Landfill gas utilization for energy to avoid greenhouse gas emissions

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Abstract

Landfill gas (LFG) is usually suited for energy utilization. It can be used as substitute for fossil fuels to avoid greenhouse gas (GHG) emissions. The amount of avoided GHG emissions through LFG utilization depends on different factors such as the amount LFG, proportion of methane in LFG, utilization techniques and the type of replaced fossil fuel. In this study, two alternatives of LFG utilization were considered to estimate the avoided GHG emissions by formulating two different scenarios.

The result shows that LFG utilization in district heat generation gives the higher reduction in GHG emission than LFG utilization in electricity production. Based on assumption that 1 000 000 m^3 of LFG can be utilized, the estimated reduction of GHG emission is 1818 $t_{CO2\text{-}eq}$ when LFG utilization is used as a substitute for district heat generation by coal. On the other hand, the LFG utilization gives 1436 $t_{CO2\text{-}eq}$ GHG emission reduction when electricity production by coal is replaced by LFG. The result suggests that the estimated avoided GHG emissions depends strongly on the data used in the estimation, and that such data have to be carefully selected.

Keywords: Landfill gas, greenhouse gas, LFG utilization

1 Introduction

1.1 Rationale

Landfill gases (LFG) accelerate global warming (GW), which is considered as the most serious environmental threat today. LFG contains mainly two compounds namely; carbon dioxide (CO_2) and methane (CH_4). Methane has more than 20 times higher global warming potential (GWP) impact than carbon dioxide [1]. Landfills generate notable amount of CH_4 which makes up approximately 18 % of the total global anthropogenic CH_4 emissions [2, 3]. In order to reduce GHG emissions which cause global warming, treatment of LFG, particularly CH_4 is therefore essential. According to the European Council (EC) Directive 1999/31/EC, LFG shall be collected and must be treated accordingly [4]. With possible thermal LFG treatment methods such as flaring or using microturbines, gas engines or boilers, CH_4 can be converted to less harmful CO_2. In addition, LFG utilization can replace fossil fuels, thus GHG emissions can be avoided.

Several factors have influence to the efficiency of treatment of LFG and the amount of avoided GHG emissions. Generated LFG has to be collected sufficiently before it can be treated and utilized. Several studies have shown that huge amount of LFG escape to the atmosphere without treatment [5, 6]. In OECD countries, where collection rate is much higher than non-OECD countries, the average estimated collection efficiency of LFG is 56 %. [5]. The LFG collection rate is one of the key parameters in defining the range of GHG emissions reduction [7]. Globally, great potential of LFG energy is wasted because less than 10 % of total CH_4 generated from landfills is utilized [6].

Other than the technical issues, there are some methodological issues associated in gas utilization such as the problems on the selection and assumption of data for the estimation of avoided GHG emissions. For example, different data assumptions regarding the LFG utilization and replacement of fossil fuels may yield to completely different estimation results. In order to address GHG emission estimation problems and to come up with better LFG utilization alternatives, this study was conducted. Hence, the objectives of this study are; to determine which LFG utilization option can give the highest GHG emission savings, and to find out how the assumed values can affect the result of the estimation of the avoided GHG emissions.

1.2 Landfill gas collection, treatment and utilization

The amount of utilizable LFG depends on the amount of biodegradable waste, gas generation and gas collection rate at the landfill site. In addition, gas quality needs to be sufficient enough for utilization. Gas generation relies on several factors such as landfill conditions and waste characteristics [8]. Landfill's specific gas collection efficiency has a remarkable influence to the overall GHG emissions from landfill. Collection efficiency is one of the most important parameters in the estimation of the GWP impact of LFG [7, 9]. Low amount of LFG can be utilized with basic technology like heating (e.g. district and space heating). High amount of LFG is suitable for varieties of utilization options. However, high amount of collected LFG does not necessarily guarantee that utilization is viable in all cases. Some gas utilization technologies such as microturbines, gas engines and fuel cells have specific minimum limits for methane and maximum limits for harmful compounds concentration. Higher methane concentration does not only give more energy, but also suits for wider variation of utilization technologies. If the quality of collected LFG is too low and the utilization is not reasonable, then the collected gas must treated by flare according to EU Directive 1999/31/EC [4]. The two generally employed LFG energy utilization methods are electricity and district heat production. For electricity production, microturbine and gas engine are the common utilization technologies. District heat generation using LFG is one of the most common utilization methods particularly in the Nordic countries. LFG is usually very suitable for district heating because extremely high temperature is not needed in district heat generation and the quality requirements of the utilized LFG are not high. One advantage of district heat generation by LFG is the very high heat generation efficiency. A typical district heat production can reach as much as 90 % efficiency or even higher.

