HOW MUCH METHANE IS RELEASED IN THE BIOMETHANE SUPPLY CHAIN?

To limit global warming to 1.5°C, an immediate transition away from coal and oil is required but doing so will be difficult given the amount of energy needed. Currently, natural gas is employed as a bridging fuel. It produces the same amount of energy as coal and oil but emits less CO_2. Methane (CH_4), a gas released by natural gas, has a greater warming effect than carbon dioxide (CO_2). As potential gas replacements with lower CO_2 and CH_4 emissions, biomethane and biogas have gained popularity. However, these replacement fuels are not CH_4 emission free. Indeed, previous studies[2-5] show that CH_4 is released at various points during production and distribution, but we still don't fully understand where, when, and how much CH_4 is released.

Global biomethane potential

According to the International Energy Agency[6], global biomethane and biogas production could meet nearly 20% of global gas demand if its sustainable potential was fully realised, and 35 million tonnes of oil equivalent biogas and biomethane were used globally in 2018. As the graph shows, the majority of the production comes from Europe. However, recent studies [2, 5] show that biomethane and biogas production facilities can also emit methane. These studies have measured on-site (measurement of emissions at each individual point source) and off-site (measurement of emissions based on observations made away from the site). However, a comprehensive evaluation by characterising the distribution of CH_4 emissions at each biomethane & biogas supply chain stage remains unclear.

Calculation of methane emissions from biomethane and biogas supply chains

In this study, datasets for each emissions source were divided into 5 subcategories seen as Figure. The stages in the biomethane supply chain are: (i) Feedstock including collecting and storing organic materials (Feedstock), (ii) biogas production stage where the feedstock is converted to biogas under anaerobic conditions (AD), and possible point sources are AD, buffer thank and hyginisation tank (iii) the third stage is the biogas upgrading. Different biogas upgrading methods can be used to generate biomethane such as PSA, water scrubber, chemical scrubber, chemical absorption and membrane, (iv) Transmission, storage and distribution, and (v) digestate stage with open and closed digestate storage.

Here we bring together the published emissions data from 51 various CH_4 measurement studies, to assess and synthesise the distribution of emissions from each supply chain stage to characterise the emissions profile of the biomethane & biogas supply chain. First, we compiled from several published studies, and obtained the data from on-site (taken at each individual emission source) and off-site measurements (reported for the entire site). The existing literature reports emission rates in different units, and some studies provide insufficient information to allow for unit conversion. In this study, CH_4 emission estimates were converted into percentage of total production (volume of CH_4 emitted/volume of produced gas) and grams of CO_2-equivalent per megajoule of energy based on higher heating value (HHV). We assume GWP of 100 years as 27.2 based on IPCC AR6 report[7], and higher heating value as 38.1 MJ per m^3. The dataset obtained from the literature exclude methane emissions from the landfill and wastewater treatment plants without anaerobic digesters.

