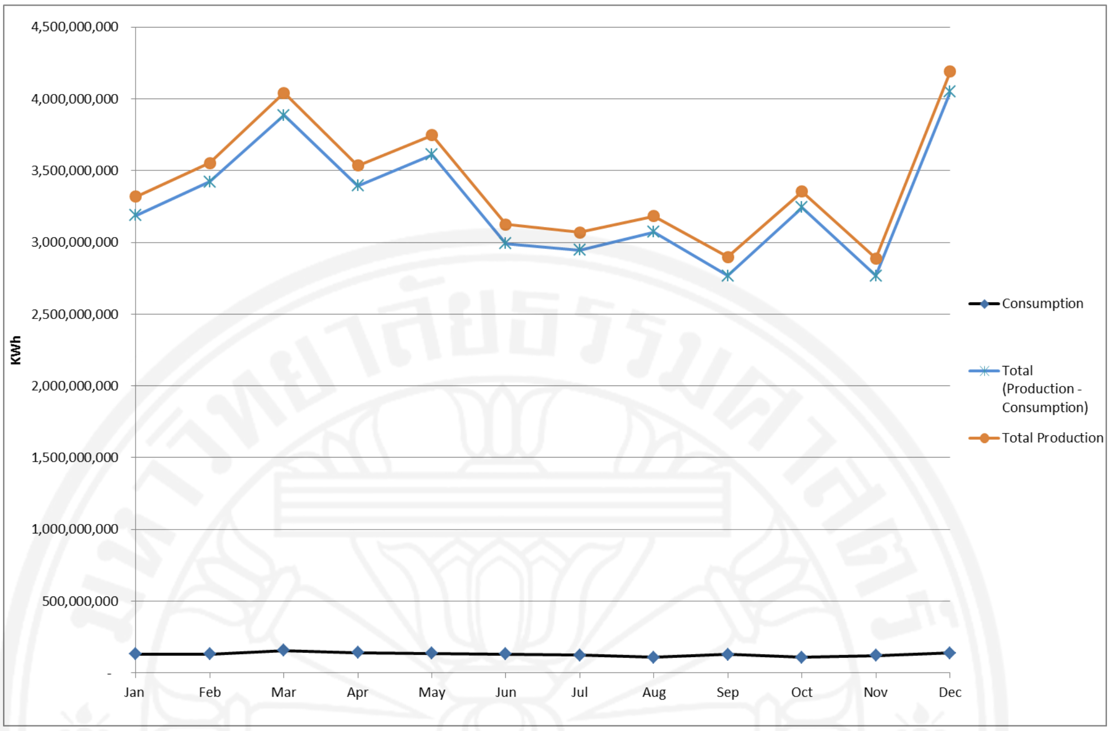

Figure 8: Monthly Overview - Consumption, Simulated Production and Difference Between Both - 2012 Pathum Thani – 100% Solar on Rice Fields

Table 12: Yearly Balance - 100% Solar Scenario Pathum Thani

Consumption	Max kW	278,940	kW	
	Total kWH	1,563,791,414	kWh	
Production	Max solar kw	27,008,476	kWh	
	Total Solar	40,900,836,149	kWh	
	Total Biomas from Agricultural	-	KWh	
	Total Biogas from Farm Waste	-	kWh	
	Sum	**40,900,836,149**		
	Total (prod. - cons)	**39,337,044,735**	**kWh**	
	% produced of total consumption	2,615.5		

The hourly values for one year in the Figure 9 are showing the enormous solar potential again, yet showing the enormous problems and the grid and storage management.

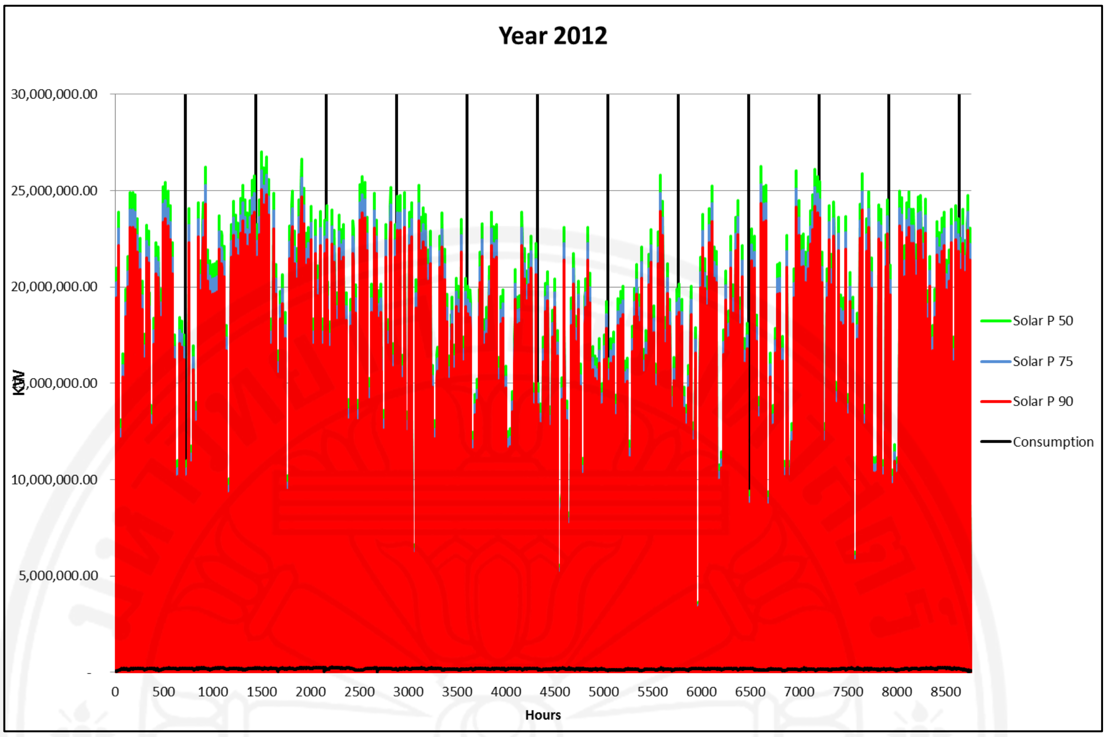

Figure 9: Yearly Overview of Hourly Production and Consumption - 100% Solar

5.1.2 Load Shifting and Storage

With an assumed storage capacity of 3,626,220 MWp what is equal to 13 hours of the maximum load in the year 2012, the minimum storage de-loading will be 7%. Furthermore a 39,337,004 MWh of excessive electricity could be exported every year.

