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AN ENVIRONMENTAL ASSESSMENT OF LANDFILL GAS MITIGATION, USING A BIOCOVER SYSTEM

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SUMMARY: A life cycle-based environmental assessment was conducted on the mitigation of landfill gas emissions, by implementing biocover and gas collection along with energy utilisation. Based on assumptions about gas generation at Danish landfills, the efficiency of the technologies involved and the composition of substituted energy production, 15 scenarios were modelled using the EASETECH life cycle assessment model, through which potential environmental impacts in the environmental impact category "Global warming" were calculated. In all scenarios, biocover and gas collection with energy utilisation led to a significant potential for environmental improvements compared to the scenario with no emission mitigation action. Scenarios representing biocovers with methane oxidation (efficiencies between 70 to 90%) were environmentally superior in terms of global warming impact in comparison to scenarios with gas collection and energy utilisation. Combining gas collection with energy utilisation and the subsequent installation of a biocover achieved major improvements in comparison to where only gas collection and energy utilisation were in effect. Overall, it can be concluded that a biocover under the given assumptions is environmentally more appropriate than gas collection and utilisation, due mainly to methane emissions escaping through the landfill cover during and after the gas collection period playing a crucial role in the latter situation.

1. INTRODUCTION

In 1997, the Danish government introduced a ban on landfilling organic waste suitable for incineration. This led to a decrease in the amount of landfilled organic waste and thus a decrease in the generation of landfill gas, albeit this continues for several decades after the waste has been deposited, which means that older Danish landfills still produce significant quantities that are emitted directly into the atmosphere. At these landfill sites, gas collection and utilisation is often not technically and/or economically feasible, but one alternative is the establishment of a biocover system whereby methane is microbially oxidised into carbon dioxide, thus significantly reducing methane emissions. Biocovers and biofilters have been installed successfully at Danish landfills and resulted in methane oxidation efficiencies higher than 90% (Scheutz et al., 2014, Scheutz et al., 2017).

The objective of this study was to perform a life cycle-based environmental assessment comparing the establishment of a gas collection and utilisation system with a biocover as a mitigation option at old Danish landfills without any existing gas management activities.

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2. MATERIAL AND METHODS

An environmental assessment was based on the handling/treatment of 1 Nm^3 methane produced in the period 2015 to 2115 at a typical Danish landfill, brought into operation in 1985 (containing a mixture of household and commercial waste, including shredder). Accumulated methane production was modelled with the landfill gas generation model Afvalzorg (Scharff and Jacobs, 2006).

The environmental assessment included only potential environmental effects in terms of global warming impact and was designed as a scenario study, whereby a number of scenarios (15 in total) were modelled using the EASETECH life cycle assessment model (Clavreul et al., 2014). Table 1 provides an overview of the scenarios, between them covering the mitigation of methane emissions from landfills via a biocover as well as gas collection with energy utilisation, respectively. For the sake of completeness, a scenario in which no mitigation action took place was also included. Within the two mitigation technologies (gas collection and utilisation and biocover), scenarios using different parameter values and boundary conditions were modelled.

The most important assumptions for modelling the treatment of the functional unit (1 Nm^3 methane) proved to be the efficiency of methane oxidation in the biocover and the efficiency of the gas collection system. Based on experiences from the biocover system installed at Klintholm Landfill (Fynen, DK), which exhibited an average methane oxidation of 80% (Scheutz et al., 2014), it was decided to run scenarios for a biocover with different methane oxidation efficiencies, namely 70, 80 and 90%, respectively, using 80% as the base value.

Gas collection efficiency has been examined in a number of Danish landfills, and collection efficiencies range between 41 and 81% of the generated methane (Mønster et al., 2015). Scenarios with gas collection were therefore modelled using gas collection efficiencies ranging between 40 and 80% and using 60% as the base value. The gas collection period was set at 20 years, occurring from 2015 to 2035, but thereafter gas generation was assumed to decline to a level that would impede profitable gas collection. The biocover was assumed to oxidise methane efficiently throughout the 100-year period from 2015 to 2115, as the efficiency of the technology is not limited by lower methane generation and load on the biocover.