1.3 GHG emissions from energy production using fossil fuels

The amount of reduced emission (avoided emissions due to LFG utilization instead of using fossil fuels in energy production) is dependent on the collected methane from LFG and its utilization efficiency. Hence, utilization efficiency has a notable effect on the amount of GHG emissions reduction.

Electricity and heat production by fossil fuel generates specific amount of GHG emissions depending on fuel or fuel mix type. In Finland, the fuel specific GHG emissions per caloric value for commonly used fuels are presented in Table 1.

Table 1. Fuel specific GHG emissions per caloric value and heat production efficiency for typical fuels used in Finland [10, 11].

	Coal (Anthracite)	Oil (Heavy fuel oil)	Natural gas
GHG-emissions [t_{CO2}/TJ]	94.6	77.4	55
η_{heat} [%]	92	92	93

Energy production distribution and energy market has significant influence in the estimation of GHG emission. In Finland, the distribution structure of electricity production is diversified into nuclear (26 %), co-generation district heating (18 %), condensing power (18 %) and hydro power (13 %) [12]. In 2007, the proportion of renewable energy in electricity production in Finland was 26.6 % while the proportion of CO_2-free production was 51.8 % [13]. Defining of marginal electricity production (the most expensive electricity production in market) is, however, problematic as pointed in a previous study [14]. GHG emissions caused by average and marginal electricity production in 2005 and forecasted GHG emissions based on estimated average electricity production distribution for 2020 are presented in Table 2.

Table 2. GHG emissions of electricity production for average, marginal and estimated average forecast in Finland [13, 15, 16]

	Average	Marginal	Forecast average in 2020
GHG-emissions [t_{CO2}/TJ]	55.5	250	32.6*

*Forecast estimation of GHG emissions in 2020 is estimated based on electricity production scenario made by Pöyry Energy and average GHG emission based on emissions data for Finland in 2005 [13, 15].

The estimated GHG emissions when district heat is generated by coal, oil and natural gas are presented in Table 3. In addition, the estimated emission for average district heat production is presented in Table 3.

Table 3. The fuel specific GHG emissions for typical fuels from district heat generation by condensing power plant[10, 11, 15].

	Average	Coal (Anthracite)	Oil (Heavy fuel oil)	Natural gas
GHG-emissions [t_{CO2}/TJ]	65	102	84	59

2 Methodology

Landfill gas utilization can provide GHG emission reduction in two ways. First, burning of LFG converts methane to less harmful carbon dioxide, thus reduces the GWP impact. Second, utilization substitutes fossil fuels, hence GHG emissions are avoided. In this study, the substitution of fossil fuels is considered for the two scenario settings.

2.1 Data for GHG estimation

The data used in the estimation of avoided GHG emissions caused by energy production and LFG utilization are based on GHG emission and energy production calculation values taken from the studies conducted by various authors [11, 13, 15, 16]. These values are presented in Tables 1, 2 and 3. GHG emissions data for electricity production is presented in Table 2. The data used in forecasting the GHG emissions is based on average electricity production in 2005 and from a scenario-based report for Finland [13, 15].

The data used in the estimation of emissions from district heat production by fossil fuels are based on fuel specific emissions per caloric value and fuel specific heat generation efficiency taken from Statistics of Finland and other studies [10, 11, 15] and are presented in Tables 1 and 3.

2.2 Assumptions

Generally, this study is an estimation of avoided GHG emissions by using LFG as substitute fossil fuels. For the estimation of avoided GHG emissions and scenario options, comparative analyses of some important assumptions were conducted. First, it is assumed that 1 000 000 m^3 of LFG with 55 % methane concentration can be utilized for energy utilization. In other words, the functional unit is 550 000 m^3 of methane which corresponds to the typical amount of collected methane from representative size of municipal solid waste landfill per year. The functional unit allows for the comparison of created scenarios. The specific energy content of methane is 36 MJ/m^3 which corresponds to the overall energy content of 19.8 TJ. It is assumed that LFG is utilized in electricity and district heat production. Utilization is assumed to be for microturbine for electricity and water boiler for district heat generation. Assumptions for energy production efficiencies, produced energy per functional unit by utilization technologies and all other utilization parameters are presented in Table 4. The assumed utilization efficiencies for electricity generation and district heat generation are 29 % and 90 %, respectively. According to the International Panel on Climate Change (IPCC), the CO_2 from LFG is generally considered as GHG-neutral due to its biogenic origin [17]. Electricity production by fossil fuels is assumed to be generated by condensing power plant.

Table 4. LFG utilization assumptions and amount of produced energy for electricity and district heat.

