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ScienceDirect
Energy Procedia 72 (2015) 71 – 78
Energy Procedia

International Scientific Conference "Environmental and Climate Technologies – CONECT 2014"

Economic assessment of biomethane supply system based on natural gas infrastructure

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Abstract

Upgraded biogas injected into a natural gas grid may provide considerable increase of renewable energy share within the natural gas-fired systems. The goal of the study is to determine the costs of biomethane produced in distributed biogas plants and injected into the natural gas grid. The analyzed system includes biogas upgrading and transport to the natural gas pipeline including the infrastructure. The total costs of biomethane production for 3 different scenarios and 5 biogas upgrading methods are determined. The results show that under the most favourable scenario the injected biomethane is approximately 19 % more expensive than the natural gas.

Peer-review under responsibility of Riga Technical University, Institute of Energy Systems and Environment

Keywords: biomethane supply; economic assessment; natural gas; renewable energy; sustainable energy systems

1. Introduction

Upgraded biogas (biomethane), unlike wind energy is a well manageable energy source which can be stored, distributed and used in the same way as natural gas. Therefore it is one of the most viable renewable substitutes for natural gas [1]. In recent years, biogas production has gained essential importance [2]. Biogas, produced in distributed units, upgraded to the quality of natural gas and injected into the natural gas grid may provide considerable opportunities for increase of renewable energy sources (RES) within the natural gas-fired systems [3]. In this way, it can abate the emissions of greenhouse gases (GHG), and thus contribute to sustainable energy supply

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Peer-review under responsibility of Riga Technical University, Institute of Energy Systems and Environment
doi:10.1016/j.egypro.2015.06.011

[4]. It can also be a tool that may be used to alleviate the problems of global warming, energy security and waste management [5, 6]. Usage of RES is important for reduction of energy dependency on imported resources and it is also a part of the European Union's (EU) common objective and therefore observed by Latvia [7]. Latvia has committed that by 2020 the share of RES in the final energy consumption will be increased to 40 % [8] and production of biomethane can help to achieve this target.

Biogas can be used on-site, in combined heat and power (CHP) units or upgraded to biomethane and used as a vehicle fuel or for the generation of power [9, 10]. When using biogas on-site for electricity-only applications (e.g. if there is insufficient local heat demand) only 30−35 % of the gas energy is utilized. But if the biogas is transported via natural gas pipeline system and used in an efficient CHP or even efficient and modern domestic boiler, more than 90 % of the energy could be utilized [4]. Biomethane injection also enables renewable heat to be delivered into the district heating grid [4]. Since over 70 % of dwellings and apartment houses in Riga [11] and other Latvian cities are connected to the district heating network, injection of biomethane into the gas grid gives the biogas producer access to a much larger market than if the biogas is sold and used locally [4]. While in Europe the number of manufacturers of biogas upgrading plants increases every year [2] there are no biogas upgrading stations in Latvia yet. Biomethane (either pure or in blend with natural gas) is used as a fuel for vehicles in 12 European countries. It is also used for heating purposes either directly or blended to natural gas [3].

Under current market conditions, biomethane cannot compete with natural gas in sales price yet [3, 7, 8]. And hereby studies are carried out to compare biogas upgrading technologies [4, 11, 12], as well as to find the most cost-effective and technically suitable way, considering also environmental benefits, for biogas and/or biomethane utilization [13−17], including grid injection and distribution [5, 6, 18, 19], or integration biogas plants in the industry [20, 21]. Research on the technical and economic potential of biomethane production and injection into the natural gas grid is also carried out in Latvia [22−24].

The aim of this study was to determine the production costs of biomethane produced in distributed generation units via five methods of the biogas upgrading and injected into the natural gas grid using Latvia's conditions as the case study.

2. Materials and methods

The geographic information system program "ArcGis" with the "ArcMap" and the "ArcCatalog" [25] was used to map all Latvia's biomethane production plants and natural gas transmission pipelines and estimate the distances from the plants to the natural gas transmission grid. 42 point and line object files were created to represent biogas stations in Latvia and to calculate distances for connections. The map was created on grounds of the data reported in different sources and previous studies [9, 26−28]. Three biogas stations were selected for technical and economic analysis with the aim to determine an optimal biomethane production and injection solution (Fig. 1).

The choice of the biogas plants and locations was based on the following criteria:

- the plants should be located in a sufficient distance from natural gas transmission pipelines;
- the plants must be sufficiently dispersed and not located a few kilometers away from each other;
- the plants should be located in the same region.

