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Investigating the Possibility of Installing Biogas Generation Systems from Agricultural Residues in The Northeast Region of Thailand

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Abstract

According to the extension of the economic and industrial sector, the need for energy demand has the potentiality to increase, which impact the current electricity supply in to have a possibility of electricity lack in the future. At present, the northeast region must import electricity from Lao PDR at a percentage 68 of the total electricity consumption of this region. Followed by self-generated within the region, 28 per cent and imported from the North and Central region 4 per cent.

A ton of residues appears after reaping during the year, with those among of residues it could convert into biogas energy. The agricultural residues can obtain after a procedure of harvest and manufacturing process. Hence, this dissertation aimed to optimise the current supply system by using biogas generation with at least 50 per cent of renewable energy fraction total. Moreover, this dissertation is going to use Ubon Ratchathani as a case study, where the new industrial settlement is going to place.

HOMER software used as a program to design and optimise the supply system. The important input data in this project consist of the energy demand profile, which assuming base on the demand profile from the southern region. Moreover, it will be added with the energy forecast to support the future industrial settlement. Secondly, three biomass resources that used as a feedstock for biogas in this project: Cassava, Rice and Paddy, and Sugar Cane; including the Lower Heating Value (MJ/kg), Price ($/ton), and carbon content (%) for each feedstock. Nevertheless, there are some constraints of the input data and software, which make the result after simulation inaccurate from reality.

After simulation four cases: base case, and another three cases, which differ in the type of feedstock, and size of both NGCC plant and biogas generator. In conclusion, the most suitable in term of financial, which is the cost of energy and initial capital cost, and the environmental aspect, which is CO_2, CO, and particle is Case 2.

Acknowledgements

The achievement and result of this dissertation required a lot of supervision and support from various people. I am incredible appreciate having this all along with the outcome of this dissertation.

I owe my sincere gratitude to this dissertation advisor Dr Daniel Costola, who got extreme attention in this dissertation. Also, guided and supported me consistently by providing all the necessary information for developing a sound system and successful completion of the dissertation.

Lastly, I am willing to appreciations to every lecturers, fellows and classmate, who have helped me during the time I studied at the University of Strathclyde. I have met many marvelous people from many countries that made a memorable experience.

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1. Introduction

1.1. Background

A ton of residues appears after reaping during the year, with those among of residues it could convert into biomass energy. The agricultural residues can obtain after a procedure of harvest and manufacturing process. Usually, fossil fuels such as coal, LPG, and fuel crude oil used in industrial areas as due to the high of their heating value. Also, the convenient to use, delivery and most importantly, the price of it is acceptable. In 2011, the market price of oil (WTI) and coal dramatically increased (as shown in figure 1 and 2); as a consequence, the cost of fuel or energy in industrial areas increased. Therefore, the use of biomass fuel has been used extensively to replace fuels like coal or oil, to reduce the cost of fuel and to mitigate the problem of agricultural waste. There are many primary biomass resources from agriculture wastes in Thailand, which has the potential to use in biomass generations such as cassava, rubber tree, palm, rice & paddy, and sugar cane (IRENA, 2017). Agricultural wastes 58,315,000 tons have been produced yearly in Thailand, which that among of residues, they can generate electricity approximately 6.76 GW. However, due to the growth of the industrial sector, the biomass demand for industrial sectors and power plants have raised; as a result, the rising cost and inadequacy of biomass.

As a result, biomass is still a primary renewable energy source in Thailand. There are two ways to use biomass as a source of energy: directed fire as solid biomass or use anaerobic digestion method (biogas). The introduction of the biogas will contribute to an increase in efficiency on the energy system more than biomass and is capable with concise advanced stable power requirements. The biogas system as a whole can reduce reliance on the grid and is more competitive as energy reliability requirements (Pérez-Navarro et al., 2010). Moreover, biogas can produce energy from local organic waste, providing renewable heat, methane gas, and dispatchable electricity distributed energy system.

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Moderately, these agricultural wastes create a new energy source markets, which rely on many aspects: the availability of a source of residues, the state of the art of converting technologies and opportunities for developments, the value of electricity generation and lastly environmental impacts (Barz, and Delivand, 2011). However, it is necessary to analyse the factors that can affect the result of the biogas power plant schemes such as energy demand, residues supply, and financial feasibility.

Figure 1: Coal Market Price (USD) (Marketinsider, 2019)

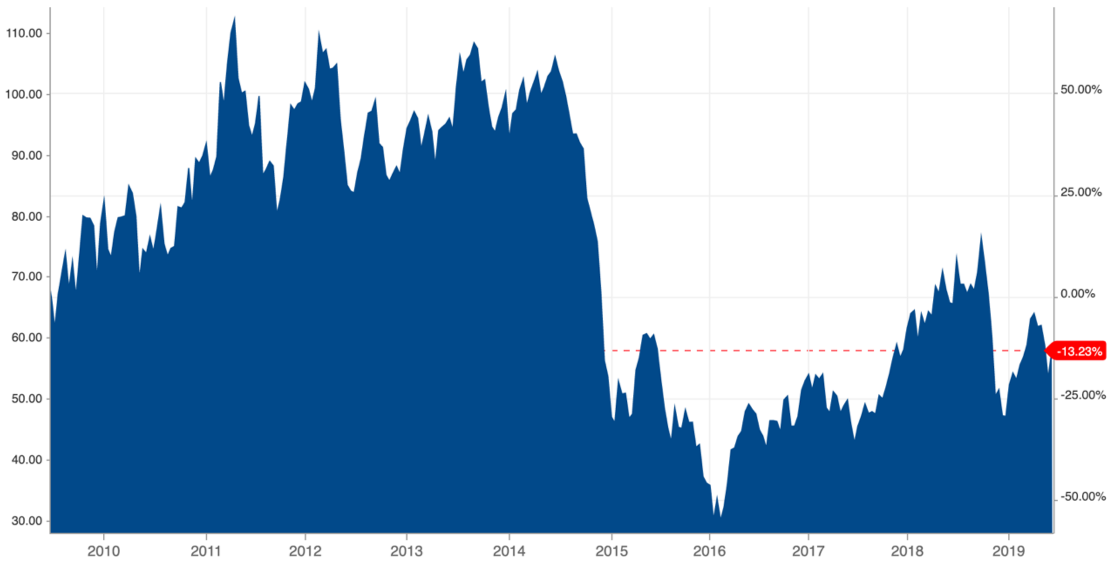

Figure 2: Oil (WTI) Market Price (USD) (Marketinsider, 2019)

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This project will demonstrate the demand for electricity used in the region, including its assumption and forecasting the future energy demand for a new industrial settlement. Moreover, the optimisation and comparison between the base model and optimised model will be analysed and designed. An optimise model will be a comparison between three feedstocks: cassava, rice and paddy, and sugar cane. For the purpose of increasing the fraction of renewable electricity used, decrease the among of electricity purchasing from a foreign country and to support the future industrial settlement at Ubon Ratchathani province in 2022 (TNEWS, 2019). As a result, the energy demand in this project is going to import from Ubon Ratchathani as a case study.

1.2. Problem Statement

This proposal is to investigate the feasibility of installing a biogas system from agricultural residues in order to reduce organic waste, decarbonization from fossil fuel usage, and be able to generate electricity efficiently. Moreover, to optimise the supply system by using biogas generation to support the new industrial settlement, which is going to appear in 2022.

1.3. Aim, Objectives, and Scope of the Project.

The aim of this dissertation is to investigate the feasibility design of the national powerplant, which achieves approximately 50 per cent renewable fraction in Northeast Thailand in order to avoid purchasing electricity from other foreign or region. After the successful scheme identified, the opportunities that exist analysed along with their outcomes, including potential energy returns, financial viability and greenhouse gas emissions.

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This aim will be met by the completion of the following objectives:

- Considered the present electricity demand and forecasted the future electricity demand once the new industrial settlement appears
- Achieves at least 50 per cent renewable fraction
- To investigated technical viability and financial feasibility solution
- To analyse the potential opportunities for feedstock of biogas and make recommendations for the future development of biogas generator in the local area
- Use feedstock at least 70 per cent of total potential
- Target location will be Ubon Ratchathani where the new industrial settlement will be built in 2022

1.4. Methodology

- **Step 1. Forecast Electricity Demand Profile:** Base energy demand profile is going to generate all over a year to comprehend its differentiation patterns in various season.
- **Step 2. Describing renewable resources:** Investigating the source of biomass from agricultural residue and will be identified their energy density and carbon contains to analyse their efficiency.
- **Step 3. Identifying renewable generation:** Types of renewable generation will be carried out in each scenario. Also, the characteristics and capacity of each case are going to detailed to understand their abilities and be able to accomplish the electricity system with higher efficiency.
- **Step 4. Financial Analysis:** After renewable energy generations are listed, investment cost, operation and maintenance, and replacement cost of each generation will illustrate to use for an input data of each generator.

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- **Step 5. Simulation and Analysis the result:** Present the efficient design of renewable generation, a tool is needed to ensure that the objectives of this dissertation are achievable. For this dissertation, HOMER has chosen as simulation software; it can assist in the optimisation of the designed system and giving simulation and financial data for cases.

- **Step 6. Results and Comparison:** The concludes, examining and comparing the benefits and limitations of each case from the systems will be carried out. Finally, recommending the future work for this dissertation.

2. Literature review

The chapter is going to demonstrate the profound background information of this dissertation in several perspectives. There are three main parts in this chapter that are going to explain in detail:

- Biogas
- The Energy in The Northeast Region of Thailand
- HOMER

2.1. Biogas

This section is going to give a context about the basis of biogas, knowledge of the biochemical process, anaerobic digestion and generator technologies. Furthermore, the feedstocks used in the process and its product also taken into account as a determinant that will affect the rationale behind the design system. Lastly, the pros and cons of the biogas will be summarized.

2.1.1. The Development of Biogas

There is some evidence show that the use of biogas existed since the 10th century as a feedstock in the fermentation method (He, 2010). Nevertheless, well evidence support that humans have been developing a method to control anaerobic digestion since the middle of the nineteenth century; also, according to Bond and Templeton (2011), sewage sludge digester from the UK has been constructed in India and New Zealand to electrify the street lamps in the 1890s. In the 1970s, the researcher has to discover an alternative energy source to resolve the oil price crisis; as a result, biogas is therefore widely interest. Between the 1970s and 1980, the use of biogas in African, Latin American, and Asia countries were spreading out rapidly (Ni and Nyns, 1996). In the

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present, it is normal that the anaerobic digestion technology is one of the facilities used in the farm. For instance, there were over six hundred farm-based digesters to treat the spectrum of a suitable farm, industrial, and municipal wastes in Europe (Penn State Extension, 2012). Moreover, the Danish energy agency was liable for the laws and regulations concerning the assistance plans and the standards of sustainable biogas production. As a result, the product from biogas in Denmark is immediately growing, and the total production is foreseen to increase higher than triple from 2012 to 2020 (Energistyrelsen, 2019).

2.1.2. Anaerobic Digestion Process

Biogas is the output of anaerobic fermentation or digestion, a method of converting biomass into biogas. Biomass sources for anaerobic digestion process come from agricultural residues, animal fertiliser and sewage sludge from industrial and domestic wastewater treatment plants. Biogas is delivered by an anaerobic fermentation process by a combination of bacteria archaea; it is a complex microbial process that happens naturally in oxygen-free environments. There are four steps for the process of biogas:

1. Hydrolysis
2. Acidogenesis
3. Acetogenesis
4. Methanogenesis

1. Hydrolysis

Firstly, this process is for biomass in anaerobic digestion as it causes chemical reactions to break down large organic polymers. These comprised of proteins, fats and carbohydrates, which are broken down through the hydrolysis process into Fatty Acids, Monosaccharide, and Amino Acids.

