Promotion and Potential Analysis of Biogas Plants to Produce Compressed Biomethane Gas for Transportation in Thailand

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Abstract

Background

The implementation of activities agriculture resulted in a large amount of wastewater and organic waste. In the past, Thailand has been using these to produce biogas to replace fossil fuels in the country. At present, biogas production has a residual amount due to no use in farms/factories. So, it to be released into the atmosphere. The government has a policy of biogas by the upgrade to produced biomethane for fuel vehicles but it is still just a prototype system. Therefore, if the government has targeted of the development biomethane in commercial plants, it is necessary to analyze the financial feasibility to an incentive of investors and plan for energy effective support. Including, people can use gas at a reasonable price and create a comprehensive energy source in sustainable agriculture.

Results

The research evaluates the commercial investment potential of compressed biomethane gas plants based on upgrading biogas by water scrubber technology. The results identified biogas plants must have a digester volume of 2,000 m^3 or more to produce compressed biomethane gas. Locations of 10 plants with the potential to establish compressed biomethane gas plants in Thailand. The capacity of compressed biomethane gas plants at 3, 6, 12 and 24 tons/day with no subsidy, subsidy 20% and 30% from the government. The plant should have a capacity of 12 tons/day or more in on subsidy from the government that there will be a financial possibility. The government should be subsidy at 30% in the plants of capacity at 3 tons/day for small plants can operate their businesses, subsidy 20% in the plants of capacity at 6 tons/day. In the part of plants more 12 tons/day which the government should be added measures such as Measures for low-interest loans, tax relief measures, etc. In addition, 10 locations will be expected to reduce greenhouse gas emissions by about 78,333 tCO_2e/year.

Conclusion

This study can be used to support decision-making on commercial investment in clean technology to promote the use of resources in agriculture for efficient transportation and support energy-efficient plans to provide an alternative sustainable fuel source to reduce global warming.

Introduction

Thailand is located in the center of mainland Southeast Asia, covering approximately 513,120 km^2 with a total population of around 66.5 million [1]. Thailand’s final energy consumption in 2019 was 85,708 ktoe. The commercial energy consumption was shared 84.2% of the total final energy consumption while the renewable energy was shared 9.9% and the traditional renewable energy was shared 5.9%. However, petroleum products consumption played the greatest proportion 49.10% of the total final energy consumption, followed by electricity 20.25%, alternative and renewable energy 9.95%, coal/lignite products 8.30%, natural gas 6.50% and traditional renewable energy 5.90% respectively [2]. Agriculture is the main economic activity in the area, predominantly consisting of livestock farms such as cattle, pigs, laying hens, etc., and cassava and sugarcane fields, which are primary economic crops and support the industrial sector. However, wastewater and waste are involved in most agricultural activities. It is considered a potentially beneficial source of wastewater and wastewater utilization. As renewable energy, biogas is a sustainable alternative to fossil fuels, fuel oil, liquefied petroleum gas (LPG), electricity, etc. However, sometimes biogas needs to be emitted into the atmosphere. Therefore, the quality of biogas should be improved to produce biomethane for vehicles and is one option for maximizing the use of agricultural waste, reducing the use of fossil energy and the emission of greenhouse gases (methane) into the atmosphere.

Over the years, the number of NGV users in Thailand has increased because of the high oil price in the global market. Therefore, the government has implemented a policy to encourage cars, public vehicles, and trucks to switch to natural gas by fixing the NGV gas price to make it cost-effective. According to the statistics as of March 2019, vehicles using NGV reached 380,931 cars increasing by 20% in the previous five years [3].

The Thai government has recently introduced the concept of biogas purification to produce biomethane and as an option to replace petroleum in areas far away from a natural gas pipeline, such as the north, northeast (south area), and south (west area), since the supply and transportation of NGV to these areas is difficult and expensive. The supply of energy is limited in these areas with the transportation costs based on the distance from the mother station or natural gas pipeline [4]. Consequently, through the Energy Policy and Planning Office, the government is promoting biomethane research to provide a solution to this problem by developing alternative energy using biogas purification for producing compressed biomethane gas (CBG). This CBG is the only renewable energy source with the potential to replace LPG and NGV, as well as being the only form of alternative energy in Thailand that can replace fuel oil for vehicles. Biomethane gas is biogas which undergoes quality upgrading by removing carbon dioxide (CO_2), hydrogen sulfide (H_2S), and moisture [5] using technologies such as water scrubbing, pressure swing adsorption, and membrane separation to meet the specifications of vehicle fuel. However, to replace NGV for use in vehicles, biomethane gas must be stored at high pressure (up to 200 bar) [6] which is why it is called compressed biomethane gas (CBG). Biomethane gas and compressed biomethane gas have similar properties: they are lighter than air, experience no accumulation when leakage occurs, and only flammable at between 5–15% by volume at 650 °C. However, they have different methane content, with biomethane containing more than 80% methane by volume. Biomethane purity standard vary according to country. For example, the Netherlands requires at least 85%, Switzerland 96%, and Sweden 97% of CH_4 content in the injected biomethane [7]. The biomethane standard in Thailand is set according to the requirements of the Department of Energy Business, and must have the same properties as NGV, namely 83–89% methane by volume [8]. Therefore, it can be directly used as an alternative to NGV. Moreover, in Thailand, the calorific value of biomethane gas for use in cars must be between 37–42 MJ/Nm^3 [9].

Biogas plant in Thailand is scattered throughout the country. Thailand still lacks the integration and cooperation in making the most of the benefits. This research is a considerable distance from the natural gas pipeline and considerable area has many biogas plants with the potential to establish a compressed biomethane gas station for local transportation. Therefore, this research focuses on the financial, investment, subsidies from the government, and environmental benefits (Reduction of greenhouse gas emissions). Investors can use the findings to help in decision-making while the government sector can use the information for the effective planning and promotion of renewable energy technologies.

Methodology Of The Financial Investment And Greenhouse Gas Emission Reduction Assessment

Methodology of the financial investment

Background of the compressed biomethane gas promotion in Thailand

The compressed biomethane gas project (CBG) is aimed at promoting alternative energy sources and supported by the Ministry of Energy to encourage the use of compressed biomethane gas to replace NGV under the Alternative Energy Development Plan (AEDP2015). The Ministry of Energy is investigating the concept of biogas purification to produce biomethane with similar properties to natural gas as an alternative to petroleum fuel in the areas far away from the natural gas pipeline. Biomethane gas is a clean fuel option for consumers and more entrepreneurs are supporting its production by investing in compressed biomethane gas stations in areas far away from the natural gas pipeline to help people gain better access to renewable energy sources. The AEDP2015 has a target to increase the proportion of energy usage by producing compressed biomethane gas from biogas to meet 5% of NGV demand with 4,800 tons per day, or about 2,000 ktoe by 2036 [10].

In accordance with AEDP2015, the Department of Alternative Energy Development and Efficiency, Ministry of Energy aims to develop renewable energy through compressed methane by upgrading technologies to replace LPG and natural gas for vehicles (NGV), by supporting owners of plants who already have a biogas system and sufficient biogas production capacity to produce compressed biomethane gas of no less than 3 tons/day. The level of support on offer for the construction and installation of biogas upgrading and compressed biomethane gas systems is no more than 15,000,000 baht per plant for large animal farm owners and the following seven potential industrial groups: cassava starch, food and beverages, palm oil, whiskey and beer, rubber, paper, and ethanol. These plants must be currently under construction, already operating a biogas system producing excess biogas from electricity or heat energy or experiencing problems in connecting to the electrical grid. Although they may have a biogas production capacity of no less than 6,000 m^3/day, plants must have the potential to produce no less than 3 tons/day of compressed biomethane gas. The total production of CBG from all project participants should be no less than 5 million kg/year. The government is supporting targeted areas more than 50 km from the natural gas pipeline. These include the northern, central, southern, and northeastern areas and those with problems connecting to the electrical grid (feeder line). The direct subsidy from the government is 20–30% of the investment cost for biogas upgrading and compressed biomethane gas systems, as shown in Table 1.

