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SCREENING METHOD TO ASSESS THE GREENHOUSE GAS MITIGATION POTENTIAL OF OLD LANDFILLS, BASED ON DOWNWIND METHANE CONCENTRATION MEASUREMENTS

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SUMMARY: a nationwide effort is taking place in Denmark to mitigate methane emissions from landfills, by using biocovers. A large number of older landfills were found to be potential candidates for biocover implementation, but very little information was available for these sites to help evaluate if significant methane emissions occur. To assess these sites, we developed a low-cost and quick remote sensing methodology, whereby downwind methane concentrations from 91 landfills were measured using a mobile analytical platform, and emission rates were calculated using an inverse dispersion model. The method was found useful in gauging whether the sites were relevant for biocover implementation or not. The method is considered a screening technique, and alternative approaches such as the tracer gas dispersion method must be applied for emission quantification.

1. INTRODUCTION

With very few exceptions, national governments around the globe are committed to the Paris Agreement, one of the central aims of which is to hold “the increase in the global average temperature to well below 2°C above pre-industrial levels” (UNFCCC, 2015). The waste sector can contribute to achieving this goal, since it accounts for approximately 3% of the world’s greenhouse gas emissions, with landfill methane constituting approximately 18% of global anthropogenic methane discharge (Bogner et al., 2008).

Several strategies, which are not mutually exclusive, can be used to reduce methane emissions from landfills, including waste minimisation, the separate treatment of organic waste (such as anaerobic digestion), incineration, landfill gas extraction combined with energy utilisation or flaring or oxidising biological methods such as biocovers or biofilters.

In this context, the Danish government has allocated €24 million to constructing biocovers, to mitigate methane emissions from landfills by improving methane oxidation. The Danish Environmental Protection Agency leads this initiative, while the Technical University of Denmark participates in an advisory role to utilise its experience in constructing and monitoring full-scale biocover systems. To maximise the value of this investment (i.e. to ensure biocovers are installed at landfills that have a relevant mitigation potential), the

Danish Environmental Protection Agency (EPA) has initiated a process for selecting at which landfills biocovers should be installed.

The biocovers are to be installed at several types of landfill, including older, closed off sites. These are relevant in a Danish context, since they often contain a higher fraction of organic matter and therefore may emit more methane than newer sites despite the high age of the landfilled waste. Approximately 4,000 older Danish landfill sites were taken into consideration when looking to find suitable landfills where sizeable methane discharge could occur and where it would be feasible to construct a biocover system. Danish regional authorities, responsible for the aftercare of many older sites, devised a desktop screening procedure to assess which of these sites would be suitable for biocover implementation. This procedure included retrieving and evaluating historical information such as disposed waste amounts, waste fractions and reported gas investigations. Landfills for which no information was available, sites located in EU Natura 2000 protected areas and sites with current activities not allowing the installation of a biocover system were disregarded. Likewise, landfills that were considered to be either too old (landfilling ceased prior to 1965) or too small (area less than 5,000 m²) were removed from consideration. In the end, 183 landfills were chosen as potential candidates through this elimination process. Further analysis of available information for the remaining sites regarding present area use, waste composition, modelling of gas generation and leachate composition reduced the number of candidates for biocover implementation from 183 to 91 landfills.

Since these 91 landfills were older sites, only sparse information was generally available to be able to predict if they were sources of significant methane emissions. It was considered desirable to perform initial measurements in order to categorise these sites. The Danish EPA recommends the use of a tracer gas dispersion method, such as the approach described in Mønster et al. (2015), to determine total methane emissions from landfills. However, due to the large number of landfills that had to be surveyed, we suggested developing a method protocol to provide initial measurements of the sites' total methane emissions at a much lower cost, albeit lower measurement accuracy would be expected. This method is the subject of this paper.

We used downwind methane concentration measurements combined with inverse dispersion modelling to assess total methane emissions from 91 landfills. The instrumentation used was the same as we employed to perform tracer gas dispersion measurements of fugitive emissions from landfills and other sources (Mønster et al., 2014; 2015), but the methodology was simplified and thereby reduced the time needed for each measurement as well as data analysis. The focus of this preceding paper is on practical issues in implementing the method, including costs, whereas a journal paper addresses the accuracy of the method through a method comparison test and sensitivity analysis of the dispersion calculations (Fredenslund et al., 2017).