Lipid → Fatty Acids

Polysaccharide → Monosaccharide

Protein → Amino Acids

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Some of these products can be used as methanogens later in the process like acetate and hydrogen. Many of these organic polymers still require to be further broken down through the next step acidogenesis.

2. Acidogenesis

After hydrolysis biomass is further broken down through the acidogenesis process as the acidogenic microorganisms create an acidic environment in the digester which produces Ammonia, Hydrogen, Carbon Dioxide, Hydrogen Sulphide and other by-products. Although the acidogenesis process further breaks down much of the organic matter, there are still large amounts left that require the acetogenesis stage.

3. Acetogenesis

The acetogenesis step is to create acetate where microorganisms catabolize the by-products produced in the acidogenesis step turning them into acetic acid, hydrogen and carbon dioxide. The biomass is further degraded by acetogens to the stage where methanogens can use most of the left-over material to produce methane as a biofuel.

4. Methanogenesis

Lastly, methanogenesis, where the two groups of co-enzymes convert the acetate and the H_2/CO_2 into methane gas, in the following reactions:

$$CH_3COOH \text{ (acetate)} \rightarrow CH_4 + CO_2$$

$$CO_2 \text{ (carbon dioxide)} + 4H_2 \text{ (hydrogen)} \rightarrow CH_4 + 2H_2O$$

After fermentation, impurities such as hydrogen sulphide and water vapour must be removed before use in boilers or CHP units, as they can cause damage to mechanical parts. Carbon dioxide must be further removed to increase the methane content to a level that is suitable for the gas to be used for grid injection or as a transport fuel (Monnet, 2003).

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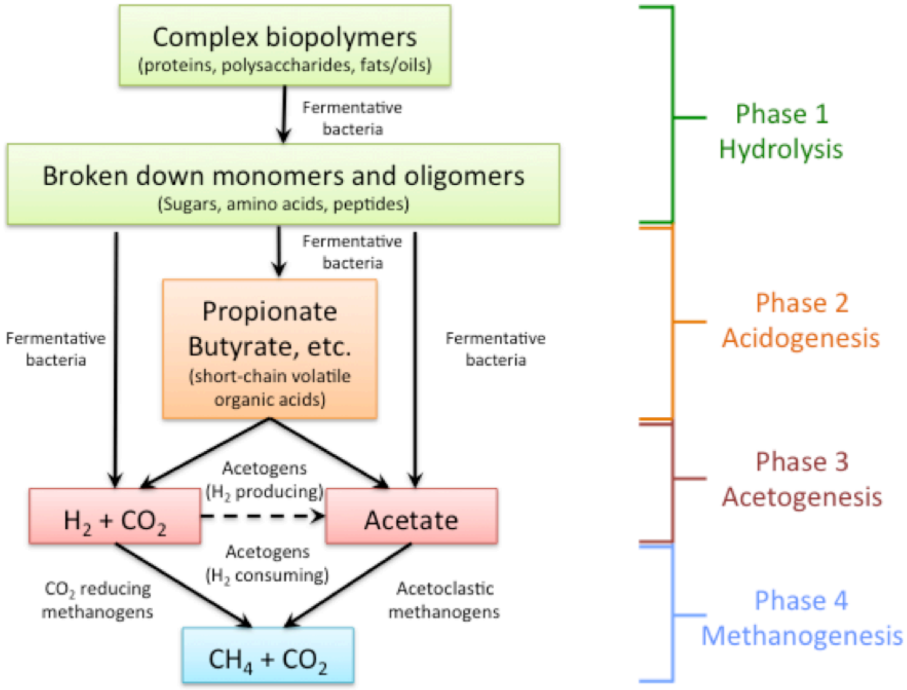

Figure 3: Anaerobic Digestion Process (Clifford, 2019)

2.1.3. Feedstocks for Biogas

There are many ways to classification the type of feedstock for biogas. One of them demonstrated in figure 4, which show four main types of feedstock or organic residues that can convert into biogas by using anaerobic digestion method:

- **Municipal Biowaste:** Food dregs, garden scrap such as grass cuttings, and sewage sludge
- **Industrial wastes and Wastewater**: Abattoir scrap, food and drink industry waste, distillery/brewery by-products
- **Agricultural waste**: Animal or vegetable and fruit by-products
- **Energy crops:** Plant explicitly grown for producing energy. These can be controversial due to competition with land for food growth.

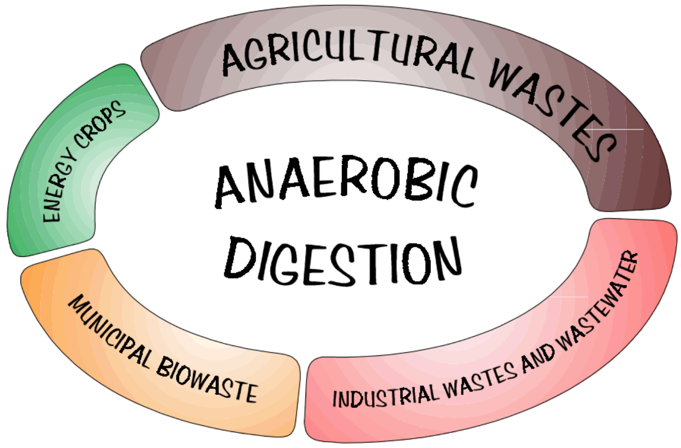

Figure 4: Sources of eligible substrates for anaerobic digestion (Steffen, Szolar, and Braun, 1998)

Another way is to categories in three various type of feedstock, as shown in figure 5: agriculture, industry, and communities. However, this dissertation will focus on agricultural areas; especially the harvest remains parts which have high among of feedstock. In this case, agricultural residues or harvest residues are the unconsumable product after harvesting, which has the potential to use as a feedstock with anaerobic digester on the farm. Frequently, those waste in the farm used as a co-substrate to manure, but in this case, some feedstocks can also be used in anaerobic digestion as well. For instance, plants and plant remains such as leaf, corn, clover, and stems, spoiled or low-quality fruits and vegetables, silo leachate and straw (Steffen, Szolar, and Braun, 1998).

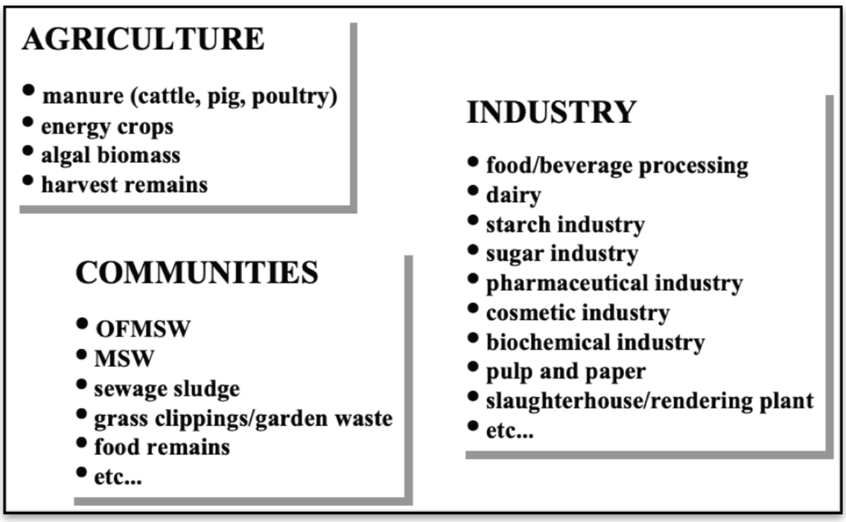

Figure 5: Survey of the various feedstocks from different sources (Steffen, Szolar, and Braun, 1998)

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Every kind of biomass is possible to convert to biogas by using digestion until they receive carbohydrates, proteins, fats, cellulose, and hemicelluloses as a principle constitutive. There is three-parameter that can impact the formulation of the biogas and methane yield: Storage time, digestion system, and type of feedstock (Braun 2007). Traditionally, animal manure such as poultry and pig, and sewage sludge have generally been a feedstock for anaerobic digestion.

Table 1: Maximal gas yields and theoretical methane contents (Baserga, 1998)

Substrate	Biogas (Nm^3/t TS)	CH_4 (%)	CO_2 (%)
Carbohydrates[a]	790–800	50	50
Raw protein	700	70–71	29–30
Raw fat	1,200–1,250	67–68	32–33
Lignin	0	0	0

[a]Only polymers from hexoses, not inulins and single hexoses

2.1.4. Biogas Production

Several useful products are created by AD which can be used for generating revenue.

The main outputs are as follows:

- Electricity or heating only (30-50% efficient)
- Combined heat and power (CHP) (up to 85% efficient)
- Injection into the gas grid
- Liquid or compressed gas transport fuel
- Digestate / Fertiliser

Biogas is composed primarily of methane with 55 – 80 per cent and carbon dioxide with 20 – 45 per cent. It is methane used for energy generation, and the yields are highly conditional on the quality and character of feedstock, time spent in the digester and digestion conditions. Biogas has a range of end uses and can be used to provide heat throughout a biogas boiler, energy through a generator or both through a CHP scheme. Excess heat generally used as a source for the AD process itself, or to provide heat to nearby dwellings, potentially in a district heating scheme.

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Alternatively, biogas can be developed to biomethane by release of CO2 and injected into the gas grid or compressed into transport fuel. Biomethane has the same composition as natural gas (> 95 per cent methane), which allows it to use in the current gas infrastructure. However, developing and injecting into the gas grid is expensive, and as it is currently developing in the UK, there are few incentives or standards currently in place. As a matter of fact, the continued growth in technology, this will be likely to change in the future. This project focuses on the production of heat and electricity, therefore, will investigate CHP and biomethane injection as end uses.

In addition to energy, a nutrient-rich digestate produces by AD. This used as a biofertiliser, or optionally separated into a soil conditioner and liquid fertiliser. The use of the digestate to grow more food and plant-based matter can evolve the system into a closed-loop process, as demonstrated in Figure 6.

