Methane reduction potential in the EU

Between 2020 and 2030

CE Delft

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Content

Summary

Methane (CH_4) is a greenhouse gas that is 86 times more potent than carbon dioxide (CO_2) over a twenty year cycle, and accounts for nearly one-fifth of global greenhouse gas emissions. Methane emissions reduction has a critical role to play in climate mitigation actions between now and 2040. The importance of methane emissions mitigation is put forward by the Intergovernmental Panel on Climate Change (IPCC), the Global Methane Pledge, the Global Methane Assessment by UNEP and CCAC, and the latest Global Methane Tracker Report from the IEA, all of which have come out over the last two years. The Global Methane Assessment notes that, according to scenarios analysed by the IPCC, "global methane emissions must be reduced by between 40–45% by 2030 to achieve least cost-pathways that limit global warming to 1.5˚C this century", and that it is possible and cost-effective to realise this reduction. This target goes beyond the 30% methane reduction that is included in the Global Methane Pledge.

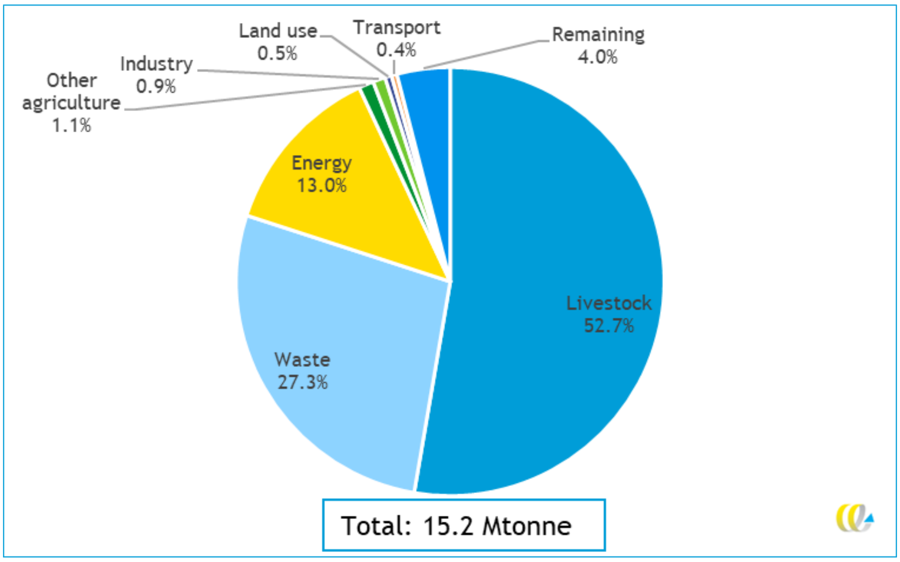
The European Commission has implemented policies that help to mitigate methane emissions in the EU's waste sector, but there are still considerable methane emissions in this sector, as well as in the energy sector and in livestock agriculture. This raises the question whether current policy efforts in the EU are sufficient in order to realise 45% methane emissions reduction by 2030. Changing Markets Foundation has asked CE Delft to estimate the potential methane emissions reduction in Europe between 2020 and 2030 by means of a literature study and own calculations, which helps to answer this question. It is worth nothing that the 30 and 45% reduction targets are global but that, for the sake of this study, these targets are applied to the EU emissions. We investigate what additional policy efforts are needed to realise these targets in the EU.

Current methane emissions

Using data from the European Environment Agency (EEA), we find that total methane emissions in the EU were 15.2 megatonne (Mt) in 2019. This is around 5% of global anthropogenic methane emissions of 330 Mt per year (UNEP & CCAC, 2021), and around 10% of greenhouse gas emissions in the EU in 2019 when applying the conventional 100-year global warming potential factors. If a 20-year time period is considered, it is more than 30% of EU GHG emissions.[1] Of this total, almost 53% was released in the livestock agriculture sector, of which 82% was caused by enteric fermentation, i.e. digestion of feed by ruminants. The remainder is linked to manure management. The waste sector was responsible for 27%. Because most of the fossil fuels consumed in the EU are imported from other world regions, the vast majority of emissions related to EU energy use (86%) are not emitted within the EU borders. As a result, the methane emissions share of the energy sector within the EU is limited to 13%.

[1] Using a GHG emissions volume in the EU-27 in 2019 of 4,067 Mton CO_2-eq., a GWP_{100} of methane of 28, and a GWP_{20} of methane of 86.

Methane emissions in the EU in 2019, by sector



Methane mitigation measures

We identify methane mitigation measures and estimate the methane reduction potential in the EU between 2020 and 2030, to arrive at potential reduction percentages per sector:

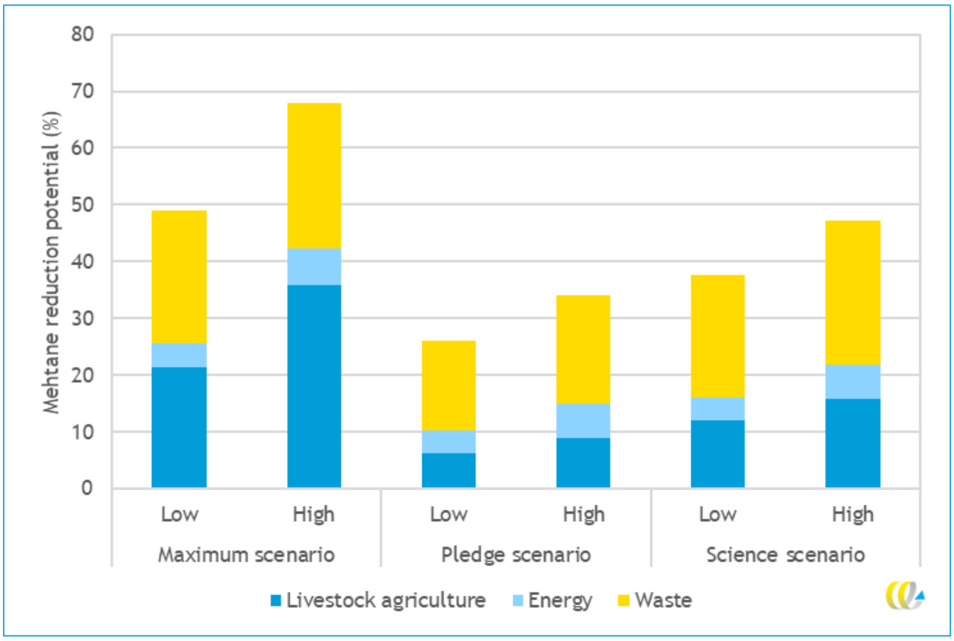
- For the livestock agriculture sector we estimate the methane reduction that could be realised if EU citizens would change their diet to an average advised diet with lower meat and dairy consumption, which follows national health guidelines, leading to a reduction of livestock volumes in the EU. This would lead to a 29 to 37% reduction of methane emissions in the sector, and 15 to 19% of overall EU emissions. We estimate that the proposed revision of the Industrial Emissions Directive could potentially result in a sectoral methane emissions reduction of 2 to 4% if anaerobic digestion of manure and other manure management are fully effective in the targeted livestock farms before the year 2030.
- In the energy sector, the measure that would have the highest impact on global methane emissions are the methane emission standards for oil and gas producers, through a 48 to 87% reduction of methane emissions related to fossil fuels imported by the EU. However, these emissions are not within the scope of the proposed EU regulation on methane reduction in the energy sector. Within the EU, the measures included in the EC proposal for methane reduction in the energy sector could cause a reduction of energy sector methane of 11 to 26% between 2020 and 2030, which translates to 1.4 to 3.4% of EU methane emissions.
- In the waste sector, the separation and use of organic waste (which is already included in the Waste Framework Directive), could potentially result in a sectoral methane reduction of roughly 18 to 30%, which means a reduction of 5 to 8% of EU emissions. In combination with other measures, such as reduction of food loss and waste and stabilisation of landfilled organic waste, the sectoral reduction could reach 90%, or an EU methane emissions reduction of 25%.

Scenarios for mitigation potential

In a business-as-usual development with current EU policies, EU methane emissions are estimated to decline by 13.4% between 2020 and 2030. When including the effect of the EC proposal on methane reduction in the energy sector, a 15% to 17% reduction could be realised. This falls short of the 30% and 45% reduction targets. Three scenarios, which constitute different combinations of methane mitigation measures, have been worked out and their effects on potential EU methane reduction examined.

- In the Maximum scenario, all methane mitigation measures are included, and 100% of EU consumers switch to an advised diet following national dietary health guidelines. This scenario indicates that the maximum methane reduction that could be realised in the EU between 2020 and 2030 is 7.5 to 10.3 Mt/year, or 49 to 68% of annual methane emissions.
- In the Pledge scenario, we have combined measures with which a total EU methane reduction of 30% can be obtained, in line with the Global Methane Pledge ambition. In this scenario, only 10% of EU consumers switch to an advised diet with lower meat and dairy consumption. A reduction of 26 to 34% is estimated to be achievable by means of various methane mitigation measures, distributed among the sectors.
- In the Science scenario, we have combined measures with which a total EU methane reduction of 45% can be obtained, following the scientific advice in the Global Methane Assessment. Here, 50% of EU consumers switch to an advised diet with lower meat and dairy consumption. A total reduction of 38 to 47% is realised through a combination of different measures across sectors.

EU methane reduction potential between 2020 and 2030 in the three included scenarios



Conclusions

Our results show that the EU methane reduction targets between 2020 and 2030 cannot be realised without implementing policies that drive the uptake of behavioural and technical measures in the livestock agriculture sector. The adoption of healthier consumer diets alone could reduce EU methane emissions by 15 to 19%, if new policy initiatives would influence all EU citizens to switch to an advised diet based on national dietary health guidelines with lower meat and dairy consumption. This makes clear that the livestock agriculture sector has an important role to play in the reduction of EU methane emissions. At the same time, EU policy initiatives on methane reduction are still the least advanced and least concrete in the livestock agriculture sector. It is therefore recommended that EU policymakers increase efforts in implementing policies that will result in dietary changes with lower production and consumption levels of meat and dairy and the adoption of technical measures by livestock farmers, prioritising more proven measures with higher emissions reduction potential.