2. MATERIALS AND METHODS

2.1 Inverse dispersion measurements

For each landfill, the following steps were taken using the mobile analytical platform described in Section 2.3:

Step 1: Screening of methane concentrations downwind of the landfill and in the surrounding area: Each measurement started with a methane concentration screening (the measurement of ambient methane concentrations at approximately 2 metres above ground level) to evaluate the location of elevated methane concentrations downwind of each landfill

and to evaluate whether any other methane sources were present in the area that could affect the measurements. At each site, both upwind and downwind measurements were performed, where possible.

Step 2: Traversing the downwind plume: If elevated methane concentrations were observed downwind from the landfill, four traverses of the downwind plume were performed, comprising four individual measurements. If downwind methane plumes were not detectable (concentrations were comparable to background levels), downwind measurements were conducted as close to the site as possible in an effort to detect small methane plumes. If no methane plume was measured close to the landfill, the landfill emission was reported as being below the detection limit, which we considered to be lower than $1 \text{ kg CH}_4 \text{ h}^{-1}$. This value has been reported as the approximate detection limit for tracer gas dispersion measurements using the same analytical instrumentation (Mønster et al., 2014).

Step 3: Modelling of methane emissions: Based on the measured methane plumes, methane emissions were estimated by inverse dispersion modelling (measured maximum methane concentrations, average of four plume traverses).

Methane emissions were estimated using a Gaussian dispersion plume model. The concentration of a gas downwind from an emitting source can be expressed as:

$$C(x, y, z) = \frac{Q}{U} \frac{1}{2\pi\sigma_y\sigma_z} e^{\left(\frac{-y^2}{2\sigma_y^2}\right)} \left[e^{\left(\frac{-(z-H)^2}{2\sigma_z^2}\right)} + e^{\left(\frac{-(z+H)^2}{2\sigma_z^2}\right)} \right] \quad (1)$$

where $C(x,y,z)$ is the concentration of methane (g m^{-3}) above background concentration at a given point in the downwind plume, Q is methane emission (g s^{-1}), U is wind speed (m s^{-1}), H the effective emission height (m), z (m) and y (m) the vertical and horizontal distances away from the measurement point to the centre of the plume and x (m) is the distance away from the source to the measurement point. The parameters σ_y (m) and σ_z (m) are the vertical and horizontal dispersion coefficients, respectively. For each landfill, the emission point was assumed as the centre of the landfill, since information on the spatial distribution of surface emissions at the sites was not available. To calculate methane emission Q from the measured downwind concentrations, the Gaussian plume model described by equation 1 was applied by using the measured peak methane concentration, taken whilst traversing the downwind plume. Since methane emitting from a landfill can be considered to occur at ground level, H was assumed to be 0. Considering $y=0$ and $H=0$, the calculation of Q can thereby be derived from Eq. 1 as follows:

$$Q = C(x, 0, z) \cdot U \cdot \pi\sigma_y\sigma_z e^{\left(\frac{z^2}{2\sigma_z^2}\right)} \quad (2)$$

The dispersion coefficients (σ_y and σ_z) were determined using the methodology described in De Visscher (2014). In this method, dispersion coefficients vary according to atmospheric stability (Pasquill-Gifford stability classes) and terrain type (urban or open environment). Further information on the estimation of dispersion coefficients can be found in De Visscher (2014). Wind speeds (U) were determined using the online service www.weatherunderground.com, which provides records of local weather measurements, typically from the nearest airport. The measurement distance (z) was defined as the distance away from the centre of the landfill to the point where the maximum methane concentration $C(x,0,z)$ was recorded. The maximum methane concentration was determined using a Gaussian fit on the measured downwind methane concentrations – see Figure 2, which shows an example.