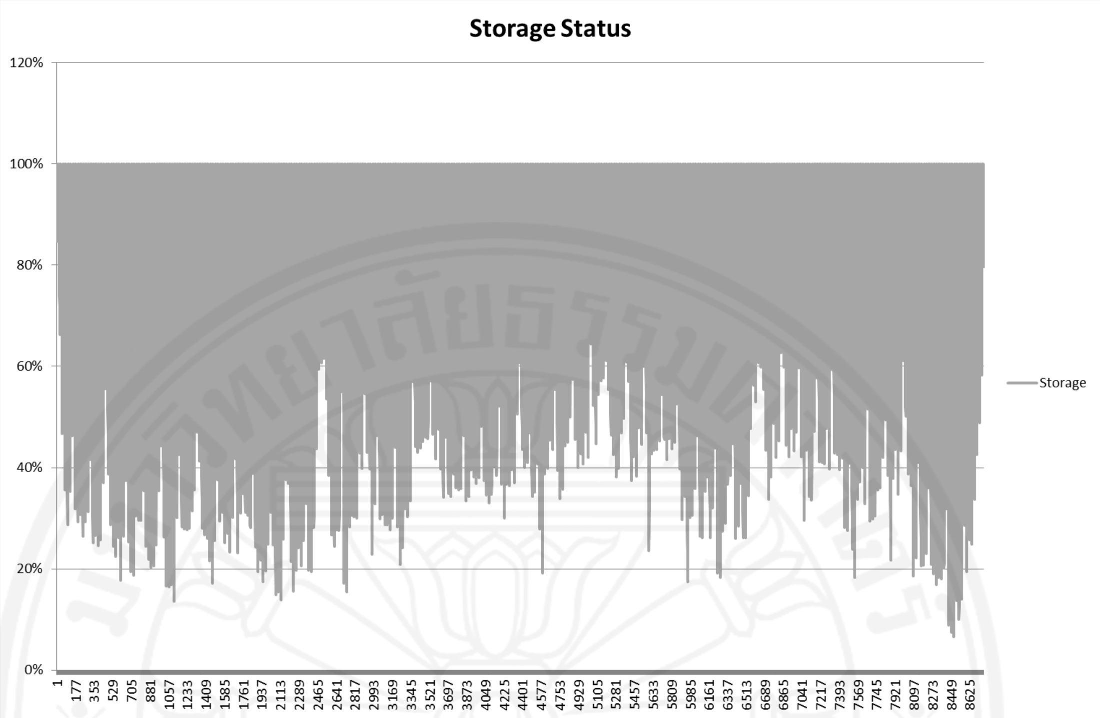

Figure 10: Storage Status - 100% Solar Simulation

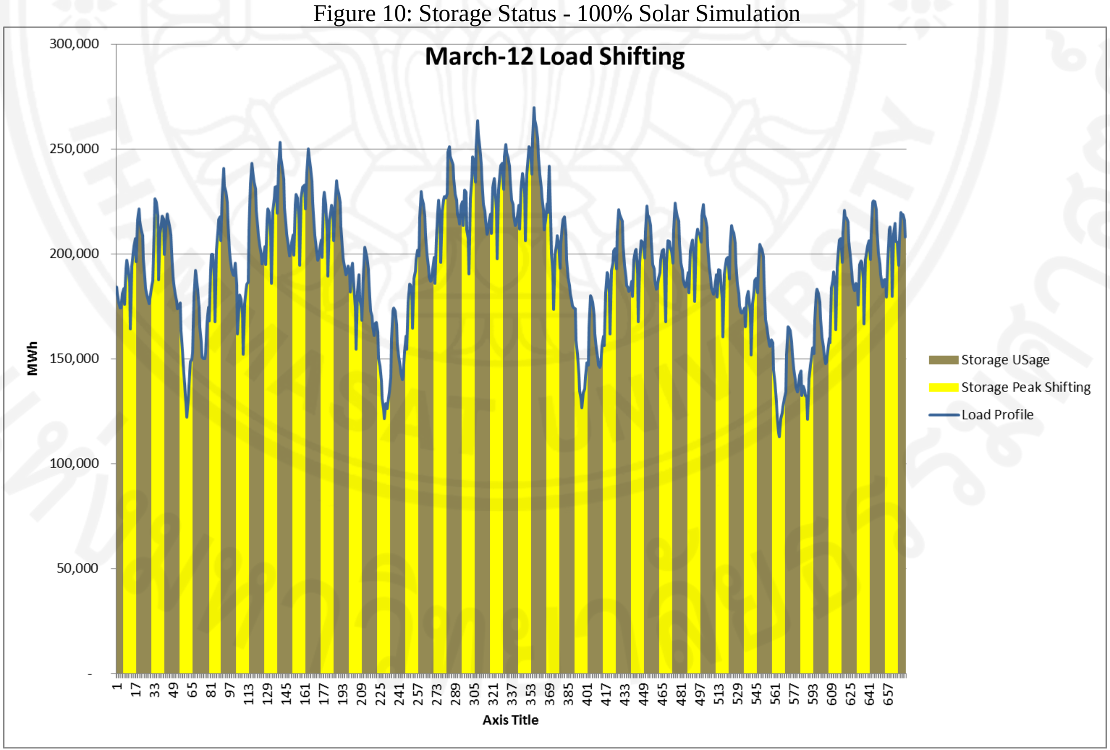

Figure 11: Load Shifting

5.1.3 Cost analysis

The cost overview for solar system is calculated with the values provided by [11]. Therefore the cost per kWh results in 0.05 USD per produced kWh.

Table 13: Cost Overview Solar System [11]

Description	Value	Used Value	Source
Specific installation costs	1000-1600 USD	1000 €/kW	100 % ERNEUERBARE ENERGIEN FÜR STROM UND WÄRME IN DEUTSCHLAND [11]
Lifetime	25a	25a	[11]
Operation / Maintenance	13 USD	1.00%	[11]

Table 14: Final Costs for 100% Solar Installation

Solar System		
Total Installed Capacity [kWp]	28,922,469	kWp
Installation Costs	37,599,209,770	USD
Installation Costs per Year	*1,503,968,390*	*USD*
Maintenance Costs	375,992,097	USD
Total Output kWh	40,900,836,149	kWh / Year
Lifetime	25	USD
Storage Costs 25 Years	1,813,110,000	USD
Storage Costs per Year	72,524,400	Years
Storage Costs Maintenance	18,131,100	USD
Total Costs Over Lifetime	50,625,232,213	USD
Costs for 1 year	2,025,009,288	USD
Cost / kWh produced	0.0495	USD/kWh

5.2 Solar Rooftop Simulation of Major University Bodies

As a special category the solar rooftop potential of major educational institutes in Pathum Thani has been analysis and simulated. The major institutes have been limited to:

- Thammasat University
- Bangkok University
- Rangsit University

Their rooftop area has been measured and the respective potential has been simulated using the Helioscope software. The results of maximum installation capacity has been imported to developed simulation tool to run a yearly output simulation and compare it to the actual consumption of Pathum Thani province. As the size of this universities as well as some industries will exceed the 0.5 MWp separations as used definition between small and large scale system, the overall potential will still be summed in the small scale system category as such rooftop systems consist of several smaller systems and thus the categorization is justified. The same technologies and set up as for the large scale system has been selected. Once the respective area has been set in Helioscope the software will then design and estimate the potential of the respective area.

5.2.1 Solar Potential of Rooftops – Thammasat University Rangsit

With Helisocope each potential building at Thammasat University has been measured and evaluated weather a solar installation might be possible or not. This does not take into consideration the actual appearance of the roof and weather an installation is possible or does require some pre work however possible rooftops with a good shape can be targeted and further major shading obstacles and other obstacles, too small roof areas and wrong shaped roofs have been excluded. While Figure shows the location and overview map of Thammasat University, Figure and Figure displaying the potential solar rooftop installation.