Acronyms

Abbreviations	
BAU	Business-as-usual
bcm	Billion cubic metres
CBAM	Carbon Border Adjustment Mechanism
CH_4	Methane
CO_2	Carbon dioxide
CO_2-eq.	Carbon dioxide equivalent
EC	European Commission
ESR	Effort Sharing Regulation
EU	European Union
EU ETS	EU Emissions Trading System
GHG	Greenhouse gas
GMA	Global Methane Assessment
IEA	International Energy Agency
IED	Industrial Emissions Directive
IPCC	Intergovernmental Panel on Climate Change
kt	Kilotonne
ktoe	Kilotonne of oil equivalent
LDAR	Leak detection and repair
MBAM	Methane Border Adjustment Mechanism
MRBT	Material recovery and biological treatment
MRV	Monitoring, reporting & verification
MSW	Municipal solid waste
Mt	Megatonne
N_2O	Nitrous oxide
WTO	World Trade Organization
WWTP	Wastewater treatment plant

1 Introduction

1.1 Goal of the study

The global methane emissions account for nearly one-fifth of global greenhouse gas emissions, and these emissions continue to rise. Methane is a greenhouse gas that is 86 times more potent than carbon dioxide (CO_2) over a twenty year cycle. The climate impact of methane emissions is three times more important than assumed under existing climate mitigation regulations(Abernethy & Jackson, 2022). The IPCC assessment report emphasizes that methane emissions reductions by 2030 and 2040 are needed to lower peak warming and reduce the likelihood of overshooting warming limits (IPCC, 2022).The global methane emissions account for nearly one-fifth of global greenhouse gas emissions, and these emissions continue to rise. Methane is a greenhouse gas that is 86 times more potent than carbon dioxide (CO_2) over a twenty year cycle. The climate impact of methane emissions is three times more important than assumed under existing climate mitigation regulations(Abernethy & Jackson, 2022). The IPCC assessment report emphasizes that methane emissions reductions by 2030 and 2040 are needed to lower peak warming and reduce the likelihood of overshooting warming limits (IPCC, 2022).

The first-ever global commitment by heads of state to reduce methane emissions, which has been signed by more than 100 countries and is led by the United States and the European Union, strives to cut global methane emissions by 30% by 2030 compared to 2020. Although a reduction of 30% is in line with the Paris Climate Agreement's goal to limit global temperature rise to 1.5˚C, one of the co-authors of the Global Methane Assessment remarks that it is 'just compatible' with this goal, and that 10% additional methane reduction would "more firmly assure" that this goal is achieved.[2]

The Global Methane Assessment (GMA), a landmark study on global methane mitigation written by the United Nations Environment Programme and the Climate & Clean Air Coalition, highlights the critical role that methane emissions reduction plays in global warming mitigation. The report argues that a 45% reduction of anthropogenic (human-caused) global methane emissions this decade is necessary to follow the 1.5˚C pathway, and it concludes this goal is achievable (UNEP & CCAC, 2021). The authors calculated that reducing methane emissions by 45% in this decade will avoid almost 0.3˚C of global warming by 2045.

The main goal of the study is to gain insight in the challenge of realising 30 to 45% methane reduction between 2020 and 2030 in the European Union. Changing Markets Foundation has asked CE Delft to perform a literature study to assess the potential for methane emission reductions in the EU by means of mitigation measures in the livestock agriculture sector, the energy sector, and the waste sector. The two main questions tackled in this study are what policy efforts are needed to realise 30 and 45% methane reduction targets in the EU, and how important the contribution of methane mitigation in livestock agriculture is to realise these targets.

[2] SEI: "The Global Methane Pledge is a good start" , accessed on May 5th 2022.

1.2 Scope of the study

In this section we describe the scope of this study. First of all, we restrict the study to anthropogenic methane emissions, which accounts for approximately 60% of global methane emissions (UNEP & CCAC, 2021). We will focus on the three sectors with the highest methane emissions worldwide and in the EU: livestock agriculture, energy and waste.

We define 'potential' in 'potential methane reduction' in this study as a theoretical potential. The methane reduction measures considered in this study are technical and behavioural measures that represent the practical means by which methane emission sources are to be mitigated. Because we estimate a theoretical potential, the feasibility of mitigation measures are not considered in the effects estimations. The (effectiveness of) policy measures that are required to bring about technical and behavioural change are not part of the main analysis either, but the policy implications of our results are discussed in Chapter 7.

The geographical scope of the project is the European Union, which does not include the UK. The focus lies on methane emissions that take place in Europe, but for the energy sector a parallel calculation of the reduction potential is made that includes emissions related to the import of fossil fuels. When estimating the effect of healthier consumer diets on livestock methane emissions in the EU, we consider only changed consumption behaviour within EU countries. Thus, the methane emissions related to the production of animal-sourced food that is exported to non-EU countries are not influenced by the measure of healthier consumer diets. In the main assessment, estimates are made for the EU as a whole. The considered time period for the estimation of the methane reduction potential is from 2020 to 2030, with 2020 being the reference year.

An estimation of the economic costs and benefits of methane mitigation measures lies outside the scope of this study.

1.3 Research approach

The research approach taken in this study is briefly described in Table 1. The different research steps are presented in consecutive chapters of the report. In Chapter 8, the conclusions of the study are given.

Table 1 – Research approach

Chapter	Research step	Description
2	Overview of EU methane emissions	Presentation of current EU methane emissions in different sectors and countries.
3	Reduction potential in livestock agriculture	Estimation of the potential methane emissions reduction that can be realised by different mitigation measures in the EU livestock agriculture sector between 2020 and 2030.
4	Reduction potential in the energy sector	Estimation of the methane reduction potential of measures in the EU energy sector.
5	Reduction potential in the waste sector	Estimation of the methane reduction potential of measures in the EU waste sector.
6	Methane reduction scenarios	Composition of scenarios that indicate the maximum (theoretical) methane reduction potential in the EU between 2020 and 2030, and the measures that need to

Chapter	Research step	Description
		be implemented to realise a 30 or 45% methane reduction within this time period.
7	Implications for methane reduction policy	Discussion of the policy implications of the study results, including required policy actions in the EU livestock agriculture, energy and waste sectors.

2 Overview of EU methane emissions

To obtain an overview of the current methane emissions in the EU, we have used data from the European Environment Agency (EEA), which collects national greenhouse gas emissions data that are reported to the United Nations Framework Convention on Climate Change (UNFCCC) and to the EU Greenhouse Gas Monitoring Mechanism in the frame of the Paris Agreement. The EU methane emissions from 2019[3] are shown in Figure 1 and Table 2 (distributed by sector), and in Figure 2 (distributed by Member State).

Figure 1 - Methane emissions in the EU in 2019, by sector (EEA, 2021)

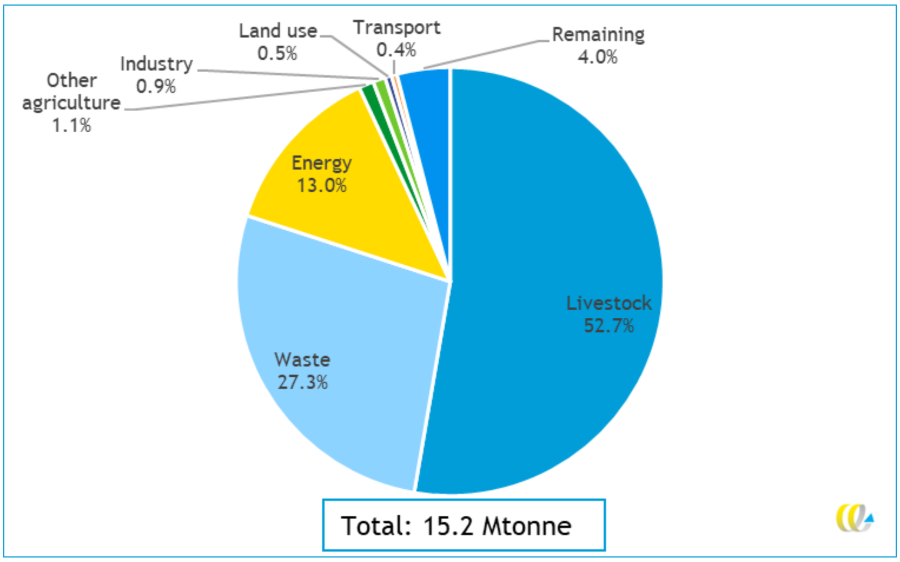


Table 2 - Methane emissions in the EU in 2019, by sector (EEA, 2021)

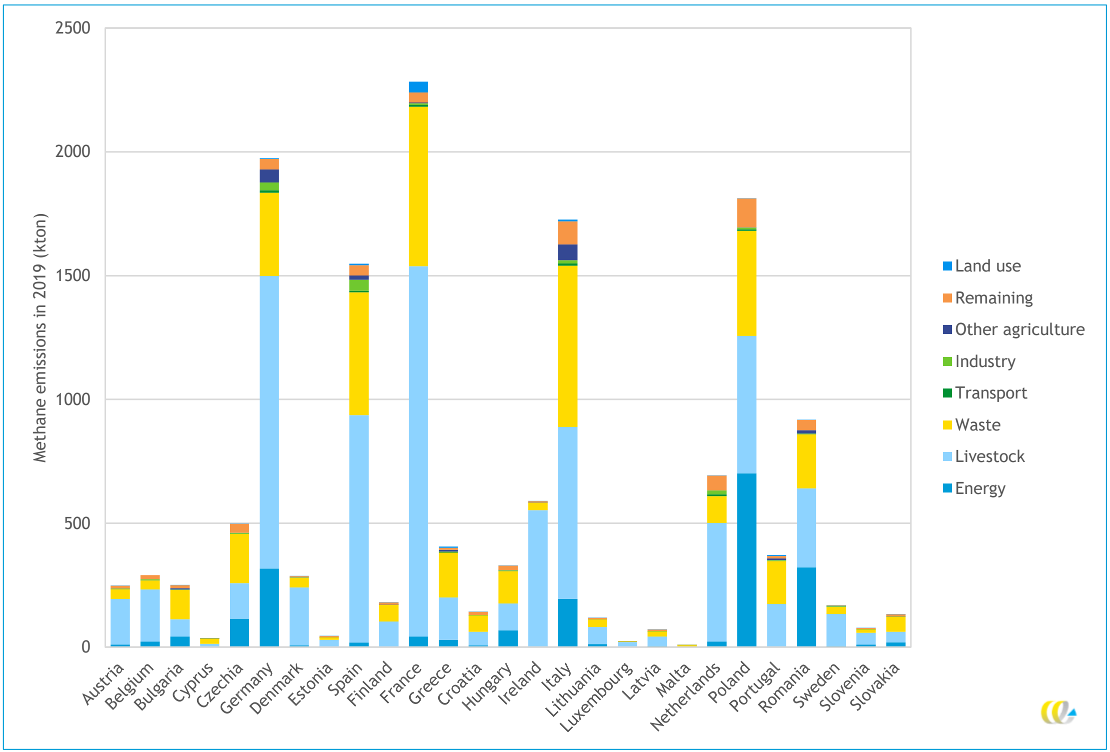
Sector	Emissions (Mt/year)
Livestock	8.03
Waste	4.16
Energy	1.98
Other agriculture	0.17
Industry	0.14
Land use	0.08
Transport	0.06
Remaining	0.61
Total	**15.2**

[3] The most recent year in the detailed EEA dataset was 2019. We assume that the data for 2019 represent the current state of EU methane emissions.

The 2019 methane emissions by sector show that livestock agriculture currently takes up the largest share of EU's methane emissions (53%), followed by the waste sector (27%) and the energy sector (13%). Other sectors have an aggregate share of about 7%, and thus contribute much less to the overall methane emissions of 15.2 megatonne (Mt) per year.

The global division of methane emissions between sectors looks quite different. Here, the contribution of the energy sector is much higher at 35%. The global share of agriculture is 40%, and the share of the waste sector is 20% (UNEP & CCAC, 2021). This difference originates from the fact that the EU imports more than 80% of the fossil fuels it uses, and the associated methane emissions are accounted for in the producer countries.