Table 1. Investment support by the Thai government for compressed biomethane gas production [11].

Capacity CBG	Subsidy conditions
3,000–5,999 kg/day	Less than or equal to 30% of the investment in biogas upgrading and compressed biomethane gas systems, but not exceeding 9 million baht per project.
6,000–11,999 kg/day	Less than or equal to 25% of the investment in biogas upgrading and compressed biomethane gas systems, but not exceeding 12 million baht per project.
Equal to or greater than 12,000 kg/day	Less than or equal to 20% of the investment in biogas upgrading and compressed biomethane gas systems, but not exceeding 15 million baht per project.

Thailand’s Ministry of Energy announced the specifications and quality of biomethane for vehicles in 2018 to build confidence and trust for investors and users. They determined that the pure methane gas content should not be less than 80% by volume, for use in vehicle fuel and can be used as direct fuel or mixed with natural gas.

The potential of biogas plants to produce biomethane gas

Thailand currently has 1,788 biogas plants, producing approximately 1,405.58 million m^3/year [12]. Wongsapai (2008) shown that Thailand has been promoting the installation of biogas systems since 1995 under the Energy Conservation Fund, Energy Policy and Planning Office (EPPO) [13]. The Thai government began promoting the use of biogas in the first swine farms, subsidizing approximately 33% of the total investment. Aggarangsi (2013) conducted a study on the development of biogas technology in Thailand's livestock farms, revealing that three main sectors in the country operate biogas systems: animal husbandry, the food industry, and community enterprises. These have the potential to produce more than 1 million m^3/year of biogas, but only 36% of the total biogas can be used to replace fossil fuels [14].

Therefore, as previously mentioned, for maximize benefit, biogas should be used to produce biomethane gas to support sustainable energy in Thailand. Accordingly, the objective of this research is to identify areas with the potential to operate compressed biomethane gas stations to provide fuel for vehicles using the biogas system database of the Energy Policy and Planning Office. Only biogas plants larger than 2,000 m^3 should be considered since these have the potential to produce sufficient biomethane gas [15]. There are 348 plants in Thailand: 88 located in the northeastern region, 75 in each of the central and western regions, 55 in the southern region, 35 in the eastern region, and 20 in the northern region, as shown in Fig. 1

The information for this research was collected via a survey questionnaire from a total sample group of 156 plants. These consisted of 81 plants in the industrial sector and 65 livestock farms, to establish the proportion of biogas produced for consumption and the excess biogas. The survey results show that the amount of biogas consumption was 51–80% of the total biogas produced by livestock farms and the industrial sector. Therefore, the amount of excess biogas was approximately 20–50% of the total biogas produced. Biogas plants with a digester no larger than 10,000 m^3 had excess biogas equal to approximately 20% of the total biogas produced, biogas digesters measuring 10,001–15,000 m^3 had excess biogas equal to approximately 30% of the total biogas produced, biogas digesters measuring 15,001–20,000 m^3 had excess biogas equal to approximately 40% of the total biogas produced, and biogas digesters larger than 20,000 m^3 had excess biogas equal to approximately 50% of the total biogas produced, as shown in Fig. 2. This data was used to calculate the capacity of biomethane production technology.

Investment structure and conditions for the commercial of CBG plants

The reviewed of the market share of biomethane technology in 2016, water scrubber (WS) was most used at about 41%, followed by Chemical scrubber (CS) approximately 25% of all available biomethane technologies. And then, found that biomethane has been growing steadily implemented around the world since 2011. Its growth with above 503 biogas upgrading plants in operation till 2016 from 187 plants in 2011 [16] (shown in fig. 3). So, this study main referenced the cost of biomethane technology based on water scrubbing (WS)

This research analyzes water scrubber in upgrading biogas technologies since it requires low capital and operating expenditure and does not require high-skilled operators (shown in Table 2). The costs of biomethane gas production can be divided into biogas cost, upgrading capital cost, upgrading operations and maintenance cost, capital cost of compressing equipment, compressing operations, and maintenance cost.[5] Energy Research and Development Institute at Chiang Mai University studied a local gas grid project submitted to the Energy Policy and Planning Office. The result showed that 1 m^3 of biogas (at CH_4 55% by volume) converted to CBG production at

0.45 kg, including the cost of biogas pipeline transportation of approximately 702,777 baht/km was used to calculate the potential total cost of CBG production [10].

Table 2. Properties of biogas upgrading technologies

Parameters	WS	AS	PSA	MS
CH_4 purity [17]	>97%	>95%	95-98%	>96%
CH_4 losses [17]	>2%	<0.1%	<0.1%	0
Power demand (kWh/m^3raw gas) [18]	0.25	0.42	0.25	0.5
Capital Expenditures (million baht) [19]				
- 3 ton-CBG/day (250 m^3-BG/hr)	41.5	62.9	44.1	40.7
- 6 ton-CBG/day (500 m^3-BG/hr)	59.7	82.2	63.7	60.1
- 12 ton-CBG/day (1,000 m^3-BG/hr)	85.5	107.4	92.0	88.6
- 24 ton-CBG/day) (2,000 m^3-BG/hr)	123.3	140.3	133.0	130.6
Operating Expenditures (million baht) [19]				
- 3 ton-CBG/day (250 m^3-BG/hr)	5.1	6.9	9.5	5.4
- 6 ton-CBG/day (500 m^3-BG/hr)	8.2	11.9	17.4	9.4
- 12 ton-CBG/day (1,000 m^3-BG/hr)	13.3	20.6	32.1	16.1
- 24 ton-CBG/day) (2,000 m^3-BG/hr)	21.6	36.5	59.0	27.7
Volume system [20]	Moderate	Low	Moderate	Lower
Site area [20]	Moderate	Low	Moderate	Low
Skills of operator [20]	Moderate	Moderate	Moderate	High

Note: WS: Water Scrubber, AS: Amine-Absorption Method, PSA: Pressure Swing Adsorption and MS: Membrane Separation, BG: Biogas and hr: hour

The researcher reviewed the appropriate biomethane cost pricing guidelines and determine the cost structure of biomethane production. The price structure is divided into two parts, separated according to the production process, namely the material cost (biogas purchase), the biogas pipeline cost and the biogas upgrading cost (biomethane produce process) and set the unit of product in the form of baht per kilogram. The scope of analysis is shown in fig. 4.

From the cost-based pricing approach according to the study results "Biomethane Promotion Strategic Plan Project for Commercial Energy Use" prepared by Energy Research Institute, Chulalongkorn University. It is proposed to use a financial model in which the project's suitable internal financial rate of return (FIRR) by determining the purchase price of biomethane reflects the investment return not lower than the investment of other businesses that are at risk at the same level. The financial model used to determine the purchase price of biomethane is a future cash flow valuation throughout the project life (this study analyzes the project life at 15 years.). The cash flow consisted of cash inflows and outflows. The cash flows must be high enough to motivate investors to invest in the development of biomethane system but it must not be too high that it is a burden to the government in the long term.

