**Upgrade technologies**
In the last years upgrade technologies have emerged. The upgrade technology removes carbon dioxide, hydrogen sulfide and other trace gases to create a pure gas only containing methane. This technology is used in Denmark to upgrade biogas from biogas plants receiving household food waste, agriculture waste and industrial waste. The upgraded gas is fed into the natural gas grid, and makes out about a third of the gas in the grid, where the remaining is natural gas.

The upgrade technology has been used at a few landfill gas utilization projects, but since several European countries have extended natural gas grids, it is an obvious choice for new utilization projects to select the upgrade technology, which ensure a full gain of the energy content. This would especially be of advantage in regions, where it is difficult to utilize the heat production from a traditional engine solution. The upgrade facilities could be used for future anaerobic digestion plants treating separate collected biowaste, especially if the anaerobic digestion plants are situation close to the existing landfills.

**Call for action**
There is an urgent need to push forward mitigation solutions in all sectors - not only the energy sector - if we should have a chance to reach the UN Methane Pledge goals for Europe on reducing the overall methane emission from the region with 30 per cent before 2030. In the landfill sector, legal framework is already established, well-proven measurement and mitigation technologies are at hand.

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# WE URGENTLY NEED TO IMPROVE LANDFILL GAS MANAGEMENT IN EU

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# We **urgently** need to improve landfill gas management in EU

SINCE 1999, THE EUROPEAN LANDFILL DIRECTIVE IS SUPPOSED TO REGULATE THESE EMISSIONS BUT STILL – ALMOST 25 YEARS LATER – MORE THAN 60% OF THE METHANE PRODUCED AT EUROPEAN LANDFILLS IS EMITTED TO THE ATMOSPHERE. THIS IS DUE TO LACK OF ENFORCEMENT OF THE DIRECTIVE. WE DO NOT NEED ANOTHER REVIEW OF THE DIRECTIVE, BUT A GENERAL SIGNIFICANT IMPROVEMENT OF THE LANDFILL GAS MANAGEMENT ACROSS EUROPEAN LANDFILLS. WE HAVE LONG KNOWN HOW THIS SHOULD BE ADDRESSED INCLUDING: INITIAL SITE IDENTIFICATION AND SOURCE QUANTIFICATION, UTILIZING ENERGY AND THE USE OF UPGRADE TECHNOLOGIES.

**The target**

Large fractions of organic waste including food waste ends up in European landfills (Figure 1)[1]. The organic waste in landfills produces landfill gas containing methane, which accounts for about 18% of man-made methane emission in the EU[2]. The methane emission from landfills continues for several decades – even after we stop landfilling of organic waste. This is because the anaerobic decomposition of the organic waste is not optimal due to heterogeneous distribution of the organic waste inside the landfill, lack of water and other factors slowing down the decomposition process. The waste sector is the second largest sector in respect to man-made methane emission, where landfills are the dominating source (Figure 2). Methane is a strong greenhouse gas contributing to climate change.

**The decision and the challenge**

At the UN Climate Conference COP26 in 2021 it was decided to initiate a special effort for a quick reduction of methane emissions. Due to the relative short lifetime of methane in the atmosphere this can make a large difference on short term. The Global Methane Pledge was signed by more than 100 countries that agreed to reduce methane emission by 30 per cent by 2030, compared with 2020 levels[3].

**Existing landfill gas regulation in EU**

In the EU, the generation and emission of landfill gas is regulated by the Landfill Directive (Council Directive 1999/31/EC of 26 April 1999), which came out in 1999. The Directive states that "Landfill gas shall be collected from all landfills receiving biodegradable waste and the landfill gas must be treated and used. If the gas cannot be used to produce energy, it must be flared". Furthermore, it states also "Whereas the measures taken to reduce the landfill of biodegradable waste should also aim at encouraging the separate collection of biodegradable waste, sorting in general, recovery a nd recycling"[4]. Compared to 1995 levels, Member States are obliged to gradually reduce biodegradable waste going to landfills to 75%, 50% and 35% by 2000, 2003 and 2014, respectively. As stated by the European Environmental Agency still more than 60% of the methane produced at European

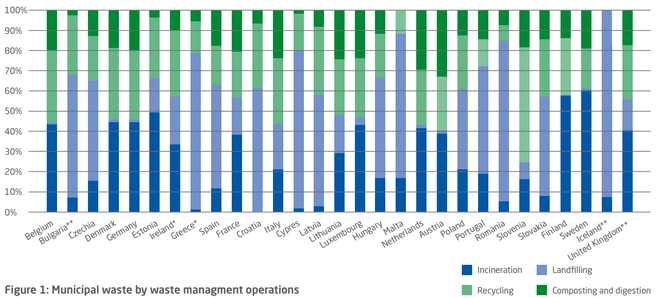


Figure 1: Municipal waste by waste managment operations

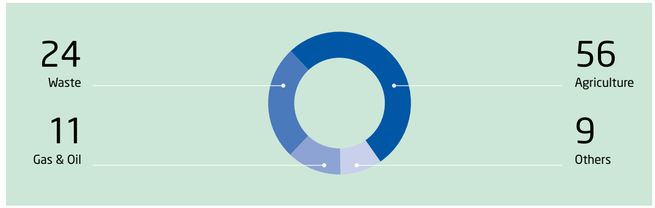


Figure 2: EU anthropogenic methane emission – 2021

landfills is emitted to the atmosphere[1] (Figure 3). This is despite that the Landfill Directive from the outset has demanded that gas from landfills receiving bio-degradable waste must be treated.

