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Business Model Innovation as a Facilitator of Biogas Diffusion in the Taiwanese Swine Industry

Rongyu Veneta Tzeng

Supervisor

Philip Peck

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Tel: +46 – 46 222 02 00, Fax: +46 – 46 222 02 10, e-mail: iiiee@iiiee.lu.se.

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"NOW GO; I WILL HELP YOU SPEAK AND WILL TEACH YOU WHAT TO SAY." –

EXODUS 4: 12

Abstract

This thesis is designed to explore the use of biogas in Taiwan and identify the barriers to biogas diffusion and is conducted with a focus on the swine industry, the major actor involving in biogas production in Taiwan. The Business Model Innovation (BMI) framework is proposed in this study to overcome the barriers through facilitating key business model (BM) elements in the swine industry. The research is done through a series of literature reviews and in-depth interviews with stakeholders as well as a case study of a renewable energy company (Taiwan New Energy Co.) with new biogas BM.

The barriers underlined in this study are the economical, infrastructure, and institutional barriers. The study argues that in swine farms, the root cause of these barriers to biogas diffusion is "incomplete BM" that features value proposition discrepancy between BM elements (value propositions and financials) and between stakeholders (farmers and the government) as well as weak partnership networks. The results reveal that BMI can help to address the root cause by strengthening cross-sectoral collaboration (e.g. the energy and agricultural sector) and to enhance the possibility of turning biogas into a disruptive niche to alter the current socio-technical system of high carbon and energy dependence as well as to contribute to sustainable agriculture.

Policy recommendations from this study for biogas development are (1) strengthening the value proposition of biogas; (2) altering the swine farming practices inadequate for biogas production; (3) developing partnership networks between biogas stakeholders; and (4) formulating supportive agricultural policies. Researches on other biogas sources such as municipality waste are also needed for further biogas development and future waste management development in Taiwan.

Keywords: Biogas, Business Model, Swine Industry, Multi-Level Perspective

Executive Summary

Background and Problem Definition

The increasing energy demand and the urgent need of reduction on greenhouse gas emissions (GHG) have been brought into the global spotlight (IEA, 2015). Under this context, biogas has become a promising solution that helps to provide renewable energy source, mitigate GHG emissions, improve waste management, and enhance the use of resources among multiple sectors (Weiland, 2010; Ericsson et al., 2013).

According to World Resources Institute, in 2016, the energy and agricultural sector, as two of the major GHG contributors in the world, account for over 80% of the global GHG emissions together. The application of biogas in agricultural sector can not only help the sector to reduce the pollution and supply extra energy but also can recycle the nutrients from the waste. However, the complexity of biogas technology and its cross-sectoral nature have impeded the further diffusion of biogas with various challenges, including economical barriers, infrastructure barriers, institutional barriers, etc.

In Taiwan, there is a rising interest in livestock industry to adopt the biogas production. However, the lack of policy analysis and comprehensive industry investigation of biogas sector in Taiwan make it difficult to predict the development of biogas in the long run.

Purpose Statement and Research Questions

The study is conducted to review the current biogas development in Taiwan with a focus on the center of Taiwanese biogas policy—the swine industry as swine industry has been a major water pollution source in Taiwan for decades. The aim is to explore possible pathway of accelerating the biogas diffusion and consequently contributing to the low carbon transition, sustainable agriculture development as well as pollution reduction in Taiwan. In this, the paper addresses research questions as follows:

RQ1: What are the barriers that hinder the diffusion of swine industry's biogas system in Taiwan?

RQ2: How does BM innovation help to overcome barriers to biogas diffusion in Taiwan?

Research Design and Methodology

In order to provide warranted results, the research utilizes a triangulation approach and investigates the question by several complementary methods.

With regard to RQ1, literature analysis and in-depth interviews are conducted to underline the barriers. The literature is built on twofold. The multi-level perspective (MLP) framework is used to understand the holistic socio-technical system of biogas (under current energy and agricultural sector), while to answer RQ2, business model (BM) theory and BM innovation is proposed as the solution to overcome the existing barriers to biogas diffusion in Taiwan. Lastly, a case study of renewable energy company in Taiwan– Taiwan New Energy Co. is presented to exemplify the findings of the study.

Findings RQ1: What are the barriers that hinder the diffusion of swine industry's biogas system in Taiwan?

In combining literature analysis and qualitative interview analysis of interviewees from swine farms, energy companies, academic institutes, politicians and other stakeholders, three types of barriers are highlighted in biogas sector. They are economical barriers, infrastructure barriers, and institutional barriers. Economical barriers are stemmed from the cost of investment, maintenance and human resource, immature market, and low feed-in tariff (FiT). The infrastructure barriers are caused by inadequate biogas generators, insufficient anaerobic (AD) digestion capacity, and the lack of technical supports whereas the institutional barriers come as a result of ineffective wastewater regulation and farming practices inadequate for biogas production.

The study also suggests that the attribution of responsibility should be redefined among the government, the energy and agricultural sector in order to more effectively address these barriers. For instance, it is argued that the economical burdens of the farmers should be apportioned by the government as well as the energy sector that have more accesses to crucial information and knowledge of biogas production.

Findings RQ2:

To explore RQ2, the study provides a series of rationale from the barriers identified to the relevant BM elements and then to how these elements can be facilitated and bring the biogas technology to a "disruptive level" to change the stagnation of biogas development in Taiwan. The study firstly points out that the root cause of these barriers is the "incomplete business model" of biogas, which is the result of (1) value proposition discrepancy between BM elements and between stakeholders and (2) weak partnership network throughout the biogas supply chain. In view of the complexity of biogas production, we propose that this problem can be solved through strengthening cross-sectoral collaboration. The study argues that close collaboration between energy sector (renewable energy company) and agricultural sector (swine farms) can create synergistic effect of policies through helping farms to reduce economical barriers and to supply renewable energy with stable biogas sources as well as narrow the value proposition discrepancy.

The case study of Taiwan New Energy Co. BM further exemplifies the findings from the literature analysis and the qualitative interviews. Collaboration between the energy and agricultural sector is built up under the new structure of biogas BM (business model innovation). The new BM takes on the economical burdens (the cost of biogas investment, maintenance and human resources) and technical burdens (biogas plant selection, digestate testing, etc.) that is borne by the farmers in existing biogas BM. Additionally, the renewable energy company helps to develop the network between upstream (e.g. biogas equipment suppliers) and downstream stakeholders (e.g. bio-fertilizer buyers). Last but not least, this BM innovation also features the strategic niche management as the company also views the biogas plant as an experimental plant to test biogas technology.

Recommendations

To further promote the diffusion of biogas in Taiwan, policy recommendations suggested by this study are (1) to strengthen the value propositions of biogas through differentiating value proposition among farms of different sizes (e.g. energy generation for larger swine farms and waste management for smaller ones) and formulating holistic biogas policy guideline covering related sectors (e.g. not only the energy and agricultural sector but also other sectors such as transport and waste sector); (2) to encourage swine farmers to alter the inadequate farming practices such as Swine House Washing, and shift solid-liquid separation from before the anaerobic digestion to after to increase the biogas production; (3) to develop biogas partnership networks between stakeholders such as farmers, renewable energy company, and academic institutes to increase the sharing of information and reducing the risk of investment; (4) to formulate supportive agricultural policies such as helping farmers to make loans for biogas plant and designing regulatory framework for digestate use to support the agricultural production.

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Abbreviations

AD	Anaerobic Digestion
BM	Business Model
BOD	Biochemical Oxygen Demand
CHP	Combine Heat and Power
COD	Chemical Oxygen Demand
EUR	Euro
FiT	Feed-in Tariff
FMD	Foot-and-Mouth Disease
GHG	Greenhouse Gas
GWP	Global Warming Potential
kW	Kilowatt
MLP	Multi-Level Perspective
NTD	New Taiwanese Dollar
PV	Photovoltaic
Taipower	Taiwan Power Company
WTO	World Trade Organization
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change

1 Introduction

Transition towards a Low Carbon Society

The global energy demand is rising and the greenhouse gases (GHG) in the atmosphere also increase rapidly (IEA, 2015). The major GHG emission contributor is the fossil fuel-derived carbon dioxide (CO_2) and even though other types of GHGs such as methane (CH_4) and nitrous oxide (N_2O) account for lower percentage of global GHG emission, their contribution to global warming is still considered significant due to the high Global Warming Potential (GWP)[1].

According to World Resource Institute (WRI), in 2016, the energy and agricultural sector together globally account for over 80% of the GHG emissions (70% and 10% respectively), followed by industrial processes (6%), land-use change and forestry (6%), waste (3%) and bunker fuels (2%). CO_2, CH_4, and N_2O are mainly emitted and enter the atmosphere through the production or combustion of fossil fuels (CO_2 CH_4 and N_2O), agricultural practices (CH_4 and N_2O), the decay or combustion of organic waste from municipal solid waste (CH_4 and N_2O), and industrial activities (N_2O) (USEPA, 2017). In addition, the security of energy supply is another challenge for global energy market as the conventional oil and gas reserves are mostly located in politically unstable areas (Weiland, 2010).

United Nations Environment Programme (UNEP)'s Emissions Gap Report in 2015 points out that while the current commitments by the governments are insufficient to keep the global temperature rise below 2°C. Therefore, to reduce the global warming and climate change speed, the level of GHG emission should be cut to less than half of the emission level in 1990. It is also highlighted by the report that an increased renewable energy and enhanced energy efficiency in transport, industry and buildings are critical to close or narrow the gap as these sectors account for 40% of the global energy consumption.

Under this context, biogas serves as a versatile renewable energy source derived from wastes, residues, and energy crops (Weiland, 2010), which can be used as an alternative of high carbon energy sources to mitigate the GHG emissions (Nielsen et al., 2002). Holm-Nielsen et al. (2007) further indicates that in European Union (EU), at least 25% of the bioenergy would be generated from biogas production through wet organic materials, including wet organic food, feed residues, animal manure, crop silages, etc. On the other hand, biogas plays an increasingly important role to reduce pollution from the waste through recycling of organic waste (e.g. animal manure, municipal waste, etc.) (Weiland, 2010; IEA, 2015). Businesses from various sectors such as agriculture, utilities, transportation and waste management are also seeking opportunities to increase the resource efficiency (Ericsson et al., 2013). Moreover, the by-product of biogas production, digested slurry (bio-fertilizer) could provide bio-fertilizer while reducing the odor comparing to conventional slurry (Lantz et al., 2007). Last but not least, biogas can not only offers a fuel for local security of energy supply but also associated economic activities and local employment (IEA, 2015).

The cross-sectoral nature of biogas production has created certain situation for biogas diffusion. Multi-level analysis involving various levels of socio-technical systems has been described by analysts such Geels, Kemp and Verbong in their studies. The study utilizes the multi-level perspective framework (MLP) considering its comprehensiveness to provide an

[1] Global Warming Potential (GWP) was developed to compare global warming impacts of various greenhouse gases based on radiative efficiency (the ability to absorb energy) and lifetime (how long the gases will stay in the atmosphere). GWPs of the gases are estimated relative to the emissions of 1 ton of CO_2. The larger the GWP, the more a given gas warms the Earth over the period of time.

overview of biogas development in Taiwan with the business model analysis to further analyzing the biogas producer's core activities.

1.1 The case of Taiwan: a High-Carbon Economy

Taiwan, as a developed as well as one of the most populated countries in Asia (3rd highest) and even in the world (17th highest), around 98% of the country's energy sources are imported from abroad (Table 1-1), indicating the high energy dependency (Energy Yearbook, 2015). The composition of imported energy also reveals the country's heavy reliance on fossil fuel and coal. In 2015, to address this problem and to move toward a society of low carbon energy production with sustainable industry practices, the Taiwanese government reset the goal of renewable energy capacity three times higher than the original goal (Energy Year Book, 2015). The capacity goals of different renewable energy are listed in Table 1-2. These goals are set under five principles, which are focusing on (1) best available techniques; (2) conducting cost and benefit analysis; (3) developing step-by-step transition; (4) balancing industrial development and (5) enhancing public acceptance of electricity prices.

Table 1-1 Energy Structure in Taiwan

		Energy source	Percentage	Tons of oil equivalent
Total			100%	14,508.42
	Imported		**98%**	**14,195.36**
		Coal	29%	4,255.32
		Oil	48%	6,989.06
		Natural gas	13%	1,894.77
		Bioenergy and waste	0.00%	0.01
		Nuclear power	7%	1,056.20
	Domestic		**2%**	**313.06**
		Oil	0.01%	0.92
		Natural gas	0.23%	33.22
		Bioenergy and waste	1.39%	201.93
		Hydro power	0.29%	42.73
		Solar photovoltaic and wind	0.16%	22.90
		Solar thermal	0.08%	11.35

Source: Taiwan Energy Yearbook, 2015

Table 1-2 Capacity Goals of Renewable Energies in Taiwan

Renewable energy	Estimated Capacity Goals for 2030 (MW)
Solar power	8,700
Wind power	5,200
Hydro power	2,200
Bioenergy	950
Geothermal power	200

Source: Energy Year Book, 2015

Bioenergy: the Intersection of Agriculture and Energy Security

The agricultural sector in Taiwan has high productivity and most of the farmlands are intensively cultivated (Kung et al., 2013). Some areas are cultivated with double or triple planting a year while only a quarter of the land area is arable (Kung et al., 2013). Taiwan once exported a large amount and variety of agricultural products (e.g. frozen pork, tuna, processed eel, fresh and frozen vegetables, sugar, tea, and rice). Therefore, it was impossible to use the arable land for bioenergy use as it was heavily cultivated for other agricultural products (Kung et al., 2013). However, after the involvement of the World Trade Organization (WTO) and a much slower agricultural growth (comparing to other rapid industrial growth like information technology industry), the use of cropland experienced a decrease from 830,000 to 280,000 hectares, constituting a one-third production reduction from 2001 to 2013 (Chen et al., 2009). The increasing idled lands brought about the potential feedstock production for energy use yet Chen et al. (2009) pointed out that the use of energy crop might compete with other existing agricultural policies that subsidized domestic food crops productions, including soybeans, black beans and sugarcanes.

Biogas Potential in Taiwan

In Taiwan, swine production has the dominant position of the livestock industry and accounts for around 90% of total feeding livestock production, followed by dairy cattle and goat (Table 1-3). In 1996, the production of swine reached up to 10 million (Figure 1-1). Regarding the potential of bioenergy derived from livestock, according to Tsai & Lin (2009), the swine industry possessed the greatest potential for methane generation among all other livestock animals in Taiwan. As the swine industry currently accounts for over 90% of the total methane generated in Taiwan, the potential of generating biogas from the livestock industry is far-reaching.

Table 1-3 Heads of livestock in Taiwan

Livestock	1990	1995	2000	2005	2010	2015
Dairy cattle (Holstein or cow)[2]	90,798	124,365	136,514	122,457	122,983	132,009
Non-dairy cattle	41,564	27,577	17,419	11,384	13,175	15,059
Buffalo	21,876	12,883	7,767	4,101	3,844	2,311
Swine[3]	8,565,250	10,508,502	7,494,954	7,171,536	6,185,952	5,496,216
Goat[4]	172,990	318,751	315,045	263,542	204,854	156,045

Source: Taiwan Livestock Yearbook, 2015.

[2] Including yellow and hybrid cattle
[3] Including meat hog, breeding hog, and piglets
[4] Including meat goat and milk goat

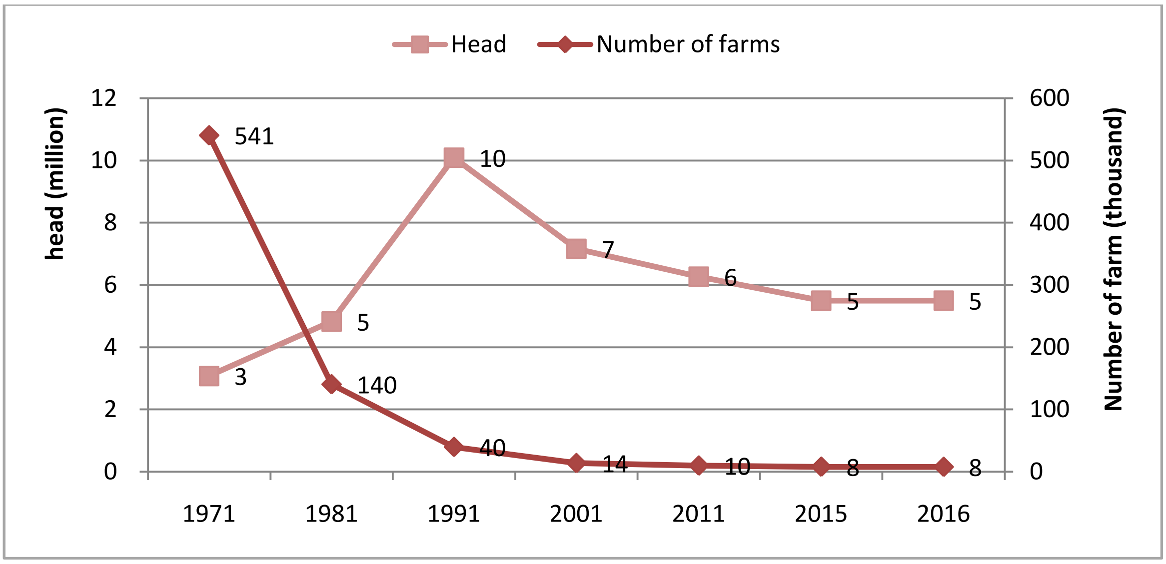

Figure 1-1 Swine Production and Numbers of Farm Change in Taiwan

Source: COA, 2016

1.2 Problem Definition

Nowadays, economic profitability, technological issues, lack of infrastructure and the incumbent utilities' lock-in effect present the most critical challenges for biogas diffusion (Lantz et al., 2007; Wainstein & Bumpus, 2016).

Financially, Lantz (2013) points out several reasons that prevent biogas plant (in Sweden) (Germany) from satisfying financial returns, including rather small market share, low prices, short-term subsidies in investment, production and market phases as well as weak perception of social benefit. High upfront (initial) investment has placed noticeable barriers to biogas production (Lantz et al., 2007). However, in some countries such as Denmark, the increasing (almost doubled) treatment capacity started to reduce the investment costs by 12% (Junginger, 2005; Maeng et al., 1999) in certain type of biogas plants (centralized co-digestion plants).

Technically, IEA (2016) report highlights that to reduce investment and operating costs as well as increase the revenue, there is a need to improve process steps in biogas production procedure, especially at small sized farms. Also, wide variation of feedstock and local conditions as well as the lack of proper parameters to control biogas production process make reliability and stability of biogas production process (especially anaerobic digestion process) more fragile (Weiland, 2010).