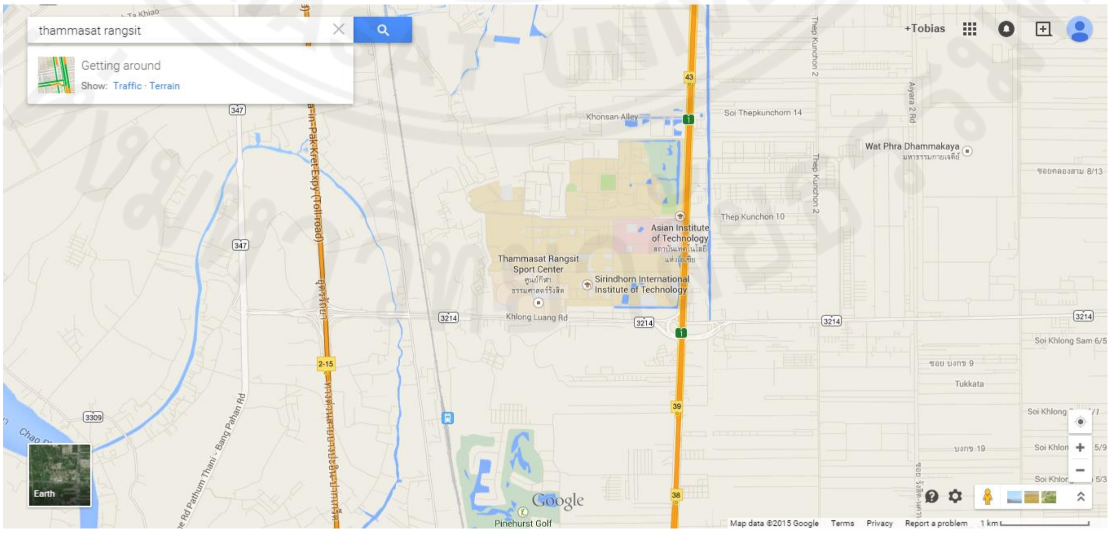

Figure 12: Thammast University Pathum Thani Area Overview in Google Maps

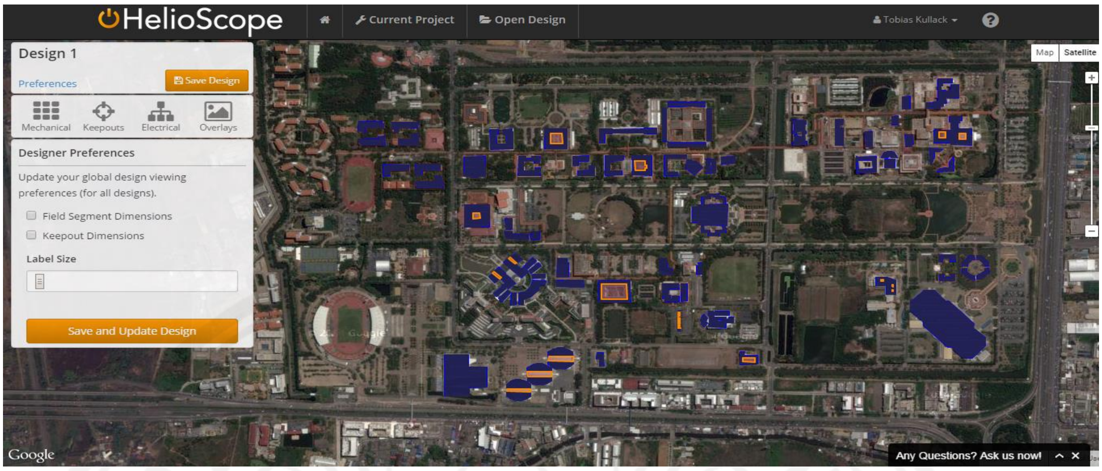

Figure 13: Solar Rooftop Overall Layout - Thammasat University

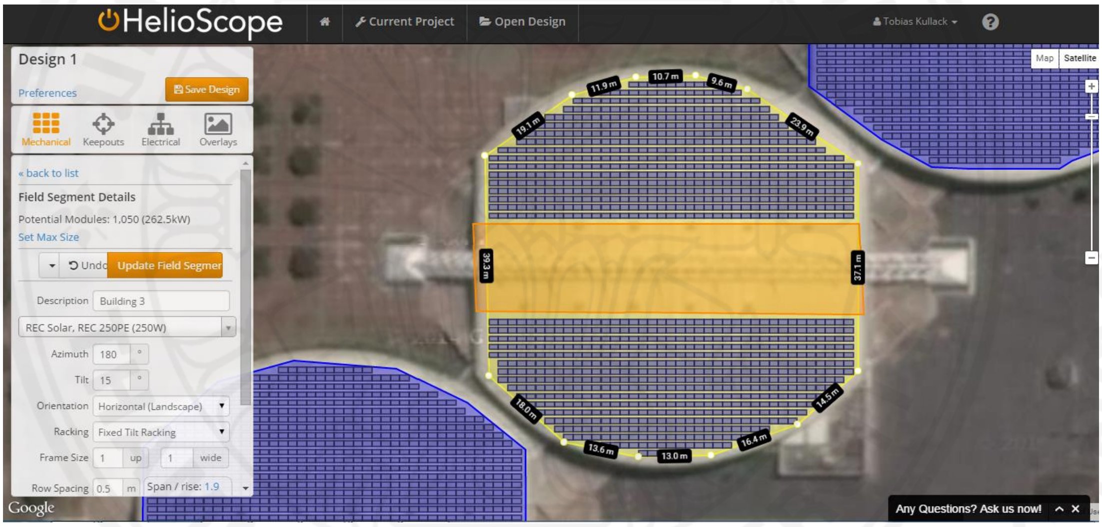

Figure 14: Design Example - Thammasat University

The total estimated potential of solar rooftop installation at Thammasat University – Rangsit Campus is 13.5 MWp. The simulated yearly overall production on a P50 value is 19,091 MWh, the hourly curves can be seen in Figure 15.

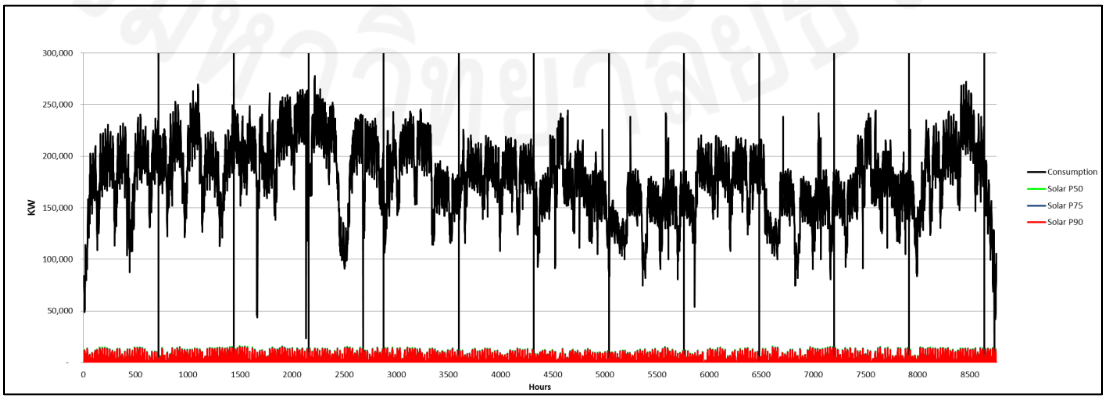

Figure 15: Daily Simulation Profile Thammasat University

5.2.2 Bangkok University

The potential of Bangkok University has been estimated to approximately 2 MWp. The simulated output is around 2,828 MWh / year. A typical installation of the rooftops can be seen in Figure 16.

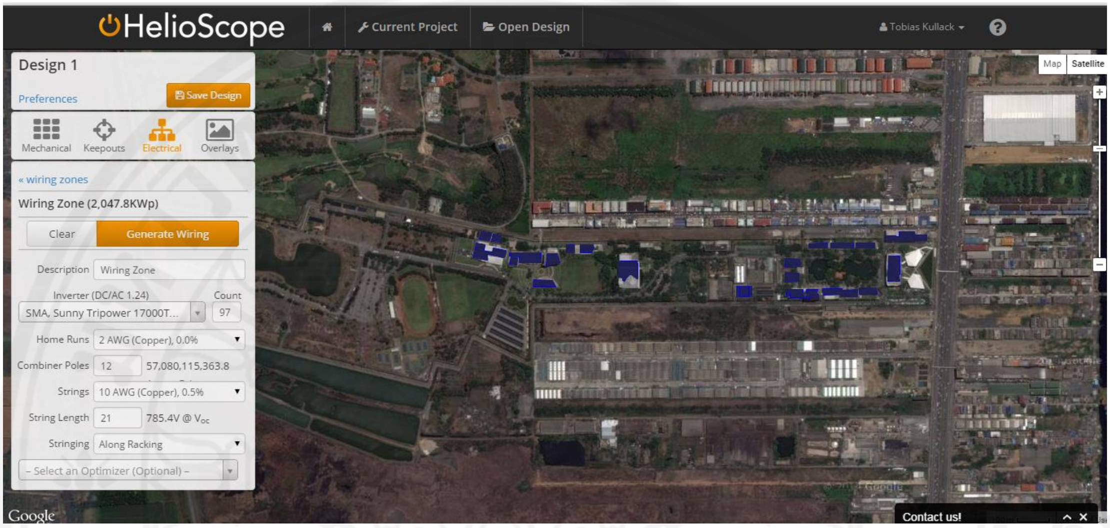

Figure 16: Bangkok University in Helioscope

5.2.3 Rangsit University

To overall potential of Rangsit university is estimated to be 2.226 MWp with a yearly output of around 3,148 MWh/year. A typical installation and usage of rooftops can be seen in Figure 17.

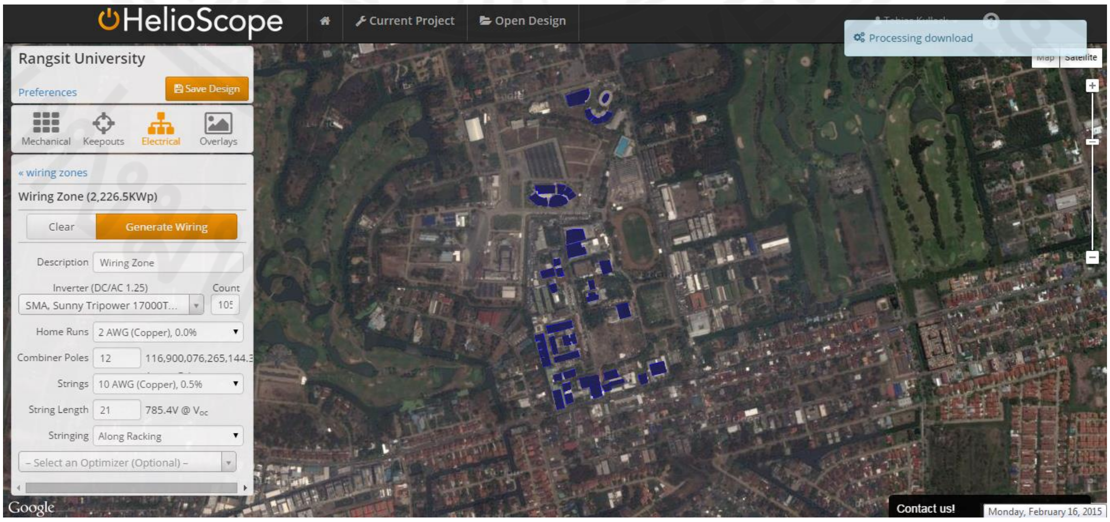

Figure17: Rangsit University in Helioscope

5.2.4 Overall Potential from University Institutes

The overall potential of the 3 universities as described in chapter 5.2.1 until chapter 5.2.3 has been summarized. With an overall potential of 17.7 MWp a total of 25,031 MWh/year could be produced which is approximately 1.6% of the overall consumption of Pathum Thani province. Figure 18 shows the yearly load profile and the simulated solar production of the university institutes.

