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Description of observation-based upscaling procedures for sectoral methane emissions in the Netherlands

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Description of observation-based upscaling procedures for sectoral methane emissions in the Netherlands

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Preface

This report is commisioned by Utrecht University in the framework of the project "Verifying and improving methane emission inventory data using atmospheric measurements" (VIME-NL) funded by the International Methane Emissions Observatory (IMEO) of the United Nations Environment Programme.

A wide range of independently funded scientific measurement activities in the Netherlands target the detection and quantification of methane emissions from various sources in individual projects. These measurements contain valuable information for verification and/or improving emission inventories. In the VIME-NL project the existing data from different measurements are synthesized to get a complete overview of the measured methane emissions from various source sectors in the Netherlands.

This report describes the procedure that can be applied to upscale the available measurement data to calculate national total methane emissions per sector. The upscaling procedure aims to take into account spatial and temporal variability in emissions and their drivers. This will form an observation-based baseline emission estimate that will be compared to the national reported emissions to gain insight into the uncertainties in the emission reporting and measurements.

Contents

1 Introduction

The Netherlands is obliged to report its greenhouse gas emissions annually to the UNFCCC and the EU, following strict guidelines (IPCC, 2019) and sector definitions. This task is carried out by the Dutch Emission Registration (hereafter, we use ER to refer to the emission registration and their reported emissions). The guidelines for emission reporting offer some flexibility, with default options (Tier-1) to country- or even facility-specific data and calculation methods (Tier-2/3). The IPCC recommends higher tier options for key emission categories, but the chosen method often depends on data availability.

The measurements on specific methane (CH_4) sources in the Netherlands detailed in Heimerl et al. (2025) provide a unique opportunity for higher Tier CH_4 emission calculations. The observations can be used to calculate country- or site-specific emissions factors and/or emissions, and as such improve Tier-1 emission calculations. Additionally, observation-based emission calculations can be used as independent validation of the reported emissions.

In this report we describe options for higher Tier methane (CH_4) emission calculations for the Netherlands based on local measurements and an upscaling procedure. The focus in this report is on the upscaling procedure, interpretation of the observations, which data are needed and available to extend local measurements to annual, country-total emission estimates, and which environmental variables need to be considered.

Each chapter describes the upscaling procedure for a specific sector. Where possible, we try to match our chapters with emission sectors in the ER for an easy comparison. Unfortunately, the observations may not always match the sector definitions used by the ER. In some cases, measurements are unable to separate between different sub-sectors treated individually in the ER, such as between animal manure and enteric fermentation. Or, vice versa, measurements target specific sources that are not listed separately in the ER, such as peatlands (which are included under the different land use categories). Hence, some sectors will need to be aggregated or split up later if we want to compare the upscaling results directly to the ER. This is discussed per sector as well.

2 Agriculture

2.1 Description

Agriculture is the dominant CH_4 source in the Netherlands, accounting for almost 80 % of all CH_4 emissions. There are several agricultural activities that cause CH_4 emissions. The main source is enteric fermentation, followed by manure in animal housing, and manure treatment and storage. CH_4 emissions from animal manure are caused by the fermentation of organic matter in an anaerobic environment. Additionally, there are CH_4 emissions from energy use in the agricultural sector, mostly related to greenhouses. Here, we focus on emissions caused by animals (fermentation + manure).

In the Netherlands, almost 75 % of the CH_4 emissions from the agricultural sector is caused by cattle (dairy cows), followed by pigs (appr. 14 %).

2.2 Overview of measurements

In the Netherlands, most measurements targeting livestock have focused on dairy cow farms. The emission factors derived from these measurements are in units of $kgCH_4/AU/d$, where 1 AU (animal unit) is 500 kg of animal weight.

Vinković et al. (2022) performed CH_4 concentration measurements with a drone downwind of one dairy cow farm on four individual days. They estimated emission factors for enteric fermentation (0.20-0.51 $kgCH_4/AU/d$) and onsite manure (< 0.04 $kgCH_4/AU/d$). Chen et al. (2025) performed single-track mobile van CH_4 concentration measurements downwind of 51 dairy cow farms over four days. The farm-scale (enteric fermentation + manure) daily emission factors were estimated to be 0.18–0.50 $kgCH_4/AU/d$, which is very similar to the results from Vinković et al. (2022). However, the uncertainty range is significant, with an average farm-scale emission factor of 0.47 [0.13-0.81] $kgCH_4/AU/d$. Similarly, Hensen et al. (2005) and Hensen et al. (2006) performed CH_4 concentration measurements downwind of 20 farms using a mobile van, which resulted in farm-level emission factors of 0.7 ± 0.4 $kgCH_4/animal/d$ for conventional farms and 1.4 ± 0.2 $kgCH_4/animal/d$ for farms that use straw bedding. Additionally, Zhang et al. (in preparation) have done mobile measurements covering multiple livestock farms (also pig, goat, and chicken), but these data are still being processed and, therefore, emission factors are not yet available. Whether these can be obtained depends on the availability of livestock numbers for the individual farms. Other studies have also estimated CH_4 emission factors at pig and goat farms (Mosquera et al., 2022a; Mosquera et al., 2022b). Other measurements targeting specific sub-activities are also available, e.g., CH_4 emissions from liquid manure management on pig and dairy farms (Petersen et al., 2024).

The studies described here are either dedicated experiments targeting a single farm with extensive measurements, hampering the extrapolation of the results to other farms, or single measurements downwind of several farms without repeating the measurements at the same farm again, hampering the extrapolation of the results to a full year. By combining all the results, we hope to get a reasonable overview of the variability between farms and over time, to support the upscaling.

2.3 Activity data

In the ER the CH_4 emissions from enteric fermentation are based solely on the average animal population per livestock category. Separation into livestock categories is needed to apply animal-specific emission factors, which also take into account feed types (energy intake) and other variables. For manure management, besides animal numbers, also the manure management system is considered, and system-specific emission factors are applied.

Country-total activity data are taken from the annual Agricultural Census. Additional details on animal population statistics are available from CBS and from the Identification and Registration (I&R) system from RVO. The I&R system contains information on animal numbers per farm. Wageningen University combines all these data into one database, the GIAB (Van Os and Kros, 2022). We could request access to aggregated data, for example per municipality. We expect this to be feasible, as long as individual farms are not recognizable due to privacy issues. Alternatively, the Central Bureau of Statistics also has information on animal numbers per municipality[1], but doesn't differentiate between mature dairy cattle, other mature cattle, and growing cattle.

In both cases, FAO livestock maps[2] and land use data[3] can be used for further spatial disaggregation of the animal numbers. Although the FAO dataset doesn't differentiate between types of cattle, it is applicable in other countries.

2.4 Environmental variables

Onsite studies at cow farms have shown that CH_4 concentrations inside barns are negatively correlated with ventilation rates, air temperature, and relative humidity (Ngwabie et al., 2009; Joo et al., 2015). Moreover, enteric emissions increase significantly with increasing animal activities, which in turn are negatively correlated with the indoor air temperature (for a range between 5-20 °C) (Ngwabie et al., 2011). The extent to which organic matter is converted into CH_4 depends on the composition of the manure, as well as on environmental factors (e.g. temperature). Therefore, the temperature and relative humidity could be considered if we are able to link the measurements to specific conditions.

2.5 Upscaling procedure

A wide range of measurements is available. The first step is to create an overview of those measurements and the conditions that apply to those measurements (e.g., types of animals and farms, number of animals (in AU for cattle), temperature, humidity). Then, the relationships between those conditions and the emission factors need to be established, which can be done using measurements or literature. In this way, emissions factors receive a spatial and temporal component. This will be the main challenge in the upscaling procedure, given the wide range of interactions that occur. It is unlikely that we can take into account farm types, but for all other variables data are available at sufficient resolution.