Moreover, Huttunen et al. (2014) indicates that how a supportive policy on biogas production might be made inefficient by other sectors' unsupportive policies. While biogas technology rises at the intersection of agriculture and energy sectors, the wide range of sectors biogas involves including energy, agriculture, and waste management inevitably complicates the situation. Biogas policies introduced by different sectors (energy or agricultural sectors) could produce changes in multiple sectors. In other words, "reverse support" from other sectors (e.g. lobbying from major incumbent companies that dominate conventional electricity production) might decrease the effectiveness of biogas policy or renewable energy.

Lastly, in Wirth et al. (2013)'s empirical study, it argues that the interplay of the support from public sector for renewable energy technologies and the cultural or professional embeddedness of farming practices (or informal institutions) play important roles on the establishment and operation of biogas plants.

Stagnation of Biogas Development in Taiwan

Many Taiwanese swine farms had once adopted biogas plant 20 years ago in accordance with wastewater regulation and incentives for biogas production (subsidies for biogas plants in swine farms). It was estimated that 1,000 biogas plants were established during that period (I1). However, most of the plant operations were forced to stop due to technical issues such as low power generation efficiency, corrosion of machines, lack of machine maintenance knowledge and other problems. The lack of durable and cheap biogas equipment has caused the cost of biogas power generation plant a great burden for biogas producers (high upfront cost with low life span) (Su, 2016). Furthermore, the farming practices and existing biogas production procedure in Taiwan drive up the production cost and reduce the efficiency (Su, 2016). These problems thus impede the continuous use of biogas in Taiwan. Nowadays, there are only 3% of the swine farms (around 200 biogas plants) still keep the biogas production running and most of them are in a small scale (Wealth Magazine, 2016) without power generation. Therefore, the study is designed to explore the biogas sector in Taiwan with a comprehensive methodology.

In view of the barriers and gaps mentioned above, Business Model (BM) analysis (motivation, profitability, etc.) comes as one of the most discussed method to investigate biogas or renewable energy in general (Engelken et al., 2015). BM dynamics and innovations on renewable energies are fairly new and mainly focusing on Northern European countries like Germany, the Netherlands and Sweden, while researches on renewable energy BM in other developed countries in Asia rarely exist. Due to the context specific feature of biogas, it is difficult for one country to duplicate the renewable energy experiences from the other without taking its political, technological, farming contexts into consideration. This is especially the case for biogas, a renewable energy source profoundly connected to local conditions. Therefore, BM of biogas producers (swine farms and renewable energy company) in Taiwan is underlined to understand the question of what are major revenues/costs, key activities, who are target customers, how is the value of the business delivered to the customer, etc.

Additionally, since academic literatures of biogas development in Taiwan is usually examined in terms of technology while the biogas policy analysis mostly appears in gray industry literatures, the interrelations between different actors in Taiwanese biogas sector are not yet carefully studied. The lack of comprehensive map of biogas sector results in poor policy implementation, misunderstanding between stakeholders, and uncertainty for potential investors. Therefore, before going into the biogas BM analysis, Multi-level Perspective (MLP) framework was selected to analyze the major sectors involving in biogas production, which are agricultural sector and energy sector in Taiwan. The author identifies the biogas key actors, their interactions, and tensions as well as barriers to biogas diffusion under the MLP framework to build up the foundation for the latter BM analysis.

In this study, the author aims to provide insights of current policy, industry, academic contexts of biogas and suggestions to address the existing barriers to biogas diffusion in Taiwan. Ultimately, the study also hopes to enlighten the Taiwanese biogas development in other sectors such as waste management sector (e.g. municipality waste).

1.3 Objective & Research Questions

The objective of this research is to understand the relationship between biogas and sustainable agricultural practices and to identify the barriers of current biogas diffusion in Taiwanese swine industry as well as to explore the potential of tackling the barriers through emerging BM. The ultimate goal of this study is to explore the possible pathway of low carbon transition, sustainable agriculture and pollution reduction in Taiwan.

Research question

Can BMI facilitate biogas diffusion in Taiwan?

RQ1: What are the barriers that hinder the diffusion of swine industry's biogas system in Taiwan?

RQ2: How does BM innovation help to conquer barriers to biogas diffusion in Taiwan?

1.4 Research Approach

Multi-Level Perspective (MLP) is selected as the foundation of the research framework since MLP framework is particularly useful to interpret the energy and agriculture sustainable transition (Elzen et al., 2002; Verbong & Geels, 2007; Verbong & Geels, 2010) due to their extensive scale and significance in society (Urry, 2014). In addition to identify actors and dynamics in sectors (regimes) through MLP, to make more proactive move, the research also incorporates the BMI (e.g. drivers, barriers and opportunities), to examine how niche-regime dynamics can influence transition and shift to sustainability from the market aspect. The systemic problem category by Negro et al. (2012) is also utilized to identify the barriers to biogas diffusion in Taiwan.

To answer the research questions, a qualitative research method is adopted, including literature review and in-depth interviews. Literature review covers literatures of MLP, BMI, renewable energy sector (energy regime) and biogas from livestock industry (agriculture regime). Since there is very few information about swine farming practices related to biogas productions in Taiwan, the in-depth interviews were conducted to complement the gaps discovered in literature reviews such as swine farming practices, biogas supply chain, etc. In order to have a holistic view of biogas development, the study aims to balance the interviewees through selecting swine farms from different regions (City, County, and Municipality), different farm sizes (Large, Medium, Small) and level of biogas involvements (non-adopter, adopter with biogas power generation, adopter without biogas power generation, etc). For large swine farms, it was easier to target the interviewees since there are only few large size swine farms involving in biogas production. For small and medium size swine farms, the interviewee pool was derived from an online swine farm database[5].

Seventeen in-depth interviews are carried out during January and May 2017 in Taiwan (personal interview) and in Sweden (Skype interview). Interviewees include: (1) owner of a large swine farm adopting biogas production (has adopted biogas technology twice: one in 1980s for few years with old technology and abandoned the plant due to technical problem; the other is from 2011 till now); (2) informant of a large swine farm without biogas involvement; (3) owner of a small scale swine farms with/without biogas involvement; (4) vice general manager/engineer of renewable energy company providing biogas total system solution to swine farms; (5) scholar who has been involved in Taiwanese agricultural biogas

[5] On-line swine farm database in Taiwan (in Chinese): http://pigbase.angrin.tlri.gov.tw/pigfarm/farm.htm

technology development and its diffusion as well as engaging in various biogas-related policy making process as a consultant; (6) NGO researchers involving in Taiwanese circular economy and biogas development.

Six unstructured interviews with interviewees inaccessible by the author are also included in this research. Opinions of these interviewees were obtained through the help of the author's social networks (e.g. friends and relatives who were acquainted with the interviewees).

1.5 Scope & Limitation

The research is to examine the interplay of biogas production actors: energy sector and agricultural sector in a qualitative fashion. The study narrows down to swine industry in agricultural sector since swine industry accounts for the majority of Taiwan's livestock production and has been at the center of biogas-related policies in Taiwan in the past 20 years. Furthermore, the need of reform in Taiwanese swine industry makes the sustainable agriculture transformation and low-carbon energy transition. (Self-sufficient energy supply, low chemical uses,

Considering the limited time and the focus of this paper (Taiwan) as well as given that the different economic, political and financial capacities between developed and developing countries, the issues in this paper are discussed specifically under the context of developed countries. However, it is undeniable that some of the results are more generalized and could be applied to most of the countries in the world.

The biogas technology involves a wide range of discussions. By considering the biogas development in Taiwan is still at its early stage, the main focus of this study is on the biogas plant diffusion in the society instead of other most discussed issues such as biogas upgrading in some developed countries.

A major limitation of this study lies in the data collection process of unstructured interviews conducted by the author's social network like friends and relatives (intermediary) instead of by the author herself. These indirect interviews are utilized due to farmers' concerns over business confidential information and cross-contamination (some farms only let people who they are acquainted with to visit swine house). This approach may results in misunderstanding or misinterpretation because of the intermediaries' limited knowledge of biogas.

The minor limitation is the language barrier. Chinese and Taiwanese which were used to carry out the interview in the study may cause challenges to the accuracy of semantic delivery and expression in English. However, this can also be regarded as a strength that the work was carried out in relevant local languages. This may truly present what the interviewees really said, consider, and the nuances of meaning can be correctly interpreted by the author.

1.6 Ethical Consideration

The author maintained due diligence with regard to the theoretical and imperial implication of this research. While this research was written through involving the case study company, Taiwan New Energy Co., the author didn't receive any financial benefit to promote its business.

With respect to the confidential treatment of primary data sources, interview contents from farmers were anonymized prior to publication. If the interviewees permitted the author to make audio recording, the recorded contents were used only for academic purposes and would not be shared with third parties.

1.7 Target Audience

The intended audience of this paper is listed as follows:

1. Units involving in supplying biogas plants, biogas production and potential investors who have great interests in biogas production such as farms, energy companies or external investors (e.g. commercial banks) yet have limited knowledge of biogas production supply chains.
2. Administrative and legislative units to explore the empirical implementations and outcomes of renewable energy and biogas related policies and regulations.
3. Academic units that are interested in the application of MLP and BMI.

1.8 Outline

The paper is structured as follows:

Chapter 2 provides the context of MLP and BM theory with a particular focus on renewable energy in general and biogas.

Chapter 3 covers the research design, methodology and literature review. Attention is given to the rationale of data collection and data analysis including literature analysis and in-depth interviews.

Chapter 4 presents the results of this paper. Firstly, the current socio-technical system of biogas is presented under the structure of MLP. Secondly, the main barriers of biogas diffusion are summarized.

Chapter 5 raises discussions from the previous results and displays the specific observations by the authors throughout the research period. It discusses the root causes of biogas diffusion barriers in Taiwan and proposes the potential solutions to them. A biogas case study is presented to support the solutions proposed.

Chapter 6 summarizes the results and discusses and provides recommendations for policy makers and future research as well as reflects on the research method.

2 Background and Literature Analysis

Biogas, an energy source involving in multiple sectors, the comprehensive understanding of related sectors and their interplay is therefore crucial. In this study the multi-level perspective (MLP) framework is utilized to map the biogas development within Taiwanese swine industry, which encompasses the most biogas potential and has long been the target of the biogas policies in Taiwan. MLP helps to underline the important items of biogas in agriculture and energy sectors. Business model innovation (BMI) is used to investigate the swine industry's biogas business model (BM) (e.g. supply chain, stakeholders) in order to identify the motivations for the stakeholders (the government, farms and renewable energy company) to involve in biogas production. The innovation of BM in swine industry is brought to the center of discussion as a disruptive innovation niche to open the window of opportunity for biogas diffusion in Taiwan through enhancing the convenience, accessibility and affordability.

In this chapter, the characteristics of biogas, theoretical framework of MLP and BM theory is explained as well as the importance of BM in a society moving toward sustainability. The BM of current biogas system under MLP framework will be presented in chapter 4 and the detailed analysis and discussion of BM as biogas technology facilitator in chapter 5.

2.1 Biogas

Comparing to other types of biofuels, biogas possesses not only the potential of strengthening the energy independence but a measure to improve waste management. For sustainable development, biogas technologies provide a promising solution with the ability to contribute to the reduction of several problems such as generating low carbon energy and bio-fertilizer, while reducing the methane emissions from waste. It also improves to improve food and energy security as well as waste management and sanitation (World Biogas Association, 2016).

In a review conducted by Biogas Research Center (2016), the benefits of biogas are placed into four categories, which are biogas, digestate, treatment, and concept. Most of the benefits are connected to the biogas and digestates as an alternative to waste treatments. The detailed benefits provided by Biogas Research Center of each category are listed in Table 2-1.

Table 2-1 Categorization of biogas benefits

BIOGAS	DIGESTATE	TREATMENT	THE CONCEPT
1. Renewable energy	1. Balanced crop rotation	1. Treating waste water	1. Increasing research and innovation
2. Sustainable energy supply	2. Less pesticides used in agriculture	2. Hygienising waste	2. Moving towards a circular economy
3. Energy efficient to produce	3. Improving soil structure	3. Treating organic waste	3. Exporting technology
4. Producing fossil free fuel	4. Increasing yield for farmers	4. Increasing resource efficiency	4. Increasing employment
5. Producing heat and power	5. High content of ammonium	5. Reducing methane from landfills	5. Increasing economic growth
6. Self-supply of energy for the nation	6. Enabling organic farming	6. Reducing methane from manure	6. Increasing small scale biogas solutions for cooking and power
7. Reducing CO2-emission	7. Less eutrophication		7. Developing rural areas
8. Less NOx	8. Circulating nutrients (not sure)		
9. Less Particles	9. Producing fertilizer		
10. Less noise	10. Reducing use of mineral fertilizer		
	11. Reducing odor		

Source: Biogas Research Center, 2016

2.1.1 Biogas Production

Biogas produced through anaerobic digestion (AD) provides significant advantages over other types of biofuel since it has been evaluated as one of the most energy-efficient and environmentally beneficial technology for bioenergy production (Fehrenbach et al., 2008). From a historical perspective, animal manure and sewage sludge from wastewater treatment have long been associated with anaerobic digestion (Weiland, 2010). The simple overview of biogas production from waste and residues as well as nutrient recycling is presented in Figure 2-1.

Raw biogas is composed of basically methane and carbon dioxide. It also contains small amounts of hydrogen sulfide (H_2S), ammonia and water vapor. The sources of biogas are mainly from organic wastes residues, and energy crops. The common practices of producing biogas are either wet or dry fermentation systems (Weiland, 2010). Since the biogas produced during co-fermentation of manure with energy crops or harvesting residues usually contains H_2S from 100-3,000 ppm, desulfurization of biogas is also crucial in the biogas production process to prevent damage of gas utilization units.

In addition, the digestate formed during the anaerobic fermentation is valuable output of biogas production process since it constitutes a bio-fertilizer with increased availability of nitrogen. Digestate used as fertilizer for agricultural purposes is regarded as the most sustainable utilization of digestate as it helps to reduce the pollution and contributes to limited natural resource use (e.g. fossil resources of mineral phosphorus) (Wellinger et al., 2013). However, the quality of digestate for agricultural use needs to be high and not containing harmful substances such as pathogens or other pollutants. Thus there have been regulatory frameworks to ensure the high quality digestate in countries like Germany, Sweden, Denmark, Austria, and Switzerland (Wellinger et al., 2013).

Furthermore, comparing to the traditional high carbon energy production, biogas has more complex production involving a wide range of actors according to the location of biogas plants. The biogas production binds with the daily farming practices and the energy generated from biogas as well as by-products (e.g. digestate and sludge) has changed the farms' business models by bringing about the extra incomes and new partnership within the biogas supply chain.

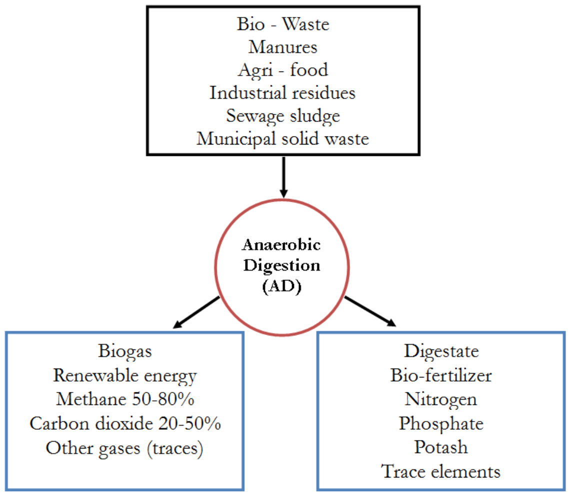

Figure 2-1 A Simple Overview of Biogas Production

Source: Lukenhurst et al., 2010

2.1.2 Biogas Utilization

Biogas is normally used as combined heat and power (CHP)[6] through gas or dual fuel engines; micro turbines and fuel cells (Weiland 2010). CHP and fuel cells have comparatively high electric efficiency while micro turbines has the advantage of good part loading efficiency and long maintenance intervals (Weiland, 2010).

The utilization of biogas through upgrading is increasingly important since the gas can be used more efficiently in terms of energy efficiency as well as the possibility of storing the energy so that it can be used whole year round. Upgraded biogas can be injected into the grid like natural gas grid or as vehicle fuels. There are several biogas utilization purposes (Table 2-2). European Union (EU) countries like Germany, Sweden, and Switzerland have defined the biogas injection to natural gas grid standards. The injection of biogas into grids or being used as vehicle fuels imply the necessity to further remove certain contents in biogas such as carbon dioxides, bacteria and molds in order to prevent risks for human health and equipment (Wempe & Dumont, 2008; Weiland, 2010).

Likewise, the utilization of biogas can vary from country to country which has a clear correlation with financial support system of the given country (IEA Bioenergy, 2014). For instance, FiT for electricity in UK and Germany has created economic advantages for generating electricity from biogas, while in Sweden the tax exemption lead to that most of the biogas is used as vehicle fuel (IEA Bioenergy, 2014).

Table 2-2 Biogas Utilization Purposes

1. Heat and/or steam
2. Electricity with combined heat and power production (CHP)
3. Industrial energy source for heat, steam and/or electricity and cooling
4. Upgraded and utilization as vehicle fuel
5. Upgrading and injection to the natural gas grids
6. Fuel for fuel cells
7. Production of chemicals and/or proteins

Source: Born, 2005; Persson et al., 2006; Kristensson et al., 2007; Holmnielsen, 2009

[6] Combined heat and power, also known as cogeneration is the use of heat engine or power station for electricity generation and useful heat at the same time.