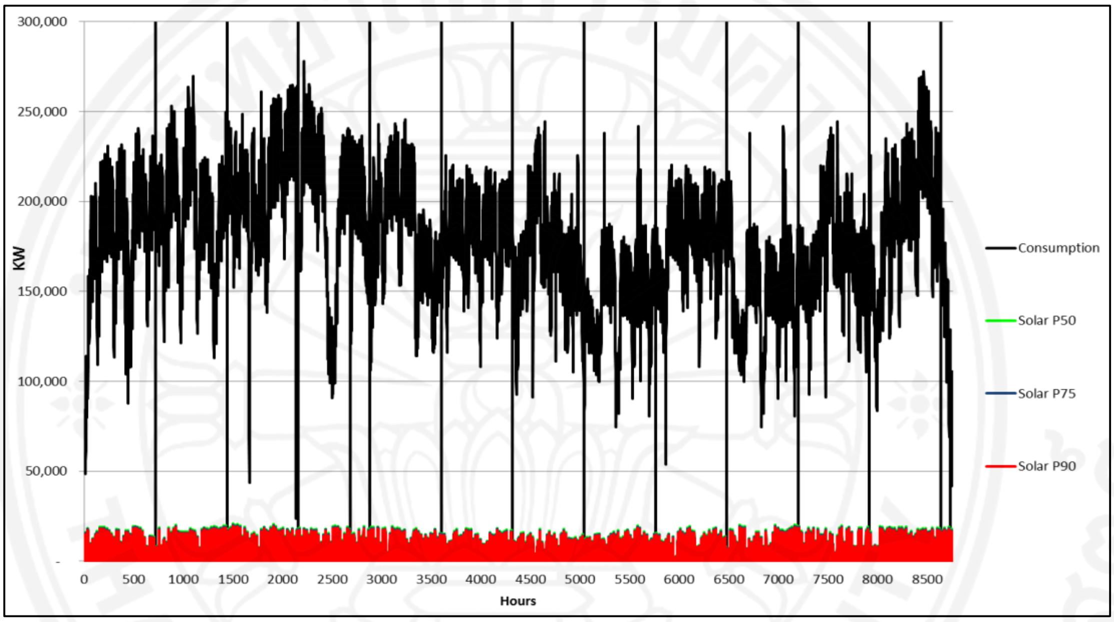

Figure 18: Overall Solar Production from major universities and total load consumption of Pathum Thani

5.2.4 Cost Analysis

The cost analysis for such a system has been carried out. As in this case no storage has been simulated the overall costs can be seen in Table 15. The cost per kWh for such a system without storage is approximately 0.046 USD

Table 15: Cost Analysis of Solar Systems on University Rooftops Without Storage

Solar System		
Total Installed Capacity [kWp]	17,700	kWp
Installation Costs	23,010,000.00	USD
Installation Costs per Year	920,400.00	USD
Maintenance Costs	230,100.00	USD
Total Output kWh	25,030,532	kWh / Year
Lifetime	25	
Total Costs Over Lifetime	28,762,500	USD
Costs for 1 year	1,150,500.00	USD
Cost / kWh produced	0.045964	USD/KWH

5.3 Small Scale Solar Systems

Small scale solar systems are systems as defined before with a capacity not exceeding 0.5 MW. As definition a maximum of 0.5% of the area of Pathum Thani might be available for such systems. Therefore the available area is set to be 7,630,000 square meter. Most of the so called small scale systems will be used to supply the electricity directly to the consumers. With a total of 7,630,000 square meter of area and the same system set up as defined under large scale solar systems, the potential is up to 382 MWp. The yearly output over the consumption can be seen in Figure 19.

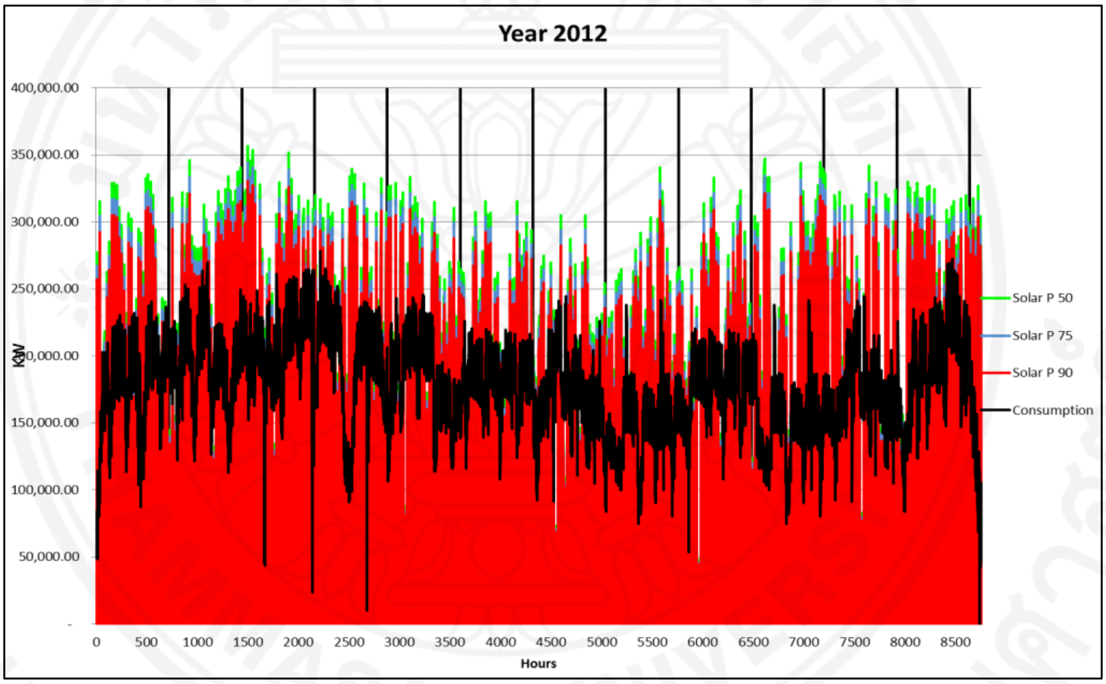

Figure 19: Potential of Small Scale Systems

The total maximum producible amount of electricity it approximately 540,206,971 kWh/year what is approximately 36% of the total consumed electricity. While the yearly overview seems to exceed the load consumption of the province, the monthly and daily load profiles as seen in Figure displays the real potential.

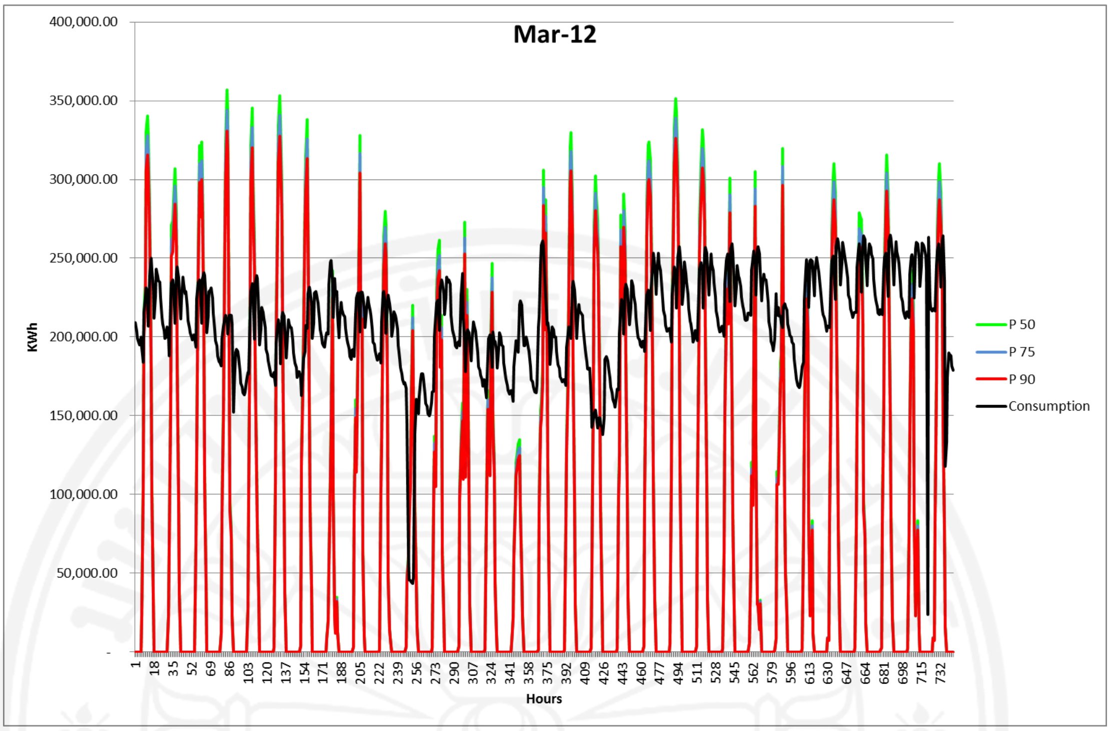

Figure 20: Monthly Load Profile - Small Scale Systems

When storage with a capacity of approximately 6,694 kWp capacities is included a load profile as seen in Figure can be achieved.