Table 1. Overview of scenarios showing methane oxidation, gross gas collection efficiency and energy efficiency (bold indicates changes in comparison to the base scenarios).

Technology	Scenario	Oxidation in landfill cover (%)	Gross gas collection efficiency (%)	Electricity efficiency (%)	District heating efficiency (%)
No mitigation action	I-no mitigation	10			
Biocover	B1-base oxidation	80[(1)]			
	B2-high oxidation	**90**			
	B3-low oxidation	**70**			
Gas collection and energy utilisation	G1-base collection	10	60	27,8[(2)]	
	G2-high collection	10	**80**	27,8	
	G3-low collection	10	**40**	27,8	
	G1 with district heating (avg.)	10	60	27,8	**51,9[(2)]**
	G1 with district heating (natural gas)	10	60	27,8	**51,9**
	G1 with high electricity	10	60	**39,3**[(3)]	
	G1 with low electricity	10	60	**19,8**[(3)]	
	G1 with base collection 30 years[(4)]	10	60	27,8	
	G2 best	10	**80**	**39,3**	**51,9**
	G3 worst	10	**40**	**19,8**	
	G1 with biocover	80	**60**	**27,8**	

[(1)] Scheutz et al., 2014.

[(2)] Calculated average based on data provided by the Danish Energy Agency (from Energiproducenttællingen 2013).

[(3)] Respectively, high and low electricity efficiency based on data from the Danish Energy Agency (from Energiproducenttællingen 2013).

[(4)] In this scenario, the gas collection period was set at 30 years, from 2015 to 2045. In all other gas collection scenarios, the gas collection period was 20 years, from 2015 to 2035.

3. RESULTS AND DISCUSSION

3.1 Total potential global warming impact in the modelled scenarios

The main results can be seen in Figure 1, which shows potential global warming impact expressed as kg CO_2 equivalents per Nm^3 methane generated in the landfill. There are four types of scenarios (15 in total): one without mitigation action, three with a biocover with varying methane oxidation efficiencies, ten with gas collection and energy utilisation, also with varying parameters, and a combination scenario where gas collection with base parameters is combined with the subsequent construction of a biocover with base efficiency.

The leftmost column shows the potential global warming impact in scenario "I-no mitigation," where there is no active emission mitigation action. The emissions in this scenario amount to 16.1 kg CO_2 equivalents / Nm_3 methane. The calculation is as follows:

Global warming impact in kg CO_2 equivalents = 1 Nm^3 CH_4 *x* 0.714 kg CH_4 / Nm^3 *x* 25 kg CO_2 equivalents / kg CH_4 *x* 0.9 (assuming 10% methane oxidation in the cover layer) = 16.1 kg CO_2 equivalents.

Similarly, potential global warming impact in the remaining scenarios is calculated, with emissions from the gas engine and saved emissions from energy substitution included.

Figure 1 shows that all treatment scenarios are environmentally better than scenario "I-no mitigation", as the total emissions are numerically smaller. The three scenarios B1, B2 and B3 represent the biocover method with respectively 80, 90, and 70% methane oxidation efficiency. The potential global warming impact is inversely proportional to methane oxidation efficiency. It is evident that the biocover under these assumptions is environmentally better in the global warming impact category than all the scenarios with gas collection and energy utilisation. By combining gas collection with energy utilisation (with basic parameters) and a subsequent biocover (scenario "G1 with biocover"), significant improvements can be made to the gas collection scenarios.