The spatial assessment of suitable areas for producing biomethane in Thailand. Researchers surveyed biogas plants that were distributed across the country by questionnaires with stratified sampling. Then, grouped of biogas plans that near area analysis for transfer biogas by pipeline to the biomethane gas distribution station sufficiently, determined the transportation distance is not more than 50 kilometers. Including, comparing the CBG production capacity of 3, 6, 12 and 24 tons/day in case of no government subsidy, subsidy 20% and 30% respectively. Currently, Thailand has actively commercial CBG in one plant that replacing CBG with NGV. This plant has biogas purchase price of 2 THB/kg_{biogas} and a purchase price of CBG at 15.68 THB/kg_{CBG}. Including, the total of capital cost and operation/maintenance of CBG capacity 3, 6, 12 and 24 tons/day was 46.6, 67.9, 98.8 and 144.9 MTHB respectively. (shown details cost in fig. 5)

This research determines the equivalent heating value of CBG to NGV for vehicles at 43.46 MJ/kg (95% mol of methane). An investment feasibility analysis on the compressed biomethane gas stations was applied to identify the financial indicators, namely: Net Present Value (NPV), Financial Internal Rate of Return (FIRR), Payback Period (PP), and cost per unit according to the conditions shown in Table 3.

Table 3. Conditions for the financial feasibility of a compressed biomethane gas plants

Factors	Details
Biogas pipeline transportation cost (baht/km) [10]	702,777
Biogas price (baht/m3)@CH4 55% by Vol. [10]	2.00
CBG price (baht/kg) [10]	15.68
Production period per year (day) [10]	330
Life of technology (year) [10]	15
Salvage value (%) [10]	10

Methodology for the Calculation of greenhouse gas emission reduction

Greenhouse gas emission reduction are calculated using the formula contained in the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Volume 2, Energy [21].

$$ER = BE - PE \quad (1)$$

$$BE = \sum(FG_{CBG} \times (NCV_{CBG} \times 10^{-6}) \times EF_{CO2,CNG/NGV}) \times 10^{-3} \quad (2)$$

$$PE = (EC_{PJ} \times 10^{-3}) \times EF_{Elec} \quad (3)$$

Where:

ER = Greenhouse gas emission reduction (tCO_2e/year)

BE = Baseline emissions (tCO_2e/year)

PE = Project emissions (tCO_2e/year)

FG_{CBG} = Fuel consumption kg/year)

NCV_{CBG} = Net calorific value of compressed biomethane gas (MJ/kg)

$EF_{CO2,CNG/NGV}$ = Emission factor of a given greenhouse gas by CNG/NGV for CO_2 ($kgCO_2$/TJ)

EC_{PJ} = Electricity consumption (kWh/year)

EF_{Elec} = Emission factor of the national grid electricity system (tCO_2/MWh)

The data value of NCV_{CBG} is 43.46 MJ/kg, equivalent to that of NGV. $EF_{CO2, CNG/NGV}$ is 56,100 $kgCO_2$/TJ [21] and EF_{Elec} or grid emission factor refers to the CO_2 emissions associated with each unit of electricity provided by system. The value of EF_{Elec} is 0.5664 tCO_2/MWh.[22] The data sourced from the grid emission factor of Thailand is endorsed by the Thailand Greenhouse Gas Management Organization. Power generation efficiency is calculated from monitored data on the amount of fuel input for power generation and the level of electricity generated from 2014–2016 by the United Nations Framework Convention on Climate Change (UNFCC) methodology (Methodological Tool), for calculating the emission factor of an electricity system) and applicable from September 28, 2017 onward.

Results

Potential biogas plant groups with the capacity to produce biomethane gas

The network of pipelines in Thailand currently stretches 4,255 km from onshore to offshore [23]. There are pipelines through the central, western, and eastern areas, meaning that most of the transportation sector chooses to use natural gas as fuel, especially as the cost of natural gas is lower than biomethane gas. According to the Ministry of Energy's biomethane production promotion plan, areas far away from natural gas pipelines must bear the burden of higher fuel costs, while other parts of the country do not. Therefore, this research analyzes only these areas and the transportation of biogas from plants to compressed biomethane gas stations no more than 50 km away. Based on the research principles of PTT in 2017, the cost of transporting NGV for a distance of more than 50 km is not worth the investment. There is also the problem of using the highway as the main route for transporting biogas from the pipeline to the compressed biomethane gas plants. The location and distance from the pipeline of potential biogas production plants can be obtained from Google Maps and the Power BI program.

The group with CBG production capacity of 3 tons/day has three groups, namely group C, I and D with the remaining biogas from the utilization of 8,324,250 m^3/year. The group with CBG capacity of 6 tons/day has two groups, namely group G and J with the remaining biogas from the utilization of 10,758,000 m^3/year. The group with CBG production capacity of 12 tons/day has three groups, namely group A, B and E with the remaining biogas from the utilization of 28,795,800 m^3/year. And, the group with CBG production capacity of 24 tons/day has two groups, namely group H and F with the remaining biogas from the utilization of 34,412,400 m^3/year, as shown in Table 4.

From the results of this study, it can be seen that Thailand has a large amount of biogas remaining from its use (approximately 82,290,450 m^3/ year), but Thailand is still unable to utilize this biogas to its full potential. Thus, Thailand should therefore use this biogas as renewable energy as much as possible, to reduce emissions into the atmosphere which causes global warming.

Table 4. Potential of biogas plant groups to biomethane production

Group of biogas plants	Quantity of biogas (m^3/year)	CBG capacity (tons/year)
A	7,048,800	3,172
B	9,570,000	4,307
C	2,244,000	1,010
D	3,606,240	1,623
E	12,177,000	5,480
F	17,820,000	8,019
G	5,049,000	2,272
H	16,592,400	7,467
I	2,474,010	1,113
J	5,709,000	2,569
Total	82,290,450	37,031

Financial investment feasibility analysis

The financial investment analysis was divided into 3 cases: 1) No subsidy from the government 2) subsidy 20% of the total investment and 3) subsidy 30% of the total investment. Including, divided into groups according to the capacity of CBG production at 3, 6, 12 and 24 tons/day in the condition of the distance biogas transporting by pipeline at 50 km. The study was as follows.

In no subsidy from the government, the financial internal rate of return (FIRR) at CBG production capacity of 3, 6, 12, 24 tons/day was 7.97%, 10.12%, 25.13% and 28.44%, respectively. Production of 3 tons/day has the most payback period of 9.28 years with a unit cost of 14.65 baht/kg_{CBG}, at a capacity of 24 tons/day has the shortest payback period was 3.58 years with a unit cost of 12.26 baht/kg_{CBG}. Therefore, the project that has the possibility of investment was CBG plants have the production capacity of 12 tons/day or more because FIRR more than the market interest rate (12%). In subsidy from the government 20% of the total investment, the financial internal rate of return (FIRR) at CBG production capacity of 3, 6, 12, 24 tons/day was 11.64%, 14.09%, 31.83% and 35.83% respectively. The production of 3 tons/day has the most payback period of 7.53 years with a unit cost of 14.02 baht/kg_{CBG}, at a capacity of 24 tons/day has the shortest payback period was 2.68 years with a unit cost of 11.99 baht/kg_{CBG}. Therefore, the project that has the possibility of investment was CBG plants have the production capacity of 6 tons/day or more because FIRR more than the market interest rate. In subsidy from the government 30% of the total investment, the financial internal rate of return (FIRR) at CBG production capacity of 3, 6, 12, 24 tons/day was 14.08%, 16.76%, 36.52% and 41.04% respectively. Production of 3 tons/day has the most payback period of 6.28 years with a unit cost of 13.70 baht/kg$_{CBG}$, at a capacity of 24 tons/day has the shortest payback period was 2.36 years with a unit cost of 11.86 baht/kg$_{CBG}$. Therefore, all CBG plants have the possibility of investment. The results are shown in Table 5.