[1] CBS: StatLine - Landbouw; gewassen, dieren en grondgebruik naar gemeente, available from: https://opendata.cbs.nl/statline/#/CBS/nl/dataset/80781NED/table?dl=B56FD.
[2] https://www.arcgis.com/home/item.html?id=d12273fa65124cb6a56d076b18a21ec4
[3] Wageningen University: Landelijk grondgebruik Nederland, available from: https://lgn.nl/.

In the ER, emission factors for enteric fermentation are based on the gross energy intake and the fraction of this energy that is converted into CH_4 per livestock category. We can use the relative differences between livestock categories to extend the measurement-based emission factors for dairy cows to other livestock categories in case we lack specific measurements for livestock categories. We assume that the emission factors of other livestock categories have the same relationship with environmental variables.

For upscaling of the measurements at individual farms we will use animal numbers (per livestock category) as a proxy. We will use data from the GIAB or CBS and will redistribute those animal numbers using the FAO livestock maps. Animal numbers are then converted into AU for cattle, by assuming an average weight of the animals per category (mature dairy cattle, other mature cattle, growing cattle).

2.6 Comparison to ER

The ER differentiates between manure in animal housing, manure on the fields, and enteric fermentation. By making assumptions we might be able to derive emission factors for these sub-activities, but this will significantly increase the uncertainty. Therefore, we will likely make farm-scale estimates based on these measurements. This means all animal-related emissions from the ER will be aggregated for comparison to the upscaled emissions. Manure on fields may not be covered by the observations, depending on how the measurements were performed, but it is possible to separate this sub-sector in the ER.

3 Landfills/waste disposal

3.1 Description

In landfills, organic waste is broken down, resulting in the production of landfill gas, which is a combination of CH_4 and CO_2. The anaerobic decomposition of waste can continue for decades, but the CH_4 emissions show an exponential decay over time after the waste is dumped. There has been a considerable decrease in the amount of waste dumped at landfills (from almost 14 million tons in 1990 to 1.8 million tons in 2022 (CLO, 2025)). Moreover, due to implementing the policy of composting easily digestible organic materials, instead of landfilling them, the share of CH_4 in landfill gas has decreased over time. Still, landfills and solid waste remain a major contributor to the Dutch CH_4 emissions (~ 10 %).

3.2 Overview of measurements

Measurements exist for several major landfill sites, which cover a range of years and conditions. For example, Hensen and Scharff (2001) have performed measurements at three landfill sites, where the Nauerna landfill was visited in three consecutive years. Clear differences exist between years, e.g., after the implementation of a landfill gas extraction system. Scharff et al. (2003) show large temporal variations, up to 50 % of the average, in emissions from two landfills over periods of 6-12 hours. Also, the heterogeneity of large landfills makes it difficult to get a reliable emission estimate from measurements targeting a selected area. More recently, measurements were done again at the Nauerna landfill and two other sites (Stroeken, 2022; Velzeboer et al., 2024). Velzeboer et al. (2024) also compared the measurement-based emission estimates at Nauerna from all these studies, covering a period of almost 30 years, against the trend in emissions from all landfills reported by the ER, which shows a good match.

Although the measurements cover some of the largest landfills in the Netherlands, only limited information is available on the conditions under which those measurements were performed. Some studies provide meteorological conditions, but information on the waste composition is lacking. Moreover, estimated oxidation rates from the different measurement studies, i.e., the amount of CH_4 that is converted to CO_2 in the top layer of the landfill, shows a large range without a clear explanation. Finally, no information on older, abandoned landfills is available.

3.3 Activity data

In the ER, the amount of dumped waste per landfill (available from ‘90s onward), and its composition (available from 2005) based on European Waste List (EWL) codes, is used as activity data. Those data are available at the landfill site operators and supplemented by information from Rijkswaterstaat[4]. For each EWL code the amount of degradable carbon is determined, which determines the potential CH_4 emissions.

[4] Rijkswaterstaat: Afvalverwerking in Nederland, gegevens 2023, available from: https://open.overheid.nl/documenten/a34b9c11-e5b3-4fcf-9c18-b57ca2151283/file.

The number of landfills has decreased dramatically from 1990 (about 90 active landfills) to 18 active landfills in 2022 (CLO, 2025). Before that, more smaller landfills were in use, and a total of about 5.000 former landfills have been identified spread all over the Netherlands. These are not covered by the ER, and their locations are not well known. Neither are these inactive landfills targeted by measurement campaigns. Therefore, we do not consider them. Locations of the major, active landfills are known and can be used to spatially allocate emissions. Also, recently closed landfills report their emissions.

Landfill gas may also be (partially) harvested, for example, to generate electricity. Flaring may also occur. This means that we need to extract the amount of harvested/flared CH_4 from the total produced CH_4 to know the emissions to the atmosphere. Landfill operators record the harvested and flared amount of CH_4 on an annual basis[4], which may also provide trend information for the overall CH_4 production at landfills.

3.4 Environmental variables

The main challenges when quantifying landfill CH_4 emissions are high spatial and temporal emission variations. These are partially due to differences in landfill management, such as the type of cover that is used and whether or not landfill gas is extracted. Also, recent dumping of waste has an impact on the emissions. This type of information could possibly be collected from site operators. Temporal variations are largely determined by differences in temperature, which has an impact on the oxidation level: a lower temperature generally results in larger CH_4 emissions (Hensen and Scharff, 2001; Velzeboer et al., 2024). Additionally, changes in air pressure have a large impact on temporal variability (Scharff et al., 2003). Temperature and air pressure data are available.

3.5 Upscaling procedure

Upscaling from one landfill to all others is challenging, because most landfills specialize in specific types of waste and the emission variability between landfills is large. Especially Nauerna, for which most measurements are available, is not typical for other landfills. Therefore, we suggest focusing on individual landfills for which measurements are available.

No emission factors have been presented in the literature. Typical emission factors for each EWL code have therefore to be based on the ER. The EF related to each measurement at a specific site can then be calculated from the waste composition, amount of waste, and environmental variables (temperature and pressure). These variables are currently considered by the landfill site operators as well. If possible, changes in landfill management should also be considered.

The activity data consists of the amount of dumped waste per site (per EWL code). For each site a range of emission factors is established and linked to specific conditions. Using information on those conditions and changes in the amount of waste, the emissions can be calculated for a full year. This will be done per landfill site. From this, the amount of CH_4 harvested and flared, multiplied by the CH_4 share in the landfill gas, needs to be extracted to get the total emissions to the atmosphere.

3.6 Comparison to ER

A direct comparison of the upscaled emissions to reported emissions per landfill site is easily done. This will indicate whether systematic errors occur.

4 Wastewater treatment plants

4.1 Description

More than 300 wastewater treatment plants (WWTPs) across the Netherlands are responsible for cleaning primarily domestic (communal) wastewater. In 2023, 99.7% of the population was connected to closed sewer systems and therefore WWTPs. In a few industrial areas, separate treatment plants handle industrial wastewater. WWTPs remove organic matter, nutrients, and other contaminants from the water before the treated water (effluent) is discharged.

WWTPs are a source of CH_4 (1% of the Dutch CH_4 emissions) due to the anaerobic decomposition of organic matter. This process can occur at several stages of the treatment process, from the sewer network to sedimentation tanks. Once the wastewater has been treated, the separated sludge is further processed. In some facilities, this sludge undergoes additional treatment in anaerobic digesters, where it is intentionally decomposed to produce biogas. While a portion of the CH_4 is captured and utilized for energy, a significant share can still be released to the atmosphere through leaks and incomplete combustion.