In this study, five commercially available biogas upgrading technologies were used for cost calculations – (1) water scrubbing, (2) amine scrubbing, (3) membrane separation, (4) physical scrubbing with organic solvents and (5) pressure swing adsorption [29]. To find the most cost-effective biomethane production method, three different scenarios for the selected biogas plants were considered:

- Scenario 1: each biogas plant has an upgrading facility and biomethane is produced at each individual biogas plant and delivered to the natural gas grid.
- Scenario 2: biogas from each plant is delivered to the large upgrading plant for biomethane production and subsequent injection into the natural gas transmission line.
- Scenario 3: instead of distributed biogas production, raw materials from the farms are delivered to a single joint biogas and biomethane production facility.

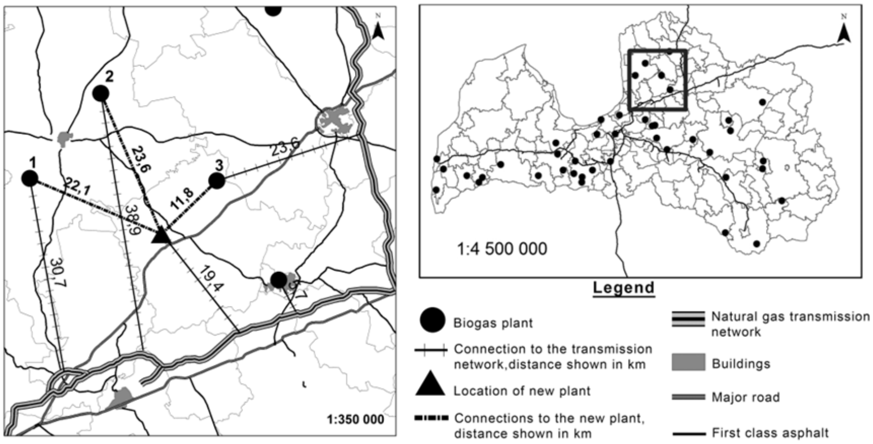

Fig. 1 Biogas plants chosen for technical and economic assessment

In Scenario 2 the total input of biogas flow from all three biogas plants in the methane extraction facility is 1280 m^3/h for the amine scrubbing method and 1345 m^3/h for other methods. In the 2nd scenario, the biogas upgrading costs are lower than in the 1st scenario due to the lower specific total investment in the upgrading facility. In Scenario 3 biomethane extraction costs are the same as in the 2nd scenario, but biogas production costs and the gas transportation costs are different. In the 3rd scenario raw materials are transported using the existing road infrastructure.

The study was based on the data available for the selected biogas plants, i.e. the amount and composition of the produced biogas reported in the polluting activity permits issued to each biogas production plant in Latvia [30−32]. Based on the data on the composition of biogas, it was assumed that 0.62 m^3 methane can be gained from 1 m^3 of the biogas on average. The total costs of biomethane production depend on the investment in connection gas pipelines and biogas upgrading facilities as well as operating costs of the upgrading facility. The operating costs include water, electricity, heat and biogas production costs. Capital costs were calculated for the economic lifetime of 10 and 20 years. Based on information of the natural gas supplier [33], it was assumed that gas pipeline construction costs are 55 EUR/m. Considering, that it may be impossible to construct the pipeline connection with the shortest distance determined by the "ArcGis" ruler, a correction factor of 1.1 was used to increase the length of the pipeline connection. To calculate the investment costs for all biogas upgrading methods, data on the specific investment depending on biogas input flowrate in m^3/h was used (Table 1) [29].

Table 1. Upgraded biogas input flowrate of the biogas plants

Plant	Size-biogas input flowrate	
	for the amine scrubbing method	for the other four biogas upgrading methods
No.1	937 m^3/h	984 m^3/h
No.2	213 m^3/h	224 m^3/h
No.3	130 m^3/h	137 m^3/h

The corresponding biogas input flowrates of the analyzed plants were taken from their "A" category pollution permits. A heat is required for biogas production and for the amine scrubbing upgrading method and it was assumed that the on-site biogas-fired boiler is used for the heat supply. Thus, the amount of the biogas available for biomethane production in the amine scrubbing method is reduced by the amount required for the heat production.

The lower heating value of biogas was assumed to be 6 MWh per 1,000 m^3 [34] and it was calculated that circa 3 % of the total amount of biogas produced at the each station is required for the heat production. Based on the data [29], the functions for calculation of the specific (per m^3/h of the biogas input flowrate) investment in biogas upgrading infrastructure were derived (Table 2).