After classifying the data collected from mobile on-site
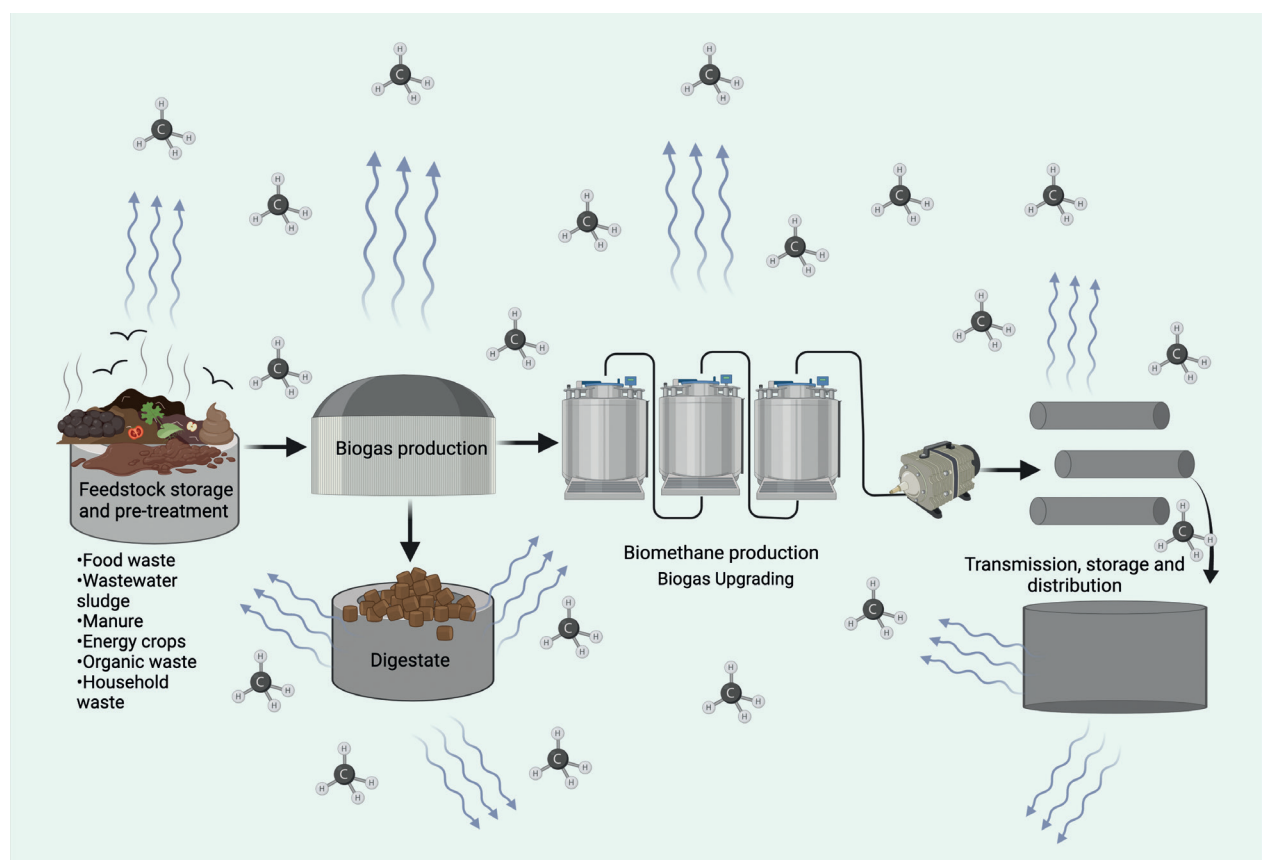
Datasets for each emissions source were divided into 5 subcategories

measurements, we need to determine the probability density function (PDF) of emissions in each stage. The PDF establishes a good fit of the emissions for each stage, including an uncertainty assessment. The emissions in each stage have distinct characteristics, particularly in terms of the various high emitters, their data and probability distributions. Due to the heavy-tailed distribution and small sample size, the nonparametric probability density function, kernel density estimations (KDE), were used to investigate the PFDs of the emissions from each stage using Python before summing up each stage. The total emissions from the supply chain were estimated using Monte Carlo simulations with 10,000 random draws.

Methane emissions along biomethane and biogas supply chains

On these figures, each curve defines the cumulative distribution for a single Monte Carlo simulation and shows that total supply chain emissions range from 2.5 to 343 g $CO_{2\,eq}$/MJ_{HHV}. Median emission is around 41 g $CO_{2\,eq}$/MJ_{HHV} at 95 confidence intervals

(CI). And mean emissions are eq./MJ_{HHV}. As you see in the figure and the mean emissions are higher than median, the biomethane supply chain emissions distribution is highly upward-skewed which is indicative of disproportionately high emitting sites referred to as "super-emitters". Also 5th percentile emission is around 15 g $CO_{2\text{-eq}}$/MJ_{HHV} (at the 95% CI) and a 95th percentile emission ranges between 131 and 133 (at the 95% CI) g $CO_{2\text{-eq}}$/MJ_{HHV} using GWP_{100} values.

Using global biogas and biomethane production of 35 Mtoe ($1.47\,10^{12}$ MJ)[6] in 2018, biomethane& biogas supply chain can emit 6.4−7.8 Tg CH_4 yr^{-1} at the 95th percentile, an average of 2.8−2.9 Tg CH_4 yr^{-1}.