4.2 Overview of measurements

Several measurement campaigns, mostly mobile plume measurements, have targeted WWTPs in the Netherlands (Denier van der Gon et al., 2024; Stroeken et al., 2022; Maazallahi et al., 2020). All these studies have estimated total fluxes, but not emission factors. Daelman et al. (2012) did measurements at one WWTP for a full year and examined which factors determine the temporal variability. They found that the CH_4 emissions are strongly correlated with the amount of sludge stored in the dewatered sludge storage tank and the residence time in the anaerobic digester. They also compared their emission factor estimate to other Dutch estimates and find a range of 0.53-1.20 % kg CH_4 / kg $COD_{influent}$ (COD = chemical oxygen demand). The ER uses a value of 0.75, which is well within this range. Daelman et al. (2012) also provide emission factors per person per year and per m^3 influent. Overall, data were collected for a wide range of WWTPs sizes, giving a good basis for testing upscaling methods.

CH_4 losses from biogas handling are not explicitly covered by these measurement campaigns. However, recent measurements showed that these unaccounted fugitive emissions are likely much larger than previously assumed (Moore et al., 2023). They identified plants with anaerobic digesters as major contributors due to leakage and incomplete combustion of biogas. While digesters aim to reduce emissions by capturing biogas, leakages can offset these benefits. Similar conclusions can be drawn from Daelman et al. (2012), who find that emissions related to anaerobic digestion of sludge counts for about three quarters of the WWTPs CH_4 emissions.

4.3 Activity data

The ER uses the total organics in wastewater influent and in the sludge produced as activity data, as suggested in the 2019 refinement of IPCC guidelines (IPCC, 2019). Detailed information on chemical oxygen demand in influent wastewater, total volume of influent, and produced sludge is available via CBS, but only per province[5]. Similarly, for emissions from biogas production facilities, the CBS data per province are useful. The dataset contains two types of activity data that could be used for estimating CH_4 emissions from leakages: the amount of sludge digested, or the amount of biogas produced. This also contains the number of WWTPs, capacity pollution equivalents and capacity person equivalents, as well as influent and effluent of wastewater, all per province. Further distribution is possible by using the population equivalent per WWTP, which is also available from CBS[6]. Additionally, information on the amount of digested sludge incinerated per WWTP[7] and biogas produced from sludge digestion[8], grouped per size of WWTP, is available.

4.4 Environmental variables

CH_4 production by microbial processes at WWTPs is in theory affected by temperature. However, no strong seasonal variability is observed (Daelman et al., 2012). This may be related to the fact that most CH_4 emissions result from the anaerobic digester, where temperature is kept constant and independent of outside temperatures. Daelman et al. (2012) do show a diurnal variation in CH_4 emissions, following the diurnal pattern of influent flow. Furthermore, emissions also seem to be higher on wet weather days than dry weather days, especially for wet weather days following a period of dry weather. After around two days of wet weather, the emissions drop down to a low level again. The CH_4 emissions are related to the biodegradable material in the sewer systems, causing CH_4 production. If rain persists, the biodegradable material is flushed out, leading to a drop in CH_4 emissions.

4.5 Upscaling procedure

From the available measurements at WWTPs emission factors need to be calculated. For this, two options are available. It is difficult to say beforehand which approach is best, so both could be tested and compared. The first, and easiest, option is to use the population per WWTP. Although it may not be the best predictor, compared to chemical oxygen demand, it is the only type of activity data that can be directly linked to an individual WWTP. A second option is to make use of the full range of CBS data per province (e.g., information on influent rates and composition and biogas production) and assign these data to individual WWTPs based on population (give each WWTP a share of the influent and biogas production).

A challenge is that large WWTPs often digest sludge produced at smaller plants in the vicinity. It is unclear at this point whether the presence of an anaerobic digester per WWTP is known. If not, we could do it on a province-level basis, considering a certain percentage of sludge in biogas productions at site vs. other locations/methods. In both cases, precipitation

[5] CBS: StatLine - Urban waste water treatment per province and river basin district, available from: https://opendata.cbs.nl/#/CBS/en/dataset/7477eng/table?ts=1753777914845.
[6] CBS: Inwoners per rioolwaterzuiveringsinstallatie, 1-1-2024, available from: https://www.cbs.nl/nl-nl/maatwerk/2025/04/inwoners-per-rioolwaterzuiveringsinstallatie-1-1-2024.
[7] Unie van Waterschappen: Slibverwerking, available from: https://waves.databank.nl/mosaic/dashboard/slibverwerking.
[8] CBS: StatLine - Zuivering van stedelijk afvalwater; energieproductie en energieverbruik, available from: https://opendata.cbs.nl/#/CBS/nl/dataset/83029NED/table.

events should be considered if these can be linked to the measurements. Short-term changes in influent flow and organic load cannot be considered, as we lack information on smaller timescales. Therefore, we use the diurnal pattern identified by Daelman et al. (2012).

For the activity data the same two options can be used as described before: population data per WWTP or CBS data per province assigned to WWTPs using population. In both cases emissions can be assigned to all individual WWTPs in the Netherlands.

4.6 Comparison to ER

The ER contains emissions per WWTP, so a comparison can be made per individual WWTP or for the whole sector (or per province, since the data from CBS is per province).

5 Onshore oil/gas production and transport/distribution

5.1 Description

The oil and gas sector consists of many different sources. Here, we separate between onshore production sites and transport/distribution network (this chapter), and offshore sites (Chapter 6). Also abandoned sites will be discussed, as these may still leak CH_4. Onshore oil/gas production and transport/distribution accounts for ~ 2 % of the Dutch CH_4 emissions, strongly dominated by distribution.

Onshore sites are mostly related to gas production and are predominantly located in the north-eastern part of the country (and on sea, see offshore) (Figure 5.1). CH_4 emissions during extraction occur as fugitives and due to the burning of natural gas for energy production. Additionally, emissions occur during venting and flaring of natural gas. Of these sources, venting is the largest source of CH_4.

Emissions also occur during the transport and distribution of natural gas. Transport refers to the long-range transport throughout the country under high pressure, whereas distribution is done through local networks to provide natural gas to end-users. Emissions are largest from the gas distribution network. The network is extensive and consists of thousands of kilometers of pipelines, compressor stations, distribution points, and export stations. Fugitive emissions of CH_4 can occur from leakages throughout the network, mostly at connection points. The old grey-cast-iron pipelines are most prone to leakage, but these have largely been replaced over time.

