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Life cycle assessment of bio-methane supply system based on natural gas infrastructure

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Abstract. Many sites for biogas production in Latvia currently do not have sufficient heat load to provide power production in co-generation mode. The alternative to relatively inefficient power production could be production of bio-methane which is known as one of the most important renewable option for gas supplies. After removal of contaminants bio-methane is of quality of natural gas and can be delivered to power plants and industry using the natural gas supply infrastructure. For analysis of environmental benefit of using bio-methane the environmental impact of the proposed solution has to be assessed. The aim of the study is to make life cycle assessment of the system for bio-methane supply to industrial plant via the natural gas grid. The analysed system includes bio-methane production and transport to the natural gas pipeline including the infrastructure. Functional unit was 1 MWh of bio-methane energy injected into the natural gas transmission pipeline. Life-cycle model was created and analysed with software '*SimaPro*'. *ReCiPe* and *Eco-Indicator'99* were used as characterization methods to analyse the life-cycle environmental impacts. Results show the influence and contribution level expressed in mid-point categories as well as in a single-score indicator. The largest impact is created by use of fossil energy sources in production of bio-methane. The results can be used to design renewable energy supply systems and for the comparison of alternatives.

Key words: bio-methane, life cycle assessment, natural gas, renewable energy.

INTRODUCTION

Many sites for biogas production in Latvia currently do not have sufficient heat load to provide power production in combined heat and power generation mode. The alternative to relatively inefficient power-only production could be production of bio-methane which is known as one of the most important renewable option for gas supplies. After removal of contaminants bio-methane is of quality of natural gas and can be delivered to combined heat and power plants in energy utilities and industry via the natural gas infrastructure. Thus, bio-methane could serve as one of the most feasible replacement of fossil fuel for firing industrial furnaces.

The focus of the study is to find a substitute of natural gas for brick manufacturing industry which is important economic branch in Latvia. As it is known from previous studies, brick firing is the most energy intensive of the brick manufacturing processes (Rose et al., 1978; Moedinger, 2005; Koroneos & Dompros, 2007; Machado et al., 2011; Skele et al., 2011; Oti & Kinuthia, 2012, Repele et al.,

2013) and natural gas is used as a firing fuel in Latvia. Also propane, oil, sawdust, coal or combinations of these fuels can be used for this purpose (Venta, 1998; Moedinger, 2005). Nonetheless, due to innovative development these traditional sources can be successfully replaced by renewable alternatives (Moedinger, 2005) and will result in significant reductions in greenhouse gas emission (Gomes & Hossain, 2003; Repele et al., 2012). One of the most viable renewable substitute of natural gas is bio-methane (Adelt et al., 2011) which can substitute natural gas after quality upgrading (EBTP, 2014). Thus, advantages of the well-developed natural gas infrastructure can be utilised. Due to sufficiently high average heating value (21 MJ $(m^3)^{-1}$ with 60% methane) biogas can also be directly used as fuel in burning processes (Ellersdorfer & Weiβ, 2014). However, use of bio-methane as a substitute of natural gas allows introducing renewable energy sources in industry to much larger extent.

Therefore, research to ascertain environmental impact caused by bio-methane production and injection in natural gas grid is necessary. The aim of this study is to make life cycle assessment of the system for bio-methane production and supply to industrial plant via the natural gas grid. The results can be used to compare alternative energy solutions for the industry.

MATERIALS AND METHODS

The aim of the study was to make LCA of the system for bio-methane supply to industrial plant via the existing natural gas grid. Geographic information system program '*ArcGis*' with *ArcMap* and *ArcCatalog* (ArcGis, 2010) was used to map the bio-methane production plants and transmission natural gas pipelines in order to estimate length of pipelines for connection of the facilities to the existing natural gas transmission grid. 42 point and line object files were created to represent bio-methane stations and to calculate distances for connections, respectively. The map was created on grounds of the data reported in different sources and previous studies (Ministry of Economics I & II, 2013; Cinis, 2013; Dzene et al., 2013). Seven biogas plants were chosen for this study – the nearest to the brick factory located in Ozolnieki district, Latvia and having relatively large annual production volume of biogas relative to the length of connection to the natural gas grid. The study was based on the data reported in the polluting activities permits issued to the bio-methane production plants in Latvia ('A' category permits No1–No7, 2011–2013). Since the database for country specific processes is not available, LCA software (SimaPro, 2013) with *EcoInvent* (v2.2) database was used to model and analyse environmental impacts caused by bio-methane production and transportation from the bio-methane production facility to the natural gas transmission pipeline via the connecting pipe. For this study only system processes that are most relevant to Latvian conditions were selected from the database:

- For bio-methane production process 'Methane, 96%, from biogas, at purification' was used. Included electricity consumption and emissions represent the raw gas compression, H2S removal, gas conditioning and methane enrichment of biogas. Infrastructure expenditures are included employing generic data for facilities of a chemical plant as a first approximation. Bio-waste production is not included. A plant using the described technology is in operation in Switzerland.
- For bio-methane transportation 'Transport, natural gas, pipeline, long distance' process was chosen. This dataset des'cribes the energy consumption and the emissions

linked to the transport of 1 ton-km average natural gas in Europe. The data for emissions and for energy requirements is based on German data.

- 'Pipeline, natural gas, low pressure distribution network' process was selected to describe the infrastructure needed for bio-methane transportation. This dataset describes the Swiss low (< 0.1 bar) pressure distribution network: life time 40 years and annual transport is 30 TJ km^{-1} a. Data is based on Swiss data.

The analysed system includes bio-waste collection and transport to the plant, bio-methane production and transport to the natural gas pipeline including the infrastructure (Fig. 1). Based on the information about the considered biogas production facilities and connection pipelines, life cycle assessment (LCA) is done for the functional unit of 1 MWh of bio-methane energy.

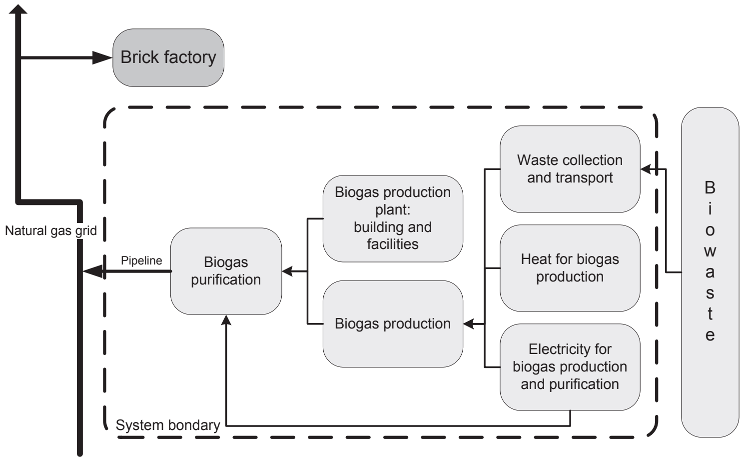


Figure 1. Processes considered within the system boundary.

Environmental characterization was done at midpoint impact category level and by calculating the single score impact indicator. To make the study results comparable with previous studies and make the results applicable for ecodesign purpose the following two impact assessment methodologies were used:

- *ReCiPe* which is the most recent and harmonised indicator approach available in life cycle impact assessment and comprises harmonised category indicators at the midpoint and the endpoint level (SimaPro Database Manual, 2013);
- *Eco-indicator'99* which is one of the most widely used impact assessment methods in LCA, which also allows the environmental load of a product to be expressed in a single score (SimaPro Database Manual, 2013).

For the study *ReCiPe* Endpoint (Europe ReCiPe HA) (Goedkoop et al., 2013) and *Eco-indicator'99* (Europe EI 99 HA) methodologies (Goedkoop & Spriensma, 2001) were selected. 'H' refers to the weighting set belonging to the 'hierarchist perspective'. 'A' refers to the average weighting set and is recommended by the developers of both methods. 'Hierarchist perspective' was chosen because it is often considered to be the default model (SimaPro Database Manual, 2013) and described (Marceau & Vangeem, 2002; De Schryver, 2010) as the one which takes a long-term look at all substances if there is consensus regarding their effect.