2.2 Multi-Level Perspective Framework

Multi-level perspective (MLP) is a conceptual link between large-scale socio-technical system and micro-level innovation processes, which has become a popular framework to understand the socio-technical shift and drivers and actors behind the shift (Geels, 2012; Smith et al., 2010). The definition of socio-technical regime can be traced back to Rip & Kemp (1998) as 'rules where the technology is embedded'. Geels (2011) underlines three elements for regime, which are actors, systems, and rules or institutions. MLP is mostly used to stress on historical assessment (Genus & Coles, 2008) and the variation of regimes scale is also significant, depending on the technology itself (Geels, 2005). According to Geels & Kemp (2007), a regime is not confined in single sector and the research on regimes has been changing from single sector (Geels, 2004) to a broader view, involving multiple regimes. This trend is especially crucial when it comes to transitions toward sustainability (Raven, 2007). By keeping these in mind, interactions within or inter regimes thus are thus highlighted. Key terms of MLP are presented and the nature of interactions is visualized (Figure 2-2) in the following subsections:

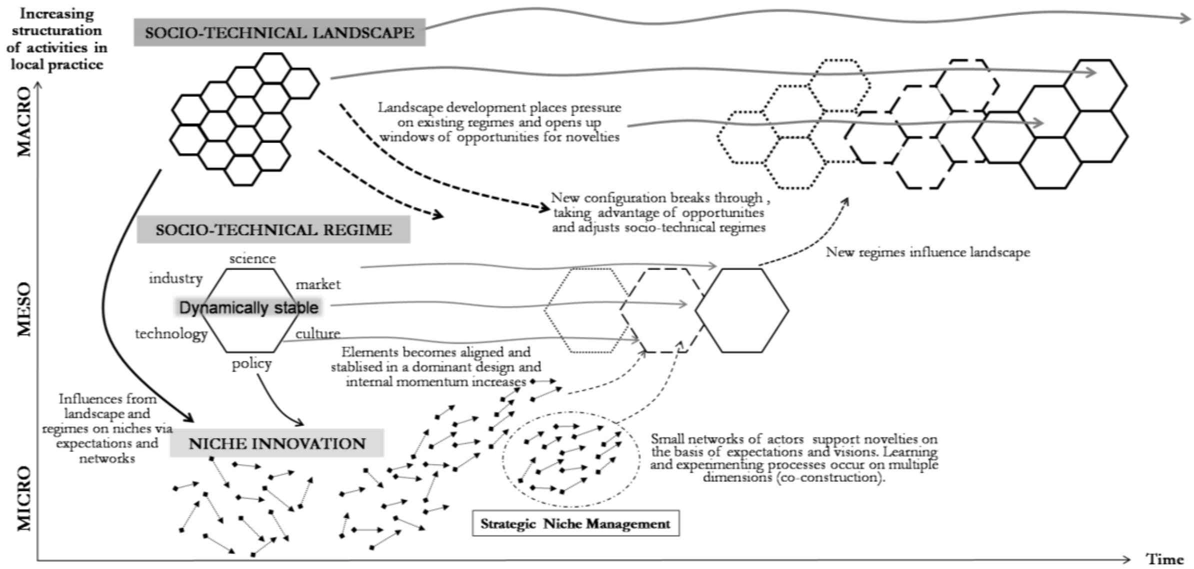

Figure 2-2 Conceptualization of the MLP Framework on Transitions

Source: Adapted from Geels, 2002, p. 1263

2.2.1 Landscape (macro-level)

A landscape refers to entire socio-technical condition encompassing tangible aspects like infrastructures, trade patterns and income; and intangible aspects like social (cultural) values, world views, and political beliefs. Landscape takes longer time to be formed such as environmental consciousness (Geels, 2010). On the other hand, changes in landscape occur rather slowly than regime and niche levels. Progress of landscape evolution can put pressures on regimes and niches (agriculture, energy, etc.) yet at the same time they can also open up the possibility of new technology development.

2.2.2 Regime (meso-level)

A regime includes the dominant practices, technologies, regulations which ensure the stability to the existing socio-technical systems. In addition to traditional technological regimes that embedded in a certain institution or infrastructure (Nelson & Winter, 1982; Rip & Kemp, 1998), Geels (2002) brought the scope of regime from a technology-centered level to a broader social level such as policy makers and actors in financial market and supply chains. A socio-technical regime usually includes six main items, which are policy, markets, culture, science, technology, and industry as shown in Figure 2-2 Prevailing regimes are highly structured entities and possess various institutional lock-ins. A regime can hold several sub-regimes due to regime's multidimensional nature. For instance, food processing industry can be seen as a sub-regime of agriculture.

Regime interactions

Interactions within or inter regime level are emphasized in MLP framework. Given that the difference of views between regimes, negotiations and agendas occur. The dynamics of these interactions can present as the pioneer to trigger the fundamental change of socio-technical system or landscape. Raven (2007) identified four types of regime interactions: (1) competition (when two regimes provide similar functionalities); (2) integration (when regimes are combined through specific activities such as mergers); (3) spillover (when practices used in one regime are adopted later by other regimes); (4) symbiosis (when regimes reach a mutual beneficial dynamic). This research provides an energy company case study featuring both spillover and symbiosis in chapter 4 (result) to illustrate the interaction between agriculture and energy regime.

2.2.3 Niche (micro-level)

Niche is a rather small world that does not act corresponding to the existing current setups (regimes and even landscapes) and is less constrained by existing markets and prevailing regulations. Niche level is where radical innovation and experimentation take place under a certain context that technological system can compete on its own term. A regime can incubate a range of niches that may challenge the status quo through facilitating the interplay of actors in regimes. Under certain socio-technical regimes, niche technology can be seen as technologies that do not fit due to lock-ins on existing technological, social, and economical contexts. However, niche-regime dynamics imply the possibility to open windows of opportunities for transition and consequently regime shift toward a new direction (Wainstein & Bumpus, 2016).

The appropriate management of a niche can enhance the possibility of lifting niches to the disruptive level that can alter the existing socio-technical system. The Harvard professor Clayton M. Christensen (1997) defined the disruptive innovation theory in 1997. The theory explains how an innovation breaks the barriers of complication and high cost and consequently transforms existing sector or market through introducing convenience, accessibility, and affordability (Christensen, 1997). Closely linked to the MLP, Strategic Niche Management (SNM) has emerged and is defined as reflexive governance (Voß et al., 2006) which is triggered by niche actors themselves such as users, social groups or creative and active agency rather than a top-down policy tool. SNM also suggests that the sustainable innovation can be facilitated by modulating technological niches, such as protected areas that allow experimentation with technologies' co-evolution of mutually reinforcing practice from the niche to structural changes (e.g. regulatory structure) in the regimes (Rip & Kemp, 1998; Hoogma et al., 2002; Schot & Geels, 2008).

2.3 Business Model Theory

The concept of business model (BM) has been presented for decades yet the term of business model is not clearly specified. Zott et al. (2011) pointed out that around 67% of the business model related literatures do not define what business model is, while the rest presented various definitions or interpretations of business model. Nevertheless, the idea of "value creation", "value capture" and "how the businesses run the value capture process (value creation)" (Zott et al., 2011; Yang, 2016). To systematically analyze BMs, Osterwalder et al. (2010) created a business model canvas (Table 2-3) consisting of value proposition, customer segments, customer relationships, channels, key partners, key activities, key resources, cost structure and revenue stream. In this study, this BM canvas architecture is adopted (Figure 2-3) to visualize the relationship between BM elements.

Table 2-3 Elements in Business Model Theory

Value Creation	*Value proposition*	Value proposition is the core ability of a business to solve customers' problem or satisfy customer's needs.
	Client segments	Client segment is a targeted group of certain characteristics as customers.
	Key activities	Key activities to complete value proposition, distribution channels, customer relationship, etc.
	Partner network	Key activities outsourced and resources acquired outside the company.
	Key resources	Key resources required to complete the value proposition and resources required in distribution channels, customer relationships, revenue stream, etc.
	Client relationship	Relationship established and maintained within the customer segment.
	Channels	Channels are methods used to deliver the value proposition is delivered to the customers, including communication, distribution, and sales.
Value Capture	*Cost structure*	Cost structure is the costs presented in the business model.
	Revenue flows	Revenue flow is the revenue obtained through successful delivery of value propositions to the customers.

Source: Osterwalder et al., 2005

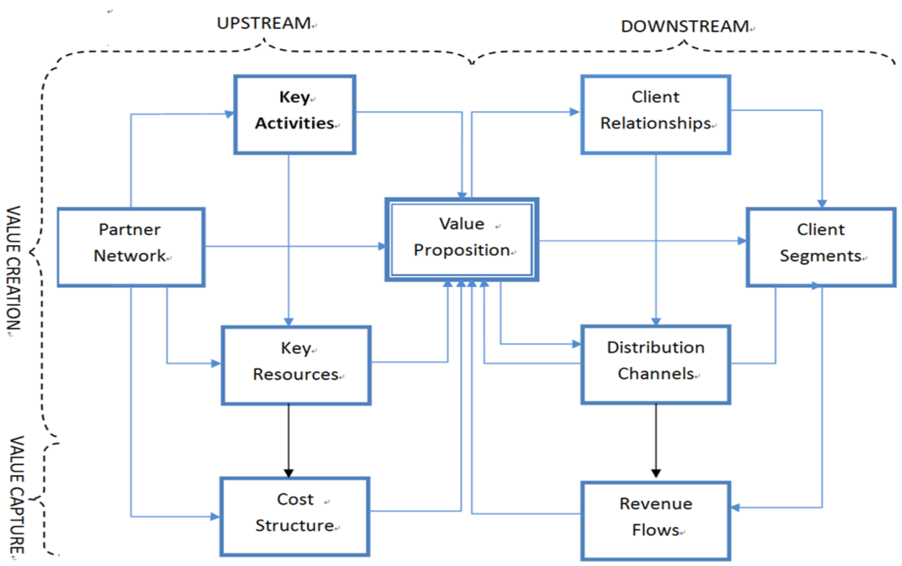

Figure 2-3 Map of Business Model Canvas

Source: Osterwalder et al., 2010; Adapted by Author

2.4 Business Model of Renewable Energy Sector

In this section, the importance and feature of BM innovation (or new BM) in the sustainable transition are highlighted.

Resistance of Reconfiguration in Existing Energy Businesses

The existing energy suppliers, especially incumbent utilities, have long been the favorite of existing socio-technical regimes. They have been locked into carbon intensive business models (Dangerman & Schellnhuber, 2013). Dangermand & Schellnhuber (2013) argue that the limited shareholder liability in energy and financial company makes it less possible to act in response to the environmental needs (landscape change like the awareness of climate change) and adjust its business model to involve in renewable energy. To maintain the profitability and reduce economic risks in fossil-fuel-focusing energy business, incumbents are generally resistant to change the BMs (Dangerman & Schellnhuber, 2013). From a market perspective, the trigger of transition of regime should be brought to the market first, which means that technological innovation requires BMs to level-up in the current socio-technical regime.

The Role of Business Model Innovation in Sustainable Transition

When it comes to sustainable development, BMs are also utilized to help to capture the value and create competitiveness for a more sustainable offering such as a low carbon technology (Chesbrough & Rosenbloom, 2002). The role of a company in a society (relationship with the customers, other companies, institutions, governments, etc.) can also alter the social network effectively with new BMs toward low carbon regime shift through reconfiguration (Chesbrough, 2007; Loorbach & Wijsman, 2013; Engelken et al*.*, 2015). The network of these external actors of a BM can potentially lead to a paradigm shift[7] (Wainstein & Bumpus, 2016).

Engelken et al. (2015) argues that business actors are main drivers in renewable energy developments and solar energy, biofuel and biogas are most discussed energy sources in renewable energy BM literatures. The rise of new BM or innovation of BMs redefines the value capture process, supply chain, and relationship with its customer of a company. The scope of disruptive innovations under certain socio-technical landscapes have gradually changed from technology-centered innovation (Christensen, 2006) to market disruption from BM innovation (Chesbrough, 2010; Teece, 2010). Furthermore, since the BM innovation is usually less appealing to an incumbent actor since it involves in larger scale of reconfiguration of the company, most of the BM innovation happens within BMs of relatively smaller size or new BMs (Charitou & Markides, 2012).

Lüdeke-Freund (2010) argues that comparing to traditional business model, these BM innovations or new business models feature maintaining customer value, while creating competitive advantages and contributing to the long-term well-being of both company and society. These new, sustainable BMs have stronger bonds between the environment and society. They bring up the market-based approaches to create social values to tackle certain environmental and social problems (Wainstein & Bumpus, 2016). This role of these businesses has been gradually changing and the purpose of a BM has re-directed from a private individual toward a fundamental role possessing influential power within a society (Phills et al., 2008).

[7] A fundamental change in a set of values, assumptions, practices that constitutes how a society views the world.

2.5 Business Model as a Disruptive Innovation Niche Facilitator

By comparing previous sections in chapter 2, in section 2.5, it is proposed that by strengthening certain BM elements, the innovative technology niche (biogas in this study) can be brought to a disruptive level and gradually transform the socio-technical system.

Relationship between Disruptive Innovation Niche and BM Elements

By concluding the findings above, this study argues that BM innovation can become the facilitator to help the sustainable transition through promoting renewable energy technology (biogas technology) to a disruptive niche level. In this study, value proposition, key activities, infrastructure management, financials, and partnership network are selected as key to BM innovation since they are the most discussed BM elements in renewable energy sector (Engelken et al., 2015).

As aforementioned in section 2.2, a disruptive innovation niche possesses the ability to lower the barriers to new market or system development by improving convenience, accessibility, and affordability. To further analyze the relationship between the characteristics of disruptive innovation niche and BM, the relationship between these characteristics and elements of BMs is identified in Table 2-4. Their relationships are discussed as follows under the context of current renewable energy development:

Table 2-4 Disruptive Innovation Niches to Corresponding Business Model Items

Characteristics of Disruptive Innovations	***Corresponding BM Items***	
Convenience (is it easy to run the system?)	Value proposition	Key activities, Infrastructure management
Affordability (cost)		Financials
Accessibility (availability on the market)		Partnership network

Source: Author

A change of value proposition (accessibility)

New value proposition under current socio-technical landscape (low carbon, sustainable development, etc.) in the world has enhanced the accessibility to new technology, electricity market, and other key elements of renewable energy. These landscape pressures create opportunities to existing BMs, including cooperative BMs, combination of mobility and electricity, load and storage solutions, higher consumer involvement, enabling and supporting distributed generation, and integration of renewable energies into industrial processes (Engelken et al., 2015).

Financials (affordability)

Low marginal costs and the grid parity of renewable have provided financial drivers to the development of many renewable energies and their BM development. This is however, not the case for biogas. The lack of financial drivers in biogas sector still obstructs the diffusion of biogas due to its high cost and technical complexity (Vasileiadou et al., 2015; Hellström et al., 2015; Wakkee et al., 2014; Strupeit & Palm, 2015; Yildiz, 2014). By recognizing the barrier of upfront costs, new actors in distributed energy business try to tackle this problem with innovative BMs. For instance, some new BMs offer the customers “service” rather than products, which significantly minify the investors’ financial burdens.

Remarkably, however, the benefit of biogas production lies in multi-layers, meaning that it can not only bring value of energy but also value for waste management and nutrient recycling. Reducing the environmental cost (e.g. environmental fines) and enhancing nutrient recycling have become more critical as the environmental regulation is expected to be more stringent in the future. Therefore, if the cost reduction, revenue generation, and increase of well-being for the society are taken into consideration or calculated, the financial benefit of biogas is expected to be much more significant.

Cooperative Business Model and the Rise of New Actors (convenience)

The high level of collaboration is also a trend of new BMs in the society and frequently mentioned in renewable energy literatures (Cucchiella & D'Adamo, 2013; Hellström et al., 2015; Engelken et al., 2015). This can be a consequence of large scale societal change. For instance, after the financial crisis in 2008, the landscape shock altered the consumers' behavior and enhanced two forms of BM innovation. One is the shifting paradigm of conventional ownership or consumption-oriented behaviors to a collaborative, peer-to-peer (P2P) or now so called sharing economy (Wainstein & Bumpus, 2016).

In terms of value change resilience, BMs with higher degree of collaboration and wider participation of various actors feature a more decentralized structure and present a higher resilience through risk sharing and collaborative investment (Miles, et al., 2006; Richter, 2013). P2P is a good example of involving more customer participation and therefore more resources can be brought to existence (Belk, 2014). These strong and widely-covered networks built up by actors enhance the convenience of the technology for the user and accelerate the development of innovations through attaining meaningful resources from multiple actors from outside the business (Chesbrough & Appleyard, 2007; Ribeiro-Soriano & Urbano, 2009).

Lastly, after the liberalization of energy sector, new actors are rising as a power to decentralize the conventional energy production. Hess (2013)'s renewable energy study of solar energy identifies these actors as "localism" grassroots development and "third-party" for-profit businesses. These emerging actors can also be seen in other types of renewable energies' developments. To the best of the author's knowledge, none of these actors are from conventional utility firms.

3 Methodology

This chapter is to provide the readers the information of what measures the author employed to collect essential data and how these measures were conducted (methods). The author selected three measures, which are literature research and qualitative interviews in order to employ as much information as possible in the limited research time.

3.1 Literature research

The literature review was conducted to review crucial information about theoretical backgrounds, including multi-level perspective (MLP) and business model (BM) theory as well as the current development (drivers, opportunities, barriers, etc.) of renewable energy/biogas in the world and in Taiwan (industrial waste, agricultural wastes, etc.).

3.1.1 Objective

To answer RQ1 and RQ2, the method used in this research examines scientific articles and gray literature with regards to biogas, utilization of MLP & BMI in sustainable agriculture and renewable energy sectors with a focus on swine farm biogas production. The objective of this method is (1) to ensure the pertinence of MLP and BMI as the analytical framework; (2) to attain broader picture of Taiwanese biogas development though identifying essential regimes and actors of biogas production and diffusion in Taiwan; and (3) to review existing studies which support the importance of BMI in renewable energy development.

3.1.2 Method

Regarding the theoretical framework, the literature on MLP are mostly from Geels (2002, 2010, 2014) and Verbong & Geels (2008, 2010) while business model canvas from Osterwald & Pigneur (2010) is utilized to analyze business models of biogas in agriculture (swine farm) sector and energy sector (renewable energy company). The connection between renewable energy and business model is based on the researches by Dangerman & Schellnhuber, 2013) and Engelken et al. (2015). Moreover, in order to systematize the barriers recognized, the study also utilizes the categories of systemic problem of renewable energy diffusion reviewed by Negro et al. (2012).

For biogas, the literature of the involved topics including energy and agriculture in this study are retrieved via the online database. These databases include Lund University Library, Google Scholar, Taiwan National Central Library search engines and other academic/online searching engines. The literature review is conducted with a range of keywords within the topic areas in the following table. The data is triangulated from academic institutes, gray industry literatures, governmental and intergovernmental sources, which are detailed in the table on the following page.