Scenarios G1, G2 and G3 represent gas collection with energy utilisation and varying gas collection efficiencies of respectively 60, 80 and 40% of the methane produced in the landfill. As expected, the highest gas collection efficiency scenario shows the lowest potential environmental impact, but the relative difference between scenarios is less than between biocover scenarios with varying oxidation efficiency. The two gas collection scenarios with 60% gas collection efficiency and the substitution of electricity production, further equipped with the utilisation of heat, "G1 with district heating (avg.)" and "G1 with district heating (natural gas)", are comparable to the "G1-base collection" scenario, which only has electricity substitution. It is notable that the district heating substitution is of little importance, as environmental savings represent only a few per cent in comparison to the scenario without employing heat production, and that the type of district heating that is substituted does not play a significant role either.

The same effect as utilising heat production can be achieved by improving the efficiency of energy utilisation for electricity production. In scenario "G1 with high electricity", electricity production is assumed to take place with an energy efficiency of approximately 39%, seen in relation to the approximate 28% used in the base scenario. However, it only results in an environmental improvement of a few percentage points, and thus it is not a parameter that can significantly change the environmental profile of gas collection with energy utilisation. Similarly, lower energy efficiency for electricity production results in a fairly small deterioration over the base scenario.

As a prerequisite for the gas collection and utilisation scenarios, it was assumed that the collection took place over a 20-year period from 2015-2035. This assumption was based on the fact that falling gas production in the subsequent period would make it difficult, for technical reasons as well as for economic reasons, to continue the collection of gas. If this were not to be the case, the scenario "G1 with 30 years of collection" shows the result of extending the gas collection period by 10 years to 2045 (with a gross gas collection efficiency assumed at 60% – as in the base scenario). This results in a lower environmental impact than with a 20-year gas collection period, but it is noted that increased gas collection efficiency in the 20-year period will be more effective, as seen from the "G2-high collection" scenario (where gas collection efficiency is 80%).

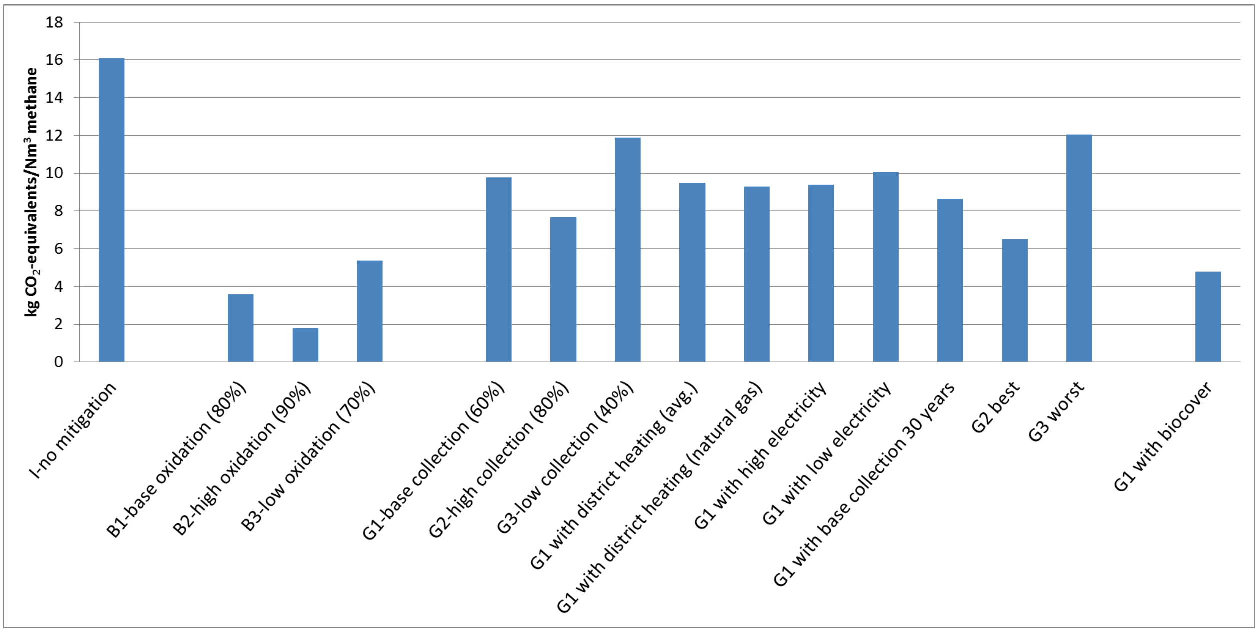

Figure 1. Total potential global warming impact in CO_2 equivalents in 15 scenarios with the implementation of varying methane mitigation actions at Danish waste landfills.