Figure 2 – Methane emissions in the EU in 2019, by country (EEA, 2021)



There are large deviations in absolute methane emissions and relative sector contributions among EU countries. Poland has the highest emissions in the energy sector, Italy has relatively high waste-related methane emissions, and Germany, France and Spain have the highest methane emissions in livestock agriculture. Differences between countries may be the result of differences in sector size, in the nature of production systems (e.g., the degree of intensive animal farming and the relative use of coal in the energy sector), and in a different level of implementation of methane mitigation measures.

3 Reduction potential in livestock agriculture

3.1 Introduction

In this chapter, we estimate the methane reduction potential of various mitigation measures in the EU livestock agriculture sector between 2020 and 2030. We present the current methane emissions (Section 3.2), the business-as-usual trend (Section 3.3), the estimation of the reduction potential of different mitigation measures in livestock agriculture (Section 3.4), and the resulting sector-level reduction potential (Section 3.5).

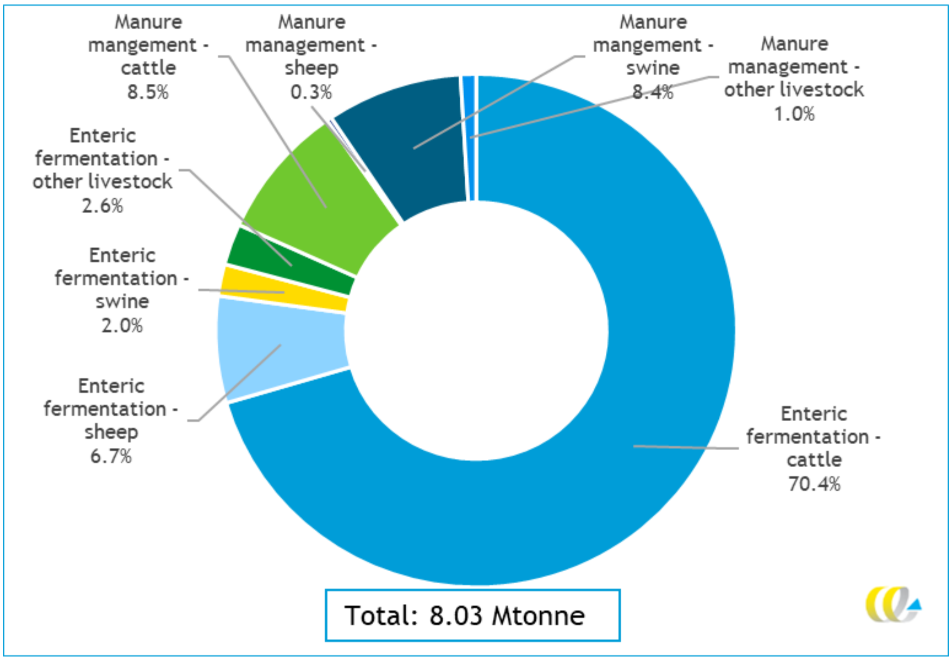
3.2 Current methane emissions

The livestock agriculture sector is responsible for about 32% of global anthropogenic methane emissions (UNEP & CCAC, 2021). This is predominantly caused by the methane emissions that are formed from enteric fermentation in ruminant livestock and manure management. Enteric fermentation is part of the digestive processes in ruminant animals such as cattle, sheep, goats, and buffalo. Microbes in the digestive tract (rumen) decompose and ferment food, which generates methane as a by-product. Enteric fermentation and manure management account for 27 and 3% of global anthropogenic methane emissions respectively (Grossi et al., 2018, Global Methane Initiative, 2015).

In the EU, methane emissions from livestock represent 53% of total anthropogenic methane emissions. The distribution of EU livestock methane emissions between different sources in 2019 is illustrated in Figure 3. The vast majority (70%) of these emissions come from enteric fermentation in (dairy and non-dairy) cattle. This is because the methane emissions per head are much higher for cattle than for other animals.[4] In total, about 82% of the sectoral methane emissions are from enteric fermentation, and about 18% from manure management.

[4] The methane emissions are, in kg CH_4/head/year: 150.8 for dairy cattle, 54.2 for non-dairy cattle, 7.4 for sheep, 6.1 for swine, and 0.2 for other livestock. These numbers include methane emissions from both enteric fermentation and manure management.

Figure 3 – Shares of methane sources in livestock agriculture in the EU in 2019 (EEA, 2021)



3.3 Business-as-usual trend

To estimate the methane reduction potential in the EU livestock agriculture sector between 2020 and 2030, we need to assume a percentage that represents the business-as-usual (BAU) trend of the EU livestock methane emissions. The BAU trend includes EU policies that have already been adopted, but not policies that are still in the pipeline. We make use of the EU Reference Scenario 2020, which is a projection of the future development of the EU energy and transport system towards 2030 and 2050 (EC, 2021b). It is used by EU policymakers and researchers to estimate the possible effects of new policies. Although the EU Reference Scenario is a projection rather than a forecast, it has been developed taking into account the current EU policy regime, historical trends and likely developments of market trends. Because it also includes a projection of the development of GHG emissions in all the different sectors, the EU Reference Scenario is a suitable source for our estimation of business-usual-trends of methane emissions.

The EU Reference Scenario 2020 includes a projection of the non-CO_2 greenhouse gas emissions in the agriculture sector.[5] This projection does not take into account the Farm to Fork Strategy (EC, 2020a), which sets goals for the EU agricultural sector, but is not a legislative proposal with concrete policy measures. It does not consider the EC proposal for the revision of the Industrial Emissions Directive either (see Section 7.2 for a discussion of its possible effect on methane emissions). We assume that the relative reduction of non-CO_2 GHG emissions between 2020 and 2030, which is 3.7%, is the same as the relative reduction of methane emissions of the livestock agriculture sector in the same period. A reduction of 3.7% of methane emissions in livestock agriculture appears to fit with the expected developments of meat and dairy production included in the EU Agricultural Outlook 2021-2031 (EC, 2021a). The world meat consumption is expected to grow around 1.4% per year in the period between 2021 and 2031, and the EU will likely remain a leading exporter of

5 Important non-CO_2 greenhouse gases are methane (16% of global GHG emissions), nitrous oxide (6%), and F-gases (2%). Thus, methane takes up around two thirds of anthropogenic non-CO_2 GHG emissions.

animal products. The EU meat consumption is set to decline by 4.0% between 2020 and 2030, but dairy consumption is projected to remain about the same. The dairy herd could decline due to increased productivity of dairy cows. In view of these projections, a 3.7% reduction of methane emissions in EU livestock agriculture in the BAU trend appears reasonable.

3.4 Mitigation measures

In this section, we estimate the reduction potential of different methane reduction measures in livestock agriculture based on literature study, complemented by our own calculations.

Because dairy cattle have the highest methane emissions per head (149 kg CH_4/head/year) and are more intensively farmed than meat cattle, literature focuses most on methane reduction in dairy cattle farms. While the emission per head of meat cattle is lower (53 kg CH_4/head/year), the livestock numbers are much higher than dairy cattle, causing similar total emissions. Both dairy cattle and meat cattle are responsible for roughly 40% of the livestock methane reductions. 80% of all livestock methane emissions are therefore caused by cattle.

We have included high-level livestock agriculture mitigation measures in this assessment. These measures are described in the Global Methane Assessment and in other literature sources as the main mitigation options in livestock agriculture. These are:
- healthier consumer diets;
- animal feed changes and additives;
- selective breeding;
- animal health management;
- anaerobic digestion of manure;
- other manure management.

The assessed measures are discussed separately below.

Healthier consumer diets

European consumers overconsume animal products. In a recent report, the European Public Health Alliance (EPHA) speaks of an ‘excessive consumption of energy, saturated fats, trans fats, sugar and salt, as well as low consumption of vegetables, fruits and whole grains’, which lead to various health risks. In addition, the EPHA notes that the high nutrient content of meat products along with a high intake in the EU has led to overconsumption, with high levels of red and processed meat consumption causing different types of health risks. In 2007, 50% of protein intake in the EU was of animal origin, while people consumed 70% more protein than required (EPHA, 2021). There is a large mismatch with national dietary health guidelines, which call for the reduction of consumption of animal-sourced proteins. In addition, healthier diets would also contribute to making food supply chains more sustainable (FAO, 2016).

In this assessment, we estimate the methane reduction potential of all EU citizens switching from a current average EU diet to an average EU advised diet that aligns with national dietary health guidelines (see Text box 1). This average advised diet centers around the reduction of meat and dairy consumption; it is not a vegetarian or vegan diet. We estimate a theoretical reduction potential, which reflects what could be the maximum possible methane reduction from dietary change.

Text box 1: Description of the average EU advised consumer diet based on national health guidelines

To meet the average advised EU diet, the current consumption of animal products in the EU should be reduced for all animal-based food product groups. When focussing on the products relevant from a methane emissions perspective, the largest reduction is required for the consumption of beef and pork. The current average consumption is 103 and 39 grams per person per day, respectively, which should be about halved to 50.1 and 19.5 grams per day. For dairy, the consumption should be about one quarter lower than current consumption (497.2 grams per day, instead of 641 grams per day).

Looking at national health guidelines of Member States, we find that most do not quantify advised consumption, but instead use words as ‘reduce’, ‘minimize’, and ‘exchange *a* for *b*’. In addition, the national health guidelines do not distinguish in the same way between different food groups. For meat, a distinction between different types of meat (beef, pork, chicken) is usually not made.

Several scientific articles attempt to interpret national health guidelines and compare them to current food intake in the EU. We have used the studies by Behrens et al., (2017) and Scherer et al., (2019), because these include most European countries. Both studies use the same dataset, but focus on different perspectives. Scherer et al (2019) reports animal products in a more disaggregated way, distinguishing between different animal products.

We take the following approach to estimate the difference between current calorie intake and advised calorie intake for different food categories at EU level:

1. We adopt data from Behrens et al., (2017) and Scherer et al., (2019) on current calorie intake for different food categories in different EU countries and calculate an EU average per food category.
2. The data from Behrens et al (2017) include a correction to equalise the advised calorie intake from national dietary health guidelines in the EU to the actual EU calorie intake. This correction is not useful for this report, as national health guidelines do in fact recommend a reduction of actual calorie intake. The data are therefore recalculated to obtain the original advised calorie intake data from national health guidelines.
3. An EU-level advised calorie intake is estimated by taking the weighted average of advised intake from EU countries (21 countries) with a national health guideline.
4. The difference between current EU average calorie intake and advised EU average calorie intake is calculated for the different food categories.

In Table 3, the current calorie intake, advised intake and required change are shown for different food groups, for several countries and the EU as a whole. In Text box 2, we reflect on how our results would change if we would have taken the Planetary Health diet from the EAT-Lancet Commission as the recommended diet, instead of the average EU diet from national health guidelines.