When we look at the Figure B for the cumulative distribution of emissions as a percentage of total CH_4 produced. The 5th percentile is around 2.0 (at the 95% CI) % of biomethane production, and the 95th percentile is around 12.6 − 12.8 (at the 95% CI) % of total gas production. The range in minimum, median, mean and maximum values were fairly consistent across all estimates. While the low and median estimates are nearly identical, the disparity between biomethane and natural gas

A)

B)
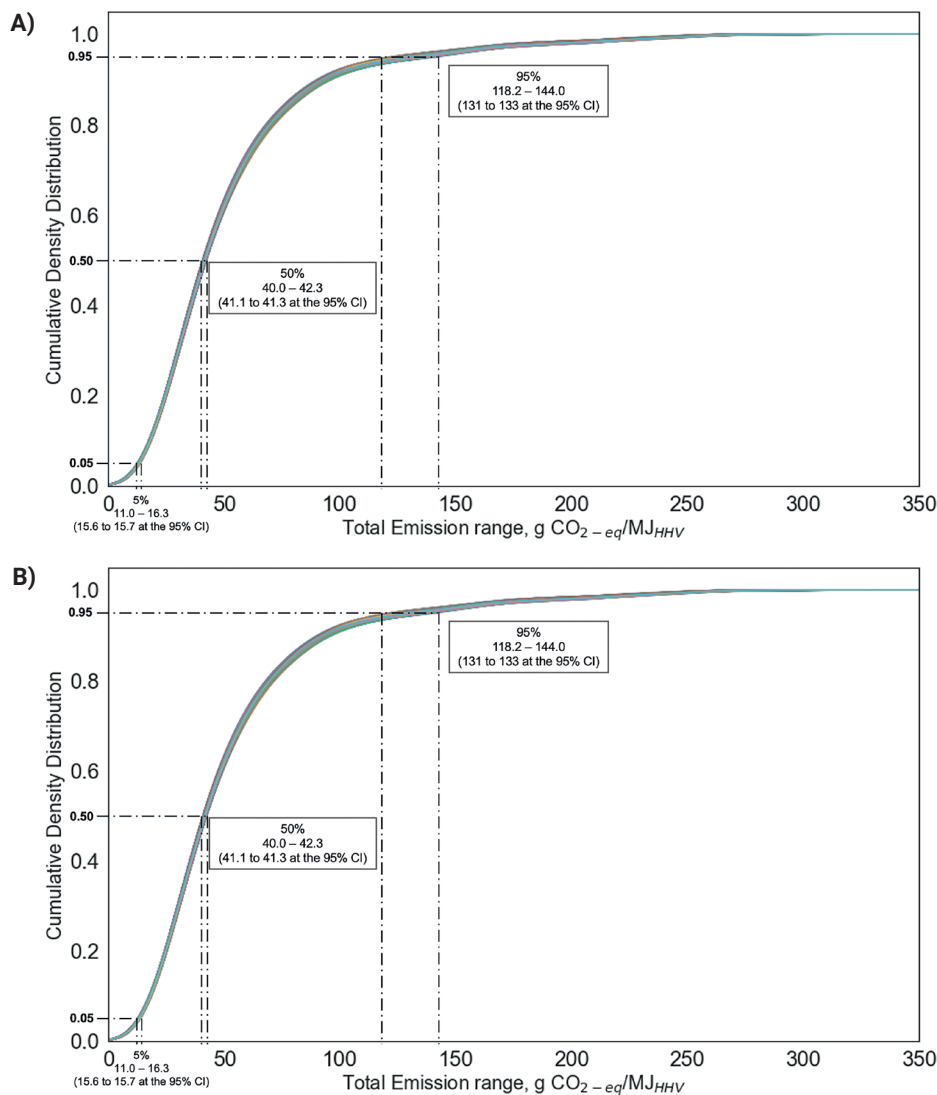
Estimated methane emissions from 10,000 Monte Carlo runs
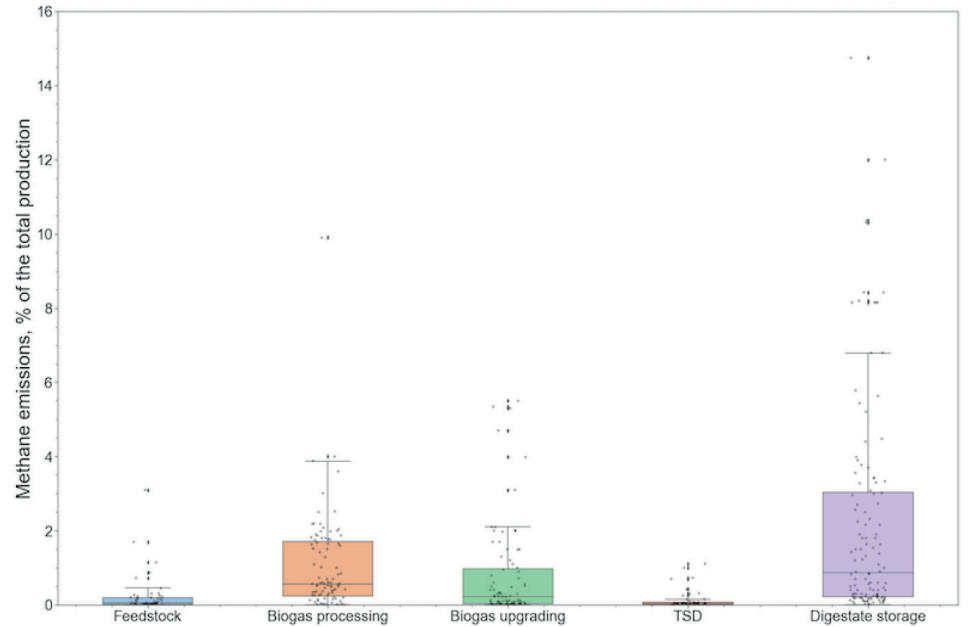
Methane emissions from each step with the digestate handling stage responsible for the majority of methane released