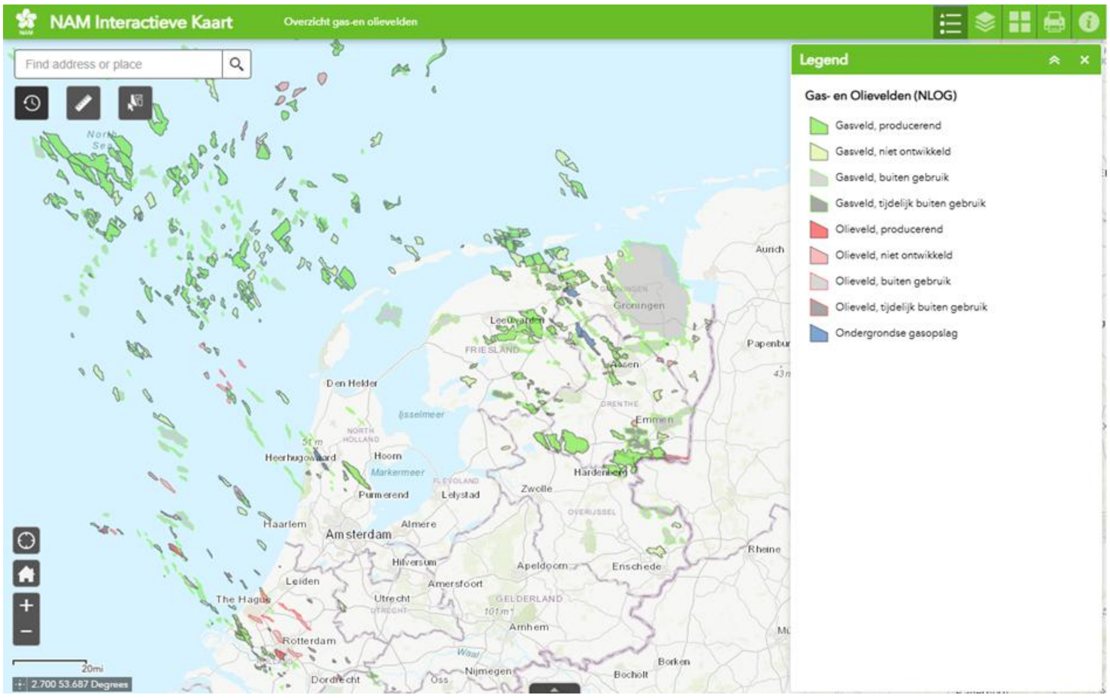

Figure 5.1: Map of (active and non-active) gas- and oilfields in the Netherlands. Source: https://www.nam.nl/gas-en-olie/locaties-en-activiteiten/overzicht-gas-en-olievelden.html.

5.2 Overview of measurements

A study on natural gas emissions from the Groningen gas field (production sites) indicated that large uncertainties exist and the official reported emissions deviate substantially from the measurements (Yacovitch et al., 2018). Measurements at active gas production sites and compressor stations show large variations across stations and times (TNO, 2019), due to maintenance, seasonal patterns in production, leakages, etc. The difficulty with these studies is that the measurements are not related to specific characteristics of the location and no emission factors are provided. Moreover, the emissions cannot be related to specific types of activities, like venting or flaring.

Different types of measurements show no significant CH_4 flux from abandoned, onshore gas and oil wells (Hensen et al., 2018; Schout et al., 2019), and these will not be considered.

Mobile measurements were done across several cities to detect and quantify (unknown) CH_4 leaks from the gas distribution network. Maazallahi et al. (2020) drove around Utrecht (Netherlands) and Hamburg (Germany) and used different methods to estimate emission rates per kilometer gas pipeline, resulting in emission factors of 0.47±0.14 and 0.19±0.03 L min^{-1} km^{-1}, respectively. Later, a student repeated the same procedure for Amsterdam, finding an emission factor of 0.33 L min^{-1} km^{-1} (Maynou, 2022). A similar measurement campaign was done in Utrecht, Groningen and other cities outside the Netherlands (Vogel et al., 2024). For Groningen, the total CH_4 flux from natural gas distribution was estimated at about 200 t yr^{-1}, and for Utrecht at about 110 t yr^{-1}. For Utrecht, Maazallahi et al. (2020) came to an estimate of 150±50 t yr^{-1}, which falls into the same range. All these studies used the same methodology to estimate fluxes and therefore the results are comparable. Moreover, all these measurements have been performed in cities, which may not be representative of rural leakages, for example, due to differences in the age/materials of the pipelines (the oldest ones are located in old city centers) and the number of connection points (which have the highest leakage risk), for example, to end-users.

5.3 Activity data

The ER makes use of annual environmental reports published by oil and gas extraction companies. These reports include information on the consumption of natural gas, drilling activities, and venting and flaring, including estimated emissions. These data are used in the ER. However, they are probably not available to us. Alternatively, monthly gas production and consumption data per site are available from 2003 onwards[9]. The locations of sites are provided as well.

For gas transport the total volume of transported natural gas is obtained from Gasunie. For the gas distribution the total length of the distribution network is used (Ophoff, 2016). These data are openly available and provide the best possible activity data. For the spatial allocation of emissions, the locations of the pipelines need to be known. The location of the main distribution network is available (indicative)[10]. For the regional networks data have to be obtained from the regional network operators. At least the three largest operators (Stedin, Liander and Enexis) have made vector datasets available through ArcGIS covering all pipelines, usually with an indication of the age of the pipelines.

5.4 Environmental variables

The emission factors of natural gas pipelines depend on the type of material and the pressure at which the natural gas is distributed. Ophoff (2016) explains how emission factors are calculated per type of material and pressure level, giving an indication of these relationships. However, the type of material of each segment of pipeline is unknown and therefore we cannot incorporate this type of information in the upscaling procedure. The pressure in the pipelines can be differentiated for the transport and distribution network.

5.5 Upscaling procedure

The measurements performed on the Groningen gas field and individual active production sites and compressor stations will be examined in more detail to see if these can be upscaled to annual estimates. For production sites the monthly gas production and consumption data could be used to estimate annual emissions if these data are also known for the times at which measurements were performed, which is unlikely. These would then only be applicable for those individual sites, but it may give an indication of the quality of the reported emissions. Upscaling to other sites is unfeasible.

For the gas distribution network, the approach is explained below. Gas transport is not considered, as no measurements are available.

We first need to make the emission factors suitable for application in rural areas. Maazallahi et al. (2020) and Maynou (2022) used total street length to estimate the emission factor. Although this may be a reasonable assumption within cities, in rural areas this should be done with care. Therefore, the emission factors from those studies need to be related to the length of the gas distribution network instead. The number of connections could be used as

[9] Nederlandse Olie- en Gasportaal: Datacenter, available from: https://www.nlog.nl/datacenter.
[10] Gasunie: Gasunie Omgevingsloket kaart met leidingen, markeringen en palen, available from: https://www.arcgis.com/home/item.html?id=c7a1867b390f4393a3e404b01aad99f3.

a weight factor as well, which may be available from the datasets provided by regional network operators. This will add spatial information, whereas an EF per length of pipeline is static. Moreover, the age of the pipelines is known from the data provided by the regional network operators and may be linked to the type of material and therefore risk of leakage according to Ophoff (2016). This results in an emission factor per length of pipeline, depending on the connection density and type of material.

If this cannot be assessed, another possibility might be the number of inhabitants as a measure for the gas distribution network density.

The activity data consists of the length of pipeline, if possible, separated into material types/age and connection density. As a default, the number of inhabitants can be used. The emission factors can be combined with the activity data directly, as no other temporal or spatial variations need to be considered.

5.6 Comparison to ER

Burning of natural gas at production sites is part of a different sector in the ER than all other activities. If we are able to estimate emissions for individual production sites these combustion-related emissions would be included, but they are likely to be small. Nevertheless, we should be careful not to forget about this source in the ER.

Gas distribution is available as a separate emission source in the ER and can be compared directly.

6 Offshore oil/gas production

6.1 Description

The offshore oil and gas production includes similar activities as discussed for onshore oil and gas production (Chapter 5), making up less than 1 % of the Dutch CH_4 emissions. We do not consider gas transport in this chapter.

6.2 Overview of measurements

A measurement campaign targeting offshore oil and gas platforms in the North Sea was performed using plume-detection from a vessel and plume modelling (Hensen et al., 2019). At some platforms a tracer release experiment was done to support emission calculations. Some platforms were visited twice. The calculated emissions show large variations across platforms. Also, the comparison to the emissions reported by the operators shows large and inconsistent differences, although the sum for all platforms was in reasonable agreement with the measurement-based emissions.

Vieldstädte et al. (2015) examined CH_4 leakage from three abandoned gas wells under the North Sea (>80 m deep), near Norway. The three wells combined emitted 24 t CH_4 yr^{-1}, but only 2 % of that reaches the atmosphere, making it a relatively small emission source. However, variations across wells are very large (1-19 t CH_4 yr^{-1}), with the number of vents being an important factor. The flux per vent is less variable (0.9-1.8 L min^{-1}), but the number of vents is difficult to establish. Also, in the Dutch sector of the North Sea CH_4 leakage from abandoned gas wells is observed (De Bruin et al., 2024). However, it was reasoned that probably only 2 % of all abandoned wells under the Dutch North Sea leaks CH_4. No emissions were calculated in this study.