Table 5. Investment feasibility analysis of compressed biomethane gas plants

Indicators	FIRR (%)	NPV (MTHB)	PP (year)	Cost per unit (THB/kg)
Case 1: No price subsidy from government				
3 tons/day	7.97%	5.35	9.28	14.65
6 tons/day	10.12%	20.32	8.38	14.22
12 tons/day	25.13%	169.27	4.15	12.45
24 tons/day	28.44%	267.43	3.58	12.26
Case 2: Subsidy from the government at 20% of the total investment				
3 tons/day	11.64%	19.69	7.53	14.02
6 tons/day	14.09%	38.07	6.29	13.67
12 tons/day	31.83%	191.90	2.99	12.15
24 tons/day	35.83%	297.07	2.68	11.99
Case 3: Subsidy from the government at 30% of the total investment				
3 tons/day	14.08%	26.86	6.28	13.70
6 tons/day	16.76%	46.94	5.61	13.39
12 tons/day	36.52%	203.22	2.63	12.01
24 tons/day	41.04%	311.90	2.36	11.86

So, in case no subsidy from the government at the maximum capacity at 24 tons/day will be lowed costs from the lowest production capacity (3 tons/day) of 16.31%, subsidy 20%, at the maximum capacity at 24 tons/day will be lowed costs from the lowest production capacity (3 tons/day) of 14.48%, subsidy 30% at the maximum capacity at 24 tons/day will be lowed costs from the lowest production capacity (3 tons/day) of 13.43%. it can be concluded that the higher the amount of CBG will have the potential for a greater return on investment, and the increased production capacity of the CBG plants, cost price of CBG per unit will be lower. (shown in Fig. 6 and Fig. 7) However, biomethane has the potential to be cost-effective in terms of performance benefits on the customers and entrepreneurs can supply fuel to operate their businesses sustainably. In particular, large scale production of more than 12 tons/day which the located near a potential source of biogas plants. It makes more competitive in the market. But, if it is a small CBG plant less than 12 tons/day, it will not be cost-effective because of the cost of producing CBG still higher than other fuels.

Reducing greenhouse gas emissions

The results show that three groups have the capacity to produce CBG at the rate of 3 tons/day can be greenhouse gas emission reduction approximately 7,924 tCO_2e/year, two groups have the capacity to produce CBG at the rate of 6 tons/day can be greenhouse gas emission reduction approximately 10,240 tCO_2e/year, three groups have the capacity to produce CBG at the rate of 12 tons/day can be greenhouse gas emission reduction approximately 27,411 tCO_2e/year and two groups have the capacity to produce CBG at the rate of 24 tons/day can be greenhouse gas emission reduction approximately 32,758 tCO_2e/year. The total amount of CBG production about 37,030,950 tons/year can be reduction in greenhouse gas emissions about 78,333 tCO_2e/year, as shown in Fig. 8.

However, if the government can facilitate the construction of all CBG plants, the consequent reduction in greenhouse gas (methane) emissions into the atmosphere will mitigate the impact of environmental pollution. Furthermore, it will support the policy of the United Nations Framework Convention on Climate Change (UNFCCC) to achieve operational cooperation and common global goals. The aim of the UNFCCC is to strengthen the global response to the threat of climate change by holding the increase in the global average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5°C above pre-industrial levels [24].

Conclusions

The integration of biogas plants is helping to strengthen of energy and agriculture sector. Promoting the adoption of clean technology in the production of renewable energy makes areas far away from the natural gas pipeline to be able to use clean energy and local resources efficiently. The results showed that Thailand has 10 potential areas for establishing CBG plants. A Plant with a large quantity of CBG capacity per day is a good financial return on investment. On the other hand, plants with a low quantity of CBG capacity per day are not financially viable. This is because larger plants have lower unit costs. The government should help finance these groups by subsidy at least 20% of the total investment. Including, increase tax measures or lower loan interest rates for large-capacity plants with incentives to continue operations in the long term. CBG has advantages in transportation compared to other fuels, because transportation is near to biogas plants within a distance of less than 50 km. In the future, the promotion of the use of CBG in the transport sector will be very cost effective when the price of natural gas tends to rise. While the cost of CBG production still the same. However, for CBG plants in Thailand to be commercially viable, the government would still have to provide subsidies to stimulate investment in the project and build confidence to encourage more vehicle owners to consider this energy choice. Furthermore, if the government decides to speed up the plan to promote CBG stations then it should have a proper plan to support all biogas plants, thus enabling them to increase or maximize production. The government also needs to manage its subsidy support and investment promotion policy at the same time. For this reason, helping to make CBG widely used all over the country, helping to reduce costs on importing energy from abroad and reduces environmental impact.

Recommendations

From the above study, can summarize the model of promotion of the establishment of compressed biomethane gas distribution station in Thailand by dividing the promotion into 3 phases as follows: The first phase (2020 to 2022) is the large investors or with financial readiness and is a technology-respected person. They have the confidence to invest. Thus, the way of promoting in this group should be promoted water scrubbing technology as it is the lowest cost technology and promote the establishment of stations in the area with potential first to be a model for other entrepreneurs. But, this groups no have subsidy from the government that they have the potential of financial investment, the government should add other policies to support such as investment support measures, tax measures and measures for low interest loans, etc. The second phase (2023 to 2030) is the start of the growth of technology. Most of the entrepreneurs began to see examples from the first phase of entrepreneurs. They were imitated and gained market share quickly. Therefore, if the government wants biomethane to be used as renewable energy for vehicles and cover remote areas. The government should be subsidizing to all CBG plants. Which subsidy 20% for CBG plants have the capacity production lower than 6 tons/day and 30% for CBG plants have the capacity production more than 12 tons/day. The third Phase (2031 onwards) is the beginning of the market saturation. Most investors are widely accepted in technology and there are many imitations to create stations. The market share may not be even half that the risk not worth the investment. In this period, if the government wants to support the continuous construction of biomethane gas stations to seriously replace fossil fuels, the government needs a relatively high subsidy for the purchase price. In addition, the government should add other policies to support same as the first phase such as investment support measures, tax measures and measures for low interest loans, etc. (shown in Fig. 9)

However, in the case of the private sector to operate a government project. Private investors invest when the financial rate of return of a private-invested project is higher than the market interest rate. The government should be set the difference of both rates at the appropriate level. In addition, the government should mainly consider the interests of the people who use the service. And then, consider the private sector will return to government organizations in the secondary order. This is to ensure the service fee is fair to users and service providers.

In addition, the government should make a significant contribution to the environment because not only is biomethane a renewable energy source, it also helps to reduce greenhouse gas emissions. Moreover, development of these biomethane plants would support the policy of the UNFCCC, reinforcing Thailand's commitment to reducing greenhouse gases by 20–25% by 2030 [25]. This policy aims to drastically reduce fossil fuel consumption while increasing the use of clean energy through environmentally friendly processes, thereby supporting the common goal of many countries around to world, namely to reduce global warming.

Declarations

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Author's contributions

The authors have read and approved the final manuscript.

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Competing interests

The authors declare that they have no competing interests.