Keywords	Government And Intergovernment Data Sources	Gray Literature	Academic Institute
Energy/biogas			
▪ Renewable Energy ▪ Energy Security ▪ Energy policies ▪ Biogas Technologies ▪ Biogas Benefits ▪ Biogas Utilizations ▪ Policies ▪ Barriers, etc.	▪ United Nations Environmental Programme (UNEP) ▪ International Energy Agency (IEA) ▪ World Resource Institute (WRI), etc.	▪ Country annual energy report ▪ Renewable energy working paper ▪ Bioenergy Annual Report (IEA) ▪ World Energy Outlook (IEA), etc.	▪ Journal of Cleaner Production, Renewable and Sustainable Energy Review, Energy Policy, Environmental Monitoring and Assessment ▪ Applied Energy, etc.
Agriculture/swine industry			
▪ Swine Market ▪ Farming Practices ▪ Agriculture Policies, etc.	▪ Custom Administration Online Database (for swine import and export data)	▪ Annual Swine Report (2016)	▪ Journal of the Science of Food and Agriculture, Journal of Agricultural Economics, Taiwan Journal of Agricultural Economics

3.2 Qualitative interviews

3.2.1 Objective

To address RQ2, 17 in-depth (semi-structured) interviews present the primary method for the collection of data in the study to approach the answers and truths with the help of narrative instead of aggregating numbers. According to Kvale & Brinkmann (2009), an interview of research is "a conversation that has a structure and a purpose" and is designed to encouraged the interviewees to express themselves in words rather than numbers. Therefore the various aspects of opinions can be attained (Kvale & Brinkmann, 2009).

There have been various academic literatures and gray industry literatures that underline the barriers of biogas diffusion in swine industry. However, the limited numbers of the literatures (both in English and Chinese) rarely display the actual opinions from majority of the swine farms (especially small and medium sized farms) since these literatures are mainly conducted at a national level (policy oriented reports, news and researches) or based on the experimental farms selected by the government. Therefore, the author aims to include opinions from a broader farm base in order to understand their needs, concerns and insights regarding the development of agriculture development and energy supply in Taiwan.

The other focus of this study is a case study of Taiwan New Energy Co. (a renewable energy company providing biogas total solution to the customer) that could serve as a renewable energy facilitator in Taiwan. The case study is done through analyzing the company's business model, how the company responses to barriers to biogas diffusion and how it intervene the current biogas supply chain in Taiwan. For this case study, the visits to farm and energy company were conducted so as to achieve comprehensive view of biogas supply chain (visit to Taiwan New Energy Co. - February 3rd and its swine farm customer-February 7th).

3.2.2 Method

For the selection of swine farm interviewees, the author aims to cover the following four categories of farms, which are listed in Table 3-1. There are two reasons to define the scope of this study (1) economics of scale (biogas production is considered more economically beneficial in larger scales (above 1,000)) and (2) market share (farms with swine number above 5,000 and 1,000-4,999 account for 23% and 46% (together 70% of the market share) of Taiwanese swine production respectively.

Table 3-1 Interviewee Selections

FARM SIZE/ BIOGAS PRODUCTION	*Yes*	*No*
Large (5,000 head or above)	Category 1	Category 3
Medium Size (1,000-4,999 head)	Category 2	Category 4

Source: Author

Interviews are conducted through semi-structured interviews and unstructured interviews. The semi-structured interview questions are presented in Appendix I.

Semi-structured interviews: the interview pool is obtained mainly from two sources. One is from the author's online keyword searching, which was done through "Online Swine Farm List"[8] that provides phone address, phone number, and fax of the farms. The author narrows down the interview pool to four counties and cities (Tainan City, Yunlin County, Changhua County, and New Taipei City) located in Western coast of Taiwan that are densely populated as well as possess large amount of swine farms in various sizes (ranging from 400 to 10,000). 4 out of 17 interviewees are "former" swine farmer whose major contribution to this research recognized by the author is their reasons of leaving the swine industry. The other source is suggested by Professor Su from National Taiwan University who has been involving in biogas technology development in the past twenty years. Professor Su's personal connection to the top two largest swine farms (one in Southern Taiwan and the other in Western Taiwan) allows the author to conduct personal interview and farm visit in Pindong County (Feb 10th, 2017).

Unstructured interviews: the interview pool is obtained through author's personal network (friends and relatives). The author randomly asked friends and relatives who had larger networks in Western Taiwan (Taichung County and Tainan County) to ask overarching questions covering questions listed in Appendix I. The questions were asked through casual conversations. The results of unstructured interviews were more diverse and included many insights, while information of the farms was less concerned (e.g. exact farm location and number of the swine). The interviews and farm visits of swine farms as well as the case study company were completed between January 23rd and May 2th in Taiwan (personal interviews) and Sweden (phone interviews through Skype).

In order to capture a more comprehensive picture of biogas development, interviews with other biogas-related stakeholders (research institutes, officials from the government, NGOs, etc.) are also used as a complementary measure.

[8] Taiwan Swine Farm List: http://pigbase.angrin.tlri.gov.tw/pigfarm/farm.htm

4 Results

This chapter presents the discoveries of desktop studies, interviews and analysis of the data collection under the theoretical framework from chapter 2. During January to May 2017, a total of 17 interviews took place, covering 8 counties or municipalities, while there are 6 municipalities, 11 counties and 3 cities in Taiwan. The top four municipality/county with the most swine heads are Yunlin County, Pingdung County, Changhua County, Tainan Municipality (Figure 4-1), which are mostly located in areas with high population density (Southwest coast). The targeted farms are located in counties or municipalities where the most dominant large/medium sized swine farms are locate (Yunlin County, Pindong County, Changhua County, Tainan City and Chiayi City). Interviews with scattered small farms were also taken into consideration as supplemented sources (New Taipei City, Taichung, and Nantou). These in-depth interviews were conducted in person or over Skype. The involved interviewees are current/former swine farmers of various sizes with/without biogas production, academic institutes, renewable energy companies, municipality director and NGOs in Taiwan. The information of interviewees (semi-structured and unstructured) is presented in Table 4-1 and Table 4-2.

The results and analysis include two parts. The socio-technical system of biogas (policy, industry & market, technology & science, culture) under current landscape pressures of energy and agriculture regimes are presented in section 4.1. To answer the RQ1, the barriers to biogas diffusion are discussed in 4.2. The root cause of the barriers and the proposed solution will be analyzed and exemplified with a case study in the next chapter.

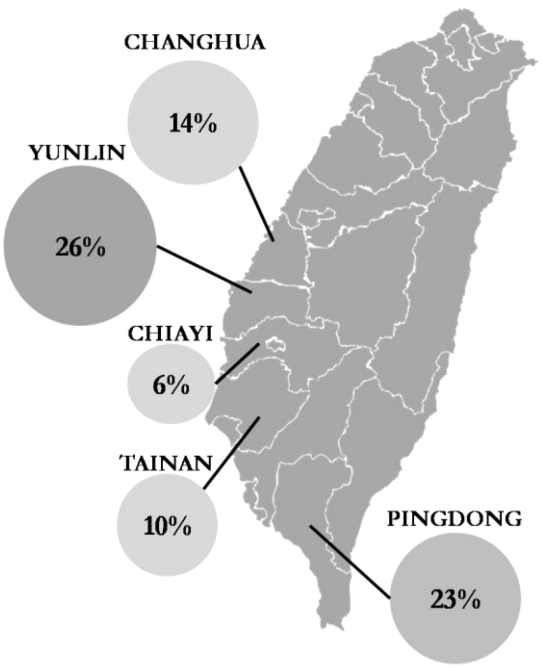

Figure 4-1 Top Municipality/County by Swine Inventory in Percentage in Taiwan

Data source: National Swine Survey Report, Taiwan, 2016

Table 4-1 Background Information of Interviewees (Other)

#	Organization / Position	Biogas involvement[a]	Introduction and contribution
I1	Academic institute	Yes/production & research[c]	The interviewee has been working in biogas development and its popularization in the past decades by involving in research (government & independent) and engaging in empirical experience (technical supports to farmers).
I2	Municipality /director	Yes/production & research	Taiwanese renewable energy service company who is recently introducing new business model to biogas production in agricultural sector (swine farms in central Taiwan).
I3	Renewable energy company/vice general manager and engineer	Yes/production & research	The company has been working on biogas production in collaboration with a large swine farm (its customer) located in western Taiwan since 2015.
I4*	Biogas generator agency/sales	Yes/production	Agricultural sales, who has been regularly visiting farms.
I5	Biogas related NGO/researchers	Yes/research	The NGO has been working on popularizing circular economy in Taiwan and biogas is one of its current focuses.

*Unstructured interviews are marked with **

Source: Author

Table 4-2 Background Information of Interviewees (Swine Farmers)

#	Organization / Position	Biogas involvement[9]	Introduction and contribution
F1	Large swine farm/owner (26,000 head)	Yes/production with power generation	Located in southern Taiwan as the second[10] largest farm, which adopts biogas production successfully[11] since 2011.
F2	Large swine farm/owner (10,000 head)	Yes/biogas production without electricity generation	Located in Western Taiwan that once tried biogas production with power generation since 1980s yet failed.
F3	Large swine farm/owner (head of swine: unknown)	No	Located in central Taiwan without adopting biogas production
F4*	Small & medium swine farm/owner (head of swine: unknown)	Yes/biogas production without power generation	Located in Western Taiwan, who once tried biogas production with power generation since 1980s yet failed.
F5*	Small & medium swine farm/ owner (head of swine: unknown)	Yes/production without power generation	Located in central Taiwan and has adopted biogas plant (domestic generator) for household use.
F6	Small & medium swine farmer/owner (1,000 head)	Yes/biogas production without power generation	Located in northern Taiwan, who has been involving in biogas production without power generation since 1965.
F7	Former small & medium swine farm/owner (2,000 head)	Yes/biogas production with power generation	Located in northern Taiwan, who once tried biogas production with power generation during 1980s-1990s but failed after several years.
F8	Former small & medium swine farm/owner (1,000 head)	Yes/biogas production without electricity generation	Located in northern Taiwan, who once tried biogas production without power generation during 1980s-1990s yet failed.
F9	Former small & medium swine farm/owner (600-700 head)	Yes/biogas production with power generation	Located in northern Taiwan, who once tried biogas production with power generation during 1980s yet failed.
F10*	Small & medium swine farm/owner (head of swine: unknown)	No	Located in central Taiwan, who once tried to set up biogas plant for wastewater treatment use yet failed.
F11	Small & medium swine farm/owner (2,000 head)	No	Located in southern Taiwan, who once tried biogas production with power generation during 1980s yet failed.
F12	Former small & medium swine farm/owner (400-500 head)	No	Located in northern Taiwan.
F13*	Large swine farm/owner (head of swine: unknown)	No	Located in southern Taiwan without biogas generation
F14*	Large swine farm/owner (head of swine: unknown)	No	Located in central Taiwan without biogas generation
F15*	Medium/staff (head of swine: unknown)	No	Located in southern Taiwan without biogas generation
F16	Medium/owner (1,930 head)	No	Located in central Taiwan without biogas generation

*Unstructured interviews are marked with **

Source: Author

[9] The involvement of biogas production includes biogas production with/without power generation. Entities solely involve in biogas research are excluded.

[10] Since the author couldn't get the permission to interview the largest farm adopting biogas plants located in central Taiwan, the information of this farm is mainly collected from news, researchers and other stakeholders such as the renewable energy company.

[11] The definition of successful biogas adoption in this research is that farms/companies involve in biogas production with/without power generation continuously since the adoption of their biogas plants.

4.1 Multi-level Perspective Analysis of Biogas in Taiwan

In this paper, to address biogas development issues, energy and agriculture are elected as regimes in response to the development of (1) low-carbon country: expanding renewable energy and reducing the dependency on electricity production and distribution; (2) sustainable agricultural sector: there is an urgent need to reduce the pollution from livestock industry. Energy regime is regarded as dominant regime while agriculture regime is the complementary regime as biogas is seen as a "sub-regime" of agriculture regime (biogas is perceived as a part of waste management in agricultural sector).

Under the existing energy regime, by identifying the value of sustainable development, technological niche in this study is defined as: biogas production standard biogas process, which the biogas plant should encompass core stages of biogas production mentioned in former section but the biogas power generation is optional.

4.1.1 Landscape Pressure from the Energy and Agricultural Sector

Main drivers of biogas development and diffusion as aforementioned are landscape pressures of global market competition, rising environmental awareness, national energy security, and emission reduction.

Like other developed countries, Taiwan submitted an Annual National Inventory Report starting from 2015, as required by UNFCCC. The report reveals that energy sector in Taiwan accounts for over 90% of the country's GHG emission inventory. In terms of GHG categories, the agricultural and waste sector account for over 90% of the methane emission (agriculture: 22%; waste: 69%) while agriculture, energy, and waste sector are responsible for over 60% of the nitrous oxide (N_2O) emission.

After the Kyoto Protocol was adopted, on the National Energy Conference (NEC), the Taiwanese government reconfirmed the importance of renewable energy and aimed to increase the renewable energy targets to 4-6% by 2020 (in 2015, renewable energy consists of 1.92% of the country's energy) and 10-12% of electricity capacity before 2025 (ITRI, n.d.b). Also, the pressure from the society has forced the Taiwanese government to accelerate the development of renewable energies and gradually altering the socio-technical regimes.

For agricultural sector, as a major meat source in Taiwan with a self-sufficient rate of 90% (2016) (Table 4-3), even though the swine export still surpasses its import (Table 4-4), most of the swine farms have been forced to change their major markets from Japan to the domestic market. The export of swine has been experiencing gradual waning (Figure 4-2).

Currently, the swine industry experiences its critical moment of survival in Taiwan. The Taiwanese Swine Association (2016) summarized the major problems faced by swine industry, which are (1) low competitiveness in a global market (production cost is 1.7-1.8 times higher than other pork export countries and low production efficiency); (2) low production efficiency; (3) fluctuation of swine price stemmed from the instability of global feed price; (4)sub-tropical climate; (5) FMD hindering the international market expansion; and (6) high population density with rising environmental awareness. Consequently, it is argued that without significant improvement in swine production and its gradual return to the global market, the swine industry will vanish in Taiwan within 10-20 years. Hence, biogas has been brought into the spotlight in this difficult period as a measure to tackle problems in the swine industry faced by policy makers.

Table 4-3 Imported Meat Ratio

Year	Pork	Beef	Mutton	Poultry
2005	6%	93%	91%	13%
2006	5%	94%	89%	15%
2007	5%	94%	89%	10%
2008	7%	94%	91%	13%
2009	10%	94%	88%	13%
2010	9%	95%	91%	17%
2011	8%	96%	91%	16%
2012	6%	95%	91%	19%
2013	7%	95%	93%	18%

Source: Food Supply and Utilization Yearbook, Council of Agriculture, Executive Yuan

Table 4-4 Top Import and Export Countries of Taiwanese Swine

Export to	1,000 mt	Import from	1,000 mt
The United States	2,264	Japan	1,223
EU	2,232	Russia	868
Canada	1,246	Mexico	783
Brazil	585	The United States	399
China	244	Hong Kong	399
Chile	164	South Korea	388
Mexico	111	Canada	221

Source: Taiwan Exports and Imports Statistical Databank (2013)

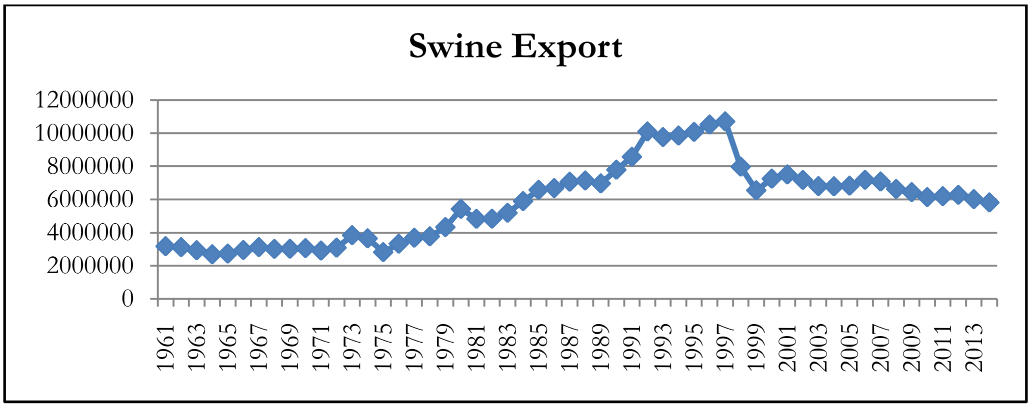

Figure 4-2 Swine Export of Taiwan

Source: FAO

4.1.2 Biogas Socio-technical System

To help the readers to better catch the picture of biogas production, biogas regime items are summarized in Table 4-5 and discussed in more details below. Some regime items are combined in the "regime item" section (industry is combined with market while technology is combined with science) as there are many overlaps in the result of these items.

Table 4-5 Biogas in Agriculture and Energy Regimes

	REGIMES	
	Energy (main region)	**Agriculture (sub-regime)**
LANDSCAPE PRESSURE	Energy security Low carbon society	Global market pressure Rising environmental awareness (e.g. complaints against farms from the neighbor)
REGIME ACTORS	Bureau of Energy Incumbent utilities Renewable energy companies Domestic/foreign biogas equipment suppliers (Germany and USA) Biogas generator import agents	Council of Agriculture Ministry of Economic Affairs Ministry of Finance Environmental Protection Agency Swine farmers
ITEMS		
1. POLICY	◆ FiT ◆ Energy-Saving and Carbon-Reduction Action Plan ◆ Renewable Energy Development Act ◆ New Electricity Act	◆ Incentives (for domestic crop productions) ◆ Subsidies (for biogas generators, for large swine farms supporting small/medium farms to deal with the wastewater, etc.) ◆ Wastewater regulations (Three-step Wastewater Treatment, Water Pollution Control Fee, etc.) ◆ Water Use Charge
2. INDUSTRY	◆ Electricity generation, distribution, electricity transmission and distribution (the grid operator), electricity sales and retail.	◆ Farming activities (cost, revenue, human resources, farming practices, etc.)
3. SCIENCE	Academic institutes (e.g. National Taiwan University, Academic Sinica, National Cheng Kung University)	
4. TECHNOLOGY	◆ Practices of biogas generation (18% of the biogas plants involves in power generation) ◆ Practices of effluent treatment	◆ Practices of effluent treatment
5. MARKET	◆ High energy dependency ◆ Liberalization of energy market	◆ Industrialization (scaling up of farms) ◆ Globalization (WTO)
6. CULTURE	◆ Innovative culture (See section 4.2)	◆ Low degree of innovation (Aging agricultural population)

Regime actors are underlined

Source: Author.

Regime Items

(1) Policy Overview

In 2008, Executive Yuan, the executive branch of the Taiwanese government adopted the Frameworks of Sustainable Energy Policy, which are Energy-Saving, and Carbon-Reduction Action Plan and Renewable Energy Development Act in 2009. Since then, a series of renewable energy policies are introduced. Combining with the concern of increasing electricity prices (Figure 4-3), the pressing need of alternative energy sources was even more highlighted in the past ten years after Fukushima Nuclear Power plant Explosion in 2011 (Japan). More and more public sectors are involved in the low carbon society transition such as the Council of Agriculture, Ministry of Economic Affairs and Ministry of Finance to provide technological and financial supports as well as to establish corresponding regulations. In 2017, the Legislative Yuan[12] has passed an extensive amendment in January 2017– Electricity Act Amendment. The new Act (amendment) is the milestone of electricity market liberalization for Taiwan and is expected to break the monopoly structure and regulatory framework lasting for 50 years and more importantly to promote the development and use of renewable energy.