Table 3 - Current intake, advised intake and required change in intake of food products for the six largest EU countries by population and for the EU as a whole (based on Behrens et al, (2017) and Scherer et al (2019))

	Dairy	Eggs	Sea-food	Poultry	Pig	Cattle	Other meat	Plants (incl. cereals)
Germany								
Current intake (kcal)	443	49	35	58	221	35	154	2,180
Advised intake (kcal)	272	42	36	24	90	14	5	2,341
Required change (%)	-38%	-15%	+2%	-59%	-59%	-59%	-97%	+7%

	Dairy	Eggs	Sea-food	Poultry	Pig	Cattle	Other meat	Plants (incl. cereals)
Spain								
Current intake (kcal)	259	53	77	90	188	37	58	2,095
Advised intake (kcal)	176	96	61	82	76	15	8	2,093
Required change (%)	-32%	+81%	-22%	-8%	-60%	-60%	-86%	-0%
France								
Current intake (kcal)	472	48	72	91	229	72	81	2,066
Advised intake (kcal)	375	22	24	42	107	34	13	1,712
Required change (%)	-20%	-53%	-66%	-53%	-53%	-53%	-84%	-17%
Italy								
Current intake (kcal)	327	45	43	56	156	104	102	2,303
Advised intake (kcal)	252	27	26	34	94	63	14	1,925
Required change (%)	-23%	-39%	-39%	-39%	-39%	-39%	-86%	-16%
Poland								
Current intake (kcal)	322	37	29	69	271	8	107	2,174
Advised intake (kcal)	285	42	34	20	80	2	0	1,754
Required change (%)	-11%	+13%	+18%	-71%	-71%	-71%	-100%	-19%
Romania								
Current intake (kcal)	419	51	11	45	110	25	84	2,122
Advised intake (kcal)	296	59	18	77	187	42	29	2,258
Required change (%)	-29%	+16%	+70%	+70%	+70%	+70%	-66%	+6%
EU (weighted average)								
Current intake (kcal)	390	47	48	67	196	54	114	2,138
Advised intake (kcal)	293	44	33	42	95	28	9	2,078
Required change (%)	-25%	-7%	-32%	-37%	-52%	-49%	-92%	-3%

Note: Current intake is taken from Scherer et al. (2019) and advised intake is calculated from Scherer et al. (2019) using total calorie intake values from Behrens et al. (2017).

The outcome of the first part of our analysis for the measure of healthier consumer diets is that, if EU citizens would switch from an average current diet to an average advised diet, the consumption of pork would be reduced by 52%, beef by 49%, and dairy by 25%, as shown in Table 3. We assume here, for each of the food categories, that there is a linear relation between calorie intake and food intake (in kilograms). As methane emissions from the production of eggs, seafood, poultry and plant-based products are small compared to those of the production of meat and dairy, these food products are excluded from the further analysis. The category ‘other meat’ is also excluded, because it could not be attributed to one of the animal types.[6]

[6] The reason for the high required calorie reduction for ‘other meat’ is that most national health guidelines in many countries do not include this category, as a result of which the advised consumption of ‘other meat’ is set to zero for these countries in the analysis of Behrens et al., (2017) and Scherer et al., (2019)

Text box 2: Comparison with the Planetary Health diet from the EAT-Lancet Commission

For this analysis we have used the nationally recommended diets and derived an average EU recommended diet. The EAT-Lancet Commission developed a healthy diet that is based on sustainable food systems (Willett et al., 2019). If this diet were followed, the required change in average calorie intake would be: dairy -61%, eggs -60%, seafood -17%, poultry -8%, pork -92% and cattle -72%.[7] For all animal products, the required reduction in animal products consumption, and therewith the potential methane emissions reduction, would thus be larger when following the EAT-Lancet diet than when following the EU average diet from our analysis.

To calculate the relative impact of this dietary change on livestock volumes, we must take into account that a part of the EU livestock agriculture produces for external markets, as the switch by EU consumers to healthier diets does not influence livestock agriculture that produces for the export market.[8] Using a consumption-to-production ratio for each of the food categories based on the EU Agricultural Outlook[9] (EC, 2021a), we have calculated the livestock reduction in the EU as a result of healthier diets. The resulting livestock reduction is 49% for non-dairy cattle, 45% for pork, and 21% for dairy cattle. For the last value, we could only use data on milk, so the estimated reduction of milk intake has been used as a proxy for the estimation of the reduction of dairy cattle.

We assume that livestock methane emissions have a linear relationship with the livestock volume. Although methane emissions per unit of product can differ between production and livestock management systems, no differentiation has been made in this assessment. Also, we assume that meat and dairy are not substituted by an increase in consumption of other food groups, which appears acceptable since the average intake is higher than the advised intake for every food group. People will still consume enough calories and proteins after the considered dietary change (Westbroek et al., 2016).

If we decrease the number of pigs, meat cattle and dairy cattle with the numbers shown above, while keeping the emissions per animal head equal, we can estimate the overall reduction of methane emissions in the EU livestock agriculture sector between 2020 and 2030 due to healthier consumer diets to be 29 to 37%. This reduction translates to a 15 to 19% methane emission reduction in the EU as a whole.

Animal feed changes and additives

This measure revolves around adaptations related to animal feeding. The two main feed-related options are to use different feeds and to influence microbial action in the rumen to reduce methane production by means of feed additives (Buckwell & Nadeu, 2018).

Feed changes

Animal feed changes encompass the adaptation of the proportion and/or composition of animal feed. In general, forage with higher nutrient quality and digestibility causes lower methane emissions from enteric fermentation. High-quality forage such as young plants can

7 In the EAT-Lancet diet, beef and lamb are combined in one category. In our own calculation, this category is assumed to be 100% beef. There is no category similar to 'other meat' in the EAT-Lancet diet.

8 For the sake of clarity: we do include the methane emissions from production for export in our analysis.

9 The total production of pork and dairy in the EU is greater than the total consumption, so there is a net export. For pork this net export is 13% of total production, for dairy the net export is 14% of total production. The share of livestock influenced by EU diets is 87% for pigs and 86% for dairy cows. For beef there is no net export, so 100% of the livestock is assumed to be influenced by EU consumption changes.

lead to lower methane production, because these are easier to digest by ruminants. Harvesting forage when grasses are less mature reduces methane emissions as well (Yáñez-Ruiz et al., 2017). Young grass or young grass silage results in up to 30% less methane emissions, but it may also increase ammonia emissions due to the high nitrogen content.[10]

Furthermore, different types of forage can influence the methane emission level as a result of differences in chemical composition. For example, the replacement of grass silage by maize silage results in lower methane emissions, as it is more digestible. C4 grasses, i.e. grasses that produce a 4-carbon molecule during photosynthesis, create more methane emissions than C3 grasses. Also, a ruminant diet with more starch and less fibres produces less methane per kilogram of feed (Haque, 2018).

Also, grazing restrictions and optimal grazing strategies may create large methane emissions reductions in pasture-based animal farming (Llonch et al., 2017, Zubieta et al., 2021) . However, compared to indoor animal farming, it is more difficult to optimise the animal feed composition, and the potential of methane mitigation from manure management is lower. No literature was found on the potential methane reduction effects of such strategies for the EU.

Although feed changes form an immediate and sustainable way to mitigate methane emissions from ruminant livestock, literature does not provide quantitative estimations of sector-level methane reductions that can be achieved by this measure. Besides, the current average composition of animal feed in the EU is unknown, while methane emission volumes depend on the exact feed composition. Furthermore, feed changes interact with the provision of additives (see below) of which the effects are also still unknown (van Gastelen et al., 2022).

For cattle and swine a maximum methane reduction of 5% due to feed changes is estimated to be realistic in the short term. Current systems are mostly optimised for production, so a rebound effect from lowered productivity could be expected when feed changes are applied only to reduce animal methane emissions.

Feed additives

Feed additives aiming to reduce methane production by ruminants are a relatively new development. However, there is not a lot of practical experience with these yet and the range of reported methane reduction levels is broad. Many additives are likely to cause an enteric methane reduction below 10% (Hegarty et al., 2021). The potential for methane reduction has been demonstrated, but data are lacking on effectiveness for the entire livestock sector and on effectiveness in the long term. Also, there is little knowledge on the effectiveness of additives when consumed once daily or once every few days, instead of being continuously mixed into animal feed, which creates large uncertainties on the profitability of using feed additives for farmers (Hegarty et al., 2021). Finally, the application of feed additives may have negative effects on animal health and productivity (Klop, 2016). More research is needed to fill these knowledge gaps.

A promising feed additive is 3NOP, which has been approved for dairy cows in the EU. A 30% methane reduction was found to be achievable with this additive in multiple empirical studies (van Gastelen et al., 2022, Honan et al., 2021). In a data analysis of various experiments, Dijkstra et al (2018) found a 22% enteric methane emission reduction for beef cattle and a 39% reduction of dairy cattle. However, it is unrealistic to assume that this

[10] Changing the cow's diet reduces methane and nitrogen emissions, accessed on May 7th 2022.

additive will be fed to the entire EU herd within ten years' time, also considering the fact that 3NOP is not yet approved for non-dairy cattle. For this study, the methane reduction for dairy cattle using 3NOP is estimated at 5 to 20%. A lower percentage than the claimed 30% was taken, as it is not realistic for the whole herd to be fed 3NOP in this timeframe, feed additives are harder to feed to grazing animals, because there are uncertainties on long-term effectiveness, and because the purchase costs of 3NOP may form a financial barrier for farmers. Although there is a claimed potential of up to 90% for non-dairy cattle[11], we estimate the potential of 3NOP at 0 to 15% for non-dairy cattle, because it is not approved yet in the EU and meat cattle are more pasture-fed. 3NOP should also have an effect on the methane emissions of sheep, but research data are still lacking. Therefore the reduction potential of 3NOP for sheep is estimated to be 0 to 5%.

Other feed additives, such as fats, nitrates, herbs and seaweed, are less market-ready. For cattle and sheep, a maximum additional methane reduction of 5% is estimated. Although different studies indicate that methane reductions may be much higher (Honan et al., 2021), there are multiple barriers to be overcome before it can be successfully introduced. Among others, long-term effectiveness and the effects on human and animal health must be proven and a profitable business model must be developed.

By multiplying the aforementioned methane reductions of the different feed change and supplement options per animal type and summing up the totals per animal type, and assuming the same EU livestock composition, the reduction potential of feed changes for the whole livestock agriculture is estimated to be between **1 and 12%**. In this estimation, the impact of a lower EU livestock volume caused by healthier consumer diets has been taken into account. If this interaction is disregarded, the estimated reduction potential is 2 to 19%. The large uncertainty is caused by the current state of research, which is still in an early phase. Uncertainties exist on long-term effectiveness and on interactions between feed changes and additives.

Selective breeding

With selective breeding, livestock can be bred with the purpose to create a herd that naturally produces fewer methane emissions by enteric fermentation. Research shows that there are differences in methane generation between individual cows, and indicates that methane production could be reduced with breeding programs. Eckard et al. (2010) estimate that a methane reduction of 10 to 20% is possible in the case of dairy cattle by the year 2030 (Vellinga et al., 2018), and de Haas et al., (2021) find that 1% reduction per year can be reached.

Selective breeding can also be applied with the goal of increasing productivity of animals and diminished loss of animals. Although in theory higher numbers are possible, methane reduction of 0 to 5% due to increased productivity by 2030 appears realistic without putting too much strain on animal welfare and health (Llonch et al., 2017).