By combining the parameters used, the "best" and "worst" scenarios with gas collection and energy utilisation can be constructed. The "G2 best" scenario has high gas collection efficiency (80%) (20-year collection period is maintained), high electricity efficiency (39%) and heat utilisation (52%) with the substitution of natural gas-fired district heating. The "G3 worst" scenario has low gas collection efficiency (40%), low electricity efficiency (20%) and no heat recovery. The difference between these scenarios is significant, as it amounts to approximately 45%, but even the "best" scenario with gas collection and energy utilisation has a greater potential global warming impact than the biocover scenario with low methane oxidation efficiency (70%).

Based on these results, it is natural to consider a situation where gas collection and utilisation are combined with the construction of a biocover. In scenario "G1 with biocover," it is assumed that gas collection and energy utilisation for 20 years with 60% gross efficiency was followed by the construction of a biocover with an oxidation efficiency of 80% – as in the B1 scenario. This results in a significant reduction in potential global warming impact in comparison to the gas collection scenarios, but compared to the B1 scenario, this solution is still not as environmentally appropriate. It is noted that the scenario "G1 with biocover" shows a lesser environmental impact than scenario "B3 low oxidation." This comparison, however, is less relevant, as it seems correct only to compare the combination scenario with gas collection and subsequent biocover with a biocover scenario, where the biocover in both cases has the same oxidation efficiency.

3.2 Potential global warming impact in the modelled scenarios divided into sub-processes

To acquire a more detailed picture of the causes of differences between scenarios, potential environmental impacts were divided into the sub-processes "Substitution of district heating (natural gas)", "Substitution of electricity production from a biogas engine", "Methane emissions through a landfill cover", "Emissions from a biogas engine" and "Substitution of district heating (avg.)". As illustrated in Figure 2, the all-dominant sub-process is "Methane emissions through landfill cover", which far exceeds environmental savings made in the gas collection scenarios in energy production and the resulting substitution of fossil energy.

Even with a high gas collection rate (80%), potential global warming impact was dominated by methane emissions through the landfill cover, because gas collection takes place only for a period of 20 years, after which 90% of the methane produced in the remaining period ends up directly in the atmosphere. In all gas collection scenarios, 36% of the methane produced in the 100-year period escapes during the period without gas collection, i.e. from 2035 to 2115. In addition, methane is lost during the gas collection period, as the maximum gas collection efficiency does not exceed 80%.