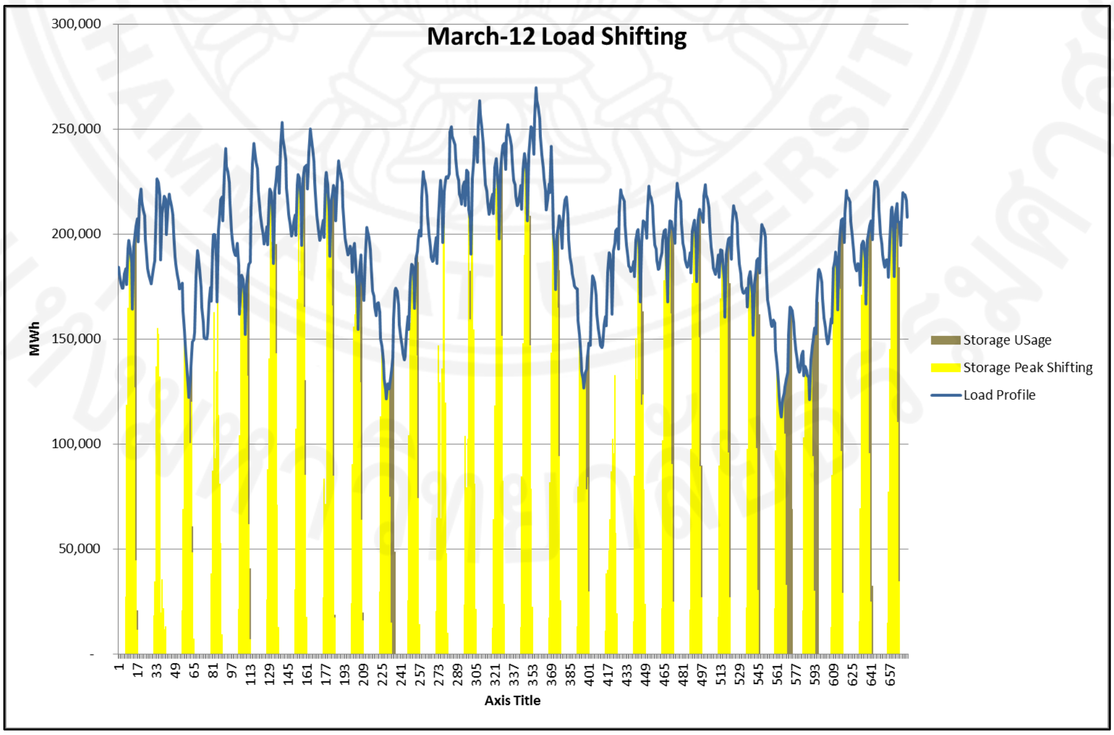

Figure 21: Small Scale Load Profile Inclusive Storage

5.3.1 Cost Analysis

Table 16: Cost Analysis Small Scale Solar Systems

Solar System		
Total Installed Capacity [kWp]	382,000	kWp
Installation Costs	496,600,000	USD
Installation Costs per Year	19,864,000	USD
Maintenance Costs	4,966,000	USD
Total Output kWh	540,206,971	kWh / Year
Lifetime	25	USD
Storage Costs 25 Years	3,347,280,000.00	USD
Storage Costs per Year	133,891,200.00	Years
Storage Costs Maintenance	33,472,800.00	USD
Total Costs Over Lifetime	7,315,310,000	USD
Costs for 1 year	292,612,400.00	USD
Cost / kWh produced	0.54	USD/kWh

Storage assumed to be 24 hours of autonomous electricity supply with the highest peak load in 1 year.

5.4 100% Biogas and Biomass – Scenario

The Biogas and Biomass scenario simulates 100% usage of Paddy Rice Fields for Biomass and the agricultural waste as Biogas. As 100% of all paddy sources can be used a total capacity as indicated in chapter 3 can be installed. The total production capacity is then considered to be 66.8 MWp/year with a total installed capacity of Biomass of 97.5 MWp assuming an average runtime of 6000 hours/year. Additionally the Biogas from farm waste as estimated in in the previous chapters to be 650 kW/h.

5.4.1 Cost Analysis

Table 17: Biomass Cost Analysis

Biomass Systems		
Total Installed Capacity [kWp]	97,798,119	kWh
Installation Costs (30 Years)	195,596,237.01	USD
Installation Costs per Year	6,519,875	USD
Maintenance Costs	48,899,059	USD
Total Output kWh	585,141,530	kWh
Lifetime	30	Years
Fuel Costs	336,138.40	USD
Total Costs Over 25 Years	1,393,876,806	USD
Costs for 1 year	55,755,072.22	USD

Cost / kWh	0.095285	USD

Anyhow this system does not regard the enormous heat amount yet. The heat developed by such a system can be used to supply process heat for industries and hence help to reduce primary energy resources used to produce the heat or if the heat is generated with electricity, it helps to reduce total electricity consumption.

5.4.2 Simulation Results

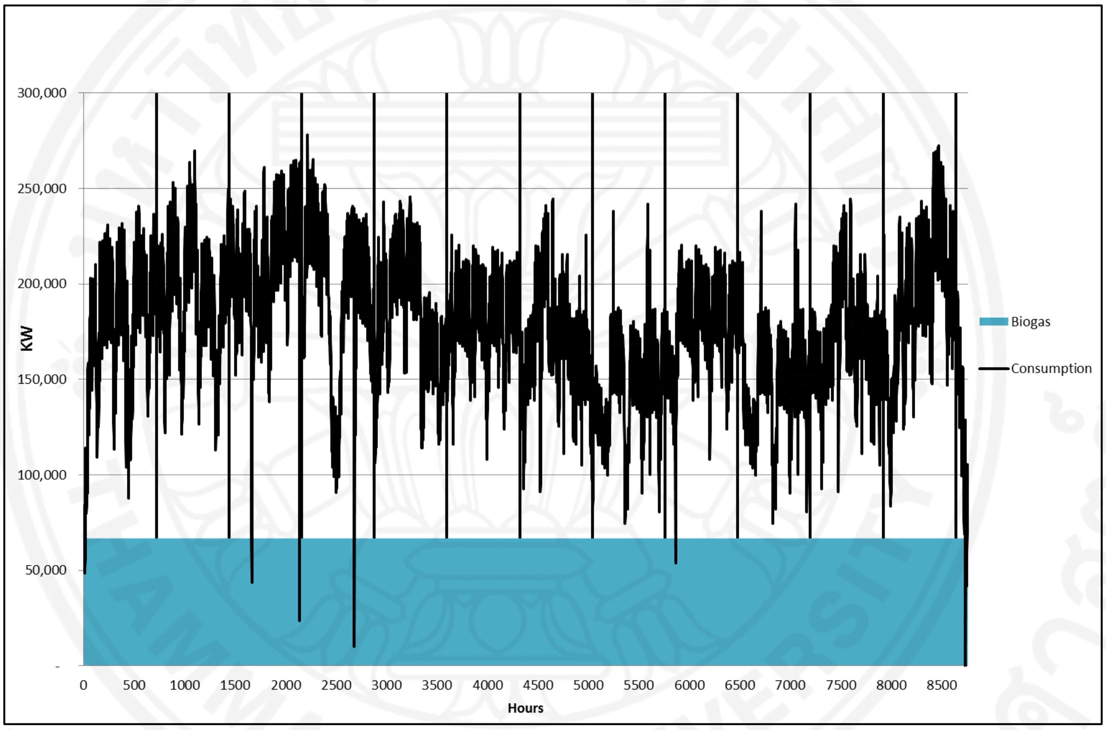

Figure 22: Biomass and Biogas Potential

Table 18: Yearly Balance - 100% Biomass/Biogas System

Consumption	Max kW	278,940	kW	
	Total kWH	1,564,015,114	kWh	
Production	Max solar kw	-	kWh	
	Total Solar	-	kWh	
	Total Biomas from Agricultural	585,141,530	KWh	
	Total Biogas from Farm Waste	5,694,000	kWh	
	Sum	**590,835,530**		
	Total (prod. - cons)	**- 973,179,584**	**kWh**	
	% produced of total consumption	37.8		