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Figures

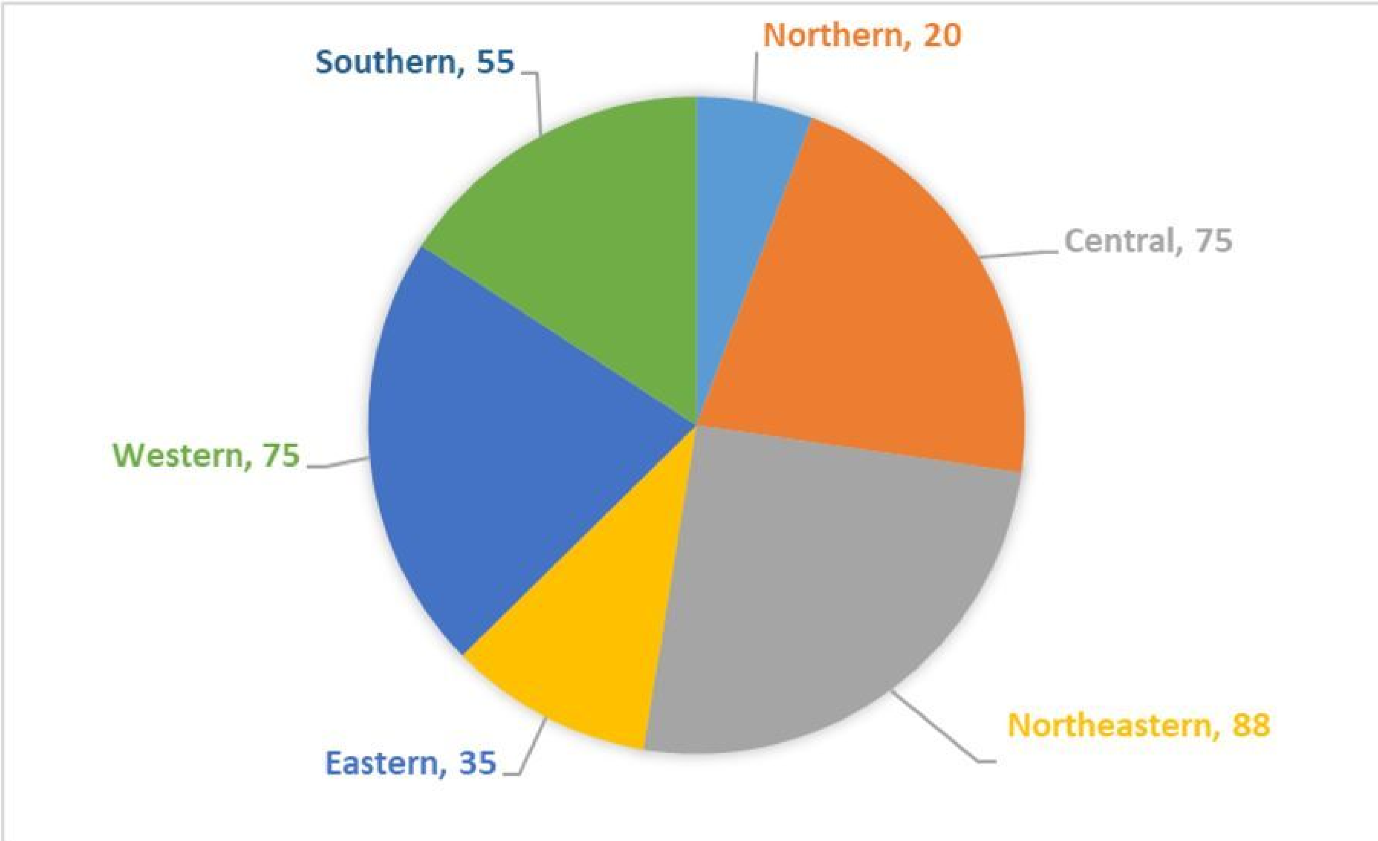

Figure 1

Biogas plants in Thailand with a digester volume equal to or greater than 2,000 m3 by region

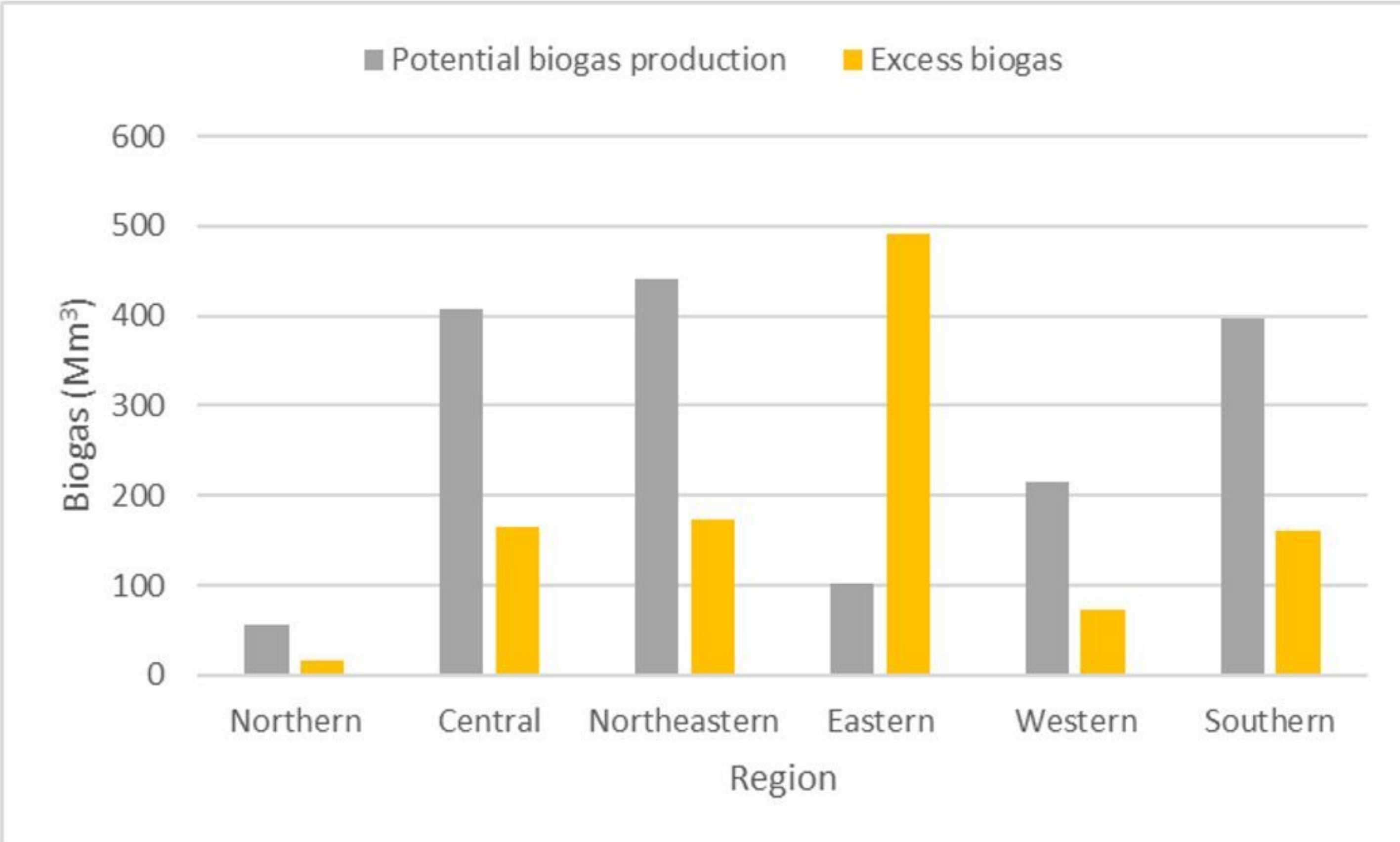

Figure 2

Comparison between potential biogas production and excess biogas by region.