	Microturbine (electricity)	**Water boiler (district heat)**
Amount of landfill gas [m^3]	1 000 000	1 000 000
Concentration of methane	55	55
Electricity production efficiency [%]	29	0
Heat product efficiency [%]	0	90
Overall efficiency [%]	29	90
Energy content of LFG [TJ]	19,8	19,8
Produced electricity [TJ]	5,7	0
Produced heat [TJ]	0	17,8
Total energy produced [TJ]	5,7	17,8

2.3 Estimation and scenarios analysis

Estimation of avoided GHG emissions due to LFG utilization is carried out by using LFG utilization scenario-based using the assumed GHG estimation data and assumptions. In the first scenario (LFG for electricity production), LFG is used as substitutes for average or marginal electricity production. In the second scenario (LFG for district heat production)

LFG substitutes for district heat produced by average or specific fuel production. The results of the estimation are descriptively shown in Figures 1 and 2 and these results are compared to find out the optimal utilization alternative.

3 Results and discussions

Avoided GHG emissions were estimated for LFG utilization based on created scenarios as follows:

- Scenario 1: LFG utilization for electricity production by microturbine
- Scenario 2: LFG utilization for district heat production by water boiler

For the first scenario, LFG is utilized in electricity production. With the assumption that microturbine produces 5.7 TJ of electricity, the estimated GHG emissions reduction when LFG utilization substitutes for average and marginal electricity production, is presented in Figure 1.

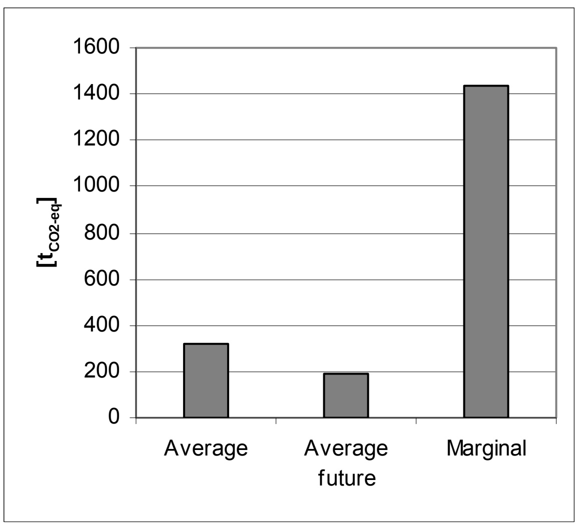

Figure 1. Estimated avoided GHG emissions due to electricity production by LFG.

Figure 1 shows that the estimated amount of avoided GHG emissions is 1436 t_{CO2-eq} when LFG utilization substitutes for marginal electricity while the estimated amount of avoided emissions is 320 t_{CO2-eq} when estimation is based on average electricity production. There is a difference between the estimated marginal and average emission.

The estimated avoided GHG emission is approximately 4.5 times lower when the estimation is based on average instead of marginal electricity data. The scenario also shows that the estimated emission reduction for average electricity production can be approximately 41 % lower in 2020 than estimated emissions reduction in 2005. Thus, in the future the difference between estimations for average and marginal energy production can be increased.

For the second, scenario LFG is utilized in district heat production. In district heat production by water boiler, heat generation efficiency is usually notably higher compared to electricity production efficiency. In this scenario, it is assumed that heat production efficiency is 90 % when water boiler produces 17.8 TJ district heat. The estimated GHG emissions reductions for district heat utilization are presented in Figure 2.

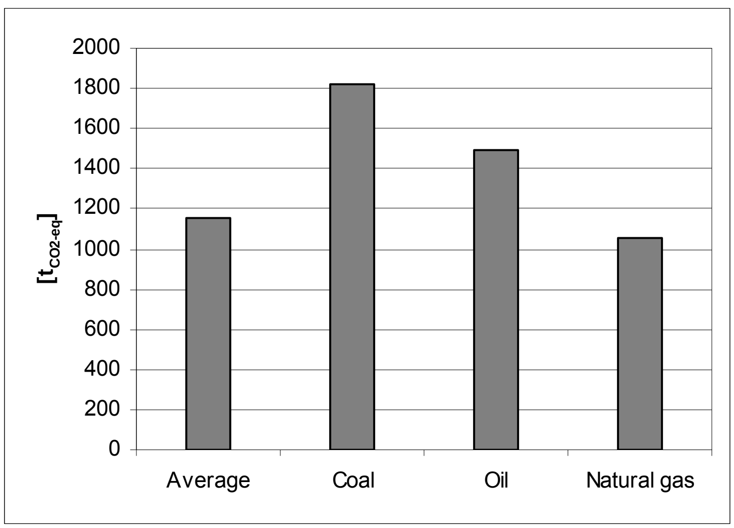

Figure 2. Avoided GHG emissions due to district heat production by LFG utilization