2.2 Instrumentation

Concentrations of methane were measured using a cavity ring down spectrometer (G2203, Picarro Inc., USA) installed in a vehicle, from where atmospheric gas was pumped into the analyser from an intake placed on the roof of the car approximately 2 m above ground level. The measurement frequency of the instrument was approximately 2 Hz, and the precision levels were 0.48 ppb (parts per billion), which enabled the detection of small variations in atmospheric concentrations.

A GNSS system was used to log the position of the measurements (R330 GNSS receiver and A43 antenna, Hemisphere, Canada), whilst a weather station mounted on the vehicle was used to log temperature and atmospheric pressure (All-In-One weather sensor, model 102780, Climatronics, USA).

2.3 Surveyed sites, measurement period and time use

Since this study concerned mostly older landfill sites, information on waste amounts, the age of disposed waste, waste types, etc. was generally limited. For example, it was sometimes unknown if the landfilling of waste containing organic materials had occurred. The 91 landfills included in this study were distributed geographically across Denmark (see Figure 1) in both rural and urban environments. According to records, the sites were finalised between 1965 and 2002. Some of the sites were old, finalised parts of landfills, whereas other sections were still in operation. Furthermore, for a number of them, operational periods were unknown.

Each landfill contained waste in the range between 12,000 and 2,550,000 tons, according to historical records. As these numbers suggest, their size varied. At some sites, analysis of landfill gas composition had previously been undertaken, and relatively high methane concentrations were noted (up to approximately 60 vol%).

The measurements were performed in the period January 28 to August 31, 2016. The bulk of the measurements were performed in June, July and August. In all, 28 days were spent taking measurements, but at first, only one or two sites were measured per day as the method was being developed. After a measurement routine had been established, it was possible to measure emissions from approximately five landfills on each measurement day and sometimes more, depending on driving distance between the sites. It was generally possible to conduct the screening of methane concentrations and traversing of downwind plumes described in section 2.1 in less than an hour per site.