Only those impact categories which had at least 3% of the total environmental impact were chosen for further analysis. Hence, the five impact categories of the *ReCiPe* and *EcoIndicator'99* methods were considered.

Tables 1, 2 summarises characteristics of the selected bio-methane plants. Bio-methane plants which were chosen for analysis are marked with numbers '1' to '7'. The plants use combination of different bio-waste to produce bio-methane (Table 1). Amount of produced biogas and upgraded bio-methane varies throughout plants due to the different sizes of the plants, i.e. installed electrical capacities, amounts and contents of input and other factors (Table 2).

Table 1. Type of bio-waste used at the selected bio-methane plants

Plant	No1	No2	No3	No4	No5	No6	No7
Manure	√	√	√	√	√	√	√
Silage, plants and/or residues	√	√	√	√	√	√	√
Corn	√	√	√	√	–	√	√
Grain and/or grain flour	√	√	√	√	√	–	√
Whey	√	–	–	√	–	√	√
Animal by-products	√	–	–	√	–	√	√

Table 2. Data for the selected bio-methane plants

Plant	No1	No2	No3	No4	No5	No6	No7
Bio-waste input [10^3 t y^{-1}]	54.50	54.50	13.07	16.50	21.40	40.00	24.90
Installed electrical capacity [MW]	1.95	2.00	0.50	0.50	0.60	1.00	1.00
Potential bio-methane yield [GWh y^{-1}]	45.26	41.23	42.46	14.67	12.32	70.58	20.66
Distance to the natural gas grid [km]	0.8	4.6	6.5	6.6	12.1	12.7	18.9

Data required for the study were obtained from the biogas station pollution permits ('A' category permits No1–No7, 2011–2013), previous studies (Cinis, 2013). Further calculations of the best scenario for injecting upgraded biogas into the natural gas pipeline were carried out by taking into account the bio-methane production capacity of the plants and distances from the plants to the natural gas transmission grid estimated with the program *ArcGis* (ArcGis, 2010).

RESULTS AND DISCUSSION

According to the calculations using *EcoInvent* (v2.2) database (SimaPro, 2013) results of environmental impact of 1 MWh energy from the biomethane plant No1 including infrastructure varies from 9.92 Pt MWh^{-1} when assessed using *ReCiPe* method (and 6.29 Pt MWh^{-1} when using the *EcoIndicator'99* method) to 10.38 Pt MWh^{-1} (6.86 Pt MWh^{-1}) for the plant No 7 respectively (Table 3). For comparison, environmental impact of 1 MWh of natural gas energy is 15.3 Pt MWh^{-1} when *ReCiPe* method is used for analysis (and 17.6 Pt MWh^{-1} obtained with *EcoIndicator'99* method).

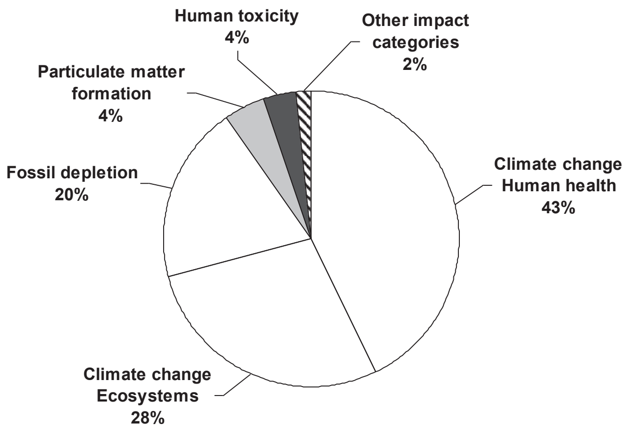
Table 3. The results of the environmental impacts per one megawatt-hour of energy produced at the selected bio-methane plants in Latvia

Plant	No1	No2	No3	No4	No5	No6	No7
Environmental impact, Pt MWh^{-1}							
ReCiPe	9.92	10.02	10.07	10.07	10.21	10.22	10.38
EcoIndicator'99	6.29	6.41	6.47	6.47	6.64	6.66	6.86