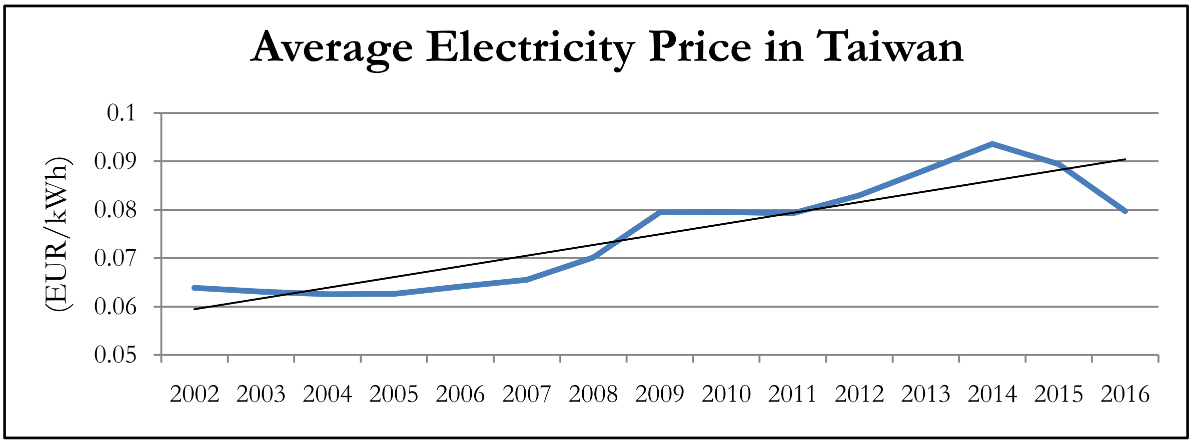

Figure 4-3 Average Electricity Price in Taiwan

Source: Taipower

Feed-in Tariffs

In 2013, Bureau of Energy, Ministry of Economic Affairs launched Regulation Regarding Biogas Power Subsidy to promote large sized livestock farms to adopt biogas production. However, comparing to other renewable energies, feed-in-tariff of biogas under the Renewable Energy Development Act was too low to attract the farmers to produce biogas (Table 4-6, the feed-in tariff (FiT) for biogas discussed in this paper is highlighted in gray). In view of this, in 2017, the government rises feed-in-tariff to over NTD 5/kWh to incentivize the large sized swine farms to produce biogas. The main governmental sectors responsible for these policies are Bureau of Energy and Council of Agriculture. Bureau of Energy subsidizes NTD 30,000/kW of biogas power generation while the Council of Agriculture provides biogas loan (raise the upper limit from NTD 10,000,000 to 30,000,000) with a lower annual interest rate of 1.04%. After the announcement of new feed-in-tariff, more energy companies

[12] The Legislative Yuan is the unicameral legislature of the Republic of China. It is one of the five branches of government stipulated by the Constitution of the Republic of China, which follows Sun Yat-sen's Three Principles of the People. Although sometimes referred to as a "parliament", the Legislative Yuan, under Sun's political theory, is a branch of government

are willing to join the biogas market and actively search for the opportunity of collaboration with swine farms (Lin, 2016).

Table 4-6 Feed-in Tariff of Renewable Energy in Taiwan

Renewable Energy Source				**Year** Unit: NTD/kWh		
				2015	**2016**	**2017**
Solar	Rooftop solar panel	1kW-19kW		6.86	6.48	6.10
		20kW-100kW		5.74	5.21	4.98
		100kW-500kW		5.36	4.81	4.54
		>500kW		5.19	4.67	4.41
	Ground solar panel	>1kW		4.88	4.67	4.55
	Floating solar panel			n/a	n/a	4.94
Wind	On land	1kW-20 kW		8.41	8.51	8.97
		> 20kW	With LVRT	2.71	2.81	2.88
			Without LVRT	2.69	2.78	2.84
	Offshore			5.74	5.74	6.44
Hydro				2.63	2.91	2.95
Geothermal				4.93	4.94	4.94
Bioenergy	without anaerobic facility			2.63	2.72	2.60
	with anaerobic facility			3.38	3.92	5.01
Municipal Solid Waste				2.82	2.94	3.98
Other				2.63	2.72	2.60

Source: Taipower

Wastewater Policy

For agricultural sector, swine production has the highest production value among all other livestock (Council of Agriculture, 2015) yet it has been a major water pollution source for decade in Taiwan (Liou et al., 2003). The rising level of environmental awareness in 1990s has forced the Taiwanese government started to implement policies and regulations to improve the wastewater treatment on the individual farm level. To tackle the wastewater problem in swine industry, "The three-step piggery wastewater treatment (TPWT)" system and wastewater effluent standards on biochemical oxygen demand (BOD) and chemical oxygen demand (COD) are promoted by Livestock Research Institute of Executive Yuan (Su et al., 1999). The three steps include solid-liquid separation, anaerobic digestion and aerobic digestion. Detailed TPWT is presented in Appendix II.

The last step of TPWT - aerobic (activated sludge) treatment, however requires considerable energy consumption. Thus, anaerobic wastewater treatment system (anaerobic digestion), which is an essential part of biogas production, has become the promising alternative of the TPWT. AD comparing to other wastewater treatment like lagoon, can limit GHGs by collecting methane and can be utilized as many other energy sources as mentioned in previous sections (section 2.1) (Su, 2003).

Moreover, the adoption of Water Pollution Control Fee started to apply to the livestock sectors since 2017. For swine farms, the farmers have to pay the fee of NTD 17 (ca EUR 0.52) for each swine. Meanwhile, to enhance the nutrient recycling from the wastewater, Environmental Protection Agency (EPA) in Taiwan also launched the Irrigation Law in the same year to encourage the farmers reuse the treated effluents and reduce the electricity cost of dealing with wastewater.

(2) Industry & Market

In the new Act, a new government agency is established to promote energy reform and monitor the electricity market- Electricity Regulatory Agency (ERA). The ERA is responsible for issuing electricity licenses, managing and monitoring electricity market (power supply, demand and distribution), ensuring carbon emission compliance and mediating disputes between electricity producers and users. ERA can be seen as a government agency and authority as well as market regulator. According to the new Act, the government divided the electricity sector (market) into three businesses (sub-sectors), which are electricity generation, distribution, electricity transmission and distribution (the grid operator), electricity sales and retail. Except the transmission and distribution, which remains state-owned, the other three sub-sectors are liberalized to the private sectors. Furthermore, the new Act requires non-renewable energy producers to sell electricity to the retailers or the grid operator but not the users, while renewable energy generators are not bounded.

The new Act provides benefit to green energy through direct sales and price flexibility of renewable, connection and distribution priority and the introduction of the carbon factors (coal: 30%, natural gas: 50%, renewable: 20%). The price of renewable energy is not restricted to various pricing rules and standards announced by the authorities (but may need to comply with other upcoming regulations). Connection and distribution of renewable energy is prioritized by the new Act. This means that electricity sold to the grid operator, which is via the FiT to the Taiwan Power Company[13] (Taipower) is of a maximum degree (highest price). Lastly, the introduction of the carbon factor links the amount of carbon emissions to extra cost such as electricity distribution and auxiliary services. The lower the carbon factor, the less service fee is required by the government. These are designed to promote the generation and use of renewable energy.

While the Act provides benefit to renewable energy generators, the further influences of the Act on renewable energy sector lie in the costs (Ou, 2017), which are a reserved margin maintenance and local electricity development fund. The Amendment requires the generators and retailers over a certain capacity (ca 2MW) to maintain a reserve margin while selling the electricity, implying that the renewable energy providers have to either ensure the effective energy storage systems or purchase reserve margins from other electricity providers. As for local electricity development fund, before the Amendment, the financial contribution and compensation to local communities are not legally applied to private producers, while after the new Act all generators are covered by the obligation, including large wind and solar energy providers.

[13] The Taiwan Power Company (Taipower) is a state-owned electric utility providing major electricity supply in Taiwan.

(3) Technology & Science

According to Council of Agriculture and as mentioned previously, there are 200 swine farm biogas plants in Taiwan and 36 of these biogas plants (Figure 4-4) (38 in livestock industry) involve in power generation, covering 5.5 million head of swine of the country. Based on this estimation, the reuse rate of swine manure is only 5.4%. The standard biogas production process is promoted by the Council of Agriculture and is shown in Figure 4-5.

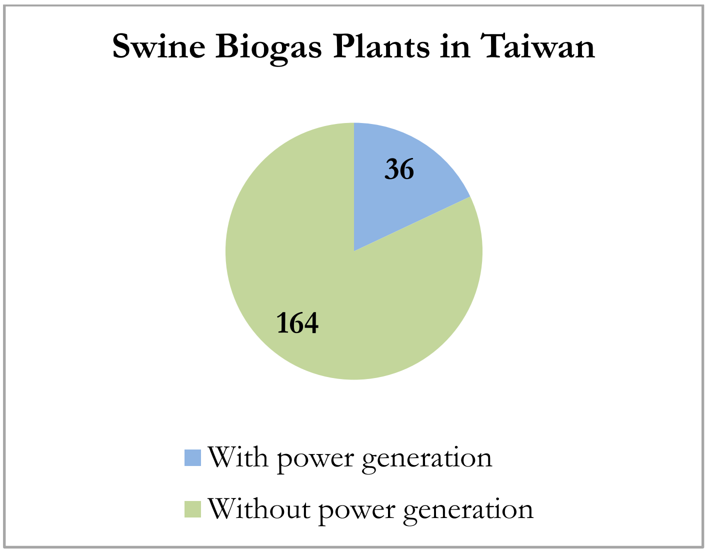

Figure 4-4 Swine Biogas Plants in Taiwan

Source: COA, 2016

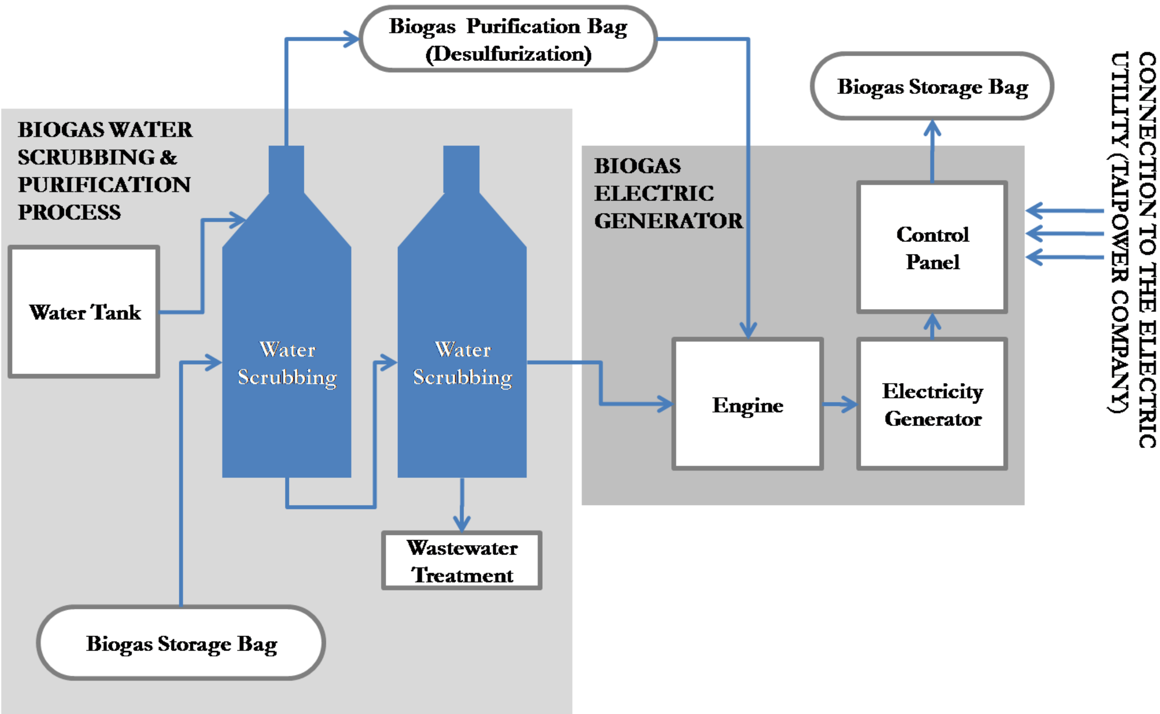

Figure 4-5 Standard process of Taiwanese Biogas Production

Source: Ministry of Economic Affairs; Adapted by Author

(4) Culture

According to the Institute for Management Development (IMD), Taiwan is ranked as the sixth country among 58 countries for green technology competitiveness. However, the Taiwanese renewable energy development is still in its early stage (Chen & Lee, 2014). On the other hand, for the main actor of biogas production - swine farms, the aging rural area in Taiwan is a critical issue for innovation and improvement on the farming practices (F1). The younger generation is rather reluctant to join agricultural sector due the low profitability (F1, F9).

According to the EPA, there are 7,468 swine farms in Taiwan and 93.8% of them are with the size under 2,000 head of swine (small and medium size swine farms). This may indicate that most of the swine farms are lacking the capacity to be involved in biogas power generation. Therefore, in 2017, the EPA announced that in order to promote the reuse of swine wastewater and biogas power generation, the government will expand the subsidies of anaerobic digestion plant for large swine farms with extra NTD 200 million (ca EUR 63 million), meaning that 40,000 head of swine is estimated to be subsidized. This is under the condition that they assist the small farms to deal with animal manure. Every 200 head of swine manure collection, the government will subsidize NTD 1 million (ca EUR 312,500) with a subsidy ceiling of 50 million per swine farm.

4.2 Barriers to Biogas Diffusion in the Existing System

Throughout the literature review and qualitative interviews, the major barrier to biogas diffusion lies in the economical challenges (e.g. upfront costs, maintenance costs, human resource costs, etc.). To systematize the findings during the study, the author utilize the systemic problem category established by Negro et al. (2012). Negro et al. (2012) identifies several systemic problem in a review, including market structure problem, infrastructure problem, institutional problem, interaction problem and capability problem. In this study, we found it useful to categorize barriers to biogas diffusion in Taiwan by these problems. Since the focus of this study is the production side (biogas production) instead of demand side (renewable energy demand, consumer behavior, etc.), market structure problem will not be discussed here. The interaction (e.g. information sharing, policy implementation, etc.) problem and capacity (e.g. the knowledge of biogas) problem are also regarded as a part of infrastructure problem in this study. Therefore, the identified barriers to biogas diffusion are (1) economical barriers, (2) institutional barriers, and (2) infrastructure barriers.

Barriers identified by the informants (interviewees) are presented in Table 4-7. Infrastructure barriers are the most frequently mentioned barriers among large and medium size farms. Economic barriers are more common among large farms while smaller-scale farms stress more on the institutional barriers as they are lack of the ability/capacity to handle wastewater. It is rather clear that the academic institute and energy company touch on wider range of barriers which is interpreted as these stakeholders encompass more comprehensive understanding of biogas development in Taiwan, such as technologies, policies, industrial practices, etc. This stems from not only their professions but also active interactions with other biogas stakeholders (farmers, government officials, etc.). As for government official, unlike officials from central government, the local government official seems to encompass less knowledge of biogas development and not being aware of the economical and institutional barriers. Lastly, NGOs are optimistic about the utilization of biogas yet they are less aware of the problem faced by the biogas producers. However, NGO acts as an important role in educating the general public about biogas.

Table 4-7 Identifications of barriers to biogas diffusion by interviewees (farmers & other stakeholders)

Nr	FARM SIZE[14]	LOCATION	ECONOMICAL BARRIERS	INFRASTRUCTURE BARRIERS	INSTITUTIONAL BARRIERS
1	Large	Southern Taiwan			
2	Large	Southern Taiwan			
3	Large	Central Taiwan			
4	Large	Central Taiwan			
5	Large	Central Taiwan			
6	Medium	Central Taiwan			
7	Medium	Central Taiwan			
8	Medium	Central Taiwan			
9	Medium	Central Taiwan			
10	Medium	Northern Taiwan			
11	Medium	Northern Taiwan			
12	Medium	Northern Taiwan			
13	Medium	Southern Taiwan			
14	Medium	Southern Taiwan			
15	Small	Northern Taiwan			
16	Small	Northern Taiwan			
17	Academia				
18	Energy company				
19	Government Official				
20	NGO				

Source: Author

Each barrier is detailed as follows:

4.2.1 Economical Barriers

The identified economical barriers are high costs, immature market, and low feed-in tariff in Taiwan.

The High Upfront, Maintenance, and Human Resource Costs

There are two types of biogas generator: imported ones and domestic ones (I1, I3). The economic barriers are especially evident in imported biogas generators, which are mostly used in large sized swine farms. The recently established biogas plants using imported biogas generators are mostly self-funded (F1, I3), while those domestic ones established during 1980s received around 50% of the subsidies from the government (F9). The cost of biogas production in Taiwan (EUR 6,250/kW) is higher than other developed countries like Germany (EUR 3,000-4,000/kWe) (Hahn, 2011; Lin, 2016). The cost of biogas generator ranges from NTD 5,000,000 to 30,000,000 for the imported ones (ca EUR 150,000 to

[14] Farm size: large—over 5,000; medium—1,000 to 4,999; Small—under 999 (head of swine)

900,000) (F1, I3) which are considered unaffordable or not worth investing in by many farmers (F1, F3, F9, F14, F15) while NTD 150,000 (ca EUR 4,600) for domestic ones. Moreover, the high annual maintenance fees required by the generator agency is also concerned by farmers (F1, 14), which is for instance, NTD 1,000,000 (ca EUR 30,000) per year for imported generators.

Immature Market

Chen & Lee (2014) points out that the most urgent need for renewable energy development in Taiwan is to strengthen the renewable supply chain, which is especially the case for biogas. In the Energy Year Book (2015), biomass energy capacity in 2012 was 167 MW. However, unlike other mature renewable energy like solar and wind energy, which are at the promotion, incentive and demonstration phases, bioenergy and geothermal energy are still in the research and demonstration phase. Therefore, the problem of taking a loan from the bank for biogas plant is brought up by interviewees (I3, F9). The main reason is that the commercial banks are not familiar with biogas plants makes the loans for biogas plants easier to be turned down (I3).