Overall, a methane reduction of 5 to 10% reduction for livestock as a whole between now and 2030 appears realistic, considering that breeding goals will not just be focussed on the goal of methane reduction (and will thus not result in the highest possible methane reduction).

[11] Bovaer®: Farm-wise, climate-friendly : Significantly less methane emissions from cattle

Taking into account the relative herd size and emissions per head of different types of animals in the EU, we estimate a methane reduction potential for selective breeding of **3 to 8%**. In this estimation, the impact of a lower EU livestock volume caused by healthier consumer diets has been taken into account. If this interaction is disregarded, the estimated reduction potential is 4 to 13%.

Animal health management

The overall goal of animal health management is to improve animal health and thereby the productivity of dairy cows. As a result, less livestock is needed to produce the same amount of dairy products, which may lead to the reduction of livestock volumes and related methane emissions. However, animal health management has more goals than just methane reduction, which means that it is not likely to be designed to minimise methane emissions. In addition, there is an overlap with selective breeding and animal feed changes and additives, as these may also lead to healthier animals and increased productivity.

Multiple studies mention health management as a methane reduction strategy, but the reduction potential is often not quantified. In the EU, animal health management is already relatively sophisticated, so the potential of this measure is lower than in the rest of the world (Hristov et al., 2013). Due to the absence of estimations in literature, we assume a methane reduction potential of **0 to 3%** for all animals. In this estimation, the impact of a lower EU livestock volume caused by healthier consumer diets has been taken into account. If this interaction is disregarded, the estimated reduction potential is 0 to 5%.

Anaerobic digestion of manure

With the anaerobic digestion of manure in digestion units, manure could be converted to biogas, consisting of about 60% methane and 40% carbon dioxide. This biogas can be upgraded to biomethane by removal of carbon dioxide and other gases, creating a gas composition that is similar to that of natural gas. After anaerobic digestion, solid matter called 'digestate' remains, which could be used as a natural fertiliser. The sooner manure is digested, the lower the methane emissions from manure storage. However, methane emissions are also released from the digestate, and methane leakages occur during the digestion process. Nisbet et al (2020) found methane leakages of about 4.6% of the (bio)methane production of the digester , while Gudmundsson et al (2021) measured an average methane leakage rate in Danish biogas plants of 4%.

In lab-based analyses, (VanderZaag et al., 2018) found a methane reduction potential of anaerobic digestion of manure of 59%, compared to conventional manure storage (without use of manure management methods to reduce methane emissions).[12] Although it is uncertain to what degree this percentage is representative of the average manure digestion process in the EU, we have not found other estimations in literature. Therefore, we adopt this value. To estimate the reduction potential on a sectoral level, we must consider that the growth of EU biogas and biomethane production between 2020 and 2030 will be limited by the availability of capital, labour and time to build new digesters. Also, livestock farmers must be willing to engage in a new kind of business, along with the regulations that govern the development and operation of a manure digestion unit.

12 The feedstock mix of the digesters in the analyses contained at least 50% manure (by volume), complemented by residues from the food processing industry (VanderZaag et al., 2018).

To estimate the potential growth of biogas/biomethane production from manure in the EU between 2020 and 2030, we take into account the EU's 'REPowerEU' plan, which was presented in May 2022 and aims to make Europe independent from Russian natural gas before 2030. One of the key pillars in this plan is to increase the production capacity of biomethane and biogas in the EU. The ambition is to produce 35 billion cubic metres (bcm) of biomethane per year by 2030.[13,14] Given that the biogas/biomethane production in the EU in 2020 was around 16 bcm (190 TWh) in 2020 [15], this would mean a doubling of current production.

The current share of manure as a feedstock for biogas production in Europe is about 33% (Brémond et al., 2021). Assuming the same share in 2030 and a total biogas/biomethane production capacity of 35 bcm/year in 2030, 11.6 bcm of manure-based biogas/biomethane would be produced in 2030. For 2020, this can be estimated at 5.3 bcm (33% times 16 bcm). This means that biogas/biomethane production from manure would increase by 6.3 bcm between 2020 and 2030. Next, we have calculated that this increase would lead to 37% of available manure that is currently not digested entering digestion units by 2030 [16]. Finally, considering that the manure-related methane emissions are only 18% of the livestock agriculture emissions (EEA, 2021), we estimate that the methane reduction potential of this measure would be **2 to 3%** of sectoral emissions between 2020 and 2030.[17] In this estimation, the impact of a lower EU livestock volume caused by healthier consumer diets has been taken into account. If this interaction is disregarded, the estimated reduction potential is 3 to 5%.

Although biomethane from manure may substitute natural gas, along with associated methane emissions in the natural gas supply chain, the estimated methane reduction potential of anaerobic digestion of manure in itself is limited, because of production capacity expansion limits, remaining methane emissions when anaerobic digestion is applied, and the relatively small share of manure-based methane emissions in livestock agriculture.

Other manure management

There are a lot of detailed measures, other than anaerobic digestion of manure, which could be deployed to reduce methane emissions from manure: the decrease of manure storage time, storage of manure at rest, cooling of manure, solid-liquid separation, better manure storage covering, composting of manure, a switch to dry manure management, and manure acidification. Hilhorst et al., (2002) provides an overview of methane mitigation options from manure. The methane reduction potential of well-covered manure storage is estimated by the authors at about 50%. Cooling of slurry (wet manure) can reduce methane and ammonia emissions by 30 to 50%, as shown in a Dutch pilot. Pig slurry at rest creates

13 REPowerEU (europa.eu)

14 In the REPowerEU plan it is not specified which biomass feedstocks are to be used. The plan does not assume an increase of EU livestock. We have calculated that the current availability of manure is sufficiently large to allow for an increased use of manure for anaerobic digestion due to this plan, as described below.

15 Scaling Up Biomethane in Te European Union, preentation 7 December 2021

16 This means that the EU livestock volume is not increased to meet the higher demand from digesters. For the calculation, we have used that the current EU manure production is 1200 Mt wet weight (Brémond et al., 2021) and a manure-to-biomethane-yield of 53.75 Mt/bcm.

17 Methane leaks from the digestion units were not included in the calculation, but given that they are in the order of 5% of (bio)methane production (Nisbet et al., 2020), their inclusion would not lead to a lower estimated reduction percentage.

fewer methane emissions than agitated slurry. The methane emissions of slurry at rest could be about 25% lower than those of thoroughly mixed slurry. Furthermore, VanderZaag et al. (2018) estimate that solid-liquid separation of animal excrements could result in 81% lower methane emissions than raw manure.

We estimate the potential methane reduction from other manure management methods at 25 to 50%. Taking into account that the share of methane emissions from manure was 18% of EU livestock agriculture methane emissions in 2019 (EEA, 2021), and assuming that manure management is carried out in the entire EU livestock sector, we arrive at an estimated theoretical reduction potential of other manure management of **2 to 4%** of sectoral methane emissions. In this estimation, the impact of both a lower EU livestock volume caused by healthier consumer diets and lower manure production due to anaerobic digestion of manure have been taken into account. If this interaction is disregarded, the estimated reduction potential is 5 to 9%.

3.5 Methane reduction potential

The estimations of the methane reduction potential of different mitigation measures in the EU livestock agriculture sector between 2020 and 2030, which are described in the previous section, are summarised in Table 4. In the shown values of individual measures, the effect of a lower livestock volume resulting from a consumer switch to healthier diets (as covered by the measure 'healthier consumer diets') has been taken into account.

Table 4 – EU methane reduction potential in livestock agriculture between 2020 and 2030

	Estimation (low)	Estimation (high)
Individual measures*		
Healthier consumer diets	30%	38%
Animal feed changes and additives	1%	12%
Selective breeding	3%	8%
Animal health management	0%	3%
Anaerobic digestion of manure	2%	3%
Other manure management	2%	4%
Sector-level		
Total reduction percentage	38%	67%
Total reduction volume (Mt/year)	2.9	5.2

*: Reduction potential of individual measures relative to sector emissions in 2030. Overlap between measures has been considered when estimating reduction percentages of the measures.

The total (theoretical) methane reduction potential in EU livestock agriculture has been estimated at 38 to 67% (2.9 to 5.2 Mt/year). The high contribution of healthier consumer diets stands out. This high contribution is caused by the large difference between current and advised consumer diets and high impact of this measure through smaller livestock volumes needed to feed Europeans. Other measures have a much smaller estimated contribution, because these are still under development (animal feed changes and additives, selective breeding), or only affect emissions from manure (anaerobic digestion, other manure management). The uncertain effect of measures, especially animal feed changes and additives, leads to a wide range of the total estimated methane reduction potential.

4 Reduction potential in the energy sector

4.1 Introduction

In this chapter we estimate the potential for methane emission reductions in the energy sector within the EU between 2020 and 2030. Although 75 to 90% of methane emissions resulting from the EU consumption of fossil energy occur outside the EU (EC, 2020c), EU methane reduction targets would only apply to the geographical area of the EU. Therefore, we consider only EU emissions that are released within the EU in the main assessment. Methane emissions that are associated with the EU consumption of fossil fuels, but which are released outside the EU (during production and export to the EU), are estimated in a separate calculation.

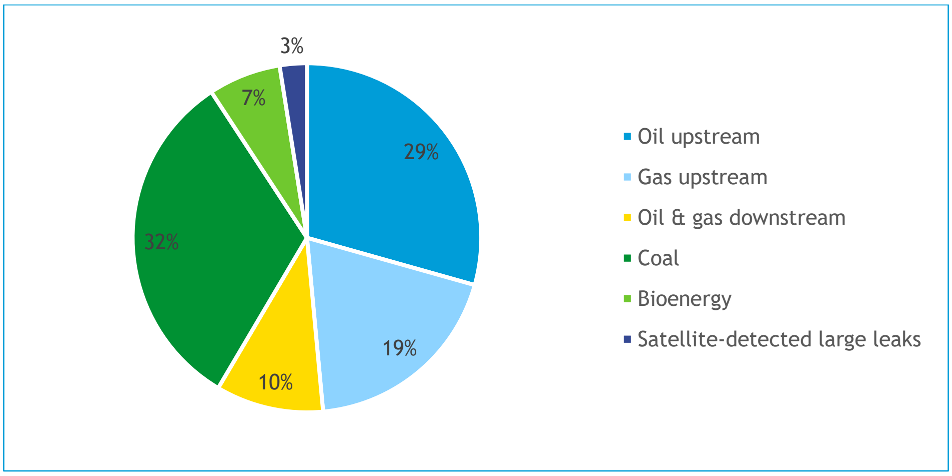
In Section 4.2, we describe the origins of energy-related methane emissions and we present both the domestic emissions in the EU and the emissions related to fossil fuels imported into the EU. In Section 4.3, a business-as-usual trend for these emissions up to 2030 is established. In Section 4.4, we assess possible mitigation measures and their potential contribution to methane emission reductions. In Section 4.5, we elaborate on measures directed at emissions from imported fossil fuels. In Section 4.6, the overall methane emission reduction potential in the energy sector is presented.