Table 2. Specific investment of biogas upgrading technologies

Biogas upgrading method	Biogas input flowrate, m^3/h					Equation for calculation of the specific investment†	"R squared"
	250	*500*	*700*	*1000*	*1400*		
Water scrubbing, EUR/(m^3/h)	5000	2000	1000	1000	1000	$y = 980693x^{-0.991}$	0.86
Amine scrubbing, EUR/(m^3/h)	5400	3000	2357	2000	1607	$y = 239254x^{-0.696}$	0.99
Membrane separation, EUR/(m^3/h)	4400	2900	2286	2000	1786	$y = 81046x^{-0.534}$	0.98
Physical scrubbing, EUR/(m^3/h)	5000	2000	1000	1000	1000	$y = 980693x^{-0.991}$	0.86
Pressure swing adsorption, EUR/(m^3/h)	-	3000	2200	1750	1500	$y = 185034x^{-0.67}$	0.98

For the plants where the biogas input flowrates were outside the range of validity of the equations shown in Table 2, the specific investment was calculated using the data for the reference plant.

The operating costs of the biogas upgrading facilities were calculated using the data shown in Table 3.

The electricity tariff applied in the calculations of electricity costs was 0.151 EUR/kWh [35]. The water price of 1.24 EUR/m^3 was used for the calculations of the water costs [36]. Heat costs are calculated considering the capital, operation and maintenance costs of the biogas boiler [37], as well as biogas and biomethane production parameters [29].

Table 3. Resources required for the biogas upgrading methods [3]

	water scrubbing	amine scrubbing	membrane separation	physical scrubbing	pressure swing adsorption
Water consumption, m^3/m^3 of biogas	$22(10^{-5})$	$3(10^{-5})$	-	-	-
Electricity consumption, kWh/m^3 of biogas	0.265	0.1	0.22	0.25	0.23
Thermal energy consumption, kWh/m^3 of biogas	-	0.55	-	-	-

The total costs of the biogas in 1 MWh of biomethane in the 3rd scenario (Table 4) is lower than in the other two scenarios, since single joint biogas production plant is used instead of the three separate biogas plants which have smaller biogas production volume each. The operating costs for 10 and 20 year economic lifetime differ due to the difference in the capital costs of heat production.

To ascertain the costs of raw material transportation from the location of each farm to the biogas production and upgrading plant in the 3rd scenario, the distances were determined using a road map [38] and the location coordinates which were entered into the "ArcGis" software. The distance from the plants No.1 to No. 3 to the biogas production and upgrading plant is 29.35 and 13 km, respectively. Data for the calculations of the transportation costs (amounts of raw materials) were obtained from the "A" category permits [30−32] and from the study funded by the European Commission (the costs per ton-km) regarding the costs of the public transport as a function of distance

† x - biogas input flowrate (m^3/h); y - specific investment cost (EUR/(m^3/h)). Note: the equations are valid within the range of biogas input flowrate from 250 to 1400 m^3/h (500-1400 m^3/h for the "pressure swing adsorption method").

traveled [39]. Because the data of transportation costs in the Baltic countries were not available, the transportation costs were calculated using the costs value given for the Eastern Union heavy vehicle (0.07 EUR/ton-km) [39].

Table 4. Biogas production parameters and the total cost of the biogas in 1 MWh of the biomethane for all 3 scenarios

Parameter		Scenario		Unit
		1 & 2	3	
Investment:				
raw biogas flow of:	4 million m^3/year	6.84		MEUR
	12 million m^3/year		15	
Capital costs (10 years)		51	36	EUR/MWh
Capital costs (20 years)		37	26	EUR/MWh
Electric power equipment capacity		18	36	kW
Equipment heat capacity		148	677	kW
Operating costs (10 years)		30614 (1.4)	70939 (1.1)	EUR (EUR/MWh)
Operating costs (20 years)		28238 (1.3)	69500 (1.0)	EUR (EUR/MWh)
Raw material costs		7	7	EUR/MWh
Total costs (10 years)		59	44	EUR/MWh
Total costs (20 years)		45	34	EUR/MWh

3. Results and discussion

The total cost of biomethane per 1 MWh in the 1st scenario is quite similar for all upgrading methods with the difference of about 3 % (Fig. 2). All five discussed biogas upgrading methods are commercially available [13]. As studied in [5], the economic performance is sensitive to such factors as the biogas yield and the biomass (raw material) costs, but pipeline costs, electricity price and biomass transportation costs are of minor influence. The total cost in the 2nd scenario (Fig. 2) is by circa 2 % to 4 % lower (depending on the type of treatment method) than in the 1st scenario. The greatest share of the total costs of biomethane (72 % to 77 % – depending on the biogas upgrading method) is taken by the biogas production costs (Fig. 2), and that is true for all other scenarios. The total cost in the 3rd scenario (Fig. 2) is by circa 22 % to 27 % lower (depending on the type of treatment method and on the economic life time) than in the 2nd scenario. Therefore, it can be concluded that the 3rd scenario has the lowest costs (Fig. 2) although it may be most difficult to implement for the existing biogas plants. However, it could be a feasible option for the new plants. For the existing biogas plants the 2nd scenario could be the preferred solution. It can also be concluded that the cheapest biogas upgrading methods are amine scrubbing and physical scrubbing with organic solvents (Fig. 2). In 2012, the water scrubber was the most popular upgrading technology, followed by the pressure swing adsorption and chemical adsorption.