> *"Apart from biogas power generation, we also involved in solar power generation and have invested quite a lot on it. It was much easier to make a loan for the solar panel investment from the commercial banks than biogas plant investment. This is because biogas power generation is a comparatively (to solar power) immature industry."–renewable energy company*

Low Feed-in Tariff

The last economic issue discovered through the desktop research is the feed-in tariff (FiT). The previous FiT is considered too low to be profitable for the farmers. The low FiT prevents the current biogas producers from connecting to the grid or selling the electricity. Instead, they use the electricity generated from biogas or give out for free to the neighbor (F1).

> *"In 2013, the price of the electricity from the incumbents is NTD 3, while the price of the electricity from biogas is only NTD 2 so it's not cost-effective if we sell it (electricity) to the government." – Farmer (F1)*

However, this problem is expected to be solved through the rising FiT from this year (2017).

> *"The Bureau of Energy raised the FiT this year to NTD 5.0087kWh. The industry (especially energy industry) thereby shows their interests to invest in biogas production since they regarded as profitable under the new FiT. There are more energy companies try to cooperate with swine farms to establish biogas plants (horizontal collaboration[15])!" - Government officials from Council of Agriculture Executive Yuan. (COA, 2017)*

4.2.2 Infrastructure Barriers (technology & science)

There are two types of infrastructure barriers, which are physical barriers and non-physical barriers (Negro et al., 2012). Physical barriers identified here are inadequate biogas generators, the lack of anaerobic digestion (AD) capacity, and farming practices while non-physical barriers are the lack of technical supports.

Physical Barriers

[15]Horizontal collaboration is a type of collaboration across rather than along the supply chain. Often, horizontal collaboration is between companies in the same industry that, while not competing directly, market and sell to similar customers and consumers.

Inadequate Biogas Generators

Biogas generators in Taiwan can be categorized into domestic produced generator and imported generator. The former is usually assembled by farmers while the latter is introduced by certain agencies from abroad. Comparing to imported generator, domestic generators have longer history in Taiwanese swine industries, which came as a result of the adoption of Water Pollution Control Act in 1974 and government subsidies on biogas plants. The tension between swine farms and neighborhoods rose because of the rising environmental awareness and increasing overlap of residential area and agricultural fields after the adoption of Agricultural Development Act in 2000. However, due to the lack of biogas knowledge, the standard biogas production procedure (Figure 4-5) is not widely adopted and most (90%) of these domestic generators faced serious mechanical problems after few years of adoption (F2, F7, F9). One of the most common issues is the corrosion of biogas plant caused by un-desulfurized biogas. The domestic biogas plant suppliers were usually a "one-person company", implying the biogas supply chains were rather weak with the absence of financial and technical support. Consequentially, many farms were forced to stop the biogas production. Nowadays, biogas plants operating in small farms are running at a very inefficient level (DIY biogas plants) (I1). During I1, it is also pointed out that the fundamental problem of biogas production is the lack of affordable and durable biogas plants (Su, 2016).

Insufficient Anaerobic Digestion Capacity

The interviewees pointed out that the capacity of AD for both municipal organic waste and agricultural waste is insufficient. For instance, the municipal organic waste in Taipei (the capital city of Taiwan) has to be sent to the AD plants in southern Taiwan (Pingdong County) because there is no AD plant in operation in Taipei (I3), while the director of Bureau of Economic Development of Taichung City Government also stated that the capacity of the AD plants for co-digestion of agricultural wastes is far below the needs in Taichung City (I2). However, the capacity is expected to increase because of the active involvement of private energy companies (Chen, 2016). The lack of biogas supply chain and market structure for agricultural waste and municipality waste is problematic for dealing with agricultural waste and municipality waste (I3).

Non-physical Barrier

The lack of technical support

The lack of technical support is frequently mentioned problem by swine farms, which happens in different sizes of farms. In recent years, the rising collaboration (project) between different entities such as farms, academic institutes and governmental research centers have helped the development of biogas technology (with standard biogas process) diffusion through popularizing the biogas technology niches in both large and small farms (I1, I2). However, the short-term-focused collaboration projects do not seem to be practical in the long run. In short, the lack of systematic framework of biogas diffusion to track the effectiveness and efficiency of these biogas plants creates uncertainties to biogas production's stability and profitability (F1). The difference of the biogas production process between Taiwan and other advanced economy such as Germany, Sweden and Denmark will be presented in the following section (4.4.2 social barriers).

4.2.3 Institutional Barriers (policy, culture & industry)

There are two institutional barriers, which are hard and soft institutional barriers (Negro et al., 2012). Hard institutional barriers are inappropriate agriculture policies and inadequate farming practices for biogas production.

Hard Institutional Barriers

Ineffective Wastewater Regulation

According to Auer et al. (2016), supportive governmental policy is the key to sustain the valuable carbon-neutral renewable energy sources by AD process in biogas production while local circumstances along with the policies form the cost-effectiveness and national acceptance.

In Taiwan, wastewater regulation can be seen as the major and initial trigger of biogas development; wastewater treatments and biogas production complement each other in terms of the process requirements. This cooperation can be dated back to 1980s when the wastewater regulation was adopted. However, several issues of the implementations are often mentioned throughout the interviews.

Firstly, there is no stringent control on livestock wastewater and the regulation seems to be a "symbolic policy" due to the absence of political will (especially during the period when the government strived hard to promote swine export). On the other hand, in recent years, environmental control seems to be more stringent and some farms have faced challenges to pass the effluent standards (F11, F12).

> *"I don't know if it is because the wastewater regulation is too strict or it is because of the social and environmental conditions in Taiwan that it is just too hard for these standards to be met. I've visited farms in Finland and Norway. Farms there were more odor than ours yet it seemed to me that they didn't face these regulation challenges as we did. I think maybe that's because their climate (cold) and they had larger land area (per person). As a result, they just didn't have to worry about it (regulation and complaints from the neighboring area)." – Farmer (F12)*

Secondly, the lack of qualified personnel makes it hard to enforce the regulation (e.g. insufficient water inspectors). Lastly, local conditions are usually not taken into consideration when it comes to the use of livestock wastewater. For instance, reuse of swine farm effluent is possible in some small farms since it has rather complete ecosystem to deal with the relatively smaller amount of wastewater, while some of them face huge challenges handling wastewater due to the farm location (located nearby residential area) and relatively large amount of wastewater. Moreover, since the treated wastewater is usually fed to the surface water of adjacent areas instead of other treatment facilities such as municipal wastewater treatment system, the consequence of the inefficient regulation include polluted irrigation, drinking water and contaminated underground water.

> *"Of course there are the wastewater effluent standards. However, I don't think they (the government) have enough human resource to check the farms regularly. They only do the water quality check once there is a complaint made by residents within their area." – Renewable Energy Company*

Lastly, the investment risk due to the changing environmental policies is also concerned especially by the energy sector.

> *"Before we made the first biogas investment decision, the changing environment has made us dare not to invest in biogas plants at some points. Yet we believe that the environmental policy in Taiwan is on the right track." – Renewable Energy Company*

Soft Institutional Barriers

Farming Practices Inadequate for Biogas Production

The anaerobic digestion (AD) of biogas production has historically been associated with manure and sewage sludge (Weiland, 2010), which should have made it intuitive for the farmers to view it as solution of wastewater problem and prevent themselves from being fined by the EPA. However, small and medium sized farms, which account for nearly 50% of the swine production, have faced the problem of less cost effectiveness of biogas production. Unlike the biogas production in large scale farms using biogas mostly for power generation, farms of smaller sizes tend to use the biogas produced more. This is mainly because the manure from smaller farms is usually not sufficient for biogas power generation. Comparing to the cost of investing in new biogas plants as well as maintenance costs, the revenue it generates is far less, which is especially the case for the smaller farms.

Cleaning and disinfecting are critical to biosecurity through minimizing pathogen load so that disease transmission does not occur. Removal of swine farm organic material can be done through specific measures including cleaning, washing and disinfecting.[16] In Taiwan, the washing stage is called "Swine House Washing". Comparing to other swine exporters, Taiwanese farm use comparatively "large amount of water" to wash away the swine manure. High proportion of water in swine manure means diluted manure and results low "total solid (TS)". It is suggested that TS content is around 15-40% (Mes et al., 2003), while Taiwanese swine farms' TS content is only 1%, which results in heavy manure and lower ratio of organic matters and makes the preparation for biogas production problematic. This practice further obstructs the development of cooperative digestion or centralized biogas plants for smaller farms due to the high transportation costs (I1, I3).

The practice of the procedure of wastewater treatment in swine farms is the other issue that makes biogas production less efficient. According to Su (2016), in order to help the swine farms to meet the effluent standards of swine treated effluent, the government demands the farmers to conduct two-stage solid-liquid separation before the wastewater go to the biogas plant (Figure 4-6). This practice is opposite to the procedure of wastewater treatment in other developed countries such as Germany (Figure 4-7), where the wastewater is firstly treated by AD plant and the solid-liquid separation comes afterward. The Taiwanese practice decreases the organic matter concentration in the wastewater and thereby reduces the biogas produced afterwards (Su, 2016).

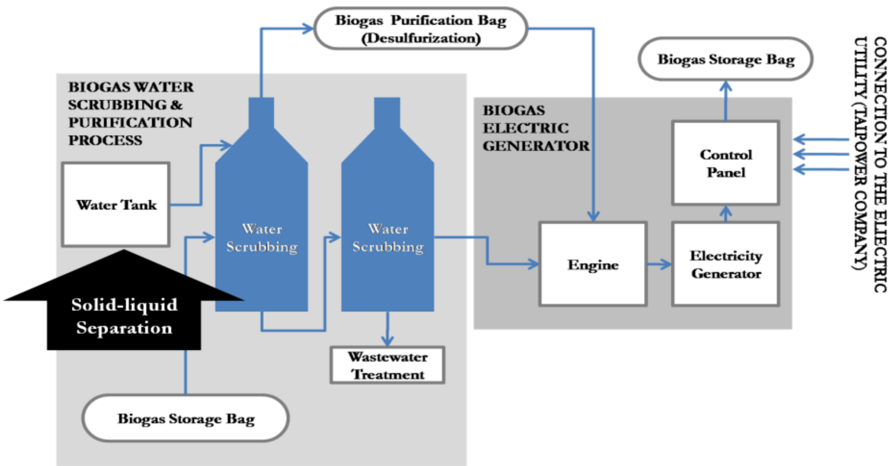

Figure 4-6 Procedure of Swine Wastewater Treatment in Taiwan

[16] Four steps to effective cleaning and disinfecting: http://www.nationalhogfarmer.com/health-diseases/1015-effective-cleaning-disinfecting-steps

Source: Su, 2016, Adapted by Author

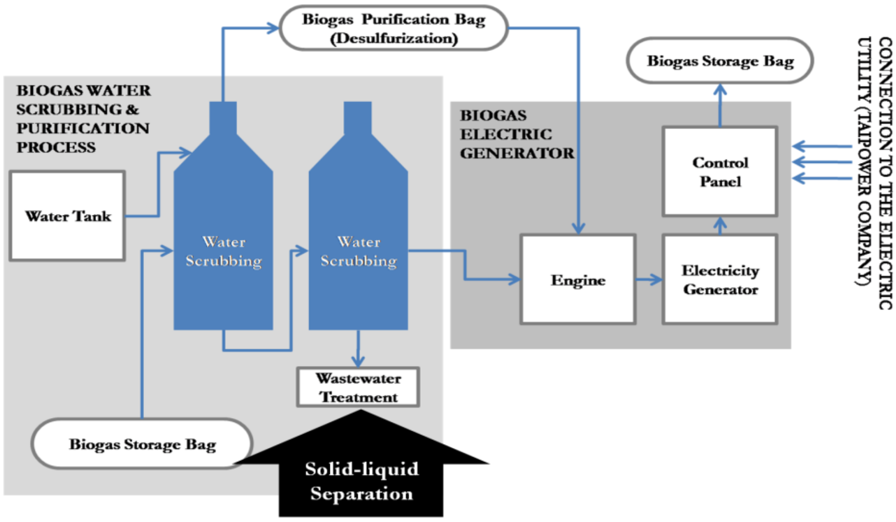

Figure 4-7 Procedure of Swine Wastewater Treatment in other developed countries

Source: Su, 2016, Adapted by Author

The barriers to biogas diffusion are summarized in the following table (Table 4-8). The relevant regime items and responsible regime actors associated with each barrier are also recognized respectively.

For economical barriers, the main responsible entities underlined are Council of Agriculture, Bureau of Energy, and farmers. Hard infrastructure barriers (biogas equipments) are usually caused by the biogas equipment suppliers, import agents while the renewable energy companies in Taiwan tend to be the problem solver of the hard infrastructure barriers, which will be discussed in the next chapter (chapter 5). On the other hand, soft infrastructure barriers (the lack of technical supports) are expected to be solved by the government (Council of Agriculture) and academic institutes from the farmer's perspective (F7). The institutional barriers have rather simple responsible actors, which are Environmental Protection Agency and farmers. However, wider range of the change is required to tackle the institutional barriers as it affects the structure of EPA (e.g. the allocation of human resource and budget) and various farming practices.

Additionally, it is worth mentioning that causal relationship of immature market and insufficient AD capacity in this study is rather vague that implies wider range of involvements from the governmental (municipalities) and market actors (potential investors, banks, etc.) may be needed.

This analysis process indicates that the attribution of responsibility should be redefined. It is obvious that public sectors play a crucial role in conquering all these barriers, while farmers and energy sectors (equipment suppliers, import agents and renewable energy) are specifically responsible for the economical and institutional barriers and the infrastructure barriers respectively. However, in this study, in view of the limited capacity of the farmer (biogas plant investment and the knowledge and information of biogas production), the author proposes that the economical burdens of the farmers should be apportioned by the government as well as the energy sector who have more accesses to crucial information and knowledge of biogas production.

Table 4-8 Barriers to Biogas Diffusion in Taiwan

		RELEVANT REGIME ITEMS	RESPONSIBLE REGIME ACTORS
Economical Barriers	▪ High upfront, maintenance, and human resource cost	▪ Market ▪ Technology ▪ Science	▪ **Government:** Council of Agriculture & Bureau of Energy ▪ **Farmers**
	▪ Immature market	▪ Industry	---
	▪ Low FiT	▪ Policy	▪ **Government**: Bureau of Energy
Infrastructure Barriers	▪ Inadequate biogas generators	▪ Technology ▪ Science	▪ **Biogas equipment suppliers** ▪ **Biogas equipment import agents** ▪ **Renewable energy company**
	▪ Insufficient anaerobic digestion capacity	▪ Policy ▪ Technology	---
	▪ The lack of technical support	▪ Policy	▪ **Government:** Council of Agriculture ▪ **Academic institutes**
Institutional Barriers	▪ Ineffective wastewater regulations	▪ Policy	▪ **Government**: Environmental Protection Agency
	▪ Farming practices inadequate for biogas production	▪ Culture	▪ **Farmers**

Source: Author

5 Discussion

In chapter 5, to answer RQ 2, the author discussed the further implications of the results from chapter 4 through comparing the results with the findings from the literature reviews, underlining how the new business model can proactively help biogas technology to become a disruptive innovation niche to overcome the existing barriers and lead to the transition of socio-technical system.

5.1 Silver Lining of biogas diffusion: Disruptive Innovation Niche Facilitator

5.1.1 The Cause of Barriers

Consideration of the phenomena observed in this study within this analysis strongly suggests that the root cause of the barrier is the "**incomplete business model"**, which has paralyzed the diffusion of biogas in Taiwan. In this study, it is argued that an incomplete business model has the following two distinguishing features:

(1) the value proposition discrepancy between stakeholders

The value proposition of biogas is perceived differently by stakeholders. The different value proposition can distort the value of governmental policies. For instance, in Germany, the policies promoting large AD plants in Germany turned out increase the energy crop plantation instead of the utilization of waste feedstock like manure (Auer et al., 2016).

In the case of Taiwan, on the one hand, farmers focus on heat and power production, crop rotation, pesticide & fertilizer use, odor, labor, biogas for household uses, etc. These become the main drivers to adopt biogas productions on the farms. The farms are usually specialized farms but some of them try to establish a more sustainable agriculture environment on their farms with either the rising awareness of sustainable agriculture or the past experiences.

On the other hand, the government and academic institutes stresses more on the benefits of biogas from a broader or higher level such as GHG emissions, energy efficiency, research and innovation. The discrepancy on value proposition has become problematic for communication and result in the inefficient popularization of new biogas technology.

Moreover, we further argue that in the swine farm's BM, farmers value biogas production less due to the discrepancy between the value proposition of biogas and the main revenue stream of the farmer. This will be discussed in the next section (5.1.2).

(2) the partnership network is too weak to stabilize the biogas supply chain

As defined in section 2.3, partnership network is the key activities outsourced and resources acquired outside the company. The biogas production requires wide range of technology, resources and multi-sector involvement. This implies that the partnership network is important a successful biogas system. A weak connection between the stakeholders can impede the biogas production chain.

In Taiwan, the swine farmers are perceived as responsible for the biogas production due to the focus of biogas policy. The major problem behind this paradigm is that swine farmers are not "capable of" running biogas plants themselves due to the limit of time and knowledge (I1, I3, F1). On the other hand, for energy sector, it is inaccessible (may take a lot of efforts) to the biogas raw materials (manure), lands, downstream buyers of biogas by-products (bio-fertilizers). Therefore, we argue that the weak biogas production partnership between the energy and agricultural sector should be strengthened.

5.1.2 Opportunity and Solution

In view of the above problem of current incomplete business model in biogas sector, the study suggests that the new BM of biogas can open up the window of opportunity for further biogas diffusion through Strategic Niche Management (SNM). To demonstrate the proposed solution of barriers clearly, in the following section, two steps are highlighted, which are identifying key drivers in existing biogas BM to close the gap of value proposition discrepancy and strengthening the collaboration between regimes.

In the section 5.2, a BM innovation case study of renewable energy company from Central Taiwan that features regime collaboration and redefines the business model (e.g. new ways of collaboration, technology, etc.) is presented to exemplify the findings from previous chapters and analysis in this chapter.

Step 1: Identifying Key Business Model Elements

It is important to keep in mind that in Taiwan, the biogas business model is mostly taken on by livestock farms (mostly swine farms) since it is the "only" sector that involves in biogas production in Taiwan". Other sectors like municipality solid waste or industrial sectors nowadays are not implementing biogas into the production process or waste management system due to the resistance from the citizens.

The business model of swine farms with biogas production is presented in Figure 5-1. Crucial BM items related to biogas production are highlighted in blue, which are value proposition, key activities, partner network, and financials (cost and revenue).