6.3 Activity data

As for onshore sites, the ER makes use of annual environmental reports published by oil and gas extraction companies, which are probably not available to us. However, also for offshore locations monthly gas production and consumption data per location are available from 2003 onwards[9]. The data portal also contains a map with all locations.
For emissions from abandoned wells, Vielstädte et al. (2015) suggest that the number of vents is an important predictor, but these are unknown. Therefore, we need to assume an average emission per well. Since abandoned wells are not included in the ER, a first assessment is already helpful. The locations of abandoned wells are known[9].

6.4 Environmental variables

Hensen et al. (2019) suggest that the implementation of CH_4-reducing measures differs across platforms and is of influence on the CH_4 emissions. Unfortunately, there is no way to assess this for individual platforms targeted by the measurements.

6.5 Upscaling procedure

For offshore platforms we suggest using the same approach as for onshore production sites. This means we aim to calculate annual emissions for sites that were targeted by the measurement campaigns, using monthly gas production and consumption data, but this is only feasible if we can estimate those data for the moment the measurements were done.

For abandoned wells we need to assume an average emission per well, since we have no activity data to differentiate between individual wells. De Bruin et al. (2024) suggest that emissions mainly stem from abandoned wells associated with shallow gas. An assessment can be made of which wells are most likely to leak based on the geological settings. Although this requires a lot of data analysis, De Bruin et al. (2024) show all necessary data are available. Based on this and the estimated share of wells that actually shows leakage, we can estimate the total emissions from abandoned wells. The spatial allocation would then be done randomly over the identified wells or based on a criterium that indicates how likely leakage is to occur from each well. The latter would require a deeper analysis.

6.6 Comparison to ER

Burning of natural gas at production sites is part of a different sector in the ER than all other activities. If we are able to estimate emissions for individual production sites these combustion-related emissions would be included, but they are likely to be small. Nevertheless, we should be careful not to forget about this source in the ER.

Abandoned wells are currently not covered in the ER.

7 (Chemical) industry

7.1 Description

The ER contains data of 506 point sources with CH_4 emissions in the period 2020-2023. This contains 380 WWTPs, which are discussed in Chapter 4. Of the remaining 186 point sources (< 1 % of total Dutch CH_4 emissions), 56 companies are categorized as chemical industry. Table 7.1 shows the 11 chemical companies with the highest emissions in this period, with an emission of over 25 tons CH_4 in at least 1 year in the period 2020-2023. Many different products are produced by these companies, like industrial gases (Air Liquide), base chemicals (ESD-SIC, Chemelot), petrochemical products (Chemelot, DOW, bioMCN, Shell Chemie, Lyondell), fertilizers (Yara), and plastics (BASF, DOW, Chemelot). Please note that the emissions have been reported by individual companies, and variations in emissions can occur due to incidents and mitigation, but also new insights by the company.

Table 7.1: CH_4 emissions (in tons per year) by the chemical plants with the highest emissions, as reported on emissieregistratie.nl.

Nic	Company	City	2020	2021	2022	2023
51105	YARA Sluiskil BV	Sluiskil	287.17	497.14	597.08	1067.31
62	Chemelot Site Permit BV	Geleen	175.08	221.24	123.73	150.64
51104	Dow Benelux BV (Hoek)	Hoek	77.39	86.12	147.68	120.84
33414	BASF Nederland BV Catalysts	De Meern			107.17	14.09
101103	Bio Methanol Chemie Nederland (BioMCN)	Farmsum	78.94	58.46		
10006	Shell Nederland Chemie BV (Pernis)	Vondelingenplaat Rotterdam	37.13	62.13	71.67	29.32
41003	Shell Nederland Chemie BV (Moerdijk)	Moerdijk	70.54	52.30	43.47	29.06
104003	Delesto BV	Farmsum	31.86	41.95	40.48	35.39
12175	Air Liquide Nederland BV	Botlek Rotterdam	36.71	41.13	8.12	7.86
115036	Lyondell Chemie Nederland B.V.	Maasvlakte Rotterdam	0.02	2.90	1.41	30.94
104710	ESD-SIC BV	Farmsum	28.51	27.44	20.37	28.46

7.2 Overview of measurement

Downwind measurements of an industrial facility (food processing) in the Amsterdam harbour shows large variations in CH_4 emissions (Stroeken, 2022), whereas no emissions were recorded in the ER for this facility. Several measurement campaigns have targeted large industrial areas. One example is the Rotterdam Ruisdael field campaign, of which the data is still being analysed. A recent study targeting hydrogen emissions in the industrial area of Delfzijl also performed CH_4 measurements alongside (Westra et al., 2024). In industrial areas multiple industrial facilities are co-located, making it difficult to separate between individual sources. Figure 7.1 shows the point source data from the ER for the chemical industry (left) and for all sectors (right).

7.3 Activity data

The emissions of large industrial companies are reported by the individual companies themselves and validated by the competent authority. The main part of the e-MJV data is available via a woo request in 2023[11] and 2024[12]. These emissions are based on measurement data at the stacks or on emission factors. These emissions are used directly in the ER.

To use the measurements for validation of the reported emissions, we need information on the production rate of individual facilities. However, the type of data needed for this depends on the type of facility and there is no good activity data available to scale the measured emissions to the other plants in the sector.

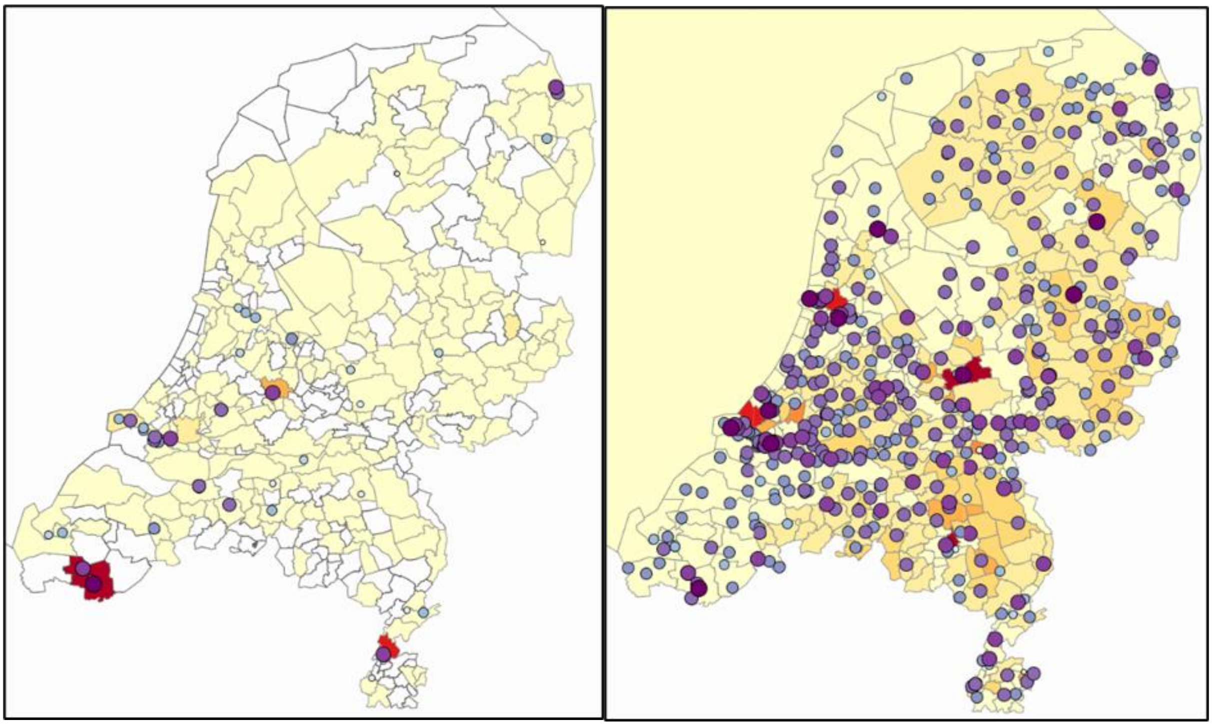

Figure 7.1: Left: CH_4 emissions from the chemical industry per municipality (kg/km2) and per point source (kg) in 2022. Right: Total national CH4 emissions per municipality (ton/km2) and per point source (ton) in 2022. Figures and legend from www.emissieregistratie.nl.