5.4.3 Napier Grass

The following simulation assumes that all available paddy rice fields could be used to grow Napier grass; however this would require a feasibility study to do so and confirm. With the relation of 1,000 Rai required to produce 1 MWp electrical output over 1 year the total potential is then 363.92 MWh

Table 19: Napier Grass Potential

Area Rice (sqm)	Area Rice (rai)	El Production [MWh/h] total	El Production [MWh/h] (80% Safety)	Installed Capacity MWp
582,278,400.00	363,924	363.9	291.14	422.2

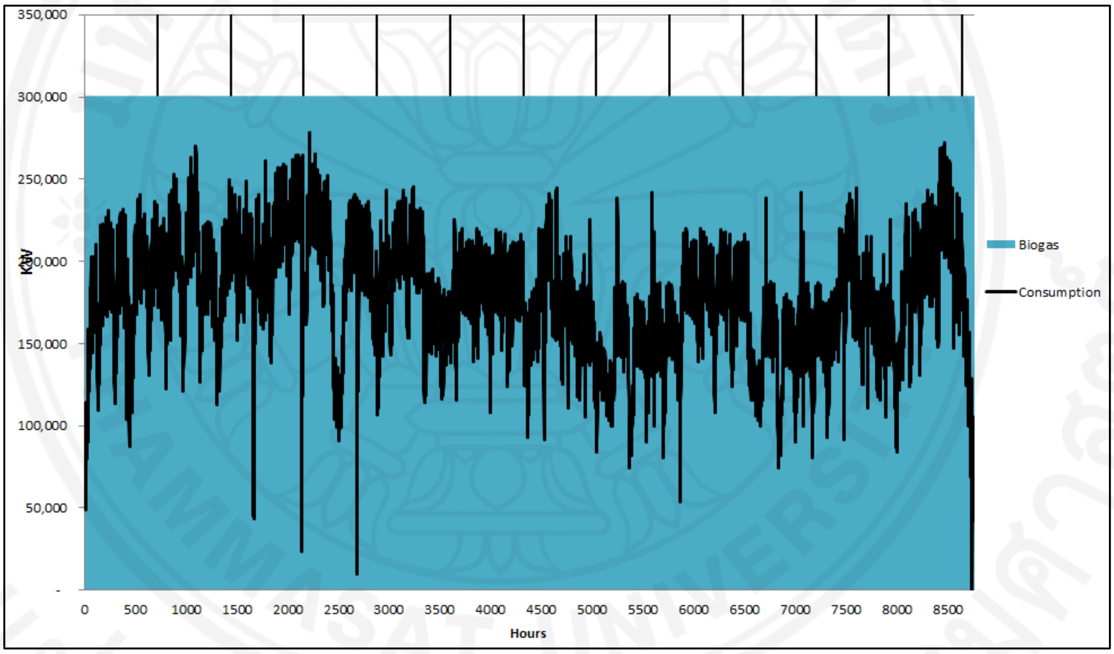

Figure 23: Biomass and Biogas Potential – Napier Grass

5.4.3.1 Cost Analysis

Table 20: Cost Analysis Napier Grass Potential

Napier Grass Biogas System 1 MWp and greater		
Total Installed Capacity [kWp]	422,151	kWp
Installation Costs (30 Years)	1,319,224,500	USD
Installation Costs per Year	43,974,150	USD
Maintenance Costs per Year	10,993,538	USD
Total Output kWh	2,550,379	kWh
Lifetime	30	
Fuel Costs	771,746	USD
Total Costs Over 30 Years	1,393,485,845	USD
Costs for 1 year	55,739,433	USD
Cost / kWh	0.0219	USD

5.5 Mixed Scenarios to cover 100%

This chapter describes actual scenarios to achieve a possible 100% match with the load curve. As there are several possible solutions and set up some logical approaches has been followed:

1. Solar installation will be firstly focused on land with soil conditions which are not preferable to grow any crops. This is clearly soil type 11, then 10 afterwards it will be 3 and 2.
2. Biogas can be a mix from Napier Grass and Rice or one of both
3. In reality a maximum share and a maximum peak of each technology should be defined to ensure a reliable system, however this simulation will not define limits moreover will ensure that there is always a share of both types of renewable energies used.
4. It is preferable to not use all available land and resources and therefore have a good mix between rooftop system, converted rice fields to solar, converted rice to Napier grass and also some rice fields for Biogas by ensuring not all resources are used completely.
5. Storage capacity will be minimized for each scenario.

Therefore several scenarios have been carried out however only 4 scenarios have been displayed below to show the general methodology and possible impacts of the respective set up. All the scenarios taking into consideration that only soil with type 11 will be used for any installation. Therefore it is agreed that small solar systems can be used up to the maximum available area, Biogas from Rice and Biogas from Napier grass will be that available area of type 11 soil unless the area planned for solar.

Table 21: Simulation Results of Mixed Scenarios

	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Solar Area sqm	79,760,662 (1/3 of Soil 11)	23928199 (1/10 of soil 11)	9571279 (1/25 of soil 11)	9571279 (1/25 of soil 11)
Solar Capacity MWp	3988	1196.4	478.6	478.6
Solar Small System Capacity MWp	382	382	382	382
Biogas/ Mass Rice Area sqm	80,443,418.95	108,359,650.58	115,538,110.13	0
Biogas/Mass Rice Capacity MWp	13.4	18.1	19.2	0
Biogas Napier Grass Area sqm	80,443,418.95	108,359,650.58	115,538,110.13	231,076,220.27
Biogas Napier Grass Capacity	58.3	78,560.75	83.8	167.5
Storage Size MWp	3,348	4,185	8,368	3,068
Minimum Storage De-load %	7	5	8	10
Total produced electricity in 1 year MWH/year	5,048,584	2,814,915	1,838,426	2,228,377
Total produced in % of load	423	180	118	143
Max difference between production and load kWh	3,920,312	1,387,685	744,546	789,061
Cost per produced USD/ kWh	0.064	0.109	0.283	0.126

As seen in Table 19 and further in Figure 24, Figure 25 and Figure 26 the scenario 4 seems to be most reasonable of all scenarios. The storage size is minimized, the base load is provided by Biogas from Napier Grass and the solar total production seems still to be reasonable in regards to other simulations and the maximum load.