4.2 Current methane emissions in the energy sector

Origins of methane emissions in the energy sector

According to the IEA Global Methane Tracker (IEA, 2022d), total global methane emissions in the energy sector amounted to 135.2 Mt in 2021. The different origins of these energy-related methane emissions and their shares in the total emissions are shown in Figure 4. This figure points out that the majority of methane emissions originate from the production and use of fossil fuels. Methane is the main component of natural gas. It is released into the atmosphere during several processes related to the extraction, storage and transport of fossil fuels (Cassidy, 2022). More than 75% of methane emissions related to oil and gas operations originate from upstream activities like production (IEA). For instance, natural gas dissipates during the extraction processes of coal and crude oil. If it cannot be captured and used — or if this is just not cost-effective to do so — the gas is released into the atmosphere in a controlled way, which is called venting. Alternatively, it can be burnt in the open air (flaring), which turns the methane into carbon dioxide, a less potent greenhouse gas.

Figure 4 – Sources of global methane emissions in the energy sector in 2021



Note: 'Upstream' includes production and storage on location; 'downstream' transport, conversion, distribution and use.

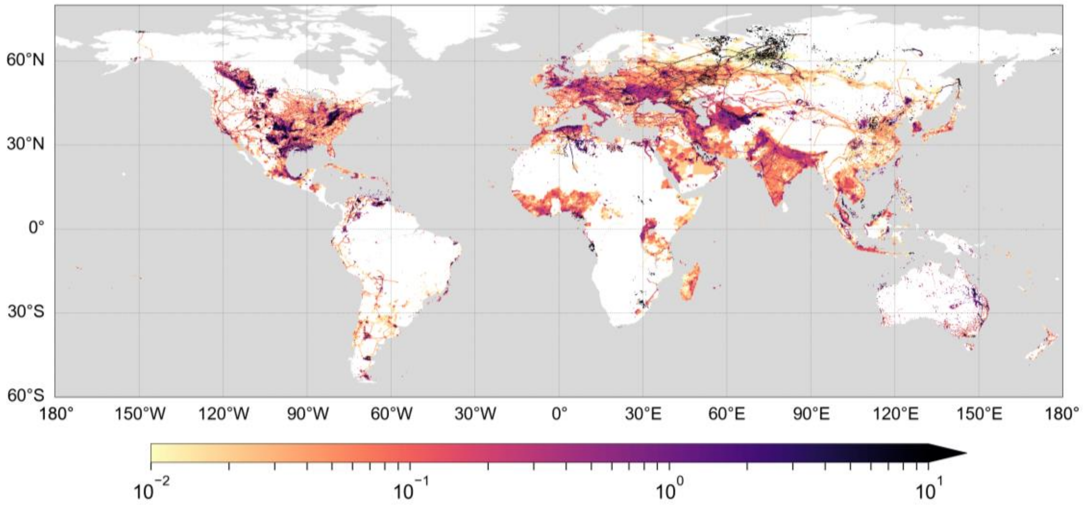
Source: (IEA, 2022a)

Methane can also leak from pipelines or other infrastructure linked to transport, storage, processing or distribution to end users. This not only happens in oil production, where natural gas is considered a by-product, but also in natural gas production itself. As methane is a colourless and odourless gas, leaks are not easily detected on the ground. In Figure 5, a map is shown of all global methane emissions related to the exploitation of oil, coal and gas in 2016.

Note that methane emissions from fossil fuel production are partly dependent on the market price of natural gas. As indicated above, natural gas is being vented especially when it is not cost-effective to capture and sell it. Also, detecting and repairing leaks becomes economically attractive as soon as the revenues from the additional gas sales are higher than the repair costs. Yet, according to the IEA, many options to reduce methane emissions from oil and gas production have not yet been realised even though gas market prices make it profitable to do so. Possible reasons for this are the volatility of the gas price, which means higher prices cannot be assumed to last for a long period of time, combined with the fact that investment costs are recovered only after the investments have been made. Based on the average gas price from 2017 to 2021, globally 32.5 Mt of methane could be captured by abatement technologies at net negative costs, representing 41% of all global emissions from oil and gas operations (compared to an overall 71% of technical abatement potential) (IEA, 2022d).
Finally, the consumption of fossil energy can cause methane emissions through incomplete combustion of natural gas in engines (methane slip). Also the process of flaring can involve incomplete combustion and hence emissions of methane to the atmosphere, next to the CO_2 emissions from flaring (IEA, 2022d).

As we can see in Figure 4, apart from fossil fuels, the production of bioenergy is also responsible for a share (7%) of the global energy-related methane emissions. These emissions are mainly related to fugitive methane emissions in biogas production facilities (digesters), for instance from the digestate storage tank, and to incomplete combustion in biogas and biomethane-fired gas engines (IEA Bioenergy, 2017).

Figure 5 – Global methane emissions from oil, coal and gas exploitation



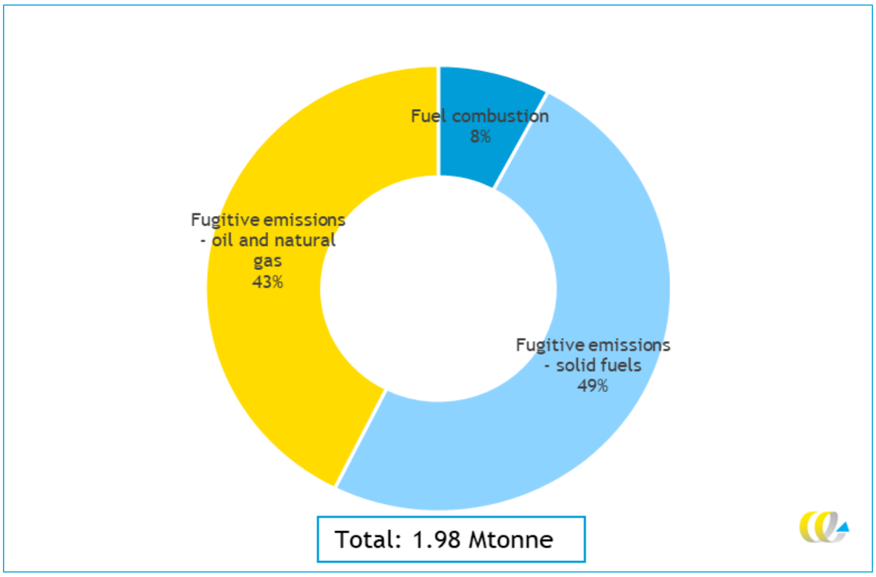
Source: Cassidy, (2022).

Note: The map makes use of a logarithmic scale, and a unit of tonnes of CH_4 per year per km^2. The map was created for NASA's Carbon Monitoring System (CMS) based on publicly available data from 2016.

Current methane emissions

In Figure 6, the total domestic methane emissions from the energy sector in the EU in 2019 are shown. It shows that the majority of methane emissions is fugitive, which means they originate from leaking and venting and flaring. Only a small share (8%) is related to fuel combustion.

Figure 6 - Shares of methane sources in the energy sector in the EU in 2019



Source: (EEA, 2021).

In this study we also look at emissions that occur outside the EU but are related to the production of fossil fuels consumed within the EU. In Table 5, the EU oil, gas and coal imports from the rest of the world in 2020 are shown, together with the methane emissions related to those imports.

Table 5 - Current fossil fuel imports by the EU and related methane emissions

Fossil fuel	Imports by EU (2020) (mtoe) [a]	Methane emissions of imports (2020) (Mt CH_4)
Petroleum oil	436	7.3[b]
Natural gas	229	2.7[b]
Solid fossil fuels (mainly coal)	77	0.4
Total	**742**	**10.4**

Notes: [a]: Eurostat, (2022); [b]: IEA, (2022c); [c]: Methane emissions of imported coal were estimated using the ratio of total global coal production (IEA, 2020) and total methane emissions from coal (IEA, 2022c).

If we add the domestic EU emissions from Figure 6 to the imported emissions from Table 5, we find an estimated EU total of 12.4 Mt/year of current annual methane emissions from the energy sector, which takes into account both domestic EU emissions and upstream emissions associated with fossil energy imported into the EU.

4.3 Business-as-usual trend

In order to establish a business-as-usual (BAU) trend for methane emissions in the energy sector, we make use of the baseline projections in the EU Reference Scenario 2020 (EC, 2021b). This scenario serves as the baseline for, amongst others, the EU's climate policy scenarios. It considers the policy framework that was in place in 2020, without taking into account any policy measures that were not yet in force at that time. This means that for instance the impact of the Commission's proposal to reduce methane emissions from the energy sector (EC, 2021c), which was presented in December 2021 but still has to be assessed by the EU's co-legislators, is not included in the BAU trend.

For the domestic EU methane emissions in the energy sector we make use of the non-CO_2 greenhouse gas emission projections of the EU Reference Scenario 2020 (EC, 2021b) [18]. For 2030, this yields a methane emission level of around 1.6 Mt. This is 20% lower than the current emission level of 2.0 Mt, as shown in Figure 6. This originates from an expected increase of renewable energy production and use in the EU, as well as energy efficiency improvements in energy production, processing and end-use installations.

For the emissions related to the production of fossil fuels imported into the EU, we look at the imports in 2030 projected in the EU Reference Scenario. In the BAU trend we assume the methane intensity of the fossil fuel imports to remain at the 2020 level, as there are no additional policy measures in place to reduce methane emissions. Note that this way we implicitly assume that the natural gas price remains at the 2020 level. This is because methane emissions from oil and gas production partly depend on the gas price, as companies will capture and sell more methane when the gas price is higher. Developments in early 2022 illustrate that the gas price can be very volatile, but in order to construct a coherent baseline scenario we choose to keep both the methane intensity of the fossil fuel imports and the gas price constant towards 2030. The projected EU imports of fossil fuels in 2030 and the related methane emissions are presented in Table 6.

[18] We do not consider the categories in Figure 87 on p. 114 of the Reference Scenario Report for which the contributions of methane (CH_4) and nitrous oxide (N_2O) have been combined, as the methane contribution cannot be isolated.

Table 6 - Projected fossil fuel imports in the EU in 2030 and related methane emissions (EC, 2021c)

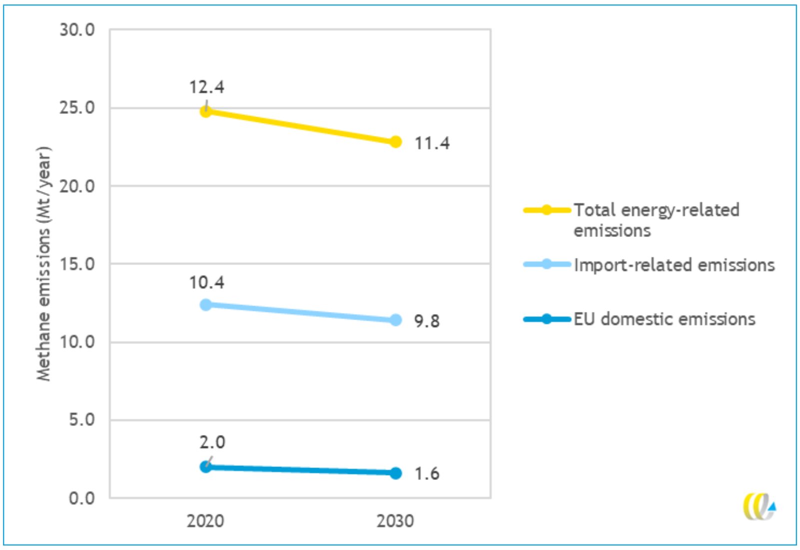
Fossil fuel	Projected net imports in the EU in 2030 (Mtoe) and change compared to 2020 (%)	Methane emissions of imports (Mt CH_4)
Petroleum oil	413 (-5.3%)	6.9
Natural gas	230 (+0.4%)	2.7
Solid fossil fuels (mainly coal)	44 (-42.9%)	0.2
Total	**687**	**9.8**

Note: For the methane emissions the methane intensities following from Table 5 are applied.