The price of natural gas, which is 39 EUR/MWh, is by about 54 % lower than the total costs of the delivered biomethane in the 1st scenario if the economic lifetime used in the calculations is 10 years and by about 40 % lower if the economic life time is 20 years, and if the most favorable upgrading method is chosen (Fig. 2). The price of natural gas is by about 52 % lower than costs of the biomethane in the 2nd scenario for 10 year economic life time and by about 36 % lower for the economic life time of 20 years (Fig. 2).

In the 3rd scenario, the price of natural gas is by about 34 % lower than the total cost of injected biomethane for a 10 year economic life time and by 16 % lower for the economic life time of 20 years (Fig. 2). In research presenting results of 2012 [40] it is shown that in the scenarios that included biogas upgrading to biomethane for the injection into the gas network, only the scenario with coupled small-scale CHP unit covering internal heat requirements could reduce the overall impact on fossil fuel degradation, compared to electricity generation alone.

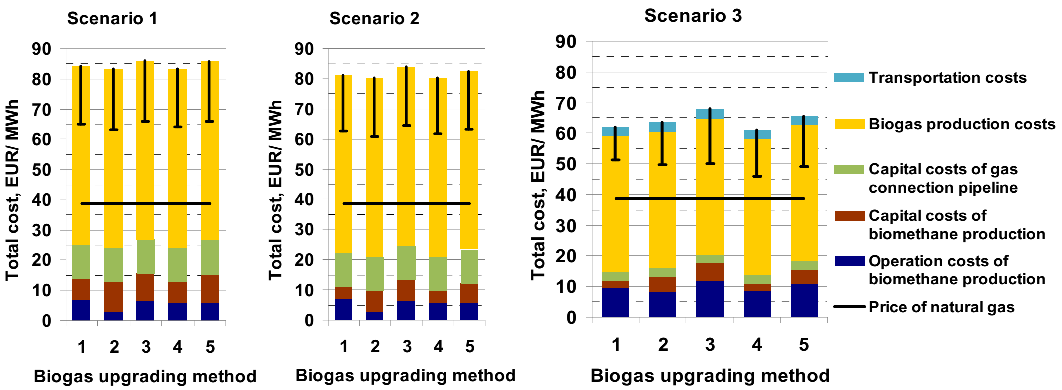

Fig. 2 Comparison of the total cost of biomethane for all scenarios and all five biogas upgrading methods for 10 and 20 years of economic life time. Reduction of the capital costs calculated for 20 year economic lifetime is marked with ⊥. Biogas upgrading methods: 1 - water scrubbing, 2 - amine scrubbing, 3 - membrane separation, 4 - physical scrubbing with organic solvents, 5 - pressure swing adsorption

Currently, the legislation of Latvia does not provide conditions for biomethane injection into the natural gas network. In conditions of no financial support for biomethane production it is not economically feasible. However, it is necessary to consider energy policy supporting the injection of biomethane into the natural gas grid. Although biomethane injection currently is not regulated at the European level, some countries, such as Germany, in 2012 have introduced legislation regulating biomethane grid injection [41]. In the initial stage, when the first biomethane generation plants were constructed in Germany, such legislation did not exist in the country. The first innovative stations were set up by the agreement between the main stakeholders, such as the operator of the biogas plant, the natural gas network operator and the authorities [41].

4. Conclusions

Results of the study show that the total cost of the biomethane produced and delivered to the natural gas grid is circa 46 EUR/MWh when the most favorable upgrading method and 20 year economic lifetime is used in calculations. Therefore, under current conditions, biomethane production would need financial support to make the costs compatible with the price of natural gas, and the minimum subsidy is about 22 EUR/MWh if the existing biogas plants decide to construct joint biogas upgrading facility. The amount of subsidy for larger joint biogas production and upgrading facilities could be reduced to as low as about 7 EUR/MWh. Results of this study also show that if the biogas producers could co-operate in constructing larger joint biogas production and upgrading facilities (Scenario 3), this would be the most economically attractive solution. This option most likely could be feasible for new plants in the future. For the existing biogas plants, the option to consider would be to construct joint biogas upgrading facilities as stipulated in Scenario 2.

Acknowledgements

We are grateful to Esri (Envirotech Ltd – distributor in Latvia) for the permission to use “ArcGis” software.

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