7.4 Environmental variables

The emissions from industry depend on operational practices, like production hours of the main emitting installations, shutdowns due to maintenance, start-up emissions and incidents.

[11] https://www.rijksoverheid.nl/documenten/publicaties/2024/02/08/nadere-documenten-bij-woo-besluit-over-verzoek-database-emissieregistratie-en-e-mjv-s-met-inbegrip-van-eerder-gepubliceerde-gegevens
[12] https://www.rijksoverheid.nl/documenten/woo-besluiten/2025/04/08/besluit-woo-verzoek-database-emissiegegevens-2023

7.5 Upscaling procedure

For upscaling the emissions of individual plants to an entire year, we need to know the production hours of the main emitting installations and whether it was in full operation at the time of measurement. Unfortunately, these data are not available. Upscaling the emissions from one plant to the entire sector is quite impossible due to the large variation in products and production processes in the chemical industry. Besides, identifying individual sources from the measurement campaigns is challenging. Therefore, we suggest ignoring this sector in the upscaling.

8 Residential/ commercial

8.1 Description

During the transportation of natural gas to end-users fugitive emissions of CH_4 occur (see Chapter 5). However, at the end-user emissions can also occur (~ 2 % of Dutch CH_4 emissions). Although this is a relatively small source, previous studies showed that end-user emissions may well be the dominant CH_4 source in urban areas (Stichaner et al., 2024). Most of these emissions occur due to leakage from pipes and appliances. Additionally, some start-stop losses (gas slip) occur when operating appliances that work on natural gas. Finally, CH_4 emissions occur during combustion, e.g., biomass burning, but this source is considered to be small.

8.2 Overview of measurements

There are no direct measurements of end-user CH_4 emissions available. However, there have been some city-wide measurement campaigns in the Netherlands, such as the Ruisdael measurement campaign in Rotterdam[13]. At the moment, the analysis of the measurements is still ongoing. If we can get simultaneous measurements of CH_4 and ethane we can estimate fugitive CH_4 fluxes using the ethane-to-methane ratio of natural gas.

8.3 Activity data

Since the amount of fugitive emissions is strongly related to natural gas consumption, the gas consumption per neighborhood from CBS can serve as activity data[14].

8.4 Environmental variables

End-user leakages are (partly) temperature dependent, because more natural gas flows through the internal pipes when more heating is required (only in buildings that use natural gas). Therefore, we may assume that temporal variations in fugitive end-user emissions can be estimated with a heating degree day approach (Mues et al., 2014). A parameterization for the temperature dependency is also provided by Stichaner et al. (2024).

8.5 Upscaling procedures

It is highly uncertain whether measurement data for this sector will be available. However, if measurement data are available, the approach could be the following. First, we calculate the emission factor from the total measured/calculated flux and the natural gas consumption within that area. This would then indicate an average relative loss of natural gas due to end-user leakage. As gas consumption data are annual totals, the outside temperature will be used to distribute the natural gas consumption over the year (Mues et al., 2014) to be able to link these data to the measurements. The activity data consists of

[13] https://ruisdael-observatory.nl/measurement-campaign-maps-ghg-emissions-and-air-pollution-in-rotterdam/
[14] CBS: StatLine - Energieverbruik particuliere woningen; woningtype, wijken en buurten, 2023, available from: https://www.cbs.nl/nl-nl/cijfers/detail/85999NED.

the natural gas consumption in residential and commercial buildings. Since there are no complex interactions, the combination of activity data and emission factors will be straightforward.

8.6 Comparison to ER

Residential and commercial emissions, including gas slip, are separated in the ER. With the measurements we cannot separate between the different sub-sources, so a summation of all residential and commercial emissions will be made.

9 Organic soils

9.1 Description

Organic soils (peat or peaty soils) emit CH_4 due to the anaerobic decomposition of organic matter (methanogenesis). Drained peatlands emit more CO_2 than CH_4 due to the availability of oxygen. The Netherlands is covered for ~9 % by peatland, mostly drained and used for dairy farming, but some rewetted to reduce CO_2 emissions. Emissions from organic soils fall under different land use categories (grassland, forest land, cropland, wetlands).

9.2 Overview of measurements

Since peatlands are abundant in the Netherlands, a special research program is established to gain insight into greenhouse gas emissions from peatlands at various locations over multiple years and how specific measures affect those emissions. This research program (Netherlands Research Programme on Greenhouse gas dynamics in Peatlands and organic soils, NOBV[15]) started in 2019 with, amongst others, flux towers and chamber measurements. For example, flux tower measurements have been used to estimate flux rates across land uses and to analyze the driving factors, such as meteorological, soil and water characteristics (e.g., Buzacott et al., 2024). The land use type has a large impact, with median fluxes ranging from 0.42 mg CH_4 m^{-2} h^{-1} for pasture to 2.63 mg CH_4 m^{-2} h^{-1} for paludiculture, and even higher fluxes were observed for semi-natural sites.

Additionally, the monitoring station at Cabauw has a long-term record of CH_4 concentration measurements at several altitudes (Vermeulen et al., 2011). The tower is surrounded by grasslands and agricultural activities on peat soils. In a modelling inversion study, Tong et al. (2023) show that seasonal variations in the CH_4 flux can be linked to emissions from managed grassland. However, it is complex to separate between the different sources of CH_4.

9.3 Activity data

Although no CH_4 emissions from organic soils are calculated in the ER, for N_2O some calculations are done. For these, the ER uses soil carbon stocks to estimate the amount and spatial allocation of emissions from organic soils. Here, the activity data consists of the surface area of peatlands. This can be obtained from a soil map[16], where peatlands are a separate category. Further differentiation is possible using information on the land use type[3] to cover for the large variations between land use types.

9.4 Environmental variables

Flux variability across sites within the same land class were found to be large (Buzacott et al., 2024). Important drivers are soil temperature and ground water level (Figure 9.1). As mentioned before, drained peatlands emit less CH_4 due to availability of oxygen, which

[15] https://www.nobveenweiden.nl/en/
[16] Basisregistratie Ondergrond: Bodemkaart (SGM), available from: https://basisregistratieondergrond.nl/inhoud-bro/registratieobjecten/modellen/bodemkaart-sgm/.

causes production of CO_2. The ER uses a model to calculate ground water levels, but at this point it is unclear whether these data could be made available. Alternatively, a dataset of average highest, lowest and springtime ground water levels at 50 m resolution is available[17]. Likely, these data could be interpolated to cover a full year. Additionally, methanogenesis is a temperature-sensitive process, with lower emissions being recorded at low temperatures (Kalhori et al., 2024). Close to the surface the soil temperature follows the atmospheric temperature, which is available from KNMI observations or from meteorological models.