From these data we conclude that in the business-as-usual scenario the methane emissions related to fossil fuels imported by the EU decrease only slightly towards 2030.

In Figure 7 the resulting business-as-usual trends are illustrated for both domestic and import-related methane emissions corresponding to the EU energy sector.

Figure 7 - Business-as-usual trend for methane emissions related to the EU energy sector



4.4 Mitigation measures (EU domestic emissions)

In this section we present possible mitigation measures that could reduce the methane emissions in the EU energy sector. Below, for each measure we first present a brief description of the measure, after which we estimate the potential reduction percentage (low and high estimate) of the measure with regard to the sector-level emissions. In this estimation we include possible interactions between measures. We indicate how we used information from literature to arrive at our estimations.

Our focus lies on measures that can be taken for the EU domestically, because in this study we investigate the methane reduction potential within the EU. Since we also distinguish between domestic EU methane emissions and import-related emissions in this chapter, we discuss in Section 4.5 what measures are available to reduce import-related emissions. The energy sector mitigation measures included in this assessment, which are discussed separately below, are:

- monitoring, reporting and verification (MRV) obligation for oil and gas operators;
- methane emission standards for oil and gas sector;
- leak detection and repair (LDAR);
- replacement of existing devices;
- instalment of new devices;
- reduction of venting and flaring in oil and gas production;
- coal mine methane management.

MRV obligation for oil and gas operators

In the context of mitigation of methane emissions, monitoring, reporting and verification (MRV) involves the legal obligation for operators of assets related to fossil fuel production (wells, mines, pipelines, LNG terminals, etc.) to monitor and report the methane emissions of their operations, and to have those emissions verified by an accredited auditor.

MRV is in the first place an important precondition for legal obligations to reduce methane emissions. Such obligations will be hard to enforce if no sound MRV framework is in place. Therefore, in other sectors (e.g. maritime shipping) MRV has been used as a stepping stone towards greenhouse gas emission reduction measures, allowing operators some time to prepare their measurement and information systems and to map their current emissions.

In December 2021, the European Commission presented a proposal which includes MRV obligations for EU-based fossil fuel operators, based on the existing, voluntary monitoring and reporting system of the Oil and Gas Methane Partnership (OGMP)[19] (EC, 2021c).

Strictly speaking, an MRV obligation is not a methane emission mitigation measure in itself, as it does not oblige operators to reduce their emissions. However, insight in current emissions can be an incentive to take methane abatement actions even without the legal obligation to do so. This is especially true in case operators can make a profit with methane abatement actions. Also, by taking such actions, operators can anticipate reduction obligations that are expected in a later phase.

As MRV does not involve an obligation to reduce methane emissions, the measure does not have a guaranteed reduction potential. We could estimate this for instance by assuming this is equal to the reduction potential from leaks that can be repaired relatively easily. However, the current reality is that a significant share of methane emissions that could be prevented at net negative costs is not abated. As stated above, this may be caused by the volatile character of the gas price and the fact that costs are recovered only after investments have been made. For these reasons, we put the lower estimate of the MRV reduction potential at 0%.

Using the data of the IEA Methane Tracker Data Explorer (IEA, 2022d) for all EU Member States, we find that in 2021 the technical abatement potential at net negative costs was 28.8% of oil and gas emissions and 5.9% of all methane emissions in the energy sector. Note that these data were obtained based on the average gas price from 2017 to 2020. At current

[19] This partnership has been set up by the United Nations Environment Programme (2018) and the Climate and Clean Air Coalition (CCAC) in 2014.

(Spring 2022) prices[20], the technical abatement that could be realised at net negative costs is probably significantly higher.
Because the mitigation actions of oil and gas operators due to a MRV obligation entail technical measures that we consider individually below, the found reduction potential of 5.9% is not included in the further analysis.

Methane emission standards for oil and gas sector

A mandatory standard for a maximum methane intensity related to oil and gas production in the EU could be a logical next step once an MRV framework has been established. The European Commission did not include such a standard in its proposal to reduce methane emissions in the energy sector, but instead included more concrete technical measures such as leak detection and repair, which we assess below. Because a methane emission standard would lead to the execution of technical measures, we do not estimate a reduction percentage here, in order to prevent an overestimation of the methane reduction potential in the EU energy sector.

The emission reduction that is achieved by implementing a methane emission standard obviously depends on the methane intensity value that is prescribed by the standard.
The current methane intensity associated with oil and gas production varies widely among countries, with Norway and the Netherlands performing best: These countries have an average methane intensity that is more than 100 times lower than those of Turkmenistan and Venezuela, the worst performers (IEA, 2022a). This suggests that a standard in the form of a maximum methane intensity has a limited potential within the EU, but a high potential if it would be applied to importers of fossil fuels (see Section 4.5).

Technical abatement measures in the oil and gas sector

A methane emissions standard does not prescribe the measures operators should take to lower the emissions of their operations. In case a methane emissions standard is not politically or practically feasible, certain technical abatement measures could be imposed on operators as an alternative. This is the strategy the European Commission has chosen in the methane reduction regulation (EC, 2021c), which includes an obligation for operators to carry out a leak detection and repair (LDAR) survey (Art. 14),to limit venting and flaring (Art. 15-17), and to mitigate methane emissions from inactive wells (Art. 18).

From a policymaking point of view, it is not recommendable to combine a legal methane emissions standard with obligations to apply certain technical abatement measures. This is because it is very complex to align the expected reduction from the technical measures with the overall emissions standard. If operators have to steer their efforts toward the measures and the emission standard at the same time, there is a high chance they do not achieve emission reduction in the most cost effective way. Therefore we consider a focus on mandatory technical abatement measures to be an alternative for a generic methane emission standard.

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[20] There are many different natural gas prices depending on the type of gas and the term of purchase, but for instance the Dutch TTF price, key for EU natural gas trade, currently is about five times as high as the average during 2017 to 2020. See trading economics eu-natural-gas : Dutch TTF Gas is a leading European benchmark price. Contracts are for physical delivery through the transfer of rights in respect of Natural Gas at the Title Transfer Facility (TTF) Virtual Trading Point, operated by Gasunie Transport Services (GTS), the transmission system operator in the Netherlands

Below we briefly describe the most important (categories of) technical measures in the oil and gas sector. In Table 7 estimations of the reduction potential of three of these measures are presented for the EU Member States and the EU as a whole, based on the IEA Methane Tracker Data (IEA, 2022d).

Leak detection and repair (LDAR)

When leak detection and repair programmes are mandatory this can yield significant methane emission reductions from oil and gas operations. The effectiveness of LDAR strongly depends on the frequency of the LDAR programme (US EPA, 2016). In the proposal of the European Commission on methane reductions in the energy sector, operators are obliged to carry out leak detection surveys at least every three months, using devices that can detect leaks of 500 parts per million or more of methane. These leaks then have to be repaired within a period of five days from detection (EC, 2021c). The IEA distinguishes between upstream and downstream LDAR, noticing that upstream LDAR is more cost effective as it takes more time to inspect compressors along transport pipelines than at a production site. To obtain the estimates of the LDAR reduction potential shown in Table 7, the IEA has included varying frequencies of LDAR programmes (from monthly to yearly) in its analysis (IEA, 2022d).

Replacement of existing devices

Many devices that are currently used in oil and gas production, such as pumps, compressors and controllers, release a small amount of natural gas (and hence methane) during normal operations. This is because their functioning is based on pneumatics, with natural gas as the power source. Devices that normally release relatively high amounts of natural gas ('high-bleed') can be replaced by devices with low emission levels ('low-bleed'), but also by devices using ambient air instead of natural gas for the pneumatics or by electric devices, which eliminates the methane emissions entirely (IEA, 2022d).

Instalment of new devices

In addition to replacing existing devices, new devices could be added at different places along the oil and gas supply chains to reduce methane emissions. These devices capture methane that would otherwise be released to prevent explosions, or that would escape when liquids need to be removed. Also, flares could be applied to burn natural gas in case it cannot be captured. However this still yields emissions of CO_2, and small emissions of methane through incomplete combustion (IEA, 2022d).

Table 7 – Methane reduction potential from technical abatement measures for EU Member States and the EU as a whole, in kt CH_4

	Leak detection & repair	Replacement of existing devices	Installation of new devices	Other	Total
Denmark	4.1	1.0	9.8	0.5	**15.3**
Estonia	0.6	0.1	0.0	0.2	**0.9**
France	35.0	6.3	1.7	6.8	**49.8**
Germany	77.9	18.4	7.0	14.6	**117.9**
Italy	82.9	22.6	7.5	15.4	**128.4**
Netherlands	2.3	0.7	0.8	0.3	**4.0**
Poland	26.0	10.6	4.1	4.2	**44.9**
Romania	25.8	23.6	8.0	2.8	**60.1**
Slovenia	4.2	0.9	2.1	1.4	**8.6**

	Leak detection & repair	Replacement of existing devices	Installation of new devices	Other	Total
Other EU Member States*	0.0	0.0	0.0	0.0	**0.0**
Total EU	**258.8**	**84.2**	**40.9**	**46.1**	**430.0**
As % of sector emissions	**9.0%**	**2.9%**	**1.4%**	**1.6%**	**15.0%**

*: The IEA reports no reduction potential for other EU countries. However, some of these countries do have oil or gas production systems and all of them have gas pipelines.

Source: (IEA, 2022a).

From Table 7 it follows that Leak Detection and Repair (LDAR) is the most potent of the three technical abatement measures assessed by the IEA. It is responsible for 60% of the reduction potential of these measures.
For our assessment, we estimate the sectoral reduction potential at 5 to 9% for LDAR, 2 to 3% for the replacement of existing devices, and 1 to 1.5% for the instalment of new devices.

Reduction of venting and flaring in oil and gas production

Venting and flaring of natural gas at oil and gas production partly occurs as a routine process, to release gas that is accumulating in the production system and is not captured and utilised. It also happens partly unintentionally, as a result of malfunctioning of production equipment. Also, venting and/or flaring can be necessary for repair and maintenance objectives or in cases of emergency (EC, 2021c).

As venting involves the direct release of methane into the atmosphere, a first step to reduce methane emissions is to allow venting only when flaring is not technically possible or is compromising the safety of operations or personnel. Furthermore, venting/flaring can be prohibited as a routine process, and only be allowed if it is unavoidable for reasons of safety or strictly necessary for the repair or maintenance of equipment, as proposed by the European Commission (EC, 2021c) and as promoted by initiatives like the World Bank's Zero Routine Flaring by 2030 (ZRF) initiative (World Bank, ongoing).