This section delivers detailed results of how biogas performs in these items as well as how the regime actors (e.g. farmers, renewable energy company, administrative units, biogas generator agencies, commercial banks, academic institutes, etc.) interact with each other in the presence of this innovation niche.

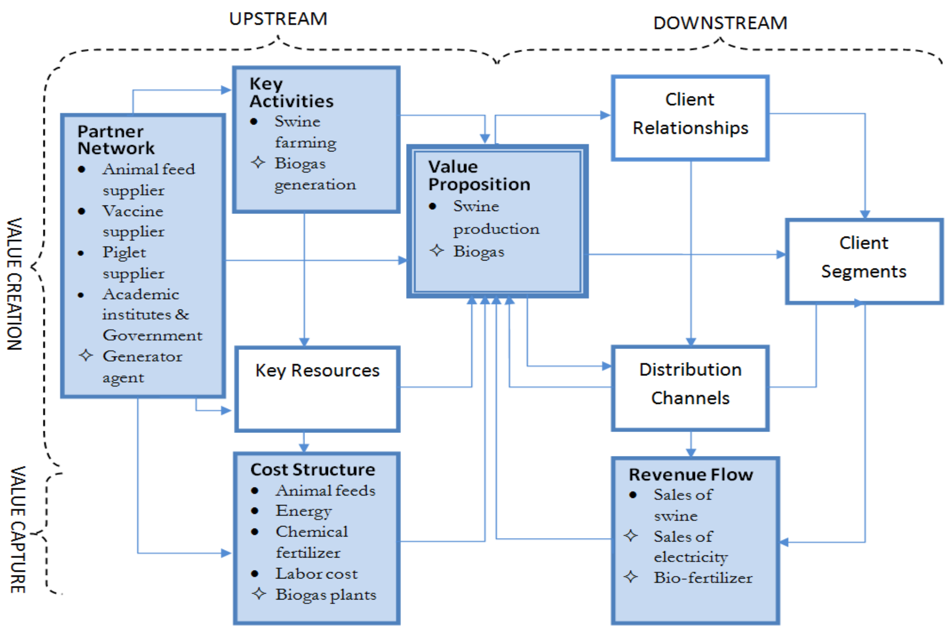

Figure 5-1 Business Model of Swine Farm with Biogas Production

Listings with star are elements that occur after the implementation of biogas production.

Source: Author

As highlighted in section 5.1.1, the incomplete BM caused by the discrepancy of value proposition and weak partnership network, in this section, the value proposition from the perspective of farmers are identified from qualitative interviews.

Value Proposition of Biogas Production

From the qualitative interviews, the study concludes four main value propositions of swine farm's biogas BM, which are (1) wastewater management; (2) alternative energy source; (3) sustainable agriculture; and (4) contribution to low carbon society. They are presented in detail as follows.

(1) Wastewater Management

Most of the biogas productions on farms are regarded as a side-product of the swine farms instead of main business activities as the revenue generated from biogas production and its related products are relatively insignificant comparing to swine sales. The value proposition of biogas production relies heavily in its ability of improving wastewater treatments rather than value capture (F1, I3) due to the relatively low profitability.

> *"We were forced to close down because we couldn't manage to handle the wastewater." – Farmer*

> *"The farmers don't usually care about the electricity. They only care about if you can help them to improve their wastewater treatment system." – Energy Company*

On the other hand, the installation of biogas plants improves the farm's environmental image in from of the government as well (F1). The risk of wastewater pollution from the farm which is not appropriately treated is regarded to be lower after biogas installation.

> *"After the installation of biogas plants, the inspections from the government never happen!"– Farmer (F1)*

However, it is also observed that as the main value proposition of biogas production is wastewater treatment, once this concern is satisfied (good wastewater treatment is in place), the willingness of implementing biogas facilities in swine might decrease (F3).

> *"We have already spent tremendous amount of money on wastewater treatment, there is no need for us to do biogas plants." – Farmer (F3)*

(2) Alternative Energy Source

It is brought up by interviewees that they perceive biogas as an <u>alternative source of energy</u> and can help the farm to reduce the energy costs (piglet house heating, mechanical stirrers for animal feeds, household cooking, etc.) (F5, F6, F8, F9). This is based on the farmers' prediction of mounting price of electricity in the long run. This is further confirmed after the Fukushima Earthquake in 2011 (F1).

> *"Biogas was an important source of alternative energy for emergency use. When the utility electricity system broke down from time to time in 1990s, we used electricity generated from biogas to stir our animal feeds." – Farmer (F9)*

(3) Sustainable Agriculture Management

In many interviews, the farmers are aware of the sustainable management of the farms through nutrient recycling. Farmers recognized that the vegetables or orchards grew better according to their own experiences (F1, F12, and F14). Not only the farmers but also the energy company tries to recycle the nutrients themselves on their customers' farm (I3).

> *"The overuse of chemical fertilizers exploits the soil in the long run."– (I3)*

> *"We used to apply bio-fertilizers on our vegetable plantation and there was a saying goes like this: Manure is the gold from the land, swine are treasures of the household. Farming without keeping swine is like a scholar who doesn't read. After starting to use chemical fertilizers, the vegetables taste less sweet (good) than before…"– Farmer (F1)*

> *"We use the swine manure for bamboo shoots, it turns out great. It tastes very good!"– Farmer (F6)*

> *"The vegetables applied the digestate (bio-fertilizer) grew better than those applied chemical fertilizers. Now we don't produce biogas but we try other ways to produce bio-fertilizers. For instance, we ferment or burn the weeds and mix them with chemical fertilizers. It also performs well! "– Farmer (F9)*

(4) Contribution to Low Carbon Society

Even though the benefit of biogas production does not exactly reflect on the products (it does not contribute to higher swine price), the contribution of biogas plants to low carbon society do reveals new customer segment for a group of consumers with higher environmental awareness (F1).

> *"I was about to be a vegetarian since I am so worried about the global warming. However, when I heard about how this swine farm tries to reduce the environmental impacts, I feel that I might have other choice! I feel less guilty to buy product from you."– Customer of Swine Farm (F1)*

Bridging the Gap between Value Proposition and Revenue Stream

Moreover, the change of cost and revenue after the implementation of biogas is listed in Table 5-1 and discussed as follows.

Table 5-1 Biogas influences on swine farm cost structure and revenue stream

VALUE PROPOSITION	**---**	**(1),(4) Alternative Energy**	**(2) Sustainable Agriculture**	**---**	**(3) Waste Management**
COST	Animal Feeds	Energy	Chemical Fertilizer	Labor Cost	Environmental Cost[17]
Change of Cost	--	↓	↓	↑[18]	↓
REVENUE	Sales of Swine	Energy	Bio-fertilizer		
Change of Revenue	--	↑	↑		

Source: Author

[17] Environmental costs can be fines of violating effluent regulation, handling of sludge, etc.

[18] Labor is required for preventive and unscheduled maintenance. Ideally, one person will be in charge of the digester, and the digester takes precedence over that person's other farm duties. http://extension.psu.edu/natural-resources/energy/waste-to-energy/resources/biogas/projects/g-77

(1) Cost Structure

Regarding the cost, biogas helps to reduce the cost of energy and chemical fertilizer. The environmental cost is also reduced once the biogas plant is implemented as the risk of being fined due to the untreated wastewater (I3, F1). However, it adds less benefit to animal feed cost reduction, which is the dominant cost (60-70% of the swine farming cost) (CommonWealth Magazine, 2016), while the labor cost may increase after the implementation due to the need of human resource such as biogas engineer or technicians (I3).

For the bio-fertilizer use, however, the residual of animal feed additives and supplementation (e.g. antibiotics, copper and zinc), and animal pathogens can increase the risk of the spreading of communicable disease such as spongiform encephalopathy and foot and FMD. These diseases can damage the main source of revenue in a serious way if the proper control is not enforced (IEA, 2014). In addition to that, the large volume of irrigation from the swine wastewater could increase the risk of heavy metal contamination of the crop lands (I3).

(2) Revenue Stream

As for revenue, the revenue generated from the biogas mainly attributes to the sales of electricity and bio-fertilizer (F1, I3). However, the revenue from the sale of electricity and bio-fertilizer seem to be less stable due to the dependency of FiT and the uncertain quality of digestates (e.g. nutrients composition). Even though the biogas plants may improve the waste management of swine farms and help Taiwanese swine to get rid of FMD, the impacts on main revenue flow (the sales of swine) is still unknown as the market mechanism of swine involves in other crucial factors, including the climate, nursery and finisher ratio, feed conversion ratio and others. The absence of biogas in cost reduction or revenue generation process makes implementing biogas less urgent for the farmers.

Step 2: Strengthening the Collaboration between Regimes

Since biogas is highly technology-demanded, indicating that without sufficient knowledge and management skills, biogas investment can be hardly paid-off. Therefore, in this study, the importance and necessity of a certain degree of regime interactions are highlighted by in this study. As mentioned in section 2.4, there are four types of regime interactions (competition, integration, spillover, and symbiosis). Considering limited ability of relatively small sized renewable energy companies (comparing to incumbent utilities) and capacity of swine farms (e.g. farmers are generally too busy to take care of biogas production), competition (e.g. renewable energy companies develop their own biogas production chain, like manure sources) and integration (e.g. to complete a merger deal with swine farm) are less feasible. By keeping this in mind, ideal interaction between regimes stands out: spillover and symbiosis. In the next section (section 4.4), we will discuss a case study featuring spillover and symbiosis between renewable energy and swine farms.

Synergistic Effect of Policies

Policy opens up the window of opportunity for actors from both regimes to collaborate with each other. In this study, it is argued that synergistic effect of agriculture policy (e.g. wastewater regulation) and energy policy (FiT, liberalization of electricity market) can stimulate biogas diffusion. This implies that once the benefit of collaboration (e.g. profitability, stability of supply chain, etc.) is recognized, the new or existing actors will intervene the market and tackle barriers.

(1) Collaboration between Farmers

Swine industry is relatively mature industries among other livestock industries (F11), which implies that in swine industry, trust between farmers is bigger. It is common for the farmers to share their experiences in terms of farming practices. This kind of collaborations within swine industry can also be seen as a strategic alliance to increase the competitiveness of the industry. They not only exchange experiences but also work in collaboration with each other to invest in new technologies such as biogas production and reduce investment risks of new technology.

(2) Collaboration between farmer & Other Stakeholders

Both farmers and renewable energy company showed high interests in the collaboration with academic institutes to improve the biogas productions (F1, I3). Collaboration for instance, including testing of the desulfurization equipments and digestate as well as the potential use of digestates as supplemental feed in algae cultivation are mentioned during the interviews (F1, I3). Some interviewees even think these technical supports more helpful than financial supports (F7). On the other hand, however, economic problem (when biogas production becomes less profitable due to several reasons) can reduce farmers' willingness of collaboration with other stakeholders like academic institutions or government (F4).

These drivers are regarded as the key in BM to facilitate the biogas diffusion in this study. Once the drivers and the responsible actors are identified, it is assumed that the barriers to the diffusion can be better addressed. In the next section (5.2), a case study is presented to demonstrate the findings and analysis.

5.2 Case study: Symbiosis & Spillover of Biogas Production: Taiwan New Energy Co.–A Renewable Energy Company with New Business Model

In this section, the case study company, Taiwan New Energy Co. recently establishes a new BM featuring two regime interactions, which are spillover and symbiosis. This BM innovation is distinctive comparing to existing biogas BMs that are mostly run by individual swine farms. The company is a creative and proactive actor that aims to reduce the value proposition discrepancy between stakeholders, to help the swine farms to reduce the economical burdens and to strengthen the network along the biogas production chain. BM items highlighted by the disruptive innovation niche (value proposition, financials, and partnership network) are further illustrated in the following paragraphs. Challenges remained are also presented in the end of this section.

The case study is done through in-depth interview with the key person of Taiwan New Energy Co. (personal interview and several social media communications) and a visit to its customer's farm in Central Taiwan in February 2017.

Brief history

The renewable energy company, Taiwan New Energy Co. that provides biogas total solution was originally a gas energy provider since 1995. It worked closely with the Environmental Protection Agency in Taiwan to tackle air pollution in its gas business. In 2015, the company decided to develop its renewable energy business and thereby started a new company (Taiwan New Energy Co.) to run the biogas production. The company's initial target of the biogas source was municipalities waste but the process of collecting food waste from household and industry required a more complex system. Thus, it turned the target to the largest livestock industry with the worst pollution problem in Taiwan, the swine industry. According to the manager, choosing swine industry is in response to the core value of the company: to develop renewable energy and to tackle the pressing pollution issues in Taiwanese society.

> *"We also have invested in solar energy but it turns out that the pollution it generated in the production phase makes solar energy less valuable to us. Those contaminated waste water and sludge. We think that biogas is a valuable energy source to provide renewable energy and to tackle waste problem in the swine industry"*- Vice general manager

New Value Proposition: a Total Solution Provider

The company introduces biogas facilities with higher biogas production and power generation efficiency comparing to other biogas generator providers or importers. The AD plant established by the Taiwan New Energy follows the biogas production process established by a German equipment suppliers and the power generation rate from gas is around 38%. This gives the company advantage in the energy sector since biogas power generation plants in most of the large swine farms have lower efficiency of 23-30%.[19]

Unlike most of the existing biogas equipments providers (agents) in Taiwan, the company is the first company to provide a total solution to its customers. It not only provides the biogas equipments but also entire design of biogas supply chain. This is crucial for swine farms since the swine farmers usually face various problems regarding planning, operation and

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[19] It is worth mentioning that the efficiency of biogas generation or energy yield is also based on other variables such as the source of substrate.The source of substrate affects the energy yield. For instance, pig manure has higher energy yield (30m3/tFM) than cow manure (25m3/tFM) in biogas production (Weiland, 2010)

maintenance as well as the arrangement of biogas by-products. The engineers from the energy company help the farms to integrate the biogas facilities into the existing farm infrastructures such as pig houses and wastewater treatment plants. The company therefore becomes the intermediary between the swine farms and foreign equipment providers throughout the process. The importance of a total solution provider is especially crucial for the biogas development in Taiwan to harmonize the foreign equipment with local conditions are crucial regarding the biogas planning and constructions since the equipment are mostly imported.

Value proposition differentiation

Taiwan New Energy Co. differentiates its customers into two types based on farm size. One is biogas production with power generation for larger sized swine farms while the other is biogas production without power generation for small sized farms. The rationale behind this is that the larger farms have more manure sources so that the power generation is more profitable, while the smaller farms have less capacity to build up the necessary wastewater treatment plants (I3, F12).

Shifting the Biogas Cost Burden and Revenue Stream

The company establishes the biogas plants with 100% of self-financed investment. The customer does not have to pay for the plant itself. As shown in Figure 5-2, the key activities, key resources, and cost structure (highlighted in dark blue) are shifted from swine farms to the renewable energy company. To ensure the sources for biogas production, the company signs a contract that the customer has to provide one-third of its manure as the source of biogas production. The company also takes the responsibility of handling wastewater to meet the wastewater effluent standard as well as the digestate and sludge generated. In terms of revenue stream, the company will receive most of the revenue from electricity generation while the swine farm can receive the revenue from the commissions of electricity sales and the sales of digestates as bio-fertilizers.

Moreover, to further reduce the cost of human resource, the company aims to automate all the biogas production process. This will shorten the payback period of the biogas plant investments. For instance, if the total investment is NTD 30,000,000 with the annual benefit it brings is NTD 2,500,000 per year and the labor cost is 500,000 annually. The returning period will be 15 years (NTD 30,000,000/ (NTD 2,500,000-NTD 500,000)). The returning period will be shortened to 12 years if the production process is automated (NTD 30,000,000/NTD 2,500,000).

Building up New Biogas Socio-technical System in Taiwan

The company's investments not only catch the attention of its competitors,[20] other biogas generator import agents but also the government. Other equipments suppliers start to review their BMs since they are no longer the oligopoly of the biogas power generation market any more. The existing biogas equipment market featuring high prices and maintenance fees is expected to be altered due to the emergence of the new competitor.

The value of investing in biogas plants for the company lies in (1) demonstration of the biogas plants for the potential customers and (2) educational purpose for its employees, which are in line with the core value of Strategic Niche Management. Biogas technology is tested under the protection of the company's new BM. One of the main drivers of establishing this new BM is that most of the potential customers (large scale farms) request to see the real applications of

[20] The two dominant biogas plant import agents in Taiwan are Aerospace Industrial Development (AIDC) and Capital Machinery (CML).

biogas plants in Taiwan, instead of pictures or videos from overseas swine farms. Additionally, the company views their biogas plants as valuable assets for training its employees as the knowledge of biogas production is not widely spread in Taiwan.

The rising attention for this new BM from the government also gives the opportunities to lower the requirements of financial supports, which is the long-standing problem for renewable energy in Taiwan. Before the establishment of this BM, small and medium sized farms are usually less willing to implement biogas in their farms. However, by seeing its success, some smaller farms start to inquire the possibility of collaboration. The observation of this study is that the establishment of this new BM opens the window of opportunities to change the current biogas socio-technical system in Taiwan.