Biography

Dr Semra Bakkaloglu is a Research Associate at the Sustainable Gas Institute with over 10 years combined experience in academia, industry and consultancy. Dr Bakkaloglu double majored in Environmental Engineering and Chemical Engineering at Middle East Technical University (METU), Turkey in 2011 and 2012. She was a Fulbright Scholar at Clemson University, US, from which she obtained a master's degree in Environmental Engineering & Earth Science in 2014. She completed her PhD at Royal Holloway University of London, UK as a Marie Curie Early-Stage Researcher. Dr Bakkaloglu research is centred on environmental process engineering, life cycle assessments and modelling, methane and hydrogen emissions from their supply chains, and energy modelling.

varies widely in the highest estimates. The median ranged from 5.1 to 5.3 (5.1 − 5.2 at the 95% CI)%, with mean emission rates of 5.90−6.04 (5.9 − 6.0 at the 95% CI) % of total CH_4 production, which is higher than natural gas (0.8 to 2.2% of CH_4 production[8, 9]). We can see that the production −normalised emission rate is considerably higher than oil and gas. This could be due to a variety of factors, including poorly managed production facilities, a lack of attention to the biomethane industry resulting in lower investments for modernisation, operation, and monitoring, as well as employment of highly skilled plant operators when compared to oil and natural gas. In addition, poor design and management of feedstock and digestate storage units, as well as a limited interest in infrastructure emissions may result in higher emission rates compared to the amount of gas produced. Because oil and natural gas supply chains have been primarily operated by large companies for decades, they have invested more in leak detection and repair.

As stated before, the cumulative distribution figure exhibits the heavy-tailed distribution. A small number of high emitters may cause under- or overestimations of emissions rate if they have intermittent emissions patterns, insufficient process equipment usage or inadequate operations and maintenance strategies. In this study, super-emitters have been investigated at various stages across the supply chain, including feeding systems, substrate storage, run-off ponds, pressure relief valves on the anaerobic digesters and gas holders, exhausts and aeration lines of upgrading units, ventilation of units such as compressors or closed digestate tanks, open digestate storage and flaring. Since we lack information on on-site CH_4 sources, we identify them the highest 5% of total emissions (199−224.8 g CO_{2-eq}/MJ_{HHV}) account for 62% (CI: 58−66%) of cumulative emissions, which is similar to oil and natural gas supply chain distribution[10, 11].

Main emissions come from digestate stage

Emissions are mainly from digestate storage, followed by production and upgrading stages. Similar results were observed by Reinelt et al. (2017) where the highest emissions are from open digestate storage and pressure release valves[12]. Similarly, Alvarez et al.[13] found production and gathering units to be the main emission source in the US oil and natural gas supply chain. Overall, the lowest emissions are exhibited in the transmission, storage and distribution (TSD) stage similar to the

US oil and natural gas supply chain[25].

To sum up, this study shows that biomethane and biogas supply chain methane emission rate can exceed those in oil and natural gas. We identified the super emitters as the highest 5% of emitters account for 62% of cumulative emissions. We would like to highlight that those emissions can be avoided if necessary measurements are taken. Given the growth in biomethane generation due to national decarbonisation strategies, more urgent efforts are also needed for the biomethane supply chain to address not only CH_4 emissions, but also the sustainability of biomethane.

This article was adapted from the study by Bakkaloglu et al. 2022[1]. The study's specifics can be found here.

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