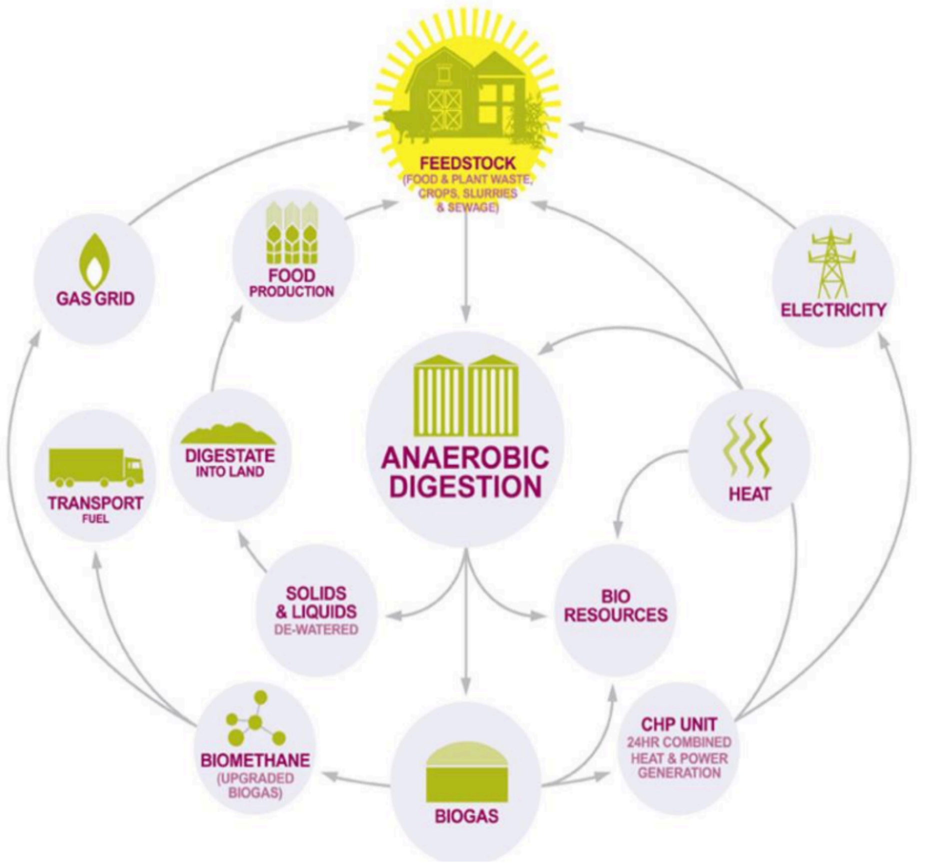

Figure 6: Diagram of closed loop AD process (ABDA, 2019)

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2.1.5. System Design

Configuration of Biogas system

Biogas generation system can be both simple and complicated system. The simple system can consist of a single vessel with a boiler, with an input feedstock to digest as biogas and store in a tank while the more complicated system can consist of many components; to improve the system efficiency such as pre-treatment or double digesters. The list below is the main components of the biogas system:

- Pre-treatment (sorting, screening, pasteurising etc.)
- Pumps
- Feeding systems for biomass
- Mixer/agitator
- CHP system or bio-methane converter
- Digestion tank

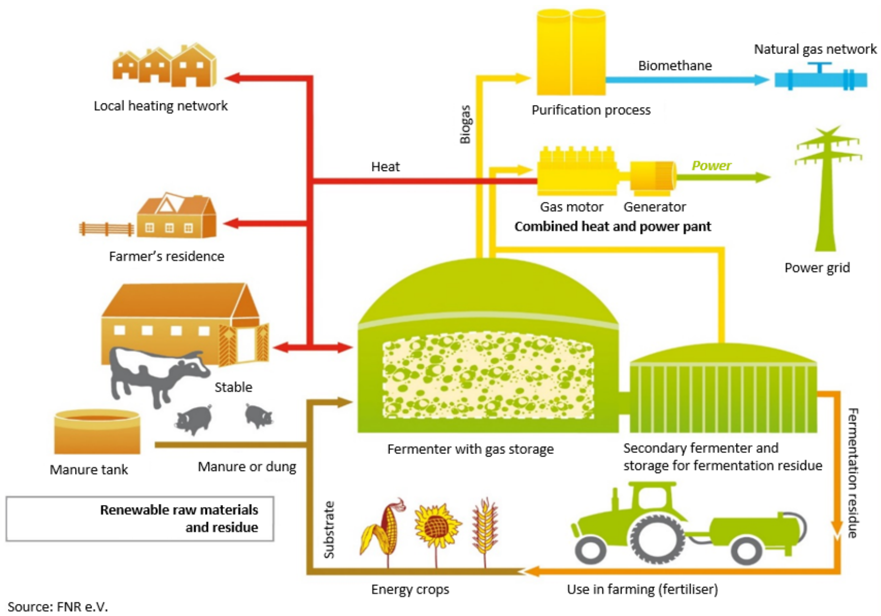

Figure 7: Diagram of (anaerobic digestion) biogas / biomethane plant (Appunn, 2016)

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Temperature

The efficiency of fermentation process and biogas production vary in many variations. One of the significant variations that affect the outcome of the biogas process is temperature, which can separate into three-level (Safley and Westerman, 1992).

- Psychrophilic, operating at temperatures between 0 – 20 ºC
- Mesophilic, operating at temperatures between 20 – 45 ºC
- Thermophilic, operating at temperatures between 45 – 60 ºC

Microorganism are unable to attach substrates from their environment if the temperature below their optimum growth because of lowered affinity (Nedwell, 1999), However, it generally accepted that 35 - 37°C is suitable for methane production as shown in figure 8 (Khalid, Arshad, Anjum, Mahmood, and Dawson, 2011).

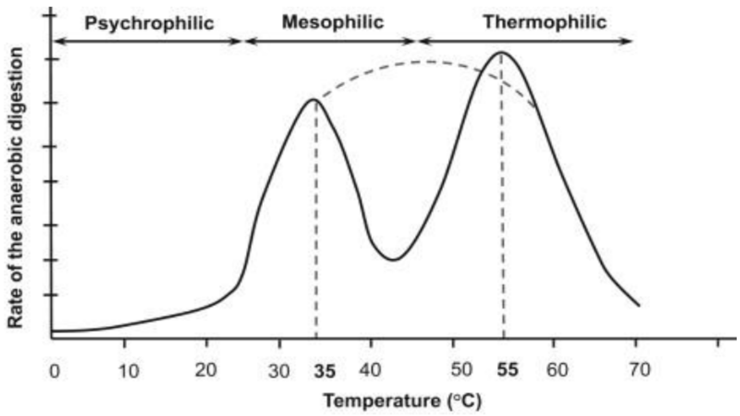

Figure 8: Stage of Anaerobic Digestion

pH

The most effective pH for producing biogas or methane by using anaerobic digestion method is between 7.0 – 7.2. However, the pH inside the fermentation tank depends on the retention time of fermentation. Because at the first stage, bacteria will produce many acids and result in pH reduced. As a consequence, it could inflict the system if the pH drops below 5, it will stop all digestion and fermentation processes, or in other words, dead bacteria. Methanogen is sensitive to acidity and will not grow if the pH is below 6.5. At the end of the process, the concentration of NH4 will increase as the nitrogen decomposition increases. As a result of an increase in pH, which may exceed eight until the production system starts to stabilise the pH until it is between 6.8 – 8.

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Total Solids Content (TSC)

The solid content of organic substances in the production of biogas divided into two levels:

- High-solid (high solid content) TSC is higher than ~ 20%
- Low-solid (low solid content) TSC below ~ 15%

The fermentation tank designed for high-solid organic filling requires more energy to pump slurry. However, the high solid system affects the water in the fermentation tank more concentrator, which consequence the area used decreased.

In contrast, the low-solid fermentation tank can use general pumps that use less energy than pump sediment. As a result, more space needed due to the higher volume of feedstock added, but the clarity of the water-sediment makes the circulation and distribution of bacteria and organic substances better. Moreover, the bacteria can touch organic waste thoroughly helps to digest and produce gas efficiency.

C/N Ratio

The ratio of carbon to nitrogen of organic waste that can be used to produce biogas is about 8 to 30; the optimal ratio for biogas production is about 23. If the C / N ratio exceeds the recommended value, nitrogen will be used by Methanogen to supplement the protein and depleted; as a consequence of low biogas produced.
However, if the C / N ratio is below the suitable point, it causes nitrogen to be rising and chemical reaction with ammonia, the consequence to increase the pH value. If the pH reaches 8.5, it affects to release the poison to bacteria, causing the amount of Methanogen to decrease. Furthermore, a high C / N ratio, which exceeds the range between 8 to 30, there is a possibility to produce another gas such as carbon dioxide.

The most optimal C / N ratio is animal manure, following with the vegetables and food wastes, while straw has a relatively high proportion of carbon to nitrogen. Notwithstanding, to achieve the require feedstock property, it is necessary to mix a low C / N ratio feedstock with the high C / N feedstock.

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Retention Time & Mixing

The retention time for feedstock in the fermentation tank relies on the quantity and character of organic substances added (which have different characteristics and properties), including the design of the system and fermentation tank. Also, the short time of retention can affect the among of biogas produced by bacteria. Moreover, the bacteria will also be taken out of the system too soon, resulting in a reduced number of bacteria. Causality to the remaining bacteria to not digest and the pH value in the fermentation tank decreased.

Most of the retention time is approximately 14 to 60 days, depending on various factors: TSC values, temperature, size and character of digester and the quantity of feedstock fed. The duration of storage is an indicator of how long the bacteria can live without supplementing other feedstocks. Wherewith, the retention time means the time that bacteria need to digest food.

Organic Loading Rate (OLR)

The quantity of feedstock adding to the system means the amount of feedstock added to the fermentation tank each day. If the among of feedstocks are overrated, it may draw to excessive pH reduces (since the first phase of the process is Acidogenesis, the acid will produce), causality to system failure. In contrast, if the volume of feedstock is lower than the system needed, it will inflict the biogas produced. However, OLR usually less than 4.5 kg/m3/day.

2.1.6. Benefits of Biogas

There are three alternative ways to manage biomass residues: Landfill, incineration, and anaerobic digestion. Landfill and Incineration are an open system which is able to release emission to the air. On the other hand, anaerobic digestion has the ability to obtain high energy in the closed system without any leak of emissions.

Anaerobic digestion can decrease global warming gas, which is CH_4 and CO_2. These two gases are the essential greenhouse gases that negatively affect the atmosphere, which reduces the ability of irradiative heat losses from the earth's surface, effectively trapping heat. As a result, the temperature of the planet keeps rising every day.

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2.2. The Energy in The Northeast Region of Thailand

This section is going to demonstrate the significant existing of powerplant in Thailand, including their potential, capacity and issues. Moreover, the context about feedstock for biogas in Thailand will also explain for further analyst.

2.2.1. The Energy structure in Thailand

According to the data from world bank in 2014, electric power consumption per capita in Thailand is 2538.8 kWh (The World Bank, 2019). which lower than the world average at 3132.1 kWh (The World Bank, 2019). Even though electrical power consumption in Thailand is lower than the world average, but the consumption values are increasing every year. In 2017, Thailand Ministry of Energy had recorded the electricity-consuming data by economic sector. The most electricity-consuming sector of the country is the industrial sector with 59.09 per cent or 105724 GWh of the country's electricity consumption. Followed by the residential sector, commercial sector, and others, which accounted for 24.61 per cent or 44025 GWh, 15.25 per cent or 27283 GWh, and 1.06 per cent or 1873 GWh, respectively (Ministry of Energy, 2019).

Most of the electricity generation capacity in Thailand comes from Independent Power Producer (IPP), which is 34.83 per cent, as shown in figure 9. Additionally, the rest have produced from Electricity Generating Authority of Thailand (EGAT) 33.93 per cent, Small Power Producer (SPP) 22.21 percentage and 9.03 per cent from a foreign country (EGAT, 2019), which mostly imported from Lao PDR Bank of Thailand. (2019).

Although most of the electricity produced by the nation. Consider the fuel used in production; it found that Thai electricity production uses natural gas as a fuel to produce at a high proportion of 67.4 per cent. Additionally, the average natural gas usage in electricity production in the world is 22.1 per cent. Thailand imports natural gas used in power generation from Myanmar as high as a percentage 42.0 The rest of natural gas from the Gulf of Thailand. Causing Thailand to rely on electrical energy from neighbouring countries, both directly and indirectly, as high as 35.6 per cent Bank of Thailand. (2019).