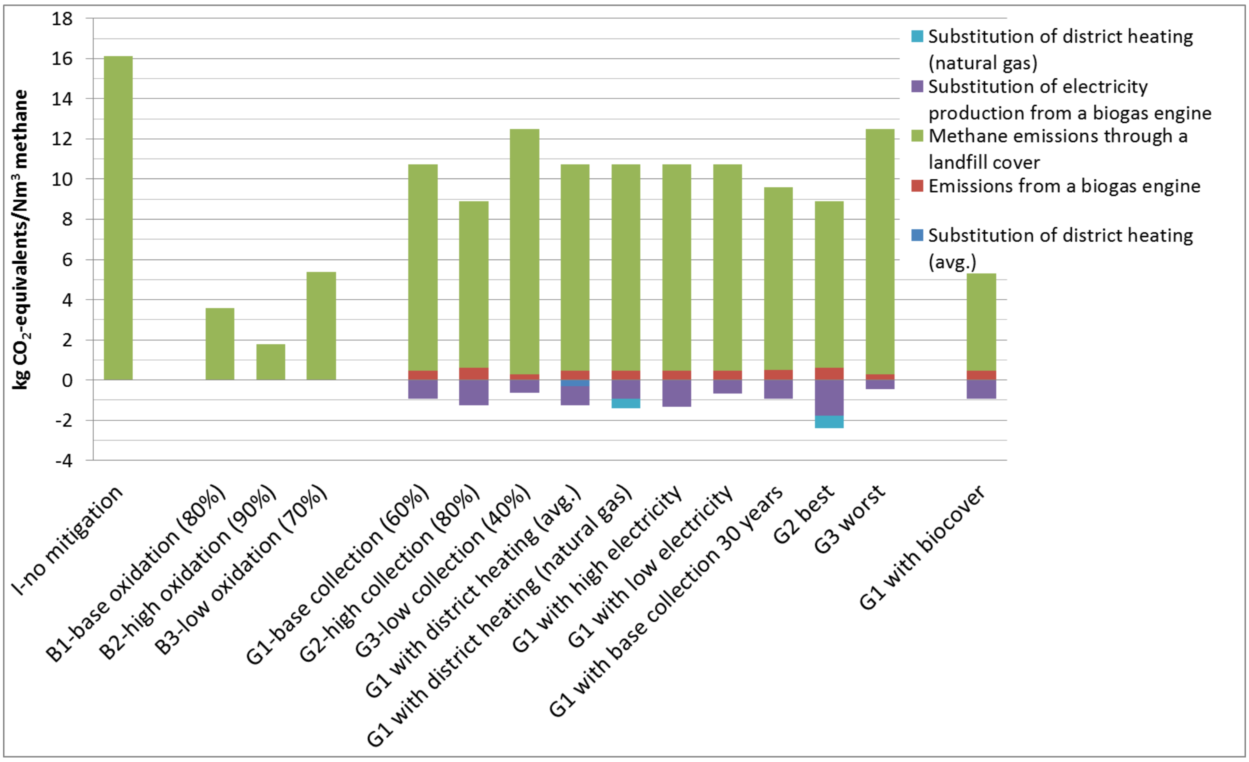

Figure 2. Potential global warming impact divided into sub-processes in 15 scenarios with the implementation of varying methane mitigation actions at Danish waste landfills.

4. CONCLUSIONS

A life cycle-based environmental assessment was conducted on the mitigation of landfill emissions, by implementing biocover and gas collection with energy utilisation. Based on a number of assumptions about gas generation at Danish landfills, the efficiency of the technologies involved and the composition of substituted energy production, a number of scenarios were modeled using the EASETECH life cycle assessment model, through which potential environmental impacts in the environmental impact category "Global warming" were calculated.

Based on these results, the following overall conclusions regarding the biocover method and gas collection with energy utilisation can be drawn:

- Both biocover and gas collection with energy utilisation lead in all scenarios to a significant potential environmental improvement in comparison to no mitigation action.
- With a biocover and methane oxidation efficiency of 70 to 90%, all biocover scenarios lead to less potential environmental impacts than the gas collection and utilisation scenarios.
- A biocover with 80% oxidation efficiency throughout the 100-year period performed better than a combination scenario, where gas collection and utilisation with base parameters (60% gross gas collection efficiency and 27.8% power efficiency) was combined with the subsequent installation of a biocover with 80% efficiency.
- Methane emissions through the landfill cover represent the dominant sub-process in all scenarios, including the gas collection and utilisation scenarios.
- The gas collection utilisation scenarios created environmental savings from the substitution of electricity and heat, but they could not offset the environmental impacts of methane emissions through the landfill cover.

Overall, it can be concluded that a biocover under the given basic assumptions is environmentally more appropriate than gas collection and utilisation. This is due mainly to methane emissions through the landfill cover, during and after the gas collection period, playing a crucial role in the gas collection scenarios.

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