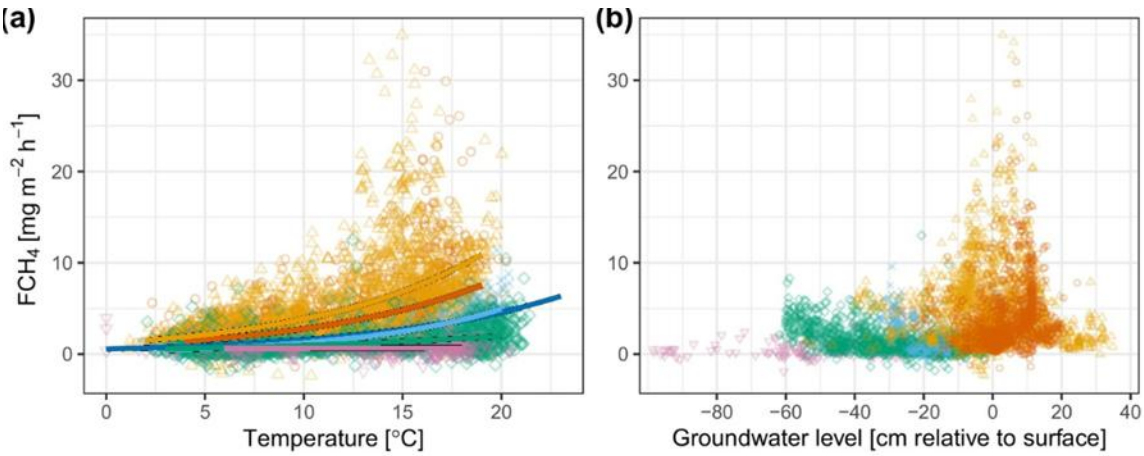

Figure 9.1: The relationship between daily median CH_4 fluxes (FCH4) and (a) surface soil temperature, (b) groundwater level relative to the surface, for different land uses. Source: Buzacott et al., 2024.

The type of vegetation covering the peatlands also has an impact on CH_4 releases to the atmosphere, as some vegetation types can support oxidation of CH_4 to CO_2 or, conversely, reduce CH_4-oxidation by facilitating the transport of CH_4 to the atmosphere (Vroom et al., 2024; Vroom et al., 2018). However, the exact impact of the surface vegetation is largely unknown, and we will not consider this in the upscaling procedure.

Another important factor is the stage of rewetting (Liu et al., 2020). Initially, rewetting can result in increased CH_4 emissions, but after 5-10 years the peatlands are restored and CH_4 emissions are similar to those of natural peatlands[18]. We are not aware of any information regarding the stage of rewetting in Dutch peatlands and will therefore not consider this variable.

9.5 Upscaling procedure

The emission factors calculated from the measurements are expressed in a flux per area and per hour. These are not fixed in time and space due to the large impact of (soil) temperature and water tables. Therefore, the relationships between these two variables and the fluxes identified by Buzacott et al. (2024) are used. They show that, once the temperature is accounted for, there is an almost linear increase of the CH_4 flux with ground water level across all data. However, the relationships differ per land use type.

[17] Basisregistratie Ondergrond: Model Grondwaterspiegeldiepte (WDM), available from: https://basisregistratieondergrond.nl/inhoud-bro/registratieobjecten/modellen/model-grondwaterspiegeldiepte-wdm/.
[18] International Union for the Conservation of Nature (IUCN) UK Peatland Programme: Peatlands and Methane, available from: https://globalpeatlands.org/sites/default/files/2024-07/202407_Briefing%20Doc%20-%20Peatlands%20and%20Methane_03.pdf.

The activity data consists of the total area of peatland per land use type. The upscaling exists of multiplying the emission factor (corrected for the temperature and water table) for a specified year with the total area of peatlands per land use type.

9.6 Comparison to ER

CH_4 emissions from organic soils are currently not included in the ER.

10 Ditches

10.1 Description

The emissions from wetlands (LULUCF category) constitute about 2 % of Dutch CH_4 emissions and consist of ditches and canals (> 3 m), freshwater ponds, reservoirs, reed swamp and open water. Emissions from drainage ditches (< 3 m) are reported under their respective land use category and make up about 1 % of the total emissions. Here, we differentiate between ditches (this chapter) and open water (Chapter 11) because of the different conditions contributing to CH_4 production.

Drainage ditches and canals are used throughout the lowest parts of the Netherlands to keep water tables low enough for agricultural activities, to redistribute water through the landscape or to drain urban areas. Drainage ditches in agricultural areas generally have a high organic carbon content, which causes CH_4 formation through methanogenesis, similarly to peatlands. Due to the low flow rate, conditions are favorable for this type of CH_4 production. Additionally, ditches may transport CH_4 produced in adjacent terrestrial environments (Peacock et al., 2021).

10.2 Overview of measurements

Few studies performed measurements on CH_4 emissions from drainage ditches near dairy farms in the Netherlands. Hensen et al. (2006) showed large differences between ditches across a single farm, with emission factors between 0.3 and 257 g CH_4 m^{-2} day^{-1}. Hendriks et al. (2024) found an average CH_4 emission factor of 0.6 g CH_4 m^{-2} day^{-1} across 10 ditches using chamber measurements. Diffusive CH_4 emissions vary a lot (0.00–2.59 g m^{-2} day^{-1}), but show no seasonal cycle. In contrast, ebullitive (bubbles) CH_4 emissions (0.00–4.21 g m^{-2} day^{-1}) show a clear seasonal pattern, with the highest fluxes in spring and summer.

Although these measurements give some indication of expected fluxes from drainage ditches, they have focused on ditches with a high organic carbon content, for example, near farms. Fluxes may be significantly lower for other land use categories and soil types. For comparison, the ER uses an emission factor of 0.14 g CH_4 m^{-2} day^{-1} for organic soils and 0.11 g CH_4 m^{-2} day^{-1} for mineral soils.

10.3 Activity data

The ER calculates a ditch fraction (< 3 m) from the Basisregistratie Grootschalige Topografie[19], which includes all physical objects in the Netherlands at approximately 20 cm resolution, also water. A further refinement is made based on the soil type[16] and land use type[3]. All these datasets are publicly available and therefore a similar approach can be taken for the upscaling, but keeping the spatial patterns instead of calculating a total fraction for the whole country. However, the differentiation of waters into different types may be complex.

[19] Kadaster: Basisregistratie Grootschalige Topografie (BGT), available from: https://www.kadaster.nl/zakelijk/registraties/basisregistraties/bgt.

For larger ditches and canals (> 3 m) the ER uses the Watertypenkaart[20], which includes all waters wider than 6 meter as a polygon with a known surface. A large part of the ditches is smaller and a fraction of these are included as line sources with an unknown surface area. For those ditches an assumption will have to be made about the average width. The challenge here is to avoid double counting of ditches in both the < 3 m and > 3 m categories.

10.4 Environmental variables

Ebullitive emissions show an exponential increase with temperature (Aben et al., 2017).

10.5 Upscaling procedure

The first step in the upscaling procedure is to try to identify a relationship between the measured fluxes and the carbon content of the soil surrounding the ditches. This can be done based on the soil map. Additional information on the organic carbon content of soils is also available (van Tol-Leenders et al. 2019; Knotters et al., 2022). In this way, an emission factor can be established for each ditch, based on its surroundings. If this is not possible, an average flux will have to be assumed for all ditches. The relationship with temperature can be taken from Aben et al. (2017).

The activity data consists of the total area of ditches and canals (large and small) per land use/soil type category. These can be combined directly with the EF per area of canal for that particular land use/soil type category, taking into account the temperature.

10.6 Comparison to ER

Emissions from small drainage ditches (< 3 m) are part of the land use category where the ditches are located (forest land, cropland and grassland). However, they are listed separately in the CRT tables and therefore the total flux for the Netherlands can be compared.

The larger ditches and canals (> 3 m) fall under the wetlands and cannot be separated from the other wetland sub-categories. Therefore, a combination of these ditches with the open waters is needed for a fair comparison of the emissions.