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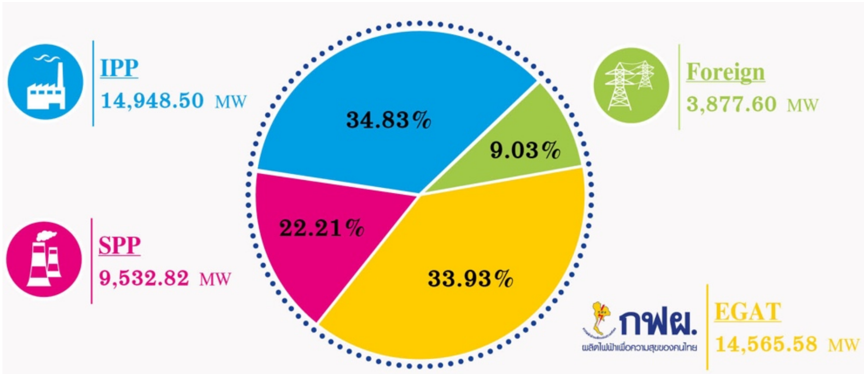

Figure 9: Total Electricity Generation Capacity in Thailand. (EGAT, 2019)

2.2.2. Electricity Issue in Northeast of Thailand

The electricity consumption of the Northeast region is likely to increase continuously according to the electricity demand of various business sectors, especially the industrial sector. The industrial sector has increased significantly, due to the urbanisation and the linkage of the economy with neighbouring countries. Also, the integration of the ASEAN Economic Community (AEC) in 2015 is one of the factors that encourage the demand for electricity in the Northeast region to increase in the future.

The electricity consumption in the northeastern region comes from 2 main parts: produced locally and imported from the Lao PDR. Before 2010, electricity in the northeast region mainly used from the national grid, which mainly dispatched from the central and northern regions. Because of the power generation capacity of the northeastern part itself is not enough. However, in the later stage, the dispatch of electricity within the national grid itself has started to have a shortage issue. As a result, the purchase of electricity from the Lao PDR has increased continuously. At present, the northeast region must import electricity from Lao PDR at a percentage 68 of the total electricity consumption of this region. Followed by self-generated within the region, 28 per cent and imported from the North and Central region 4 per cent. Furthermore, all of the electricity imported from Lao PDR used northeast regions (Bank of Thailand, 2019).

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Before 2015, the northeast region has seven power plants operated by the Electricity Generating Authority of Thailand (EGAT) with an overall installed capacity of 1,453.2 MW, generated electricity at 5,559 million kWh. The most significant power plant is Nam Phong power plant (Combined Cycle Power Plant) which uses natural gas as fuel with the installed capacity of 710 MW (Bank of Thailand, 2019). As well, the Lam Ta Khong power plant, which generated by hydropower with an installed capacity of 500 MW (Bank of Thailand, 2019 and Ministry of Energy, 2019). However, the Ministry of Energy planned to decrease the capacity of Nam Phong power plant in 2015 to 650 MW (Ministry of Energy, 2019). As a result of this power plant has low electricity generated efficiency of only 30 per cent Bank of Thailand. (2019). Which brings the reason for building an additional power plant in order to reduce the cost of importing electricity from neighbours become eligible.

2.2.3. Biogas and Biomass resources potential in Northeast Region of Thailand

There are five economic agricultural plants in the Northeast region:

- Rice
- Cassava
- Sugar Cane
- Palm
- Rubber Tree

According to the IRENA (2017), Most of the production of Rice, Cassava, and Sugar Cane is in the Northeast region, while the potential of palm and rubber tree also have in the Southern region. Consequently, analysis of the total potential of Rice, Cassava and Sugar Cane is less complicated compare to the other two plants. Table 2 is shown the total residue both harvest and process of three economic crops: Cassava, Rice and Paddy, and Sugar Cane, which is going to use in the simulation method.

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Table 2: Harvest and Process Residues in Thailand (IRENA, 2017)

Economic Crops	Harvest Residue (kTons)	Process Residue (kTons)	(kTons)
Cassava	6,167	3,996	
Rice and Paddy	11,299	7,058	
Sugarcane	5,443	13,894	
Total	29,700	28,615	58,315

2.3. HOMER Software

HOMER (Hybrid Optimisation of Model with Multiple Energy Resources) is the program for design and optimizing on-grid and off-grid hybrid power system, including microgrid design in various type of systems, starting from small community scale to nation scale: military bases and community scale.

Moreover, this program helps to analyse the financial aspect for each possible situation to provide an alternative way for a user to consider, to balance the source of energy availability and other variants (HOMER, 2018). Although the result from the HOMER simulation software is involved with technical and economic aspects, on the other hand, the environment and social impact will not be one of the variations in this software (Cherni et al., 2007). However, HOMER Pro has fixed those issues by providing a new version of the software which added the environmental aspect: particulate matter and emissions, as a result, this software is more realistic in analysis and simulation; even that improvement it still has some limitation on components for simulation.

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3. Renewable Energy System Modelling

3.1. Input Data of The Project

Firstly, this dissertation is going to illustrate the demand for electricity used in the region, including its assumption and forecasting the future energy demand for a new industrial settlement. Secondly, the optimisation and comparison between the base model and optimised model will be analysed and designed. An optimise model will be a comparison between three feedstocks: cassava, rice and paddy, and sugar cane. For the purpose of increasing the fraction of renewable electricity used, decrease the among of electricity purchasing from a foreign country and to support the future industrial settlement at Ubon Ratchathani province in 2022. Currently, the original model was mainly using hydropower and natural gas, but the optimized model is going to add a biogas generator which uses feedstock from agricultural wastes. Chapter 3.11-3.13 is going to explain a significant factor related to simulations. However, most of the input data come from country or region data (which provided by government) calculated by an assumed fraction.

3.1.1. Demand Profile

As mention in chapter 3.1, this dissertation is going to forecast electricity demand to support the new industrial settlement at Ubon Ratchathani province in 2022 as shown in equation 1. However, the electricity demand pattern in HOMER software calculated by a fraction from demand used in Southern Thailand, which collected by EGAT. Furthermore, an average demand for industrial settlement in Ubon Ratchathani province calculated from overall electricity demand of industrial settlement in Thailand divided by the number of them.

Equation 1: Future Demand Forecast Equation

$$Future\ D. = Current\ D. + Avg. D. for\ Industrail\ Settlement$$

For the forecasting electricity demand, there is a variation throughout the year with the average demand. During the year, the average energy used is 4,097,155.36 kWh/day and reach the maximum power at 385,621.75 kW. Nevertheless, the excess electricity ten per cent will be calculated in case of an emergency in HOMER including with the average demand for an industrial settlement, which makes the maximum power used in

August go to 440,987.98 kW; while the annual average energy used reached 6,756,098.27 kWh/day, as shown in figure 10. In conclusion, the highest energy demand is in Summer, which is March. As a result, where Thailand is in tropical areas which the use of cooling load is the most significant energy used, in contrast to the UK where the heat recovery load is one of the substantial loads. In the same way, the least average demand is January, which is winter. However, since the differentiation of average temperature in each month in Thailand is not dramatically fluctuation, which makes the energy demand rather stable or slightly different.

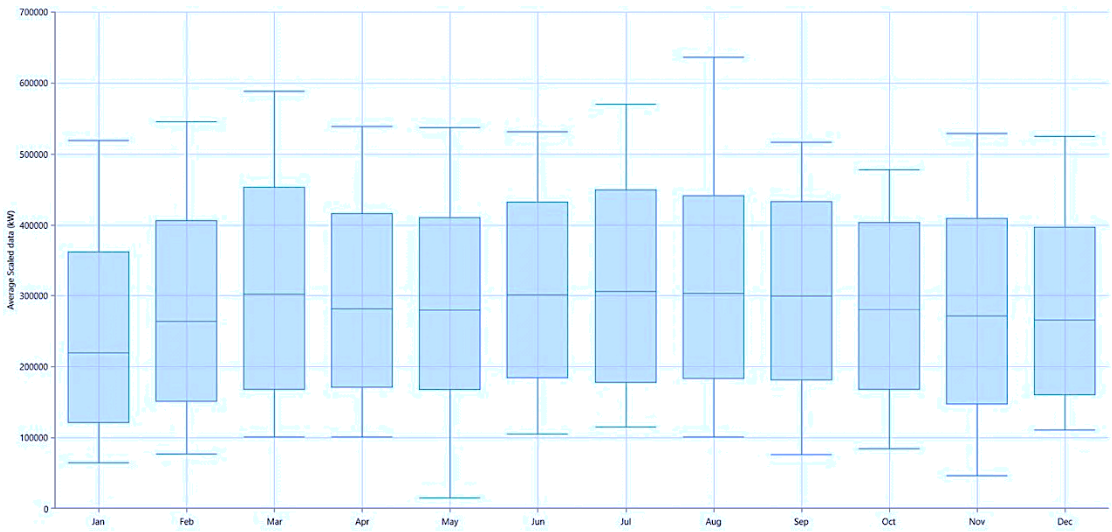

Figure 10: Future Average monthly demand in Ubon Ratchathani

In fact, Thailand has three seasons, which are divided into 4 months for each season: summer, rainy season and winter season, starting from March to June, July to October and November to January respectively. In Figure 11 and 12, it is an example that manifests about the daily electricity consumption data of each season.

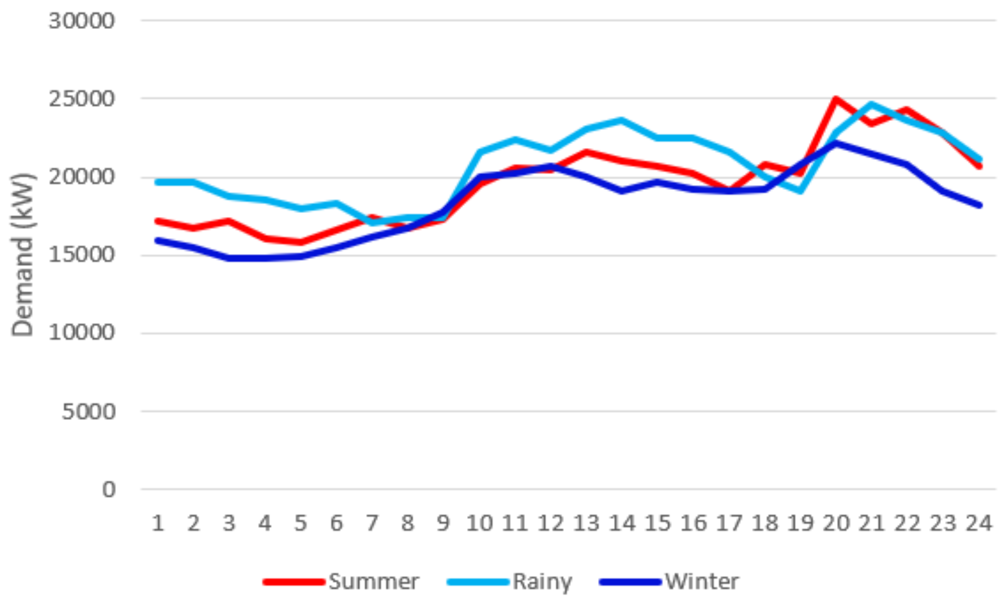

Figure 11: Current Seasonal Energy Demand in Ubon Ratchathani

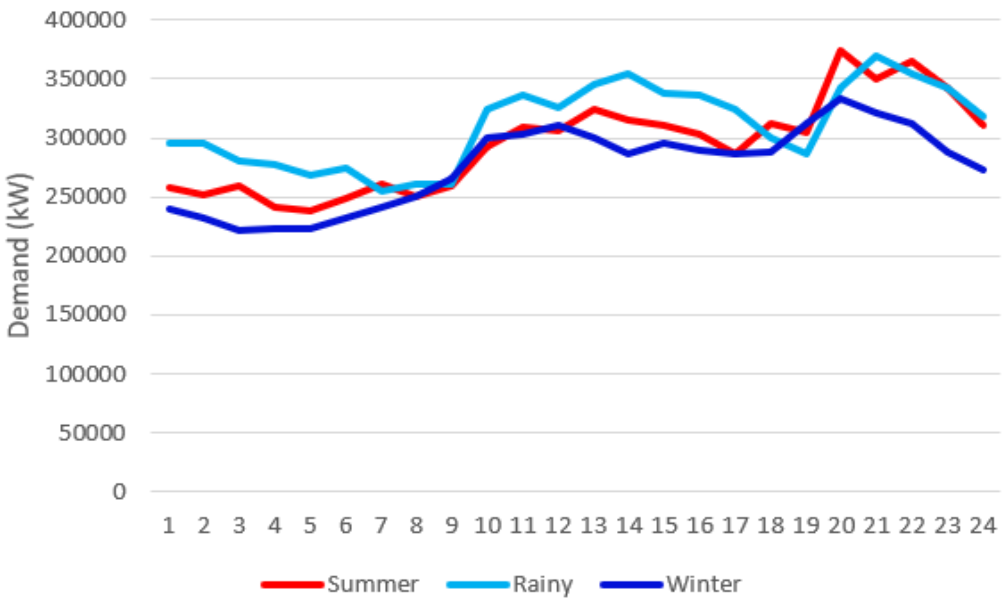

Figure 12: Future Seasonal Energy Demand in Ubon Ratchathani

After the new industrial settlement arises, the daily demand for electricity in Ubon Ratchathani between current and future appears to be different all through three seasons. As shown in figure 11 and 12, it is evident that all three seasons have a similar model of electricity consumption, with the lowest demand around 5 a.m. Then, it is starting to increase until 12.00-14.00 hrs. and drop to approximate 300,000 kW from 6 to 7 p.m. due to the office hours has ended. Lastly, the peak demand for all three seasons is in between 8 p.m. and 10 p.m. when people are coming back from their daily life.