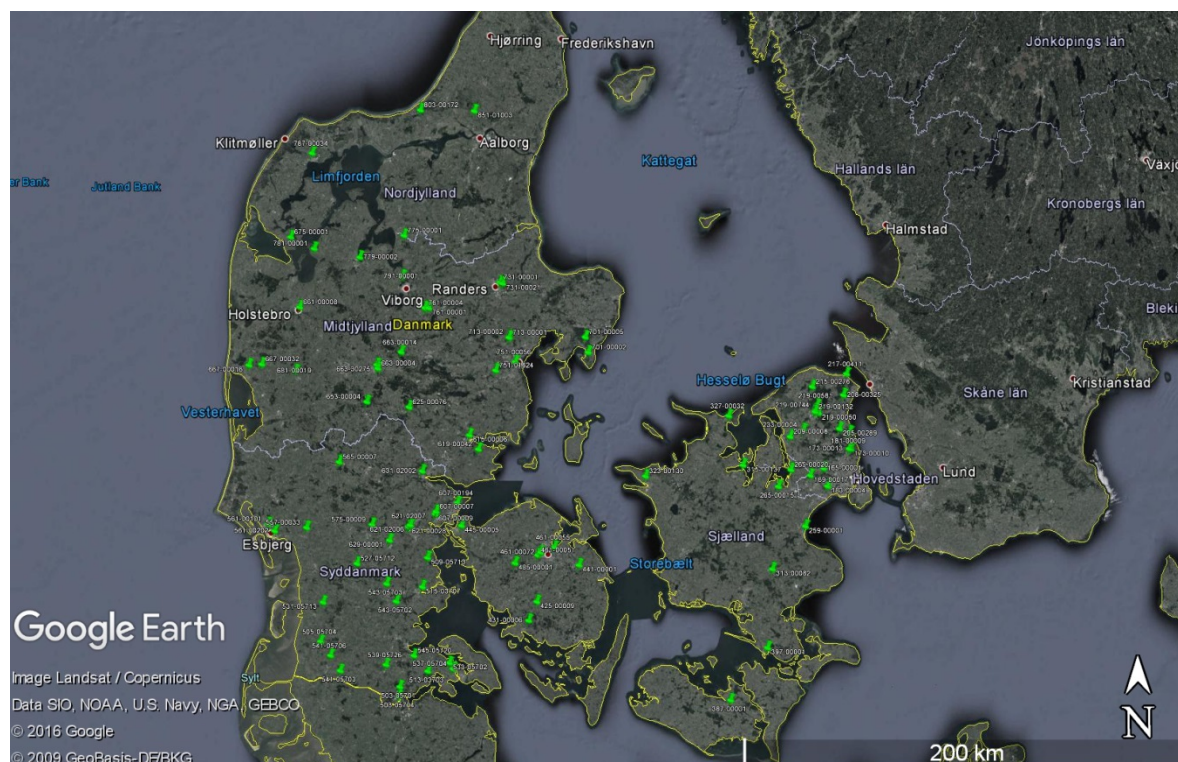


Figure 1. Locations of the 91 landfills surveyed in this study.

3. RESULTS AND DISCUSSION

3.1 Measurement results

Figure 2 shows an example of measured methane concentrations recorded while traversing the downwind methane plume at one of the landfills. In the figure, the distance (z) and peak concentration ($C(x,0,z)$), which were used to calculate methane discharge from the site, using Equation 2, are shown. Here the values of these parameters were $z=600\text{m}$ and $C(x,0,z)=30.4\text{ ppb CH}_4$ (average value of four plume traverses). Using Equation 2, methane release from the site was calculated to be $2.3\text{ kg CH}_4\text{ h}^{-1}$.

The estimated methane emission rates were used to categorise the landfills into three categories, thereby signifying mitigation potential with regards to methane emissions. These categories were:

- Low emission ($<2\text{ kg CH}_4\text{ h}^{-1}$): not relevant for a biocover
- Medium emission ($2\text{-}6\text{ kg CH}_4\text{ h}^{-1}$): potentially relevant for a biocover
- High emission ($>6\text{ kg CH}_4\text{ h}^{-1}$): relevant for a biocover

Of the 91 landfills surveyed, 66 were determined irrelevant for biocover implementation, since their emissions were measured at less than $2\text{ kg CH}_4\text{ h}^{-1}$ or below the detection limit. The remaining 23 landfills were thereby in the high or medium emissions categories. To implement biocovers on these sites, more precise determinations of methane emissions will be needed, but using this quicker method, it was possible to direct resources at sites with a high probability of mitigation potential.