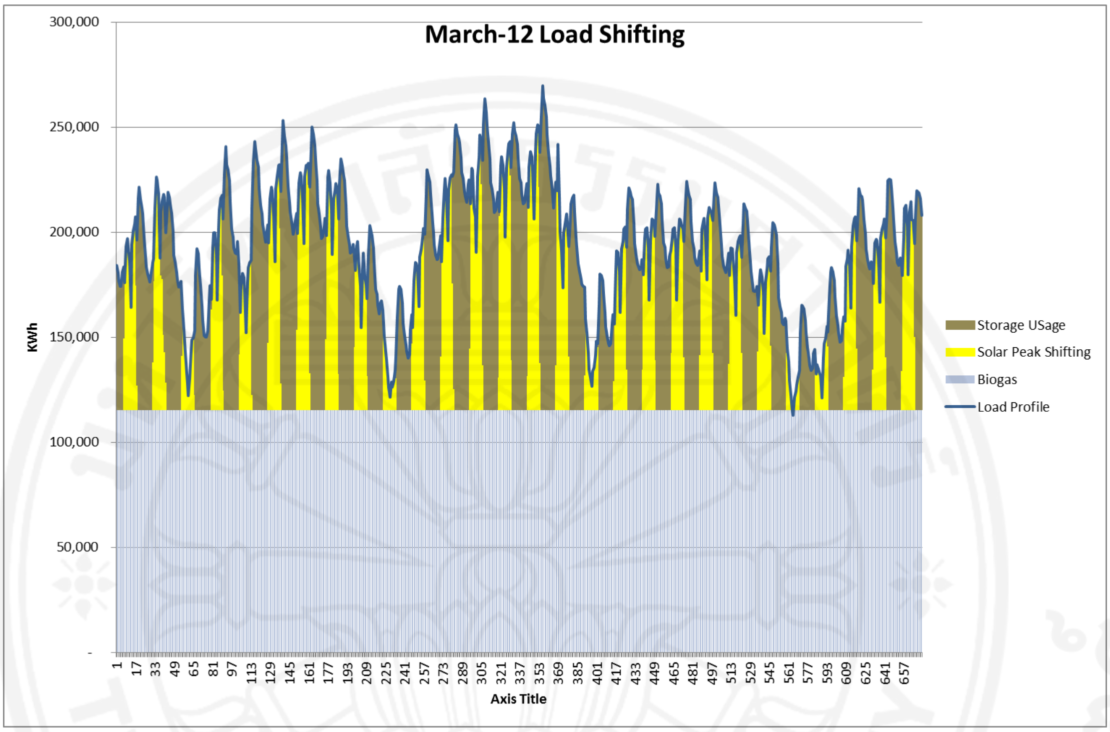

Figure 24: Scenario 4 - March inclusive Load Shifting and Storage

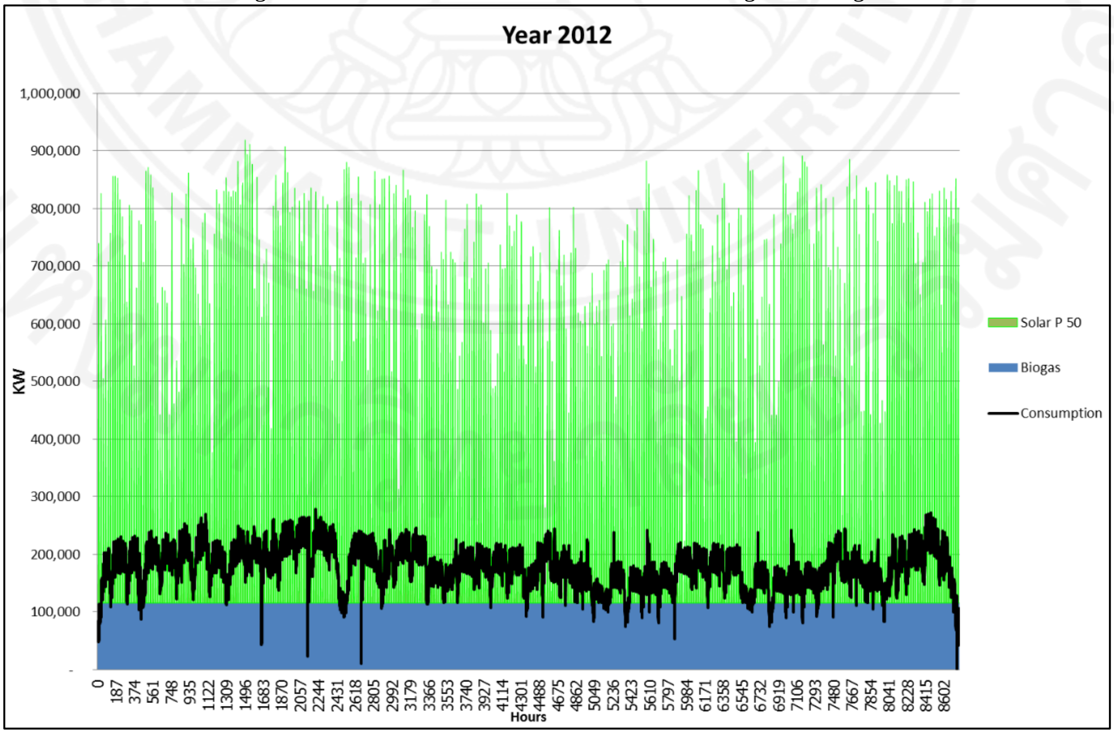

Figure 25: Scenario 4 - Yearly Overview of Production and Consumption with Stacked Values

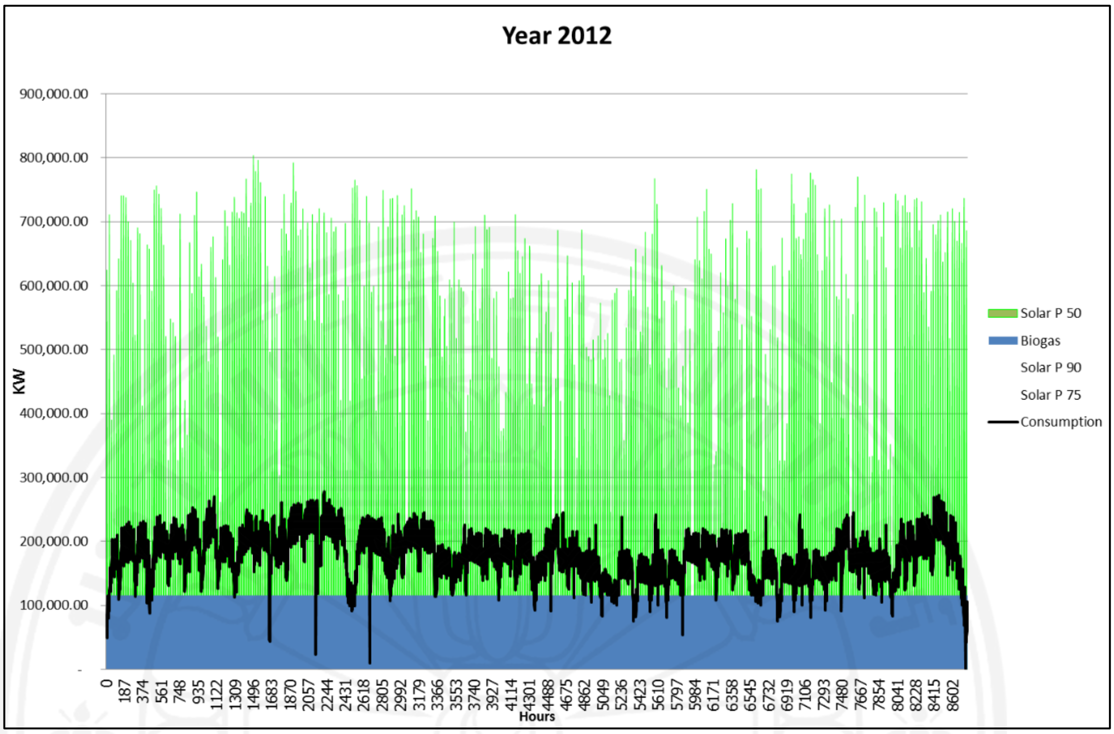

Figure 26: Yearly Overview of Scenario 4 as Non Stacked Graph

Chapter 6

Result and Discussion

The results in the Thesis are surely simulated results assuming several factors as described and with a selection of available technologies. It would be advisable to confirm such numbers with real experiments rather than only relying on simulation software's. However the simulation software as used such as "PVsyst" tend to provided conservative results and with the assumed safety factors in the research, there it is most likely that the simulated output can be achieved or even exceeded.

Also a discussion on the topic weather natural resources to be used for energy supply and what the maximum percentage of such a usage should be has not been regarded in this research but surely should be figured in when planning such systems. The current simulation model provides a very good overview of actual resources and their hourly impact on available area and natural resourced and thus further studies to find an optimized maximum to ensure the natural resources are being used in a balanced way by achieving a set target of renewable energy sources should be conducted.

The current simulation model is a model based on the past, however with minor adjustments and with verification of the results with actual projects the simulation model could be upgraded by an electricity consumption forecast model, weather forecast model and then being used as forecasting model for a couple of hours, days, weeks or month to ensure sufficient planning on backup sources are in place.

Chapter 7

Conclusions and Recommendations

The optimizations to find the cost efficient system on the one hand and to find a system with a maximum amount of renewable energies that should be integrated, different approaches were made with the following results:

1. To find possible solutions such as installation of solar only around villages, biogas only with rice paddy grown on soil 11. This approach was regarded but due to its high variation in different solutions only 2- 3 case studies could be provided, however this is not an optimization yet.
2. Another option is to find for different scenarios the costs, while regarding all driving forces such as storage size, amount of Solar Biogas and so on. With this approach, different scenarios could be implemented and reviewed easier than with the method mentioned above. Furthermore several possible solutions can be compared and the optimum solution might be found. The Figure assumes that 100% of the available area will be used for an installation.

   Reading from left to write, we will start to use 100% for solar and hence no Biogas installation is done. While moving to the right, the share of solar decreases while the share of biogas is increasing until reaching 100%. The blue line indicates the storage size. For the storage size, the minimum capacity, to never reach a 20% discharge status, was calculated.

   If such an analysis would be carried out for 10-20 different scenarios, costs included, different "optimized" systems might be found.