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During this period, it can reach to 374,756.4 kW in the summer season, according to the graph. However, the steadiest demand period appears to be from 1 a.m. to 6 a.m. when people are sleeping. In conclusion, the highest energy demand in each season is possible to reach 707.55 MWh/day (summer), 681.15 MWh/day (rainy season), and 534.3 MWh/day (winter).

3.1.2. Natural Gas Combined Cycle (NGCC)

In this project, Jenbacher Gas Engines (GE) used in simulation as an engine in NGCC plant, as a representative of the base case for non-renewable energy resource. There are three separate NGCC size for this project to be analysed, which are 650 MW, 300MW, and 200 MW. The capital cost of energy (COE) or in this case is NGCC plant, and operation & maintenance cost (O&M) are 978 $/kW and 1 $/operate hr. respectively, according to the U.S Department of Energy (2016). However, the replacement cost is assuming as 50 per cent of the initial capital cost. To sum up, the specification and characteristics of this engine are stated below in Table 3.

Table 3: Data Input for NGCCs

Specification	Value
Type	Jenbacher Gas Engines
Fuel	Natural Gas
Capacity (MW)	650, 300, 200
Capital cost ($/kW)	978
Replacement cost ($/kW)	489
O&M ($/operate hour)	1
Minimum Load Ratio (%)	25
Lifetime (year)	25
Fuel curve slope (m^3/hour/kW)	0.253
Fuel price ($/$m^3$)	0.3

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Emissions	Value
CO (g/m^3 fuel)	6.42
Particulates (g/m^3 fuel)	0.181
NO_x (g/m^3 fuel)	3.47

3.1.3. Biogas Generator

Generic Biogas Generator considered a renewable generator in this project. There is three various capacity for this biogas generator that is going to utilise for another three scenarios to optimise power system. According to a study from IRENA (2017), the northeast region of Thailand has numerous agricultural from both harvest and manufacturing process. The agricultural wastes that are going to used in this project is cassava, rice and paddy, and sugar cane. The resource potential for those 3 plants within northeast Thailand region are approximately 27,844 tons/day, 50,293 tons/day, and 52,978 tons/day, respectively (IRENA, 2017).

According to the report from IRENA (2018), the capital cost of biomass plant is 1,400 $/kW and as mention in chapter 3.1.1, the assumption of replacement cost is 50 per cent of the capital cost. However, this simulation input the cost of feedstock instead of the cost of operation and maintenance, which make cost of operation and maintenance equal to 0 $/operate hour in the HOMER software. The feed stock that is going to use in this project is Cassava, Rice and Paddy, and Sugar Cane which have the lower heating value is 18.42, 12.26, and 15.90 (Ministry of Energy, 2009), respectively, price per kg (Nettathai, 2019, Kasettumkin, 2017, and My Green Gardens, 2013)and percentage carbon content (Sudaryanto, Hartono, Irawaty, Hindarso, and Ismadji, 2006, Bakker, Elbersen, Poppens, and Lesschen, 2013 and do Lago, Bonomi, Cavalett, da Cunha, and Lima, 2012) is state below in table 4. However, according to the area size and energy demand in Ubon Ratchathani, the biomass resource input data in the HOMER software will be 30 per cent from total biomass potential. To sum up, specification and characteristics of this biogas generators are stated below in Table 4.

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Table 4: Data input for Biogas Generators

Specification	Value
Type	Generic
Fuel	Biogas
Capacity (MW)	700, 650
Capital cost ($/kW)	1400
Replacement cost ($/kW)	700
O&M ($/operate hour)	0
Minimum Load Ratio (%)	25
Lifetime (years)	25
Feedstock Price ($/t)	103.91, 81.05, 97.24
Lower Heating Value (MJ/kg)	18.42, 12.26, 15.90
Carbon Content (%)	51.59, 48.70, 44
Fuel curve slope (m^3/hour/kW)	2
Emissions	**Value**
CO (g/m^3 fuel)	2
Particulates (g/m^3 fuel)	0
NO_x (g/m^3 fuel)	1.25

3.1.4. Limitation and Assumption of The Project in HOMER

After analysing the data, limitations and assumptions of each type of generator in this project, the next sequence is to give a list of the limitations and other assumptions of other parts. As a result of some of the input data in HOMER cannot be adjusted to meet the probable consequences. Therefore, some renewable resources are challenging to find the exact outcome, limitations and assumptions are set to make the most realistic

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results. Therefore, a parameter such as finance is one thing that needs to be considering in this project.

Project Constrains

- 50 per cent of renewable energy fraction
- Project lifetime 25 years
- Maximum 0.01 per cent annual capacity shortage
- 6 per cent discount rate
- Excess electricity 10 per cent added in case of peak demand
- Support an addition load from new industrial settlement in 2022
- Electricity load 6,756,098.27 kWh/day

Project Assumptions

- NGGC referred to as energy imported from the grid due to its low COE
- The replacement cost of every generator is 50 per cent of capital cost
- An average biomass source for biogas is equal throughout a year

4. Simulation and Result

After input, all the needed parameters, limitation and presumptions, the next step is to analyse the data by using HOMER to evaluate the outcomes of the electrical systems. The scenario in this project is separated into 4 cases including the base case:

- Base Model – 650 MW NGCC.
- Case 1 – 300 MW NGCC and 700 MW biogas generator with cassava as a feedstock
- Case 2 – 200 MW NGCC and biogas generator 650 MW with rice and paddy as a feedstock
- Case 3 – 200 MW NGCC and biogas generator 700 MW with sugar cane as a feedstock

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Every optimises systems will perform through the different type of feedstocks, while the constant parameter for each case except base case will be NGCC. The next chapter is going to analyse the outcome, including the economic and technical perspective for various circumstances.

4.1. Base Model

The base model is a represent criterion of the other 3 cases in various aspects such as renewable fraction, initial capital cost, percentage emission, and COE. This system has only one NGCC generator with 650 MW capacity and electricity demand profile as shown in figure 13.

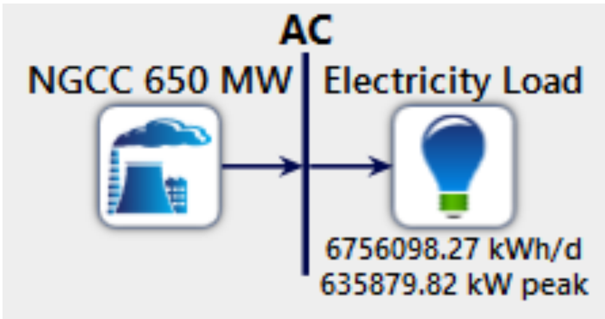

Figure 13: Base Model's System

4.1.1. Result of Base Model

Table 5: Result of Base Model

Characteristic	Value
Renewable Fraction (%)	0
CO_2 Emission (kg/year)	1.211B
CO Emission (kg/year)	4.028M
Particulate Matter	0.114M
Net Present Cost ($)	3.04B
Cost of Energy ($/kWh)	0.0965
Operating Cost ($/year)	188M
Initial Capital Cost ($)	636M

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Excess electricity (%/year)	0.432
Capacity shortage (%/year)	0.002

4.1.2. Discussion of Base Model

One of the most efficient non-renewable technologies is NGCC, which chosen as the system's power supply in this project to become a standard for comparing with the other cases. Also, the electricity consumption is 6,756,098.27 kWh/day, the minimum capacity of NGCC plant to enables the yearly capacity shortage is about 0.002 per cent or 49,468 kWh/year. However, the maximum energy consumption is 635,879.82 kW, which is slightly lower than the maximum production capacity of NGCC, which is 635,880 kW. Besides, since this peak occurs only once a year, it may be a small defect in HOMER. Hence, it does not affect the lack of production of this model. To illustrate, in Figure 14, the capacity shortage is indicated by the black circle below.

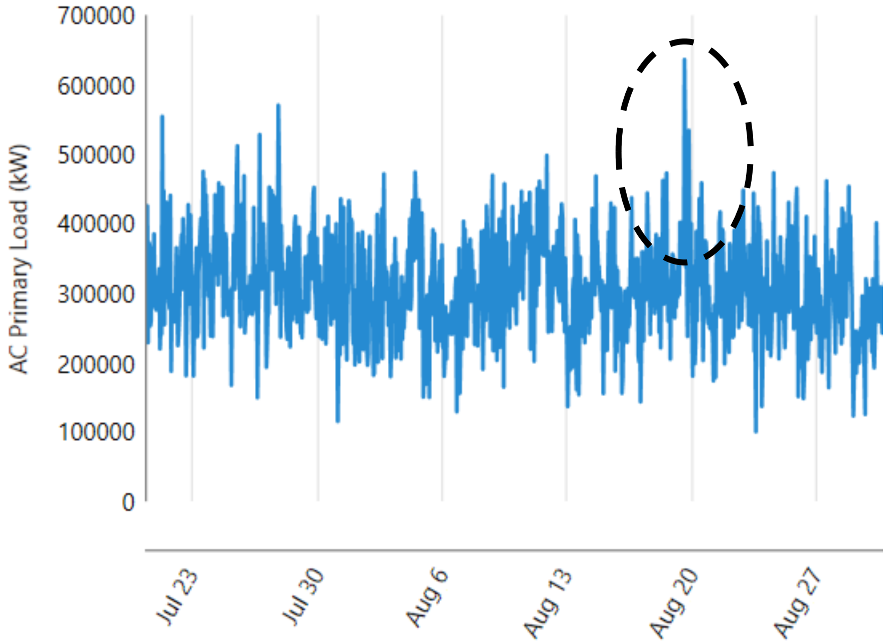

Figure 14: Peak Annual Demand in Ubon Ratchathani

According to the cost of energy (COE), the model could represent Thailand power system due to both the cost of energy systems is a similarity. COE could separate into many categories in Thailand, for instance, residential, commercial, industrial sectors, or by region. Moreover, the rate is about 0.115 $/kWh, which the base model of COE

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is 0.0965 $/kWh as indicated in Table 5. Therefore, the northeast people or the industrial settlement areas will advantage from NGCC factory construction, also, because of the cost of energy is cheaper than the standard rate.