From figure 2, it is shown that the estimated amount of avoided GHG emission is 1818 $t_{CO2\text{-}eq}$ when LFG substitutes for coal and estimated avoided emission amount is 1497 $t_{CO2\text{-}eq}$ when LFG substitutes oil. The result shows that LFG utilization in district heat production can provides the greater amount of avoided GHG emission than LFG utilization in electricity production. The difference between average (avoided emission: 1158 $t_{CO2\text{-}eq}$) and natural gas (avoided emission: 1051 $t_{CO2\text{-}eq}$) production is almost negligible, although the difference between the average district heat production and district heat production by coal is still notable. Apparently, the high heat generation efficiency of the water boiler can result to high GHG emission savings.

The electricity and district heat markets differ notably from each other because of district heat is typically distributed to consumers locally, where as electricity can be transferred via power grid and sold to some Nordic countries. Previous difference between electricity and heat markets influences considerably to the estimation of GHG emissions reduction. Besides, electricity and heat markets have their own specific production distributions. Clearly, energy production distribution also has strong outcome for emission estimation.

Typically, small-scale renewable electricity production such as LFG utilization substitutes the most expensive electricity production. The most expensive electricity production is marginal production is usually done by condensing power plant production by coal. If the avoided GHG emissions are calculated based on average electricity production data instead of marginal production, the emission saving estimation can lead to totally incorrect result.

District heat can be produced by using fossil fuels or renewable energy which is considered carbon neutral. District heat is usually distributed to consumers via local district heating network. Hence, individual district heat generation plant can have a strong influence on GHG emissions generation in a given area. Therefore, it is important to use case-specific data when GHG emissions are estimated for district heat generation. The estimations result shows that by employing district heat utilization option, the highest amount of avoided GHG emissions can be achieved. However, the difference between the estimated amount of avoided emissions is not more than 21 %. The need for district heat usually varies because of the seasonal variation in demand. If landfill gas is not utilized for district heat generation in summer period, the GHG emissions reduction could be higher for electricity than district heat utilization. Therefore, the utilization period of maximum load of water boiler have to be completely taken into account.

The result of this study shows that GHG emission estimation is affected by factors which can vary widely, thus, choosing estimation data should be done carefully. The differences between electricity and district heat markets have to be also taken into the estimation. This is because district heat is usually used seasonally and locally, whereas electricity can be used continuously via national or international grid. On the other hand, the amount of avoided GHG emissions depends strongly on the type of replaced fossil fuel or fuel mix.

Therefore, the use of appropriate data for describing replaced fuel or fuel mix is important in order to carry out the estimation of GHG emissions correctly.

4 Conclusion

In this paper, the reduction and avoided GHG emissions through LFG energy utilization options were estimated in a Finnish setting. The estimation result shows that the highest avoided GHG emissions can be achieved in district heat production when LFG utilization substitutes for heat generation by coal. The landfill gas utilization in district heat production is advantageous because it has a very high energy production efficiency.

It is shown that the highest GHG emissions reduction of 1818 $t_{CO2\text{-}eq}$ can achieved when LFG utilization is substituted for coal in district heat generation. In electricity production, the highest estimated amount of avoided GHG emissions was 1436 $t_{CO2\text{-}eq}$. LFG utilization in district heat production clearly gives higher emission reduction than LFG utilization in electricity production. If landfill gas is not utilized for district heat generation in summer period, the GHG emission reduction could be higher for electricity utilization than district heat utilization.

Furthermore, the amount of avoided GHG emissions is dependent on the replaced fossil fuel or fuel mix. For the district heat production, the estimated amount of avoided GHG emissions varies from 1051 $t_{CO2\text{-}eq}$ (natural gas) to 1818 $t_{CO2\text{-}eq}$ (coal). For the electricity production, the estimated amounts of avoided GHG emissions are 320 $t_{CO2\text{-}eq}$ for average electricity production and 1436 $t_{CO2\text{-}eq}$ for marginal electricity production. The estimated avoided emission for average electricity production is 4.5 times lower than marginal production. Obviously, the selected data has strong influence on the result of the estimation. Therefore, the use of appropriate data for describing replaced fuel or fuel mix is important in order to carry out the estimation of GHG emissions correctly. It is recommended that assumptions and definitions have to be done carefully and case data have to be used specifically. However, even if estimation includes many challenges, it can offer useful information for decision-makers and significantly improve landfill gas utilization if it is carried out with good quality.

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