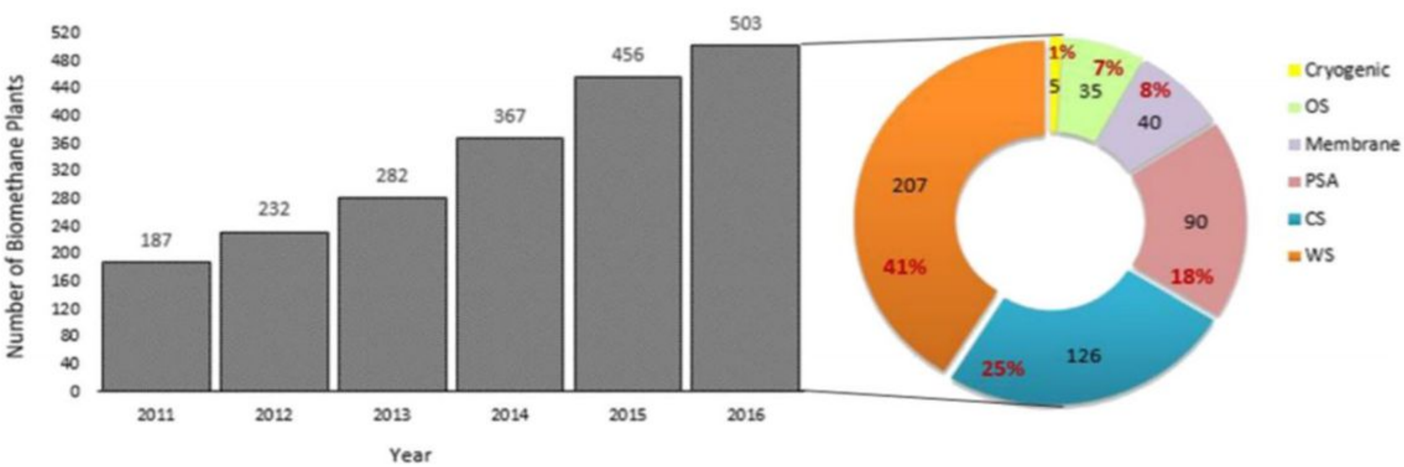

Figure 3

Biogas upgradation market since year 2011-2016

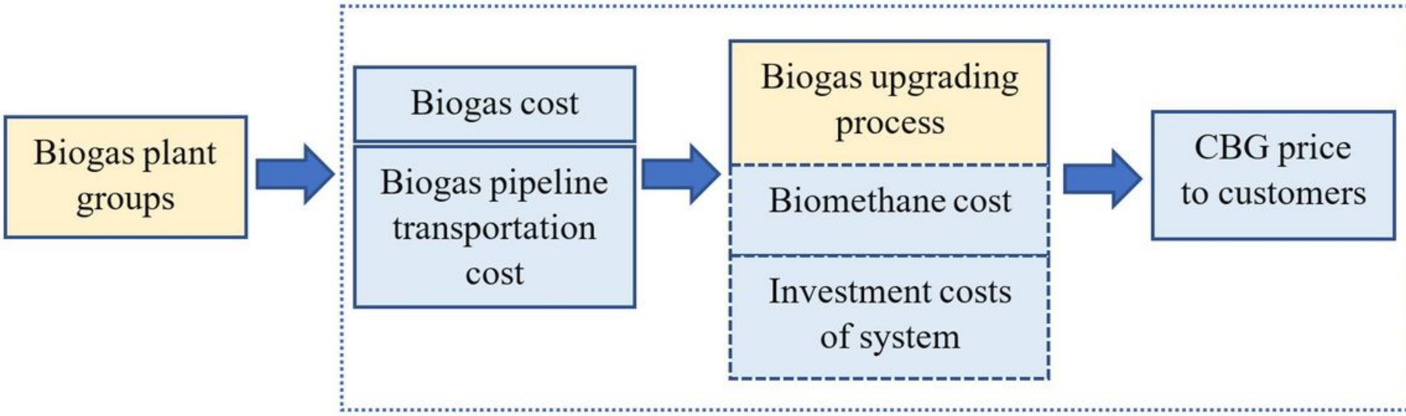

Figure 4

Scope of CBG cost analysis to consumers

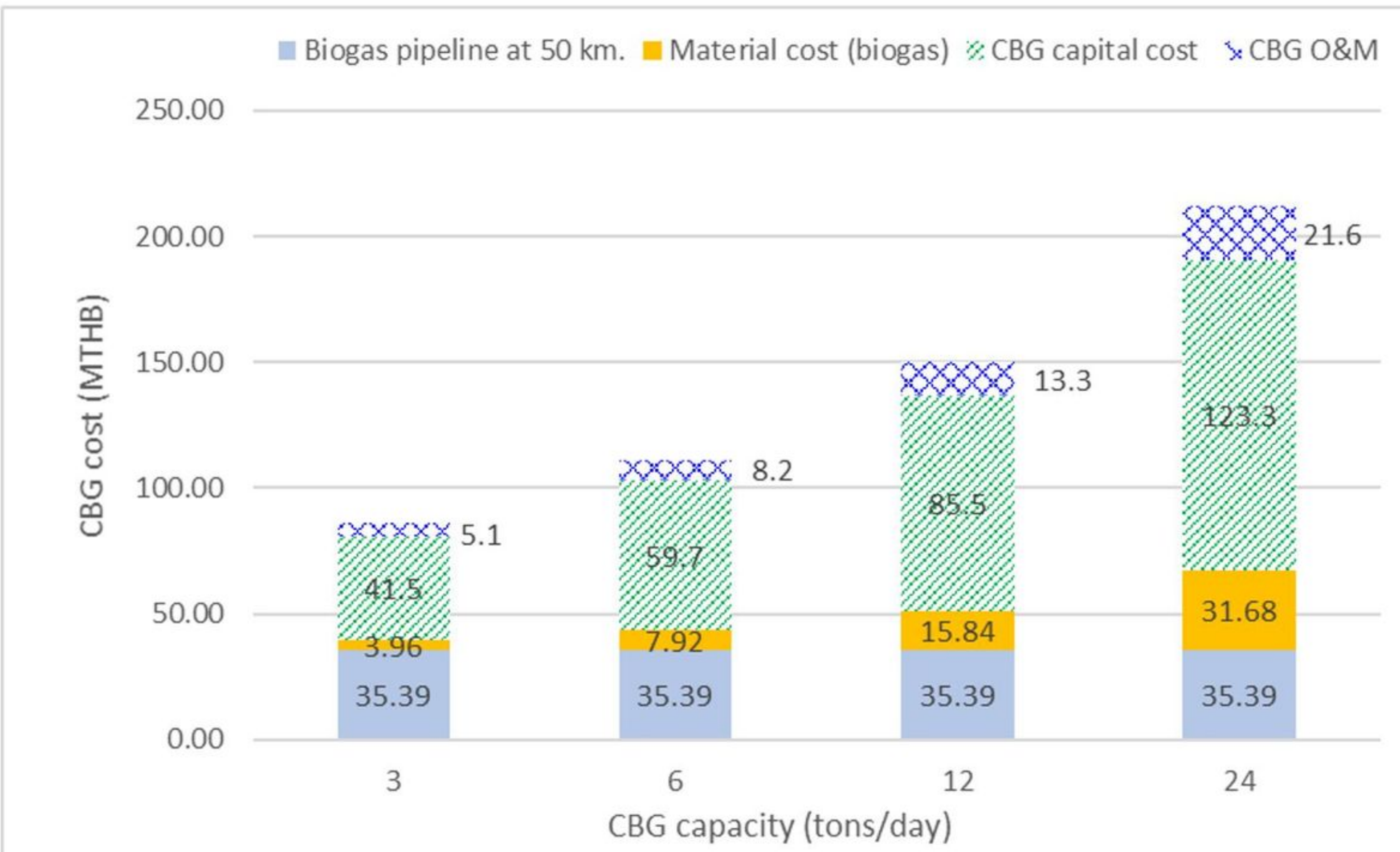

Figure 5

The structure of compressed biomethane gas cost (excluded cost of biogas system)