Referring to power generation, NGCC has a satisfying performance to support a variety of energy needs, since it can quickly change energy without the battery needed, unlike a renewable energy system. Consequently, the shortage of production capacity and excess electricity is only 0.002 per cent and 0.432 per cent per year, respectively.

Even though the benefit of this system is the cost of energy and power generation performance, however, there is a drawback about CO2 emissions for this model because the NGCC plant is only producing non-renewable electricity in the system. As a result of the emission problem, the system produces about 1.211 billion kg per year of carbon dioxide emissions, which is more than every system with renewable technology. Nevertheless, this disadvantage may cause people to accept this technology less because of the enormous amount of carbon dioxide emissions that have a long-term impact on global warming. Due to various aspect advantage of NGCC, not only the power plant areas required for construction, but also the complex design issue of the system is less than other renewable generators. However, the most significant reason is that the COE of this NGCC system is less than other systems. By this reason, it makes the chance of building NGCC plant more realistic, but it a reality, there is a need to concern about among of emissions that emitted from the system.

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4.2. Case 1 – 300 MW NGCC and 700 MW Biogas Generator with Cassava as a Feedstock

The first optimisation model cannot accomplishes the aim with at least 50 per cent renewable fraction, it gets only 33.2 per cent of renewable fraction due to the among of biomass potential, as shown in table 6. According to figure 15, the system consists of the combination of 300 MW NGCC and 700 MW biogas generator as a supply system to distribute electricity to an area load. In this case, cassava wastes used as a feedstock for biogas generator.

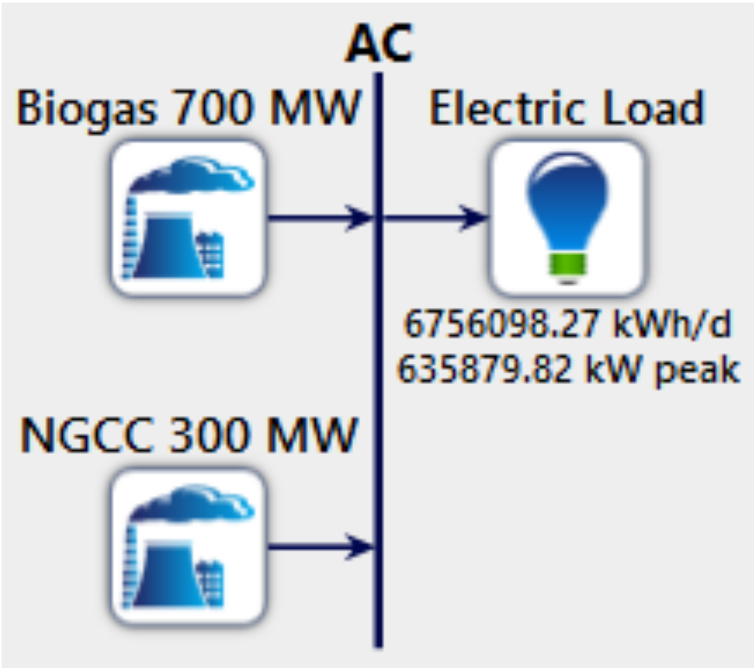

Figure 15: Case 1's System

4.2.1. Optimisation Result of Case 1

Table 6: Optimisation Result of Case 1

Characteristic	Value
Renewable Fraction (%)	33.2
CO_2 Emission (kg/year)	810M
CO Emission (kg/year)	2.68M
Particulate Matter	75,533

Net Present Cost ($)	5.93B
Cost of Energy ($/kWh)	0.188
Operating Cost ($/year)	364M
Initial Capital Cost ($)	1.27B
Excess Electricity (%/year)	0.005
Capacity Shortage (%/year)	0
Avg Feedstock per Day (tons)	6,417
Total Feedstock input per Day (tons)	8,353

4.2.2. Discussion of Case 1

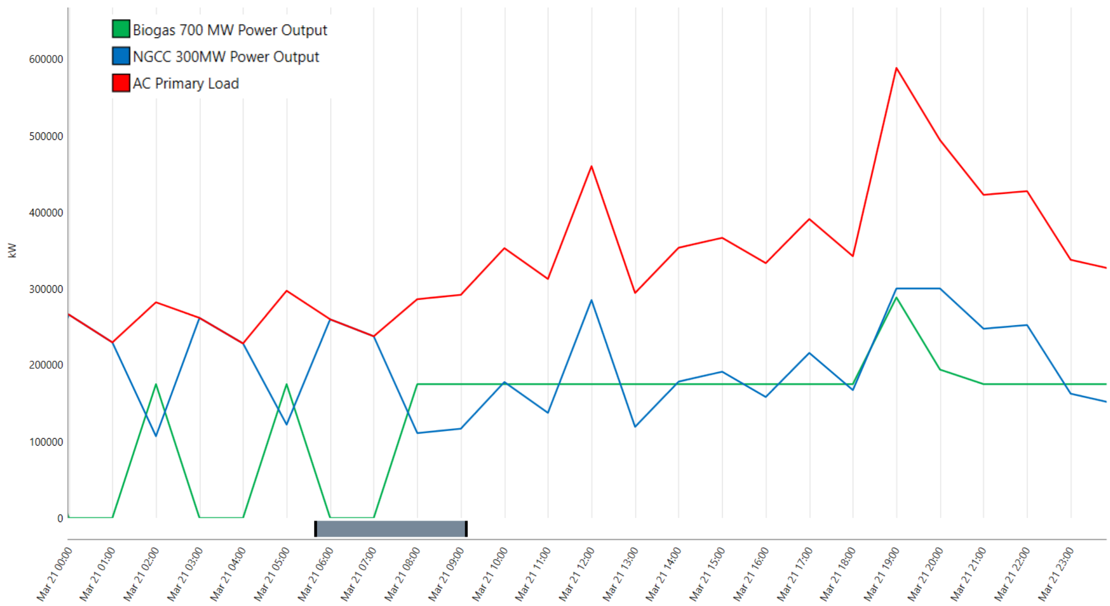

Figure 16: Electricity Supply and Demand for Case 1 (Summer)

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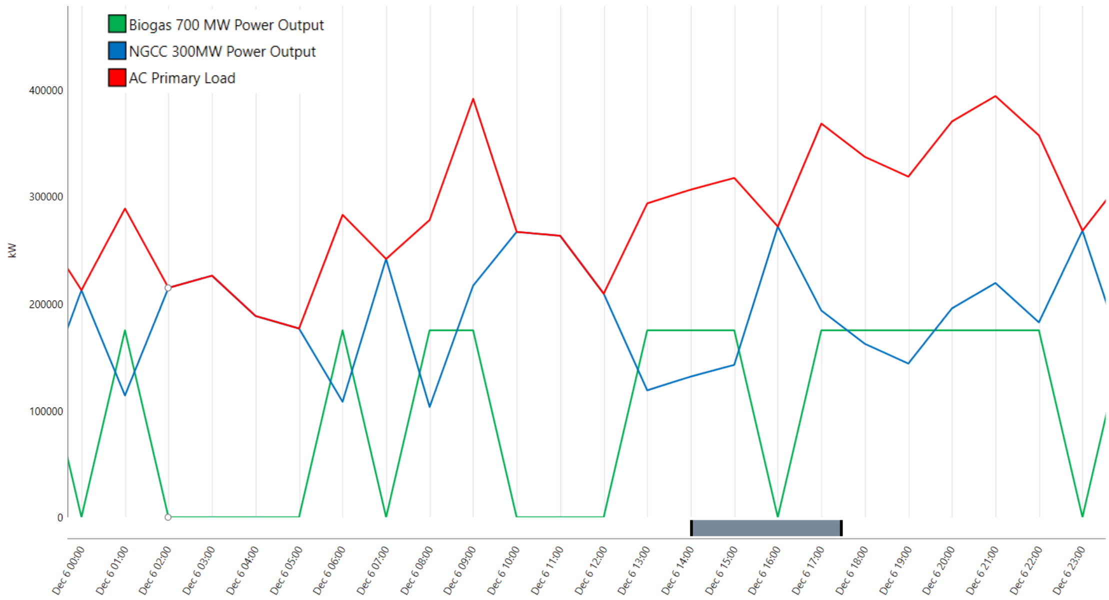

Figure 17: Electricity Supply and Demand for Case 1 (Winter)

According to figure 15, this scheme is a combination of non-renewable and renewable energy supply system: a 300 MW Jenbacher Gas Engines NGCC and a 700 MW Generic biogas generator. In contrast to the size of the generator, the majority of electricity supply comes from NGCC with about 66.8 per cent of the total system generation. Also, Cassava is a feedstock for biogas generator in case 1 with a maximum potential resource for Cassava is 8,353 tons/day. However, this system uses Cassava as a feedstock average 6,417 tons/day or approximately 80 per cent from the total resource, which could be benefits in case of an instantaneous demand.

After the system has optimised, the cost of electricity has increased about twice to 0.188 $/kWh compared to the base case, which is 0.0965 $/kWh. As a result, this could be a considerable disadvantage to the industrial settlement, which has to use a large quantity of demand. Also, it could affect some communities of business sectors. Furthermore, as shown in Table 6, it aggravates with the initial capital cost and NPC, which increases to 1.27 billion $/kWh and 5.930 billion $/kWh, respectively.

This system has increased its efficacy evidently by reducing the capacity shortage to 0 per cent throughout the entire year. Moreover, the excess electricity also reduces to 0.005 per cent or 123,887 kWh/year. However, the renewable fraction cannot reach the objective minimum (50 per cent) and reach only to 33.2 per cent. Besides, it also affects to the environment aspect directly due to among of CO2 has been significantly

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decreasing compare to the base model which is about 33.1 per cent or 810,111,801 kg/year, due to the addition of biogas generator.

According to figure 16 and 17, which represent the electricity supply and demand for both season summer and winter, respectively, it shows the pattern of how biogas generator and NGCC are working together. During 1 a.m. to 6 a.m., the system tends to us NGCC as a leading supplier, while using a biogas generator to support the system, especially when the output from NGCC drop. However, in the summer season, HOMER uses biogas generator mostly as constant electricity supply and use NGCC to support the system for a rapid load. Lastly, during the peak demand, which is between 7 p.m. and 8 p.m., where both supplies increase to meet the demand to support each other.

For winter as shown in figure 17, both generations seem to work with the same operation through the day. As a result of the demand in winter is significantly lower than the demand from summer which makes the supply rely on NGCC system. However, the temperature during winter could affect the efficiency of biogas generator in contrast to the summer.

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4.3. Case 2 – 200 MW NGCC and 650 MW Biogas Generator with Rice and Paddy as a Feedstock

The second optimisation model accomplishes the aim with at least 50 per cent renewable fraction with 54.3 per cent of renewable fraction, as shown in table 7. According to figure 18, the system consists of the combination of 200 MW NGCC and 650 MW biogas generator as a supply system to distribute electricity to an area load. In this case, rice and paddy wastes used as a feedstock for biogas generator.