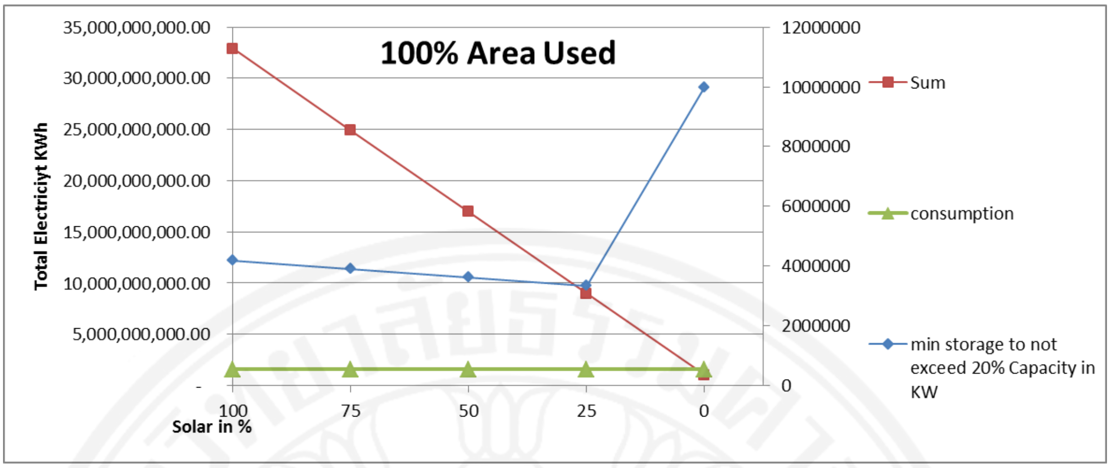

Figure 27: Solar Biogas and Storage overview for scenario: all area available used

The overall renewable energy potential of Pathum Thani has been displayed for each technology. Mixed scenarios to cover a 100% supply of electricity by renewable energies are possible but would require major storage and or communication as well as high efficient grid operations. Therefore as a next step, the maximum deployable amount of renewable energies for each 23 kV substation needs to be deployed and with a grid evacuation study confirmed. Based on the maximum potential several scenarios of renewable energy supply can be simulated. Moreover with the upgrading of the grid towards a so called Smart Grid, a higher share of renewable energies can be deployed to the grid. If an upgrade is about to happen, a potential analysis such as done in this study would be required to ensure the upgrade enables the available resources to be used efficiently.

Therefore in a conclusion it can be said that a simulation and partial optimization is available however the systems should be upgraded to allow a better optimization, the current system can also be easily adopted for output forecasts if weather conditions in the near futures are known. Another recommendation would be a cooperation with already existing researches and developed software's such as the software developed by the Fraunhofer Institute.

References

[1] Department of Information and Communication of Pathum Thani. (n.d.). Pathum Thani. Retrieved January 26, 2007, http://www.pathumthani.go.th/index%20k.html

[2] http://www.esri.com/software/arcgis

[3] Department of Land Development Pathum Thani

[4] Office of Agricultural Economics, Thailand

[5] AGRICULTURAL STATISTICS OF THAILAND 2012, OFFICE OF AGRICULTURAL ECONOMICS, MINISTRY FOR AGRICULTURAL AND COOPERATIVES BANGKOK, THAILAND, http://www.oae.go.th, ISSN 0857-6610,

[6] Logistics cost analysis of rice straw for biomass power generation in Thailand, Energy 36 (2011) 1435-1441, Delivand MK, Barz M, Gheewala http://www.thaiscience.info/Article%20for%20ThaiScience/Article/3/Ts-3%20logistics%20cost%20analysis%20of%20rice%20straw%20for%20biomass%20power%20generation%20in%20thailand.pdf

[7] Overall Analyses of Using Rice Straw Residues for Power Generation in Thailand- Project Feasibility and Environmental GHG Impacts Assessment Mitra Kami Delivand, Mirko Barz, Savitri Garivait, http://www.jseejournal.com/JSEE%202011/Special%20Issue/12.%20Overall%20analysed_Mir a_p.%2039-46.pdf

[8] http://www.rcogenasia.com/biomass-power-cogen-2/rice-husk-to-power/ The 6th Biomass Asia Workshop Presented under Theme : Research and Technological Development for Sustainable Biomass Utilization in Asian Countries Organized by MAFF, METI, Biomass Asia Research Consortium, JAPAN at Hotel Granvia Hiroshima, Hiroshima, JAPAN, November 19, 2009 Peesamai Jenvanitpanjakul and Paritud Bhandhubanyongม National Science and Technology Development Agency (NSTDA), THAILAND

[9] Office of the District Livestock. (Data as of August 6, 2556)

[10] Assessment of sustainable energy potential of non-plantation biomass resources in Thailand" – Science Direct, Biomass and Bioenergy 29 (2005) 214–224 Boonrod Sajjakulnukita, Rungrawee Yingyuada, VirachManeekh, Veerawan Pongnarintasuta, S.C. Bhattacharyab, P. Abdul Salam

[11] 100 % ERNEUERBARE ENERGIEN FÜR STROM UND WÄRME IN DEUTSCHLAND

[12] Pathum Thani Administration Office

[13] Land Development Department

[14] http://www.tgo.or.th/index.php?option=com_content&view=article&id=349:thailand-%09grid-%09emission-2010-report&catid=62:tgo-research&Itemid=29
[15] http://pvsyst-wiki.wikispaces.com/About+PVsyst, URL accessed, 28.11.2012
[16] http://www.pvsyst.com/en/, URL accessed, 30.11.2012
[17] http://forum.pvsyst.com/viewtopic.php?f=18&t=1217 , URL accessed, 16. 02.2015
[18] http://www.folsomlabs.com/about URL accessed 04.03.2015
[19] http://www.giz.de/fachexpertise/downloads/2014-en-aggarangsi-pep-infoveranstaltung-biogas-biomasse-philippinen-thailand.pd f URL accessed 06.04.2015
[20] http://files.sma.de/dl/7680/Perfratio-UEN100810.pdf URL accessed 07.04.2015
[21] Renewable energy sources for peak load demand management in India, Surekha Dudhani, , A.K. Sinha, S.S. Inamdar, International Journal of Electrical Power & Energy Systems Volume 28, Issue 6, July 2006, Pages 396–400
[22] Simulations of scenarios with 100% renewable electricity in the Australian National Electricity, Market, Ben Elliston, Mark Diesendorf, Iain MacGill, April 16, 2012
[23] Connolly, D., Lund, H., Mathiesen, B., Leahy, M., 2011. The rst step towards 100% renewable energy-system for Ireland.
[24] Krajcic, G., Duic, N., da GracaCarvalho, M., 2011. How to achieve a 100%RES electricity supply for Portugal, Applied Energy
[25] Lehmann, H., 2003. Energy Rich Japan. Technical Report. Institute for Sustainable Solutions and Innovations. Retrieved December 02, 2012, from:http://energyrichjapan.info
[26] Lund, H., Mathiesen, B., 2009. Energy system analysis of 100% renewable energy systems, The case of Denmark in years 2030 and 2050
[27] Delucchi, M.A., Jacobson, M.Z., 2011. Providing all global energy with wind, water, and solar power, Part II: Reliability, system and transmission costs, and policies.
[28] Thailand Green Islands Renewable Energy Investment on Remote Islands; Twarath Sutabutr, Sc.D v Deputy Director-General; Department of Alternative Energy Development and Efficiency; Ministry of Energy, Thailand, 5 June 2012
[29] Energy Planning and Policy, Maxime Kleinpeter, 1995
[30] Solar energy; fundamentals and applications / H.P. Garg, J. Prakash. Imprint New Delhi : Tata McGraw-Hill
[31] Solar electricity: a practical guide to designing and installing small photovoltaic systems / Simon Roberts.
[32] YIELD FACTORS OF A PHOTOVOLTAIC PLANT, CRISTIAN P. CHIONCEL, DIETER KOHAKE, LADISLAU AUGUSTINOV, PETRU CHIONCEL, GELU OVIDIU TIRIAN,UNIVERSITY OF HUNEDOARA, ROMANIA

[33] SMA Performance ratio, Quality factor for the PV plant, http://files.sma.de/dl/7680/Perfratio-UEN100810.pdf
[34] http://www.nrc.gov/reading-rm/basic-ref/glossary/capacity-factor-net.html, 2012.12.03
[35] Nachwachsende Rohstoffe" Federal Ministry for Food, Agriculture and Consumer Protection, Germany
[36] Community Based Bioenergy Systems - Technologies for Energy from Agricultural Biomass Sources Conference on Community Based Renewables: Thai-German Cooperation on Sustainable Energy Development Sept. 2nd, 2013, Ministry of Foreign Affairs, Narathip Room, Sri Ayudhya Road, Bangkok (Thailand) (Mirko Barz**)**
[37] http://weben.dede.go.th/webmax/sites/default/files/factsfigures_2012.pdf