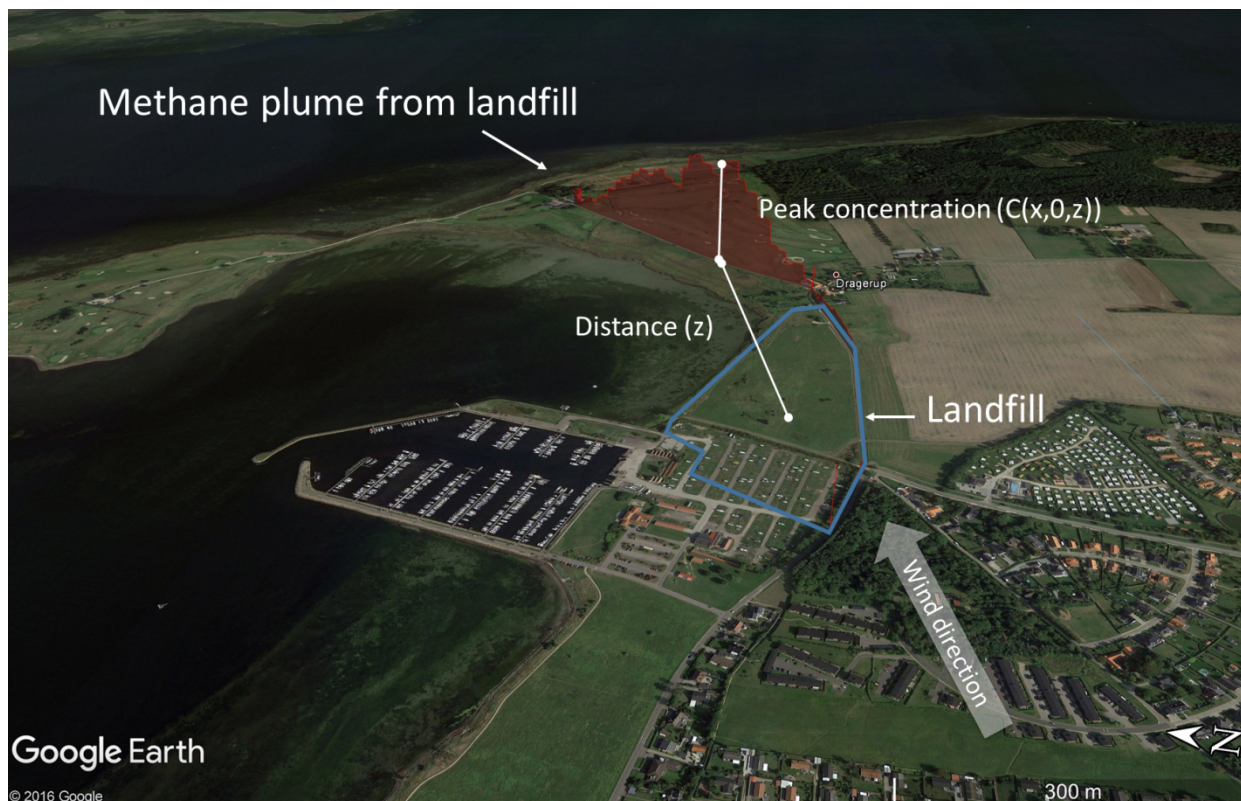


Figure 2. Example of measured methane concentrations while traversing a downwind plume from a landfill. The red line signifies methane concentrations measured above background level.

3.2 Costs, possibilities and limitations

The total cost of the measurement campaign was approximately €54,000, corresponding to € 600 per site. Approximately 75% of the costs were personnel costs, while the remaining expenses were attributed to equipment, transportation, accommodation, etc. This relatively low level of costs was possible due to the low requirement of time needed to complete each measurement and data analysis.

Performing these measurements, however, does require equipment capable of detecting quite small concentration differences. The apparatus used in this study was able to detect concentration differences below 1 ppb, but using less sensitive equipment may cause false negatives, where the emission from a site is relevant for mitigation, but it is not possible to distinguish elevated methane levels from background noise. Although recent developments in mobile gas detection equipment have made these kinds of capabilities more widespread among consulting companies and the like, it may not be possible to acquire this service everywhere.

Compared to tracer gas dispersion methods such as the one described in Mønster et al. (2015), this screening method is less able to determine if the elevated methane levels are caused by emissions from the landfill or by another nearby source, such as a farm. This may in turn create false positives, since wind direction is the only means to evaluate from where the downwind elevated concentrations emit, and nearby methane sources may be mistaken for releases from the landfill.

Another limitation is variations in emissions over time. It is well known that variations in atmospheric pressure can cause landfill gas emissions to vary, in that decreasing pressure

can lead to increased emissions and vice versa (Scheutz et al., 2009). We therefore recommend avoiding using this method in the presence of increasing atmospheric pressure, due to the risk of creating false negatives, where low emissions are measured from sites that may, in fact have significant methane emissions and thus be suitable candidates for mitigation measures.

Finally, the accuracy of the method is likely much lower than more elaborate strategies, such as the tracer gas dispersion method. Causes of inaccuracy include errors in estimating distance (z), due to emissions drifting inhomogeneously from the site, inaccurate estimation of dispersion coefficients and emission patterns causing the Gaussian dispersion model to describe poorly the actual emission from the site to the measurement location.

4. CONCLUSIONS

A quick, low-cost remote sensing method was developed and implemented to categorise 91 landfills with regards to methane emissions. The method was found to be relatively easy to use in real-world conditions, but it does, however, require relatively sensitive equipment capable of detecting very low variations in atmospheric concentrations of methane.

The method was useful for providing a quick estimate of emission levels, but we believe its accuracy is considerably lower than more elaborate methods looking to determine total methane emissions from landfills, such as the tracer gas dispersion method.

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