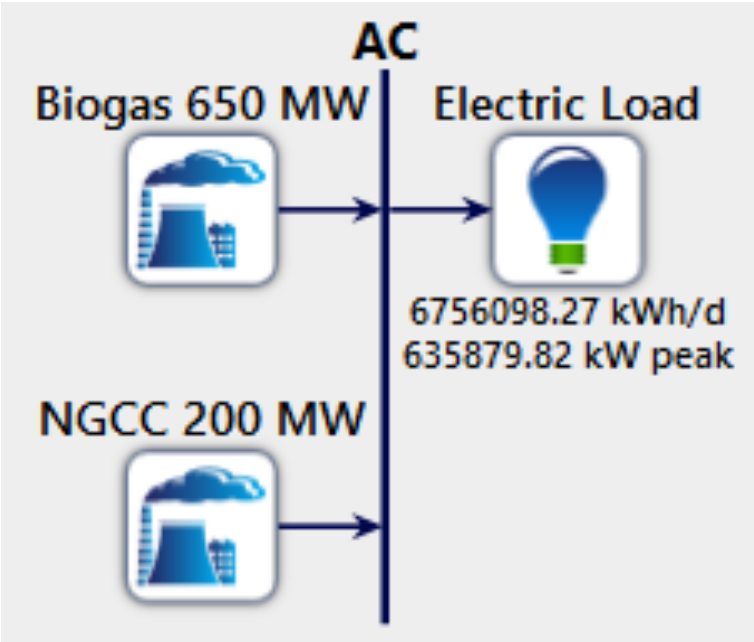

Figure 18: Case 2's System

4.3.1. Optimisation Result of Case 2

Table 7: Optimisation Result of Case 2

Characteristic	Value
Renewable Fraction (%)	54.3
CO_2 Emission (kg/year)	558.4M
CO Emission (kg/year)	1.84M
Particulate Matter	51,704
Net Present Cost ($)	6.19B

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Cost of Energy ($/kWh)	0.196
Operating Cost ($/year)	398M
Initial Capital Cost ($)	1.11B
Excess Electricity (%/year)	0.44
Capacity Shortage (%/year)	0
Avg Feedstock per Day (tons)	10,578
Total Feedstock input per Day (tons)	15,088

4.3.2. Discussion of Case 2

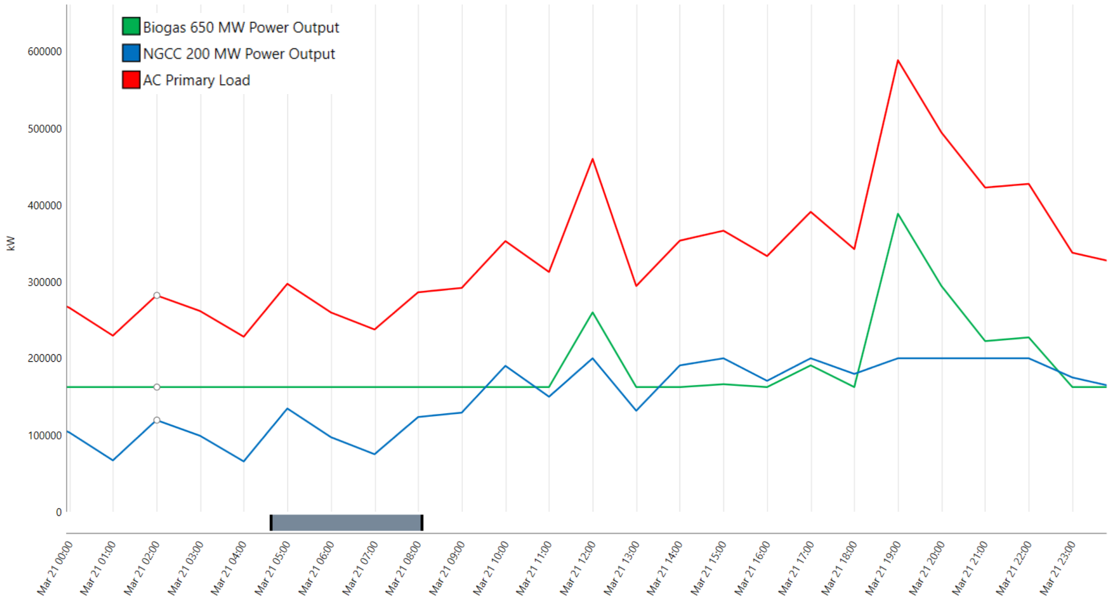

Figure 19: Electricity Supply and Demand for Case 2 (Summer)

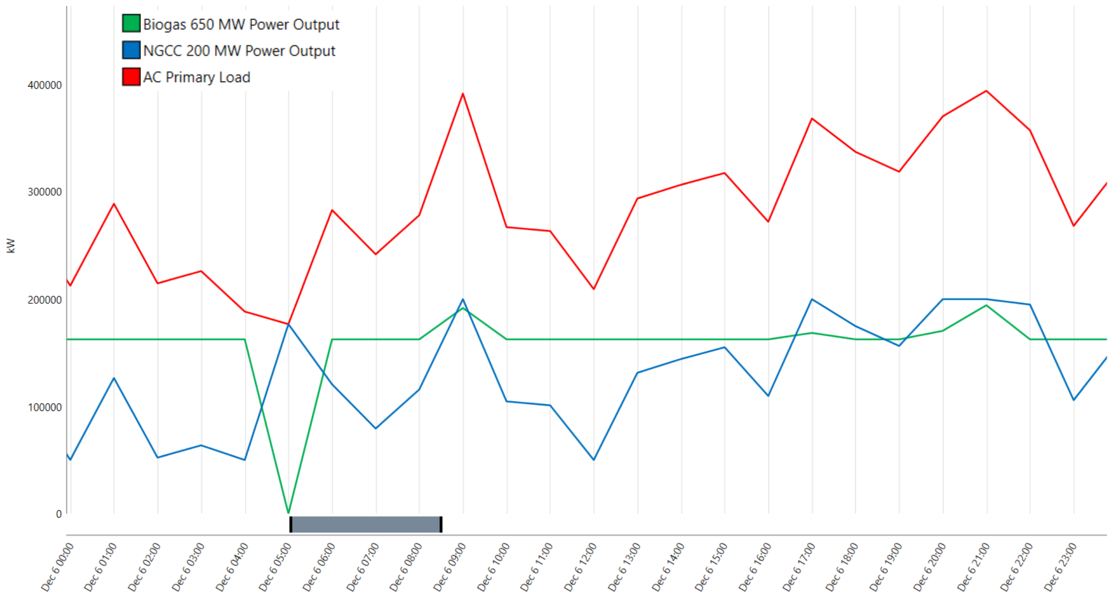

Figure 20: Electricity Supply and Demand for Case 2 (Winter)

According to figure 18, this scheme is a combination of non-renewable and renewable energy supply system: a 200 MW Jenbacher Gas Engines NGCC and a 650 MW Generic biogas generator. In the same way as the size of the generator, the majority of electricity supply comes from biogas generator with about 54.3 per cent of the total system generation. Also, Rice and Paddy is a feedstock for biogas generator in case 2 with a maximum potential resource for Rice and Paddy is 15,088 tons/day. However, this system uses Rice and Paddy as a feedstock average 10,578 tons/day or approximately 70 per cent from the total resource, which could be benefits in case of an instantaneous demand.

After the system has optimised, the cost of electricity has increased about twice to 0.196 $/kWh compared to the base case, which is 0.0965 $/kWh. As a result, this could be a considerable disadvantage to the industrial settlement, which has to use a large quantity of demand. Also, it could affect some communities of business sectors. Furthermore, as shown in Table 7, it aggravates with the initial capital cost and NPC, which increases to 1.11 billion $/kWh or 6.19 billion $/kWh, respectively.

This system has increased its efficacy evidently by reducing the capacity shortage to 0 per cent throughout the entire year. However, the excess electricity has slightly gained to 0.44 per cent or 10,902,713 kWh/year, more importantly, the renewable fraction reached the objective minimum (50 per cent) to 54.3 per cent. Besides, it also affects to

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the environment aspect directly due to among of CO_2 has been significantly decreasing compare to the base model which is about 53.89 per cent or 558,393,067 kg/year, due to the addition of biogas generator.

According to figure 19 and 20, which represent the electricity supply and demand for both season summer and winter, respectively, it shows the pattern of how biogas generator and NGCC are working together. During 1 a.m. to 11 a.m. in summer, the system tends to us biogas generator as a principle supplier, while using a NGCC to support the system, especially when the demand increases rapidly. However, during the peak demand, which is between 11 a.m. to 12 p.m., and 7 p.m. to 9 p.m., where both supplies increase to meet the demand to support each other.

For winter aspect, both generations seem to work with the same operation as summer through the day. Moreover, the demand in winter is lower than the demand from summer which makes the supply rely on NGCC system more than the summer. However, the temperature during winter could affect the efficiency of biogas generator in contrast to the summer.

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4.4. Case 3 – 200 MW NGCC and 700 MW Biogas Generator with Sugar Cane as a Feedstock

The second optimisation model accomplishes the aim with at least 50 per cent renewable fraction with 57.6 per cent of renewable fraction, as shown in table 8. According to figure 21, the system consists of the combination of 200 MW NGCC and 700 MW biogas generator as a supply system to distribute electricity to an area load. In this case, Sugar Cane wastes used as a feedstock for biogas generator.

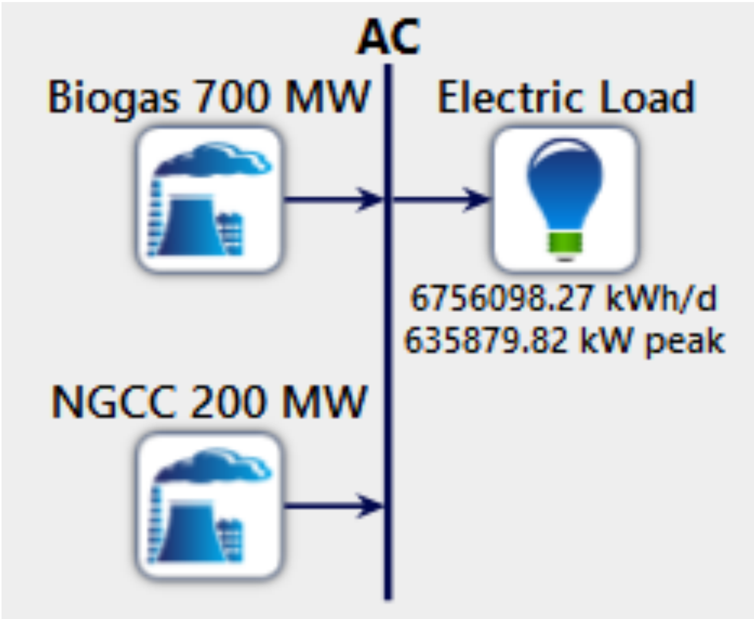

Figure 21: Case 3's System

4.4.1. Optimisation Result of Case 3

Table 8: Optimisation Result of Case 3

Characteristic	Value
Renewable Fraction (%)	57.6
CO_2 Emission (kg/year)	517.5M
CO Emission (kg/year)	1.71M
Particulate Matter	47,894
Net Present Cost ($)	7.29B

Cost of Energy ($/kWh)	0.231
Operating Cost ($/year)	479M
Initial Capital Cost ($)	1.18B
Excess Electricity (%/year)	0.657
Capacity Shortage (%/year)	0
Avg Feedstock per Day (tons)	11,273
Total Feedstock input per Day (tons)	15,893