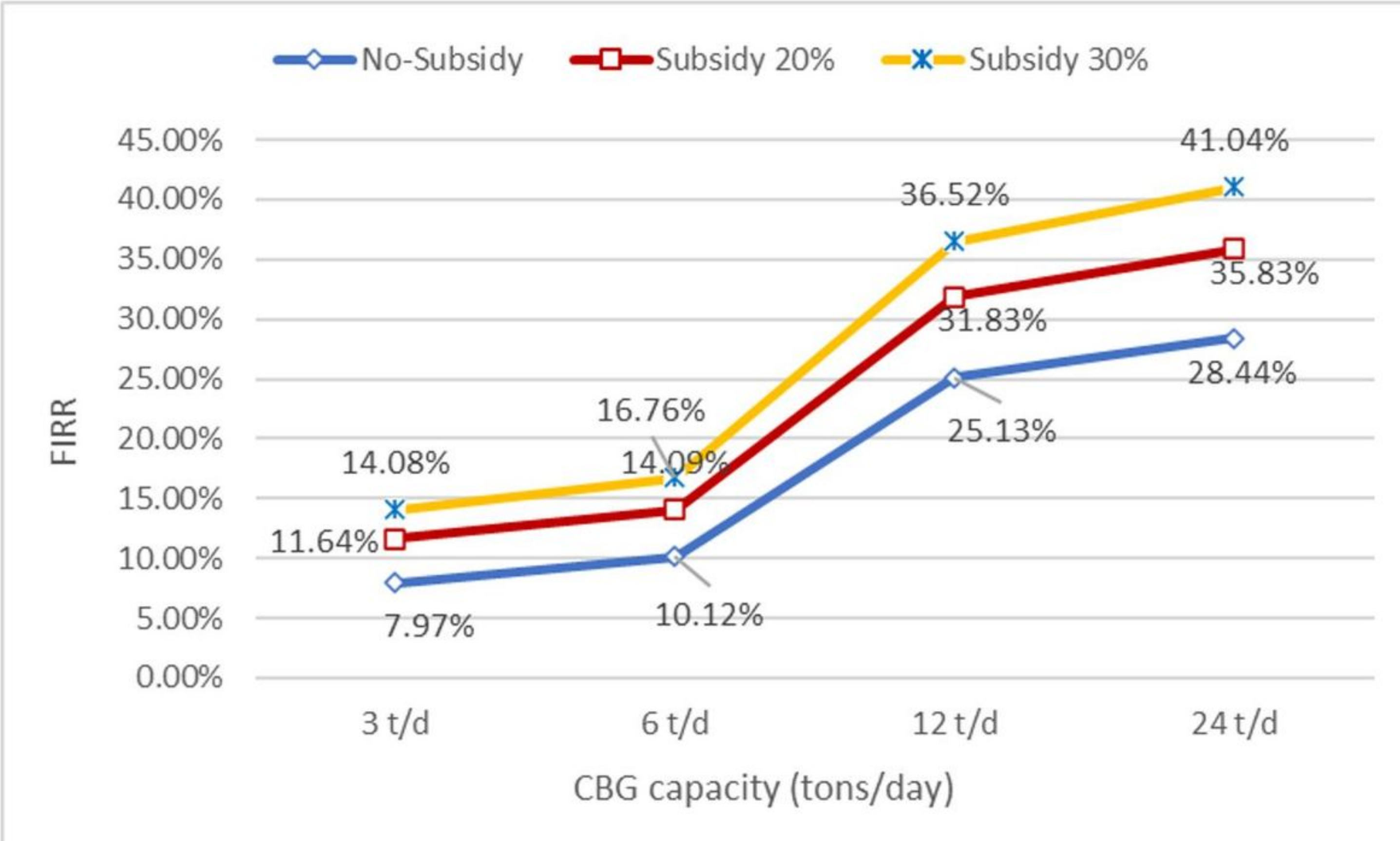

Figure 6

FIRR with the subsidy by CBG capacity

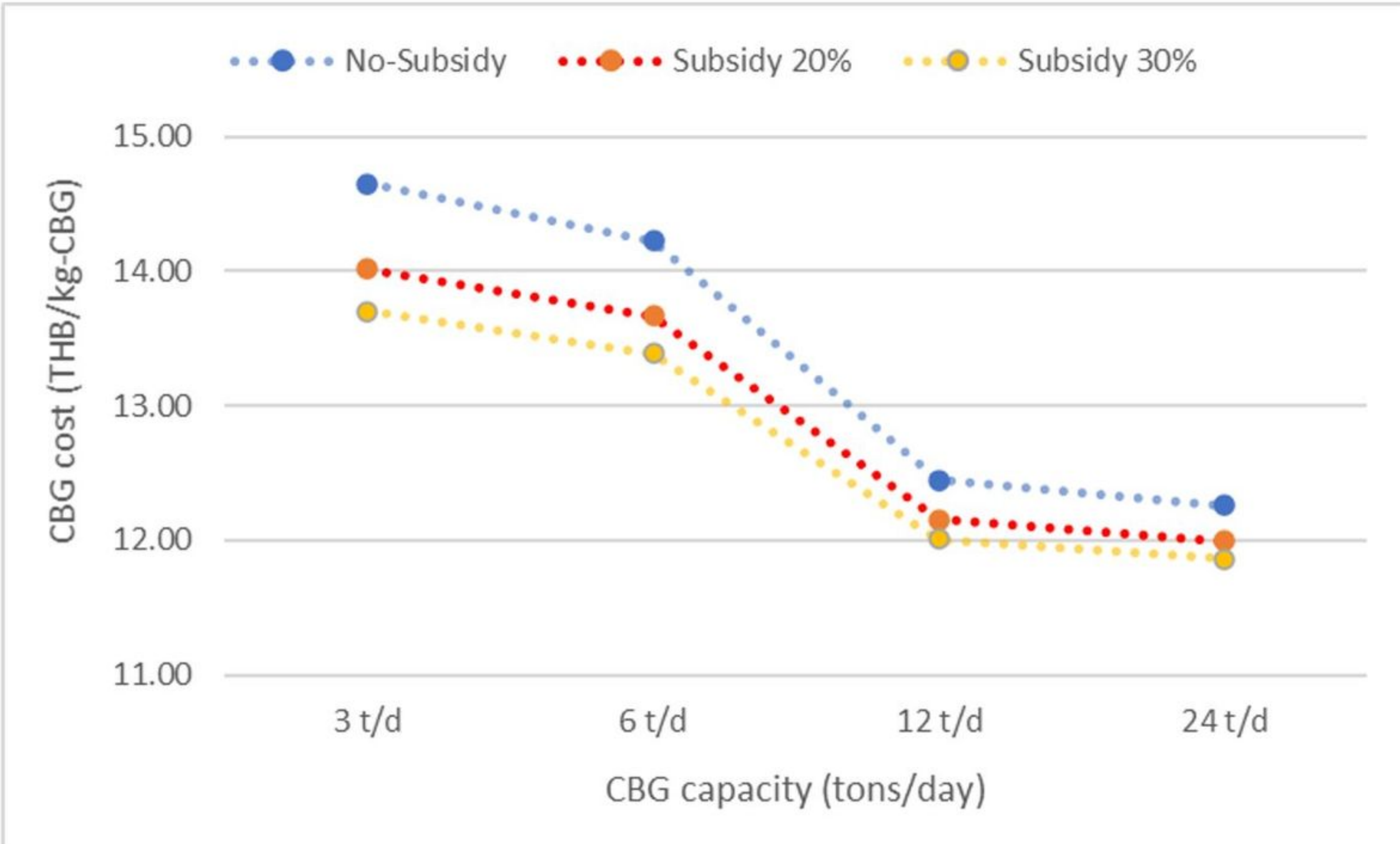

Figure 7

Cost per unit with the subsidy by CBG capacity

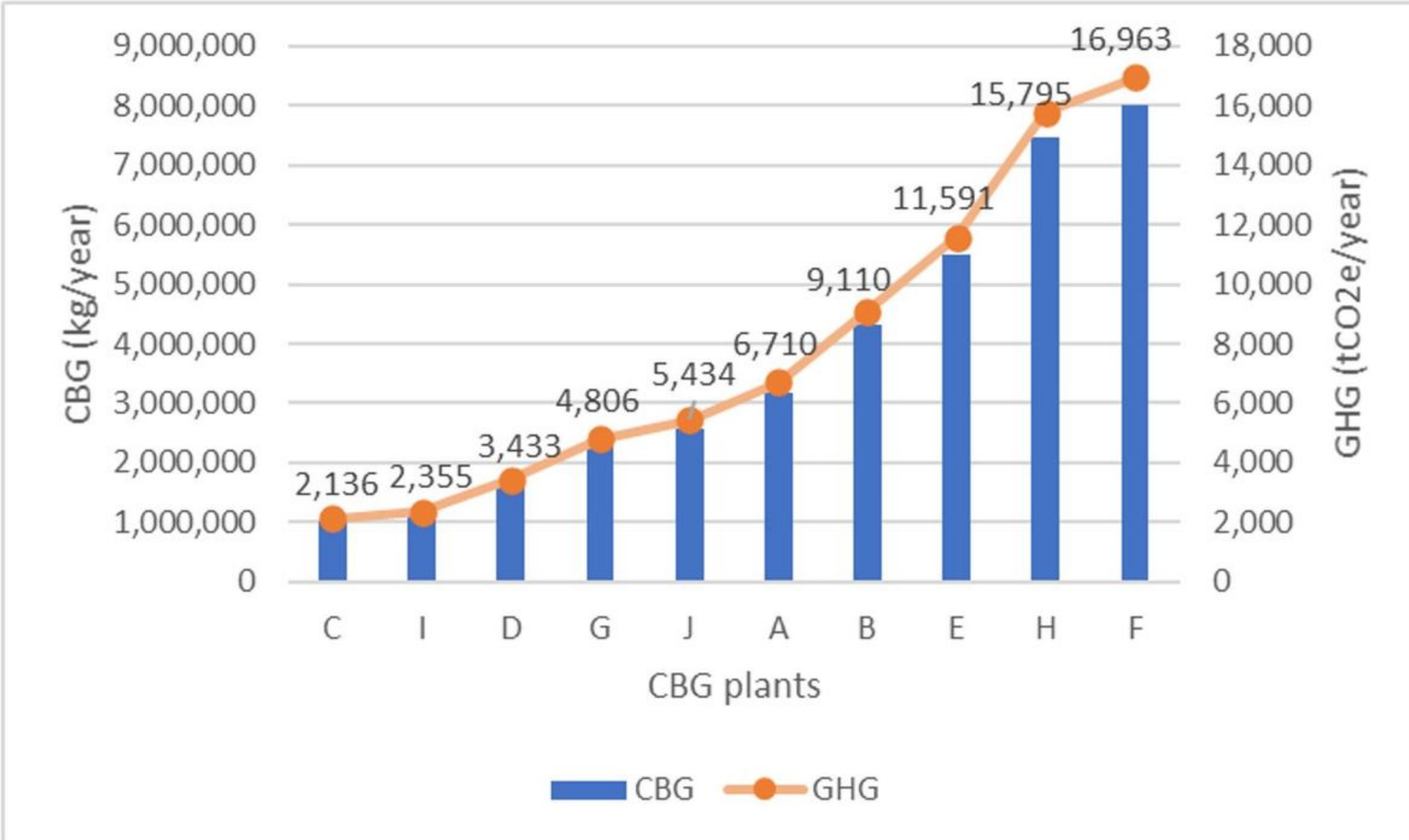