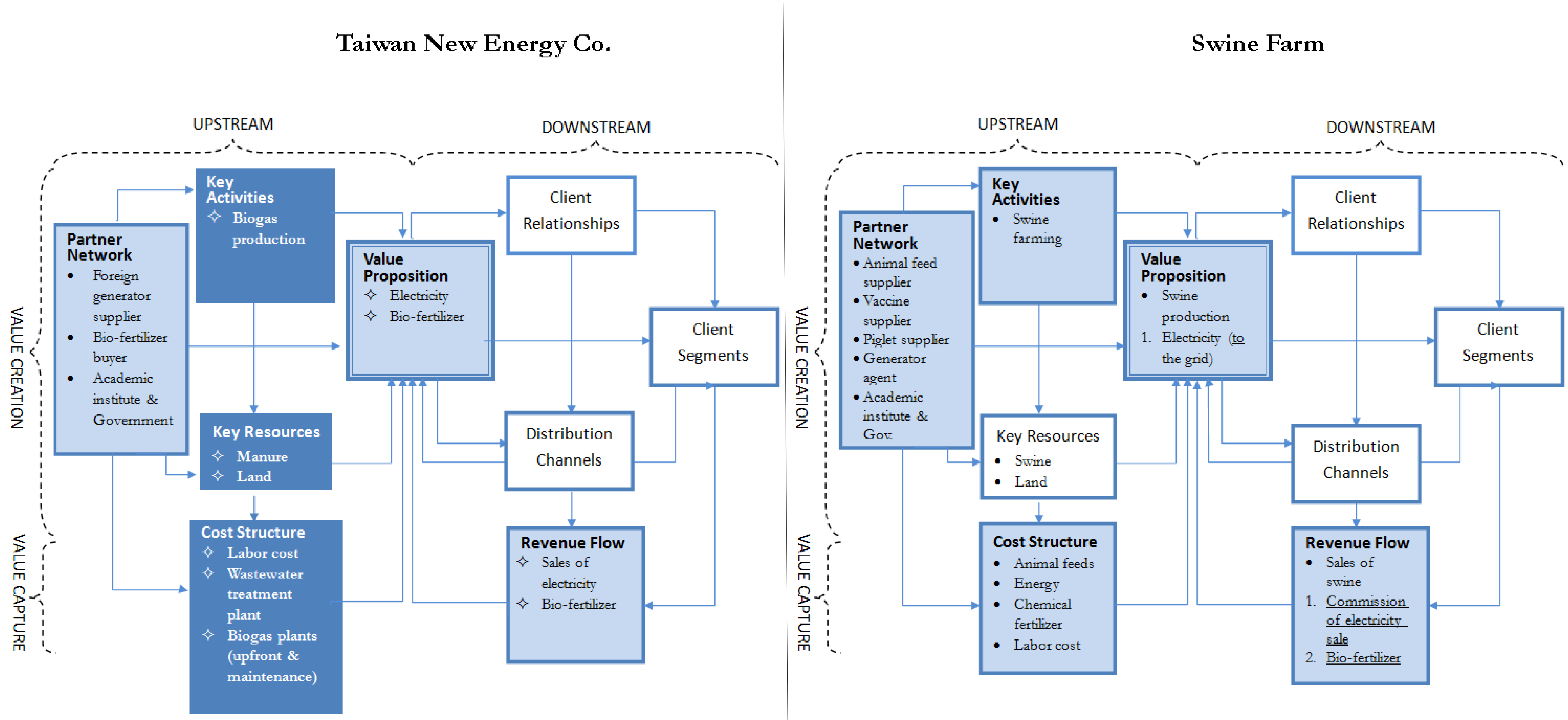

Figure 5-2 Flows of Technology, Material and Financials of New Business Model

Source: Author

5.3 Characteristics of Disruptive Innovation Niche Facilitator

In section 5.2, the study reflects on the characteristics of disruptive innovation niche. The significance of the new business model in Taiwanese biogas development is recognized in this study because of the multiple solutions it offers to solve the barriers under current socio-technical system. The company plays the multiple roles in promoting biogas technology to a disruptive level as it helps to improve the convenience, accessibility and affordability. The roles are described as the follows.

A Knowledge Intermediary to Infrastructure barriers (convenience)

Biogas has been recognized as a complex technology and relies heavily on local conditions. The limited ability of swine farmers makes the biogas operation and maintenance fairly difficult. The experienced technicians and experts from the energy company provide the knowledge needed to establish "useable and durable" biogas plants through its total solutions. Here we argue that the energy company can be seen as an information or knowledge intermediary that is responsible for up-to-date technologies on the farm, the arrangement of the by-products (e.g. digestate) and the quality of final effluents, while the farm is only obligated to ensure the supply of biogas production sources. In other words, the company takes care of not only the infrastructure, equipment and maintenance of biogas production but also the whole biogas supply chain, including upstream (farms, equipment suppliers) and downstream (digestate buyers, electricity buyers).It improves the **convenience** of biogas among swine farms as it simplifies the complex production process with the total solution.

A Cross-Regime Observer to Institutional Barriers

The energy company is involved in various renewable energy productions and is experienced with Taiwanese environmental regulations in many aspects as well as has good understanding of agricultural sector (swine industry, irrigation system, etc.).Therefore, unlike farmers specializing in swine farming practices, the company has a holistic picture of the biogas production and related regulations so that it is capable of providing practical and objective suggestions to the government regarding the current biogas socio-technical system. For instance, the Irrigation Law is said to be beneficial for the swine farmers by the general public while in energy company's opinion, this Law seems to be unrealistic since the amount of wastewater from the swine farms surpasses significantly the amount the land needed to be irrigated. Moreover, the irrigation is seasonal while the effluents are produced whole year round. Lastly, the problem of effluent transport costs and the infrastructures delivering the effluents have to be addressed. These constraints may make the Law infeasible.

A Strategic Niche Manager to Economical Barriers (affordability)

The government has risen the loan amount of "preventing livestock industry pollutions" from NTD 10,000,000 (ca EUR 310,000) to NTD 30,000,000 (ca EUR 926,000) according to Loans for Agricultural Energy Saving and Carbon Reduction Directive. However, for commercial banks, the degree of mature of an industry is crucial to agree on the approval of a loan. The role of the company's biogas plants on the swine farm is identified as an experimenting site by the company and allows the company to test the biogas production under the local conditions. This biogas plant demonstrates the biogas production has been noticed by the government. The government officials were surprised by the way it collaborates with the farms and thereby opened up the doors of communication between the company and the government regarding financial barriers to the biogas diffusion. In the discussion, the recommendation of lowering the requirements of making loans for biogas production (which was also strongly recommended by scholars) was delivered to the government. Therefore while biogas production is very new to most of the commercial banks, the guarantee from the government may make huge difference for the financial situations. Most importantly, the success of the BM in some degree convinces the government and the society about the feasibility of biogas production and enhancing its potential to change the socio-technical system.

A Communicator to Socio-technical Barriers (accessibility)

From the very beginning, the company has stated clearly that the core values of biogas are to increase renewable energy supply and enhance resource efficiency in its vision. The proactive communication with the farms makes it important for the biogas knowledge to spread within the swine industry, and potentially in waste management sector in the future. This can be seen as a kind of strategic partnership to break the exiting socio-technical barriers. The trust between the company and the farms is also deepened after numerous farm visits. Thus, the company has influenced the farmers' ways of thinking regarding the biogas production and its wastewater treatments and gradually changes the swine farming practices. Furthermore, after the success of the demonstration plants, other farms including small and large ones expressed their interests of cooperation. The company becomes another channel for the swine farms to acquire biogas technology and increase the accessibility to the niche. This can help the technology to expand its market in the existing socio-technical system. Most importantly, the more demand of the biogas plants, the higher the possibility of bringing down the high market price of biogas plants set by the dominant biogas generator import agents.

To sum up, the importance of the facilitator lies not only in the biogas diffusion in swine industry but also the waste management system in Taiwan. As the government is expected to enact more stringent environmental regulations in the future, more and more waste treatment plants are needed. For instance, after the Water Pollution Control Fee is enacted, the New Taipei City government decides to establish its own livestock wastewater treatment system (centralized wastewater treatment). Once the biogas waste treatment system is established, diffusion of biogas plants can be expected to be much faster. This means that in the worst situation - swine industry may keep diminishing in Taiwan, the new biogas system will be created based on the foundation of the previous symbiosis of the biogas.

Challenges Remained

The major challenges highlighted by the energy company are financials and customers mindset. The former can be solved through the help from the government or other financial instruments like loans from commercial banks. However, financial banks' lack of knowledge of biogas production makes it harder for the biogas producers to pass the checks or requirements on the loans. The latter is rather challenging since if the customer does not have the mindsets of sustainable production such as circulation of nutrients on farms, self-sustained energy consumption, and minimization of pollution. This makes it very difficult to persuade the customer to implement biogas production in their farms.

In addition, the findings from the farms reveal that even though the government provides favorable interest rates, the farmers still prefer the biogas plants to be invested and run by professional entities such as renewable energy companies. However, while the importance of new BM featuring collaboration between the energy and agricultural sector is highlighted in this study, the question of "once the energy sector join the biogas production, are they eligible to apply for the low interest loans, which is designed for agricultural sector?" and "who should be responsible for other costs such as operational cost and maintenance cost?"

These questions require how the government synergizes the existing policy and take the energy sector into consideration while they formulate the biogas policies.

6 Conclusion

In this chapter, conclusions drawn from the chapter 4 and chapter 5 are presented. Reflections on the methodology and suggestions for future research are also proposed.

6.1 Revisiting the research questions

Regarding the complexity of biogas production, one-size-fits-all solution to overcome the barriers underlined in the research doesn't exist. The conditions of the farms decide the feasibility of biogas production in the farms. These conditions include farm size, location, production method, accessibility to crucial information, etc. The agricultural policy can not only impact on the agricultural production but also the related renewable energy development since the biogas production is identified as secondary products. Only when the production and the market are secured, the biogas development will be stable.

The two research questions are the foundation and guideline of the study. The first research question has been addressed in Chapter 4 and discussed in Chapter 5.

RQ 1: What are barriers that hinder the diffusion of biogas system in Taiwan?

The results are consistent throughout the research that the major barriers lie in lack of knowledge, inappropriate regulations, existing swine farming practices and financial problems. These barriers not only block the development of biogas but also further slowdown the prosperity of swine industry and sustainable agriculture as well as the low carbon society transition.

RQ 2: How does new BM conquer barriers to biogas diffusion in Taiwan?

The business model of the case study company illustrates how the business model innovation can help to solve the barriers to biogas diffusion under existing socio-technical regimes. It brings new trajectory of crucial business model items such as value proposition (high efficiency biogas generator), financials (biogas plant invested by the company instead of by farms) and partnership networks (integrating the biogas supply chain). Consequently the willingness of implementing biogas plants increases in swine industry. Therefore, according to the analysis process, it is argued that biogas diffusion among swine industry can be accelerated by new business models that can act as multiple roles to improve convenience, accessibility, and affordability of the innovation niche and at the end of the day, make the niche to the disruptive level and change the existing regime.

Recommendations

In the last part of this thesis, policy recommendations for future biogas development are made based on four parts, which cover the biogas value proposition, farming practices, network building, and suggestions on agricultural policies.

Strengthening the Value Proposition

To effectively promote biogas production among swine farms, the emphasis of value proposition should be differentiated according to the size of farms. For large farms, sound FiT is the key to increase the degree of biogas production involvement and stimulate the power generation as they have more biogas power surplus. As for smaller farms, the benefit of biogas in waste management should be highlighted since the lack of ability to cope with farm waste is a common issue for small sized farms.

It is without doubt that the appropriate utilization of biogas is fundamental to maximize its value. However, so far, the biogas is still at its early stage of development in Taiwan and most of the policies related to biogas are just recently introduced to Taiwanese society (new FiT, incentives, research projects, etc.). Since the utilization of biogas is strongly related to a country's financial support system as mentioned in section 2.1.2 and the policies from various sectors (e.g. the energy, agricultural, transport, waste management and other sectors involving in biogas production), a clear and comprehensive policy guideline is needed for the stakeholders to visualize the opportunities in Taiwan.

Altering the Swine Farming Practices

Encouraging the swine farmers through continuous educational or training programs from the government can help to popularize the biogas knowledge among farmers and change the farming practices, which hinder the development of biogas. Three practices that needs to be changed are (1) abandoning the practice of Swine House Washing, which increases the transport costs of biogas, reduce the biogas production efficiency and consequently obstruct the development of cooperative biogas plant in a local level and instead, applying swine house scrubbing; (2) adjusting the procedure of biogas production such as changing anaerobic digestion stage before solid-liquid separation stage to maintain sufficient organic matter for biogas production; (3) the uses of animal feed additives and supplementation such as antibiotics, copper and zinc that may pose threats to human health as well as to the environment like affecting the quality of bio-fertilizer and underground water.

Developing Partnership Network

In view of the complexity of biogas production and the features of swine farm biogas production, the study suggests a higher level of partnership such as partnership between the energy and agricultural sector is very beneficial as energy sector encompasses greater technological capacity (comparing to agricultural sector) and energy companies are more market-driven (comparing to academic institute and the government).

A local level collaboration should also be promoted to strengthen the agricultural sector. For smaller scale swine farms, developing the collaborative biogas production is suggested to popularize the biogas technology and reduce the financial burdens for farmers. This can be achieved through two measures: (1) strengthening existing partnership networks among small farms and (2) establishing new partnership networks based on swine farm locations (mapping the swine farms). It is not only valuable in terms of biogas production but also for the industry as a whole since the close cooperation can be expected to be physical and emotional supportive to the farmers.

Formulating Supportive Agricultural Policies

With the rising awareness of food security and energy security in Taiwan, the agricultural sector should be considered as a whole. Therefore, the policy could involve various agriculture sub-sectors such as crop farmers of animal feed to reduce the dependency on imported crop feeds, which can be done through (1) helping farmers to make a loan for biogas plant; (2) encouraging the farmers to utilize abandoned farmlands for animal feed; (3) subsidizing the production or guaranteeing the price of domestic animal feed crops; (4) matching swine farms and crop land farmers to enhance the irrigation from swine wastewater; (5) assessing the land suitable for irrigation use; and (6) designing regulatory framework for digestate use to reduce the contaminants such as residues of antibiotics, heavy metals, and animal pathogens so as to avoid environmental damages, including pathogen and disease transmission.

6.2 Reflections on the method used

While looking back on the research, it would have been more objective if the interview pool is larger, especially for the electricity sector. Also the biogas production in other livestock industries like poultry industry can also be a good study target due to its great potential of biogas production. However, this has not been possible in terms of the time constraint and accessibility to the interviewees.

6.3 Suggestions for further research

(1) The research has been on a micro level (swine biogas production) and meso level (biogas socio-technical system); while there are few integrated researches are conducted on a macro level (national biogas policy). Therefore, further integrated biogas development and potential of various biogas sources (e.g. other agricultural waste, municipality waste and algae) is suggested.

(2) Detailed research on biogas related policy (e.g. evaluation, cost-effective analysis, etc.) is needed to provide further economical impacts assessments since this is an important driver of biogas diffusion for energy sector.

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Appendix

6.4 Appendix I. Interview Questions about biogas production BM

A. Swine farms about biogas production BM

#	Questions
1.	**Background Information**
1.1	What products do you provide?
1.2	Where is your main markets (e.g. regions of Taiwan/overseas)?
1.3	Do you adopt biogas plant on the farm?
1.4	For how long have you adopted the biogas plant?
1.5	Who are the biogas plant suppliers?
1.6	What kind of biogas plant the farm is using?
1.7	What competencies are required to adopt a biogas plant?
2.	**Infrastructure Management**
2.1	What are requirements to acquire loan if it is needed (esp. for upfront costs)?
2.2	What activities do you involve to underpin the value of biogas production?
2.3	In addition to swine manure, do you use other sources to produce biogas?
2.4	In addition to you own swine manure, do you acquire external sources?
2.5	Do you sell the electricity generated from biogas to the utilities?
2.6	Do you receive external supports on biogas production?
3.	**Financials**
3.1	What are the major costs to run the biogas plant?
3.2	What are the major revenues generated from the biogas plant?
4	**Social Aspect (Customer value, social image, etc.)**
4.1	What do your current customers think about the farm's adoption of biogas?
4.2	What do the neighbors think about the farm's biogas production?
5.	**General Questions**
5.1	In your opinion, what are the major advantages of implementing biogas plant?
5.2	In your opinion, what are the major disadvantages of implementing biogas plant?
5.3	Is implementation of biogas plant corresponds with your initial expectation?
5.4	How do you think about this collaboration?
5.5	**Other recommendations**

*other entities: For instance, government sectors, corporations, academic institutes, NGOs, etc.

B. Energy Company

#	Questions
1.	**Background Information**
1.1	How many projects of biogas production have you involved?
1.2	Who are the biogas plant suppliers?
1.3	What kinds of biogas plant the company is using (leasing)?
1.4	What competencies are required to adopt a biogas plant?
2.	**Customer Interface**
2.1	What products do you provide?
2.2	Who are the target customers?
2.3	Where are the main markets (e.g. regions of Taiwan/overseas)?
3.	**Customer Value**
3.1	How do you convey value and engage your customers to adopt biogas plants?
4.	**Infrastructure Management**
4.1	What are requirements to acquire loan if it is needed (esp. for upfront costs)?
4.2	What activities do you involve to underpin the value of biogas production?
4.3	In addition to swine manure, do you use other sources to produce biogas?
4.4	In addition to you own swine manure, do you acquire external sources?
4.5	Who are your partners to run the biogas plants?
4.6	Do you receive external supports on biogas production?
5.	**Financials**
5.1	What are the major costs to run the biogas plant?
5.2	What are the major revenues generated from the biogas plant?
6.	**Social Aspect (Customer value, social image, etc.)**
6.1	What do your current customers think about the farm's adoption of biogas?
6.2	What do the neighbors think about the farm's biogas production?
7.	**General Questions**
7.1	In your opinion, what are the major advantages of implementing biogas plant?
7.2	In your opinion, what are the major disadvantages of implementing biogas plant?
7.3	Is implementation of biogas plant corresponds with your initial expectation?
7.4	How do you think about this collaboration?
7.5	**Other recommendations**

*other entities: For instance, government sectors, corporations, academic institutes, NGOs, etc.

6.5 Appendix II. The Three-Step Piggery Wastewater Treatment (TPWT)

Step one: Solid/Liquid Separation

Separation of the solid from the wastewater is to increase the usability of solid fraction through screens and scrabblers (Sheen et al. 1994). Throughout the process, the BOD can be reduced around 15-30% and suspended solid (SS) can be reduced by 50%. Extruder is also applied to decrease the solid rate in the wastewater to below 70% to make it more suitable for composting.

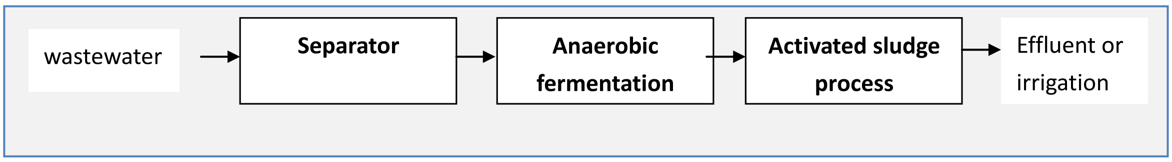
Step two: Anaerobic Treatment

After solid/liquid separation, anaerobic treatment takes place in anaerobic basins, covered with "red-mud plastic cover". In this process, it produces biogas, consisting of methane, carbon dioxide and other gases. It can be used directly as fuel in cooking stoves, water heaters, water pumps, electric power generators, heating up piglets, vehicle use, dead animal incineration, etc.

Step three: Aerobic Treatment (Activated Sludge Treatment)

Taiwan is in subtropical climate zone, activated sludge processing and oxidation ditches are more suitable for this climate. In the aerobic treatment facility, organic matter decomposed through aerobic oxidation.

After the treatment in the three-step facilities, most of the biodegradable matters are decomposed



Three-Step Treatment System for swine farm wastewater

Source: Su et al., 1999