4.4.2. Discussion of Case 3

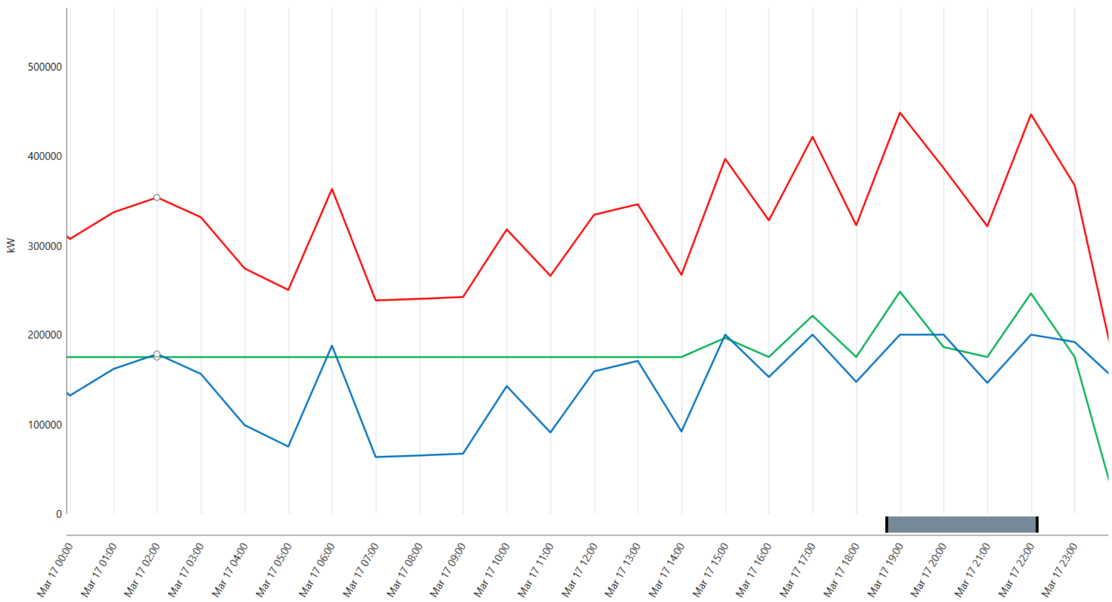

Figure 22: Electricity Supply and Demand for Case 3 (Summer)

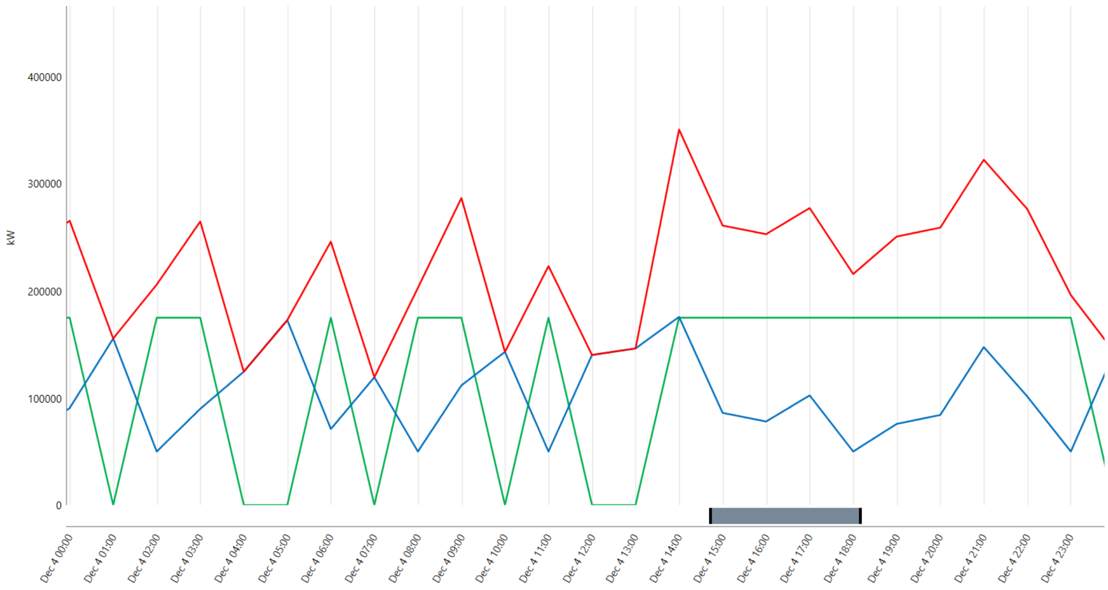

Figure 23: Electricity Supply and Demand for Case 3 (Winter)

According to figure 21, this scheme is a combination of non-renewable and renewable energy supply system: a 200 MW Jenbacher Gas Engines NGCC and a 700 MW Generic biogas generator. In the same way as the size of the generator, the majority of electricity supply comes from biogas generator with about 57.6 per cent of the total system generation. Also, Sugar Cane is a feedstock for biogas generator in case 3 with a maximum potential resource for Sugar Cane is 15,893 tons/day. However, this system uses Sugar Cane as a feedstock average 11,273 tons/day or approximately 71 per cent from the total resource, which could be benefits in case of an instantaneous demand.

After the system has optimised, the cost of electricity has increased by about 2.5 times to 0.231 $/kWh compared to the base case, which is 0.0965 $/kWh. As a result, this could be a considerable disadvantage to the industrial settlement, which has to use a large quantity of demand. Also, it could affect some communities of business sectors. Furthermore, as shown in Table 8, it aggravates with the initial capital cost and NPC, which increases to 1.18 billion $/kWh or 7.29 billion $/kWh, respectively.

This system has increased its efficacy evidently by reducing the capacity shortage to 0 per cent throughout the entire year. However, the excess electricity has slightly gained to 0.657 per cent or 16,313,897 kWh/year, more importantly, the renewable fraction reached the objective minimum (50 per cent) to 57.6 per cent. Besides, it also affects to the environment aspect directly due to among of CO2 has been significantly decreasing

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compare to the base model which is about 57.27 per cent or 517,499,161 kg/year, due to the addition of biogas generator.

According to figure 22 and 23, which represent the electricity supply and demand for both season summer and winter, respectively, it shows the pattern of how biogas generator and NGCC are working together. During 1 a.m. to 2 p.m. in summer, the system tends to us biogas generator as a principle supplier, while using a NGCC to support the system, especially when the demand increases rapidly. Nevertheless, during the peak demand, which is between 3 p.m. and 11 p.m., where both supplies increase to meet the demand to support each other.

For winter aspect, both generations seem to have the working operation in contrary toward each other, especially between midnight to 2 p.m. Moreover, the demand in winter is lower than the demand from summer which makes the supply rely on NGCC system more than the summer. As a result, the temperature during winter could affect the efficiency of biogas generator in contrast to the summer. However, after 2 p.m. the working operation of both generators seems to work with the same operation as summer case.

4.5. Discussion and Comparison

Table 9: Comparison Between 4 Cases

Characteristic	Base Case	Case1	Case 2	Case3
Renewable Fraction (%)	0	33.2	54.3	57.6
CO_2 Emission (kg/year)	1.211B	810M	558.4M	517.5M
CO Emission (kg/year)	4.028M	2.68M	1.84M	1.71M
Particulate Matter	0.114M	75,533	51,704	47,894
Net Present Cost ($)	3.04B	5.93B	6.19B	7.29B
Cost of Energy ($/kWh)	0.0965	0.188	0.196	0.231
Operating Cost ($/year)	188M	364M	398M	479M

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Initial Capital Cost ($)	636M	1.27B	1.11B	1.18B
Excess Electricity (%/year)	0.432	0.005	0.44	0.657
Capacity Shortage (%/year)	0.002	0	0	0
Avg Feedstock per Day (tons)	-	6,417	10,578	11,273
Total Feedstock input per Day (tons)	-	8,353	15,088	15,893

According to table 9, the comparison between case 1, 2, and 3 is the define the most suitable system to install in Ubon Ratchathani. There are several aspects to be considered: renewable fraction and feedstock wasted, emissions, and financial perspective. For case 2 and 3, they appear to have a similarity toward each other due to the quantity of feedstock and have an advantageous outcome for the environment compare to the case 1. On the other hand, case 1 has a benefit in the financial aspect compared to the other 2 cases.

However, since the criteria of the project aim to have a renewable fraction above 50 per cent; only case 2 and three are in the requirements. So, considering the initial capital cost and COE of case 2 is lower than case 3, it makes case 2 with Rice and Paddy is the highest possible case.

5. Conclusion

As mention in chapter 2.2, the status of the electricity supply system in the Northeast region currently relies on Lao PDR approximately 68 per cent, self-generated within the region, 28 per cent and imported from the North and Central region 4 per cent. Consequently, these areas lacked self-rely in term of energy usage and have extensive feasibility to confront an energy shortage in the future. Due to the new industrial settlement which going to located in Ubon Ratchathani, which lead to the significant electricity demand increased in 2022. Moreover, numerous agricultural residues have produced every day, which cause a problem in term of environmental aspect. Therefore, this dissertation proposed to solve the electricity problem while fixing the ecological problem by reducing agricultural wasted. As a result, the biogas generation seems to be the result to fix both issues. Also, this dissertation is intended to optimise the system to have the most proper model that concludes with various criteria. For instance, a renewable fraction of at least 50 per cent, use feedstock at least 70 per cent from overall, financial feasibility, and environmental aspect. Hence, HOMER has chosen as a program for the simulations section.

Even though, HOMER can present the result from simulating in various aspect such as technical, environmental, and financial. However, the software still has some constraint such as social impact aspect and limitation on the type of power generation component. Besides, the model of NGCC plant does not exist in the software; also, some input parameters for simulation are in lack of specific essential data. For example, demand profile from new industrial settlement and biomass resource potential. Therefore, there is a need to assume some parameter based on the data from another location to complete the most accurate outcomes as much as possible.

According to the results of this dissertation, there are 3 cases (excluding the base case) that use HOMER to simulate to get the most feasibility case in term of a technical perspective. These cases classified by type of feedstock, therein Case one, two, and three use feedstocks: Cassava, Rice and Paddy, and Sugar Cane, respectively. Each case contains the various size of NGCC plant and biogas generator with the same electricity demand quantity. According to the outcomes, all cases with the biogas generation gain advantage to the environmental aspect due to the decreasing percentage of CO2

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emissions. On the other hand, the obstacle to achieving this project to solve a lack of reliable energy source and organic wasted would be a financial and social issue. Later on, there is a list that summarises the main overview of this dissertation.

- During winter, the efficiency of biogas generator seems to be decreased due to the daily temperature.
- Biogas generation is the mains electricity supply for case 2 and 3, especially during summer. However, in between 11 a.m. to 12 p.m., and 7 p.m. to 9 p.m. biogas generator and NGCC plant will support each other to meet the electricity demand.
- Even though emissions such as CO_2, CO, and particle can decrease by gaining renewable fraction. However, the cost of energy and initial capital cost also increase inversely to the emissions percentage.
- Case 2 and 3 appear to be feasible for the northeast region or to be specific Ubon Ratchathani. However, the best choice in term of financial, and emissions seem to be case 2.

To sum up, 4 cases of Ubon Ratchathani including base case can be illustrated that case 2 with a renewable fraction of 54.3 seems to have the most possible and suitable system refer to objective of the dissertation. Moreover, this system has the potential to be developed in term of efficiency and dispatchable; if the government subsidy for the system. Lastly, this dissertation may have some drawback due to the constraints stated before. So, the next chapter will demonstrate the suggestion to improve this dissertation for better realistic and usable.

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6. Future Work

According to the constrain of this dissertation whether it is input data for simulation or limitation of the software, which make the reliable of the result is drop. However, the list below illustrates a way to improve this dissertation.

- **Location of Biogas Generation** – For additional development, the suggestion of exact locations for installing biogas generation should be stated and estimated under the distance from feedstock resource to decrease the cost of delivery. Also, social impacts should be considered to avoid the issue with community.

- **Sensitivity analysis** – Only three types of feedstocks used in this project, sensitivity analysis of their feedstock should demonstrate another result for another size of electricity demand.

- **Accurate parameters** – In this project, there are many fixed and assumption value such as daily biomass resource, electricity demand profile, and other financial value. In order to have a more accurate number, the input data should import from the actual source.

- **Energy Storage** – There is no energy storage in this dissertation. Energy storage such as a lithium-ion battery or digestion tank can help the supply system to decrease the energy excess and dispatch it later.

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