Flaring leads to the conversion of methane into CO_2, but due to partial combustion some methane is still directly released into the atmosphere. In 2020, the global average combustion efficiency of flaring was about 92%, leading to around 8 Mt of methane emissions (IEA, 2021). In theory, when conditions are optimal and best available techniques are being applied, the combustion rate can be as high as 99% (IEA, 2021). Therefore, an additional legal measure that could be adopted is an efficiency requirement for the flaring process and/or mandatory use of certain equipment that increases this efficiency, for instance a pilot burner (EC, 2021c).

Five countries (Russia, Iraq, Iran, the USA and Algeria) were responsible for more than half of all flared volumes of natural gas in 2020, whereas Europe accounted for only 1.1% of all flaring emissions (IEA, 2021). Eliminating all non-emergency flaring globally would lead to a 90% decrease in flared volumes (IEA, 2021), but the potential within the EU is much lower as routine flaring is already practised to a far lesser extent. This is partly because the flared emissions are subject to the EU Emissions Trading System (EU ETS): Oil and gas companies must submit ETS allowances for all flared CO_2 emissions (ABLE, 2016). According to the IEA Methane Tracker, the reduction potential of ending routine venting and flaring is only 42 kt CH_4/year for all EU Member States, corresponding to 1.5% of energy sector methane emissions (IEA, 2022d).

Specific reduction potentials of changing from venting to flaring where possible or of a minimum efficiency requirement for the flaring process are not available from literature. For our assessment, we estimate the sectoral reduction potential at 1 to 1.5%.

Coal mine methane management

The methane reduction measures that have been presented so far mostly apply to oil and gas operations. Emissions from coal mines, however, represent a significant share of the EU's methane emissions in the energy sector. According to the EU's GHG inventory data, coal was responsible for 31% of energy-related methane emissions in 2019, compared to 33% for oil and gas combined (EC, 2021c).

Both surface and underground mines cause methane emissions. In 2019, operating surface mines were estimated to be responsible for 166 kt of CH_4, compared to 828 kt from underground mines (EC, 2021c). Due to their diffuse nature, however, emissions from surface mines are hard to measure. Furthermore, mines that have been closed and abandoned continue to emit methane, at about 40% of their original emission level after ten years (EC, 2021c). As most EU Member States are phasing out coal production, emissions from abandoned mines are projected to grow in the coming years if not abated.

A main mitigation option for underground mines, both operating and abandoned, consists of phasing out venting and flaring. This now happens mostly at certain well-defined point sources, such as ventilation shafts or vents or degasification systems (EC, 2021c). For abandoned mines, there is also the option of flooding the entire mine. This will completely eliminate methane emissions, but comes with environmental risks (EC, 2021c). On the other hand, flooded coal mines may be able to deliver a renewable source of heat to nearby buildings (Limb, 2022).

In general, mitigating methane emissions from coal mines is more challenging than from oil and gas production (IEA, 2022b), although large reduction steps could be taken by means of mitigation efforts at high methane-emitting coal mines[21]. As the use of coal leads to higher GHG emissions than oil or natural gas, the EU tends to reduce coal consumption at a higher pace than other fossil fuels, and several EU Member States have committed to a complete phase-out of coal use by 2030 (Euractiv, 2019, Plumer & Friedman, 2021). Although in practice a decrease in coal consumption may prove the most important driver of reduction of coal-related methane emissions, measures to prevent venting and flaring also have a significant reduction potential. In abandoned mines, to make sure that the phase-out of coal production does not lead to the continuation of methane emissions, but also in operating mines. This is because technical options to reduce venting and flaring have been implemented at several mines, but are still far from being standard practice (IEA, 2022b). With the installation of drainage equipment in underground coal mines, methane can be captured and for exampled be utilised to generate electricity. However, a barrier to the realisation of electricity production units at coal mines is formed by the high EU ETS costs related to the CO_2 emissions resulting from methane combustion.
The EC proposal on methane reduction in the energy sector includes a ban on flaring and venting from underground thermal coal mines, as well as an obligation to limit flaring and venting from metallurgical (coking) coal mines.

[21] The ten largest methane-emitting coal mines, located in Poland, were responsible for 282 kt of methane in 2020 (ESA Observing the Earth : Methane detected over Poland's coal mines), which is roughly equal to 30% of total (domestic) EU coal methane emissions.

There are no exact data on the reduction potential of methane emissions from EU coal mines, especially not for surface mines and abandoned mines. Given the above remarks, however, emissions from operating underground mines are probably significant, as measures to abate them are not widely applied yet. We estimate that mandatory phasing out of venting and flaring could yield a reduction of 25% (low estimate) to 75% (high estimate) of the reported 828 kt of annual emissions. This corresponds to 7 and 22%, respectively, of total energy-related methane emissions according to the IEA (2022d).

4.5 Measures directed at emissions from imported fossil fuels

In this section we assess to what extent the measures presented above could (also) be applied to importers of fossil fuels into the EU and whether other measures to address imported methane emissions are possible.

An MRV obligation could also be imposed on importers of fossil fuels. The proposal of the European Commission directed at reducing methane emissions from the energy sector does include a general information obligation on methane emissions for importers of fossil energy from outside the EU, which is less detailed than the MRV obligation for EU operators (EC, 2021c). The Commission has announced that more specific regulations may follow once more information on methane emissions is available.

If all oil and gas producing countries would realise the methane intensity of Norway (< 0.01 kg CH_4/GJ), global methane emissions related to oil and gas production would be reduced by more than 90% (IEA, 2022a). Thus, assuming that the methane intensity related to the EU's oil and gas imports does not differ significantly from the global average [22], a 90% reduction potential of the associated methane emissions seems technically possible. Of course, Norway has a GDP/capita largely exceeding that of most oil and gas producing countries, which means the realistic potential is lower due to high investments needed in the exporting countries, at least in the short-term.

Taking into account that 96% of import-related methane emissions in 2030 is estimated to originate from the oil and gas sector, and acknowledging that it may not be possible to realise the same methane intensity as of Norway and that some countries will not carry out mitigation measures, we estimate the impact of the methane emission standards for oil and gas producers on methane emissions related to fossil fuel imports to be 48 to 87%, or 4.7 to 8.5 Mt/year. This reduction percentage is not included in the reduction scenarios in Chapter 6, because these non-EU emissions do not count towards an EU methane reduction target.

Methane border tax for fossil energy imports

In July 2021, the European Commission has proposed a Carbon Border Adjustment Mechanism (CBAM), which introduces a levy on certain goods imported into the EU based on the CO_2 emissions associated with their production (EC, 2021d).

Theoretically, a Methane Border Adjustment Mechanism (MBAM) could be designed analogously for fossil fuels that are imported by the EU. However, a major difference between carbon and methane emissions is that within the EU an effective CO_2 price exists

[22] This assumption seems plausible as the EU imports are a mix of imports from countries with a relatively high methane emission intensity, such as Russia (0.29 kg/GJ) and Algeria (0.43 kg/GJ) and countries with a relatively low methane emission intensity, such as Norway (< 0.01 kg/GJ) and Saudi Arabia (0.11 kg/GJ) (IEA, 2022a) (Eurostat, 2022).

by means of the EU Emissions Trading System (EU ETS). Without such a CO_2 price, the CBAM would certainly not be allowed under World Trading Organization (WTO) rules as it would violate the principle of national treatment (Townsend, 2021).

This means that a MBAM would not be viable unless an effective methane price would be established within the EU. This could for instance be done by extending the ETS to cover methane emissions. However, as anthropogenic methane sources are very different in origin and character, the inclusion of methane in the ETS or otherwise introducing a single methane price covering all sectors would be very complex to implement. For example, livestock is currently not in the ETS, measurement of methane emissions in livestock agriculture will be difficult and it will put an additional administrative burden on farmers. Starting with only one sector such as energy production might be possible, but the establishment of a methane price within the EU remains a precondition. Therefore, in the current context an MBAM is not feasible in the near future and no mitigation potential of this measure can be estimated at this point.

4.6 Methane reduction potential

The estimations of the methane reduction potential of the different mitigation measures in the EU energy sector between 2020 and 2030, which are described in Section 4.4, are summarised in Table 8.

Table 8 - EU methane reduction potential in the energy sector between 2020 and 2030 (domestic emissions)

	Estimation (low)	Estimation (high)
Individual measures*		
Leak detection and repair (LDAR)	5%	9%
Replacement of existing devices	2%	3%
Instalment of new devices	1%	1.5%
Reduction of venting and flaring in oil and gas production	1%	1.5%
Coal mine methane management	7%	22%
Sector		
Total reduction percentage	**16%**	**37%**
Total reduction volume (Mt/year)	**0.3**	**0.6**

*: Reduction potential of individual measures relative to sector emissions in 2030. Overlap between measures has been considered when estimating reduction percentages of the measures.

The total methane reduction potential in the EU energy sector is estimated at 16 to 37%. This reduction potential is quite low compared to the ones estimated for the livestock agriculture and waste sectors. This is because more than 80% of the methane emissions that are associated with fossil fuels consumption in the EU are related to the production of imported fuels, which do not count as EU emissions and are therefore not considered in the estimation of the EU methane reduction potential.
Leak detection and repair (LDAR) and coal mine methane management are estimated to have the largest contribution to methane reduction in the energy sector within the EU. There are substantial uncertainties in the effectiveness of these two measures, which explains the large uncertainty range for the EU methane reduction potential in the energy sector.

With a monitoring, reporting and verification (MRV) obligation, fossil fuel operators could already be induced to reduce methane emissions, but they will do so by taking technical measures that are included in this assessment. The same holds true for methane emission standards. To prevent double-counting, these measures have not been included in this quantitative assessment.

When considering the methane emissions related to fossil fuel imports, 49 to 89% of these emissions (4.8 to 8.8 Mt/year) could be reduced between 2020 and 2030, predominantly by adopting methane emission standards that oil and gas importers should meet. Considering that current EU energy sector methane emissions are in the order of 2 Mt/year, there is much more potential to be reaped in the mitigation of methane emitted during production and transport of imported fuels than in methane mitigation within the EU. However, it is more difficult for EU policymakers to effectuate mitigation outside the EU, and such mitigation will not count towards an EU methane reduction target.

5 Reduction potential in the waste sector

5.1 Introduction

In this chapter, we estimate the methane reduction potential of various mitigation measures in the EU waste sector between 2020 and 2030. The reduction potential of these measures are very interrelated: The prevention of the creation of organic waste diminishes the reduction potential of measures related to organic waste separation, which in turn affects the reduction potential of landfill-related measures.

In the following sections, we present the current methane emissions (Section 5.2), the business-as-usual trend (Section 5.3), the estimation of the reduction potential of different mitigation measures in the waste sector (Section 5.4), and the resulting estimated sector-level reduction potential (Section 5.5).

For a proper understanding of different waste-related terms, we have listed the definitions of these terms in Table 9.

Table 9 – Definitions of waste-related terms