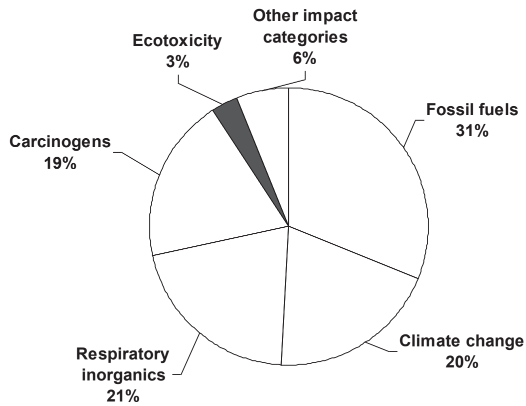
The share of the environmental impact of the infrastructure and transport of the gas, which includes energy consumption and the emissions linked to the transport, in the total impact is rather insignificant in the case when bio-methane plant is located close to the natural gas grid and increases with the distance from it. For example, in the case of the plant No1 which is the closest to the natural gas pipeline the share of the infrastructure and transport is 0.21% (0.4%) of the total environmental impact. But for the most distant plant, i.e. No7, the share is 4.63% (8.73%). It was found in the study, that infrastructure and transport can represent more than 10% (or even more than 15% depending on the evaluation method) of the total environmental impact for the complete bio-methane generation and injection if the distance between the bio-methane production plant and the natural gas grid is increased up to 30–40 km. Even if this percentage could be lower or higher depending on the distance from the natural gas grid, our opinion is that the gas supply infrastructure is still rather important element and should be taken into account if new energy supply systems are designed and considered, which seems to contradict with the opinion in Patterson et al (2011). Whereby, in order to reduce the potential environmental impact, efforts should be made to find the best location for a new bio-methane plant, also taking into account the distance to the existing gas transmission network as well as the location of resources for biogas production.

When using the *ReCiPe* method the greatest environmental impact occurs in the following impact categories (Fig. 2): climate change (human health and ecosystem), fossil depletion, particulate matter formation and human toxicity. Analysis with the *EcoIndicator'99* method shows that the largest impact is caused in the categories fossil fuels, climate change, respiratory inorganics, carcinogens and ecotoxicity. It may mean that the energy use for production and transportation of bio-methane is the largest impact factor.

With the increasing distance of the bio-methane production plant from the grid, impact increases most in the category 'human toxicity' (by ~ 16%), 'particulate matter formation' (~9%) and 'fossil depletion' (~8%), but slightly (~ 2%) in the categories 'climate change (human health and ecosystem)' when analysis is carried out with the *ReCiPe* method. If the *EcoIndicator'99* method is used, environmental impact mostly increases in such categories as 'carcinogens' (~ 16%), 'respiratory inorganics' and 'ecotoxicity' (both by ~ 11%) and 'fossil fuels' (~ 8%), but slightly increases (~ 3%) in the category 'climate change'. Whichever method is used, the environmental impact increases remarkably in the categories that do not have a large overall impact. These categories are related to the land use: *ReCiPe* categories 'natural land transformation' (~ 40%) and 'agricultural and urban land occupation' (~ 34–39%) and *EcoIndicator'99* category 'land use' (~ 28%).



(a)



(b)

Figure 2. Environmental impact by impact category of 1 MWh of bio-methane produced at the plant No7 (*ReCiPe* method (a); *EcoIndicator'99* method (b)).

CONCLUSIONS

Results of this study show that although the share of the environmental impact from the infrastructure which connects distributed bio-methane production facilities to the natural gas pipeline infrastructure is rather insignificant in the case when the plant is located in close proximity to the natural gas grid, nevertheless the impact increases with the distance and in overall can represent more than 10% of the total environmental impact. It can be concluded, that even if the percentage of environmental impact of bio-methane injection infrastructure is lower in case of smaller distance from the grid, it is still rather important element and should be taken into account when new energy supply systems are considered.

Results also indicate that even though the environmental impact of the gas injection infrastructure increases with distance of the bio-methane plant from the natural gas grid, the bio-methane still could be considered as environmentally better alternative than the natural gas.

Further studies are necessary to evaluate also economic aspects of the development of bio-methane system as a renewable energy substitute for the natural gas supply system.

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