[20] PBL: Basiskaart Aquatisch: de Watertypenkaart, available from: https://www.nationaalgeoregister.nl/geonetwork/srv/api/records/f59a886c-9f34-4ffc-a24e-fe65d12dfade.

11 Large open water bodies

11.1 Description

About 18,4% of the Netherlands (7,650 km^2) is covered by water. In shallow water bodies, CH_4 production can be substantial due to the anaerobic digestion (methanogenesis) of large amounts of organic matter. Moreover, CH_4 bubbles are formed and transported to the surface (ebullition). In the ER these are covered by the LULUCF sector 'wetlands', which includes open water (both natural and artificial). However, no emissions are reported in the ER at the moment. A preliminary assessment comes to a contribution of about 4 % of the total CH_4 emissions.

In this chapter we focus specifically on large open water bodies (so no rivers and ponds). The Dutch part of the North Sea stretches up to the Dogger Bank and contains gas reservoirs and many oil and gas extraction facilities (covered in Chapter 6). It covers an area of about 57,000 km^2 (about 10% of the North Sea) with an average depth of about 30 meters. The Wadden Sea, an important nature reserve, is a large body of open water between the Dutch coast and the islands off the coast, that is heavily influenced by tides. The Dutch part of the Wadden Sea covers an area of about 2,200 km^2 with an average depth of 1-2 meters to a maximum of about 45 meters. The Lake IJssel is the largest (artificial) lake in the Netherlands. It covers an area of 1,100 km^2, with an average depth of about 4.5 meters. The Western Scheldt estuary is an important shipping route to the Port of Antwerp in Belgium, that is influenced by tides. It covers an area of about 330 km^2 with a maximum depth of about 17 meters.

11.2 Overview of measurements

Measurements at the North Sea, using ships, have mostly targeted offshore oil/gas production facilities (Hensen et al., 2019) and abandoned wells (De Bruin et al., 2025), but natural seepage also occurs (De Bruin et al., 2025; Mau et al., 2015). However, seepage fluxes are not quantified. At the Wadden Sea, an extensive study was done to estimate fugitive CH_4 fluxes and to establish relationships with other environmental variables (De Groot et al., 2023). Moreover, direct chamber measurements at Lake Grevelingen show CH_4 fluxes ranging from 0.01 to 1.15 mmol m^{-2} d^{-1}, exhibiting a strong seasonal cycle (Zygadlowska et al., 2024). The seasonality is largely explained by the level of stratification/mixing of the water layers. The average ebullitive flux was estimated to be 30-120 mmol m^{-2} d^{-1}. Although these values are based on a specific lake, the fluxes are comparable to other studies in coastal systems. Nevertheless, the ranges are very large.

11.3 Activity data

The emission factors provided above can be used in combination with a land use map (area of open water bodies).

11.4 Environmental variables

De Groot et al. (2023) show that diurnal variations in CH_4 fluxes are related to the tidal regime, which affects the hydrostatic pressure. Seasonal patterns were also distinguished. The water column CH_4 concentrations were larger in summer due to the higher temperatures, and the CH_4 oxidation rates show a clear seasonal cycle, which is also affected by salinity. The water-to-atmospheric flux strongly depends on the wind speed, as also shown by Mau et al. (2015). Other studies also suggest that CH_4 concentrations in sea water might correlate with salinity (Osudar et al., 2015) and temperature (Borges et al., 2019). Detailed and up-to-date information on water levels, salinity and tidal regimes is available at Rijkswaterstaat[21] for several locations in Lake IJssel and the Western Scheldt estuary. The Wadden Sea and North Sea are not covered by this dataset, and we need to assume a fixed value for salinity.

A recent study looked at the impact of pressure changes induced by ships on CH_4 emissions in large open water bodies (Nylund et al., 2025). They conclude that ignoring ship-triggered CH_4 emissions in shipping lanes causes a significant underestimation when assessing estuarine/coastal CH_4 emissions. Important factors are the size and the speed of the vessel, but also the screw propellor configuration. The most important (commercial) shipping channels in the Dutch part of the North Sea are the Eurogeul towards Rotterdam and the IJgeul towards IJmuiden/Amsterdam. On an annual basis about 260,000 ships pass by and about 50,000 vessels pay a visit to Dutch harbors via these shipping lanes. The total area of shipping lanes is known and can be used to include these elevated emissions, perhaps in combination with AIS data from individual ships.

11.5 Upscaling procedure

The main challenge is to consider all the difficult processes that cause large variations over space and time, such as changes in wind speed, salinity, temperature and tidal regime. We may assume that those variables are not independent from each other, and complex relationships exist between the variables and the CH_4 fluxes. Therefore, we advise trying to identify the 1-2 best predictors and only accounting for those. The emission factors established from available measurements (the main focus is on the data from De Groot et al. (2023) and Zygadlowska et al. (2024)) then need to be linked to the selected variables, which requires exact dates and locations.

The activity data consists of the total area of open water bodies and information on the selection variables, which will be spatially explicit.

The additional CH_4 emissions as a result of ship passages can be treated separately. Nylund et al. (2025) provide information on the emission factors and how they relate to ship types. An average EF per area of shipping lane could be extracted from this and combined with the total area of shipping lanes. Or the identified relationships can be applied to ship-specific activity data (AIS).

11.6 Comparison to ER

Open water bodies are currently not included in the ER.

[21] Rijkswaterstaat: Waterdata, available from: https://www.rijkswaterstaat.nl/water/waterdata-en-waterberichtgeving/waterdata.

12 Conclusions and outlook

This report describes possible upscaling procedures for a wide range of activities causing CH_4 emissions. For some sectors the procedures are rather straightforward, because we have access to detailed datasets and know the most important processes affecting those emissions. However, for other sectors relationships with environmental variables are not well-known (e.g., for open water bodies) or there is a lack of measurements (e.g., for (chemical) industry), which makes the upscaling more difficult.

There are also CH_4 sources that are not covered at all in this report because no measurements are available, for example, for biogas plants and waste incineration. Also, rivers and ponds are currently not covered, as they don't fit under large open water bodies and ditches due to the different conditions that affect CH_4 production. Finally, we discuss the impact of shipping activities on outgassing of CH_4 from open water bodies, but other types of activities (e.g., sand extractions, dredging, and using trawl nets in coastal waters) may have a similar impact, which is currently not quantified.

When performing the upscaling and comparison to the ER there are several important points of attention:

1) One measurement may cover several sources of CH_4. For example, agricultural activities may take place on organic soils, and offshore oil/gas activities overlap with emissions from open waters. It is important to be aware of this and try to avoid double counting as much as possible.
2) Also, in the comparison to the ER we should be careful to avoid overlap or double counting. Because the sector definitions used by the ER can be complex to an outsider it is advisable to involve people from the ER here, to make sure we are not comparing apples and oranges.
3) The activity data from databases and reports should be handled with care to make sure that the data is interpreted correctly (e.g., in terms of units and which processes are included/represented). In case of doubt, the data providers should be asked for advice. Data providers can sometimes also provide useful insights into the main driving factors and their relationship with CH_4 emissions, as they are experts on that specific domain.
4) Similarly, the interpretation of measurements should be done with care, for example, to understand the limitations and uncertainties. We strongly advise involving the data experts when working with the measurements.

Given the limitations of the upscaling procedures described above, it may not be possible to cover all sectors. Therefore, we recommend starting with the sectors where most can be gained from an observation-based emission estimated, for example:

- Sectors with a large contribution to the total emissions, which have the most impact on the reporting.
- Sectors which are not included in the ER, to get an idea of what the ER is currently overlooking.
- Sectors for which we have high-quality observations, which can provide useful insights into country-specific emission factors, potentially to be taken up by the ER.

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