There is certainly room for improvement of the landfill gas management across European landfills on a European as well as on a national level.

**Limitations of EU's Methane Strategy**

In 2020, the European Commission published a communication on an EU strategy to reduce methane emissions with special focus on the energy, agriculture and waste sectors[5]. The strategy announces the establishment of the International Methane Emissions Observatory, which started up in 2021, with an initially focus on the Energy sector (Oil, Natural Gas and Coal). However, as stated in the EU Methane Strategy, the agriculture, energy, and waste sector account for 40-53%, 19-30% and 20-26%, respectively, of the methane emissions.

The International Methane Emissions Observatory will later also focus on the waste sector and a review on the Landfill Directive is planned to be initiated in 2024[5]. However, we believe that all needed regulatory drivers are already in place in respect to management of the generated landfill gas in Landfill Directive from 1999. The problem has been and is that the Directive has not been enforced when it comes to managing the generated landfill gas so that more than 60% of the generated methane still ends up in the atmosphere. Instead of waiting for a marginally needed review of the Landfill Directive starting in 2024, the level of proper enforcement should be increased. Otherwise, it is very questionable whether any significant reduction of methane generated in EU landfills will happened before the Global Methane Pledge's target year of 2030.

The EU Methane Strategy also has a strong focus on satellite detection of sources for methane emission, and for quantification of emission from the sources[5]. With the current satellite-based methodologies, however, only sources with very high emissions, so-called "super-emitters" can be identified and quantified with satellite-based methodologies[6]. This is maybe adequate in the energy sector, where – according to the EU Methane Strategy - 5% of methane leaks contribute to 50% of the energy sector's emissions[5]. However, the use of ground-based methodologies are needed in the landfill sector to have adequate sensitivity for identifying and prioritizing sources, and measure mitigation efficiencies of established mitigation activities at landfills ( see more in a later section).

**EU targets biowaste collection**

Adding to the problems with lack of enforcement, the European Parliament and the Council has decided to boost biowaste collection. The Waste Framework Directive (2008/98/EC) from 2018 puts an obligation on all EU Member States to collect bio-waste separately or ensure recycling at source from end of 2023 onwards"[7]. Member States need to choose treatment options (composting or anaerobic digestion). This will change the emission of methane from landfills in the future because less biodegradable waste will end up in landfills. However, the existing landfills will continue for decades to emit significant volumes of methane from degradation of already landfilled biodegradable waste, if the required landfill gas treatment is not enforced.

**Kick starting methane mitigation in the landfill sector – the solutions**

The number of landfills – both old, uncontrolled landfills, and sanitary landfills has been estimated to be around 500,000, about 10% being sanitary landfills following the construction rules set up by the Landfill Directive[8]. Most of these landfills generate methane to a smaller and larger extend, depending on the waste types and waste volumes received, and the age of the waste disposed of. Therefore, there is a need for using sensitive and cost-efficient methodologies for source identification and emission quantification before and after mitigation activities have been established at a given site.

**Initial site identification and source quantification**

An initial site identification and source quantification can be done using the inverse modelling approach, which quickly gives a cost-efficient, and enough precise estimate of the methane emission to be able to prioritize sites for further measurement and mitigation activities[9]. Guidelines and methodologies for establishing mitigation activities at landfills and document the mitigation efficiency have already been published[10], and is based on a robust, well-proven ground-based methodology[11]. With this methodology, the whole-landfill methane emission can be measured. Such measurements make it possible to set limit values for whole-site methane emission, which could enforce the establishment of new gas utilization at a huge number of existing landfills. Studies on landfill gas collection systems already established at landfills have shown that in most cases the gas collection efficiency can be optimized following guiding methodologies for that[12] to reach even higher mitigation efficiencies.

As already regulated by the Landfill Directive, generated landfill gas must be used to produce energy (or alternatively flared). Besides, the EU Methane Strategy[5] recommends to use "bio-oxidation technology" in "hot spots" at landfills after it is no longer viable to utilize the landfill gas. In Denmark a government-supported initiative to establish biocover systems following the "bio-oxidation technology" was initiated in 2016 and will be finalized in 2024[13]. The initiative is based on technology development made at DTU Sustain, Technical University of Denmark[14].

**Utilizing energy**

Utilizing the energy content of methane presence in the landfill gas can be done in several ways. The most common is to feed the extracted landfill gas to an engine to produce electricity – in some cases with additional utilization of the heat generated by the engine in district heating systems or other methods[15]. Landfill gas utilization has been established at several European landfills. However, there is room for many more implemented landfill gas extraction and utilization project to reduce the significant methane emission from European landfills. Calculation of Return of Investment (ROI) for established methane utilization projects at landfills show ROI in a typical range of 3-5 years[16]. For a Danish project, which was established at the Stige Ø Landfill after waste disposal had stopped, the ROI was a little over 5 years. The landfill contains about 6 million tons of waste. The yearly revenue in 1998-prices was 2 mio. Euros (sale of electricity and heat produced)[16].

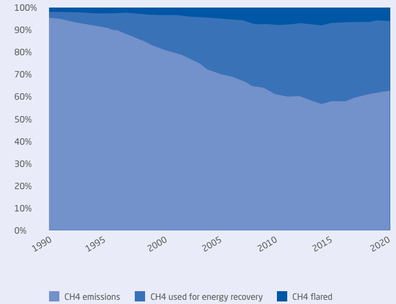


Figure 3: Evolution of the share of methane used for energy recovery, methane flared and CH4 emissions in managed landfills in the EU (EEA, 2022)