Figure 8

Potential for reducing greenhouse gas emissions of CBG plants.

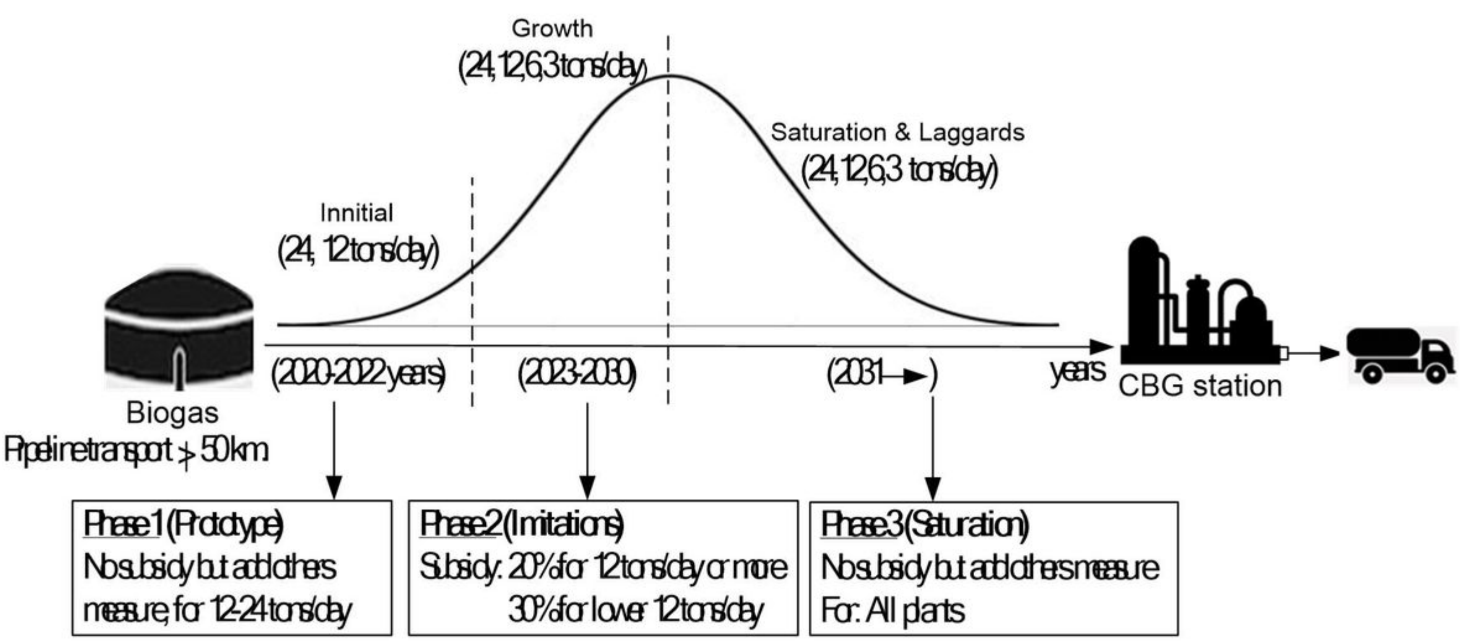

Figure 9

Policy model for the compressed biomethane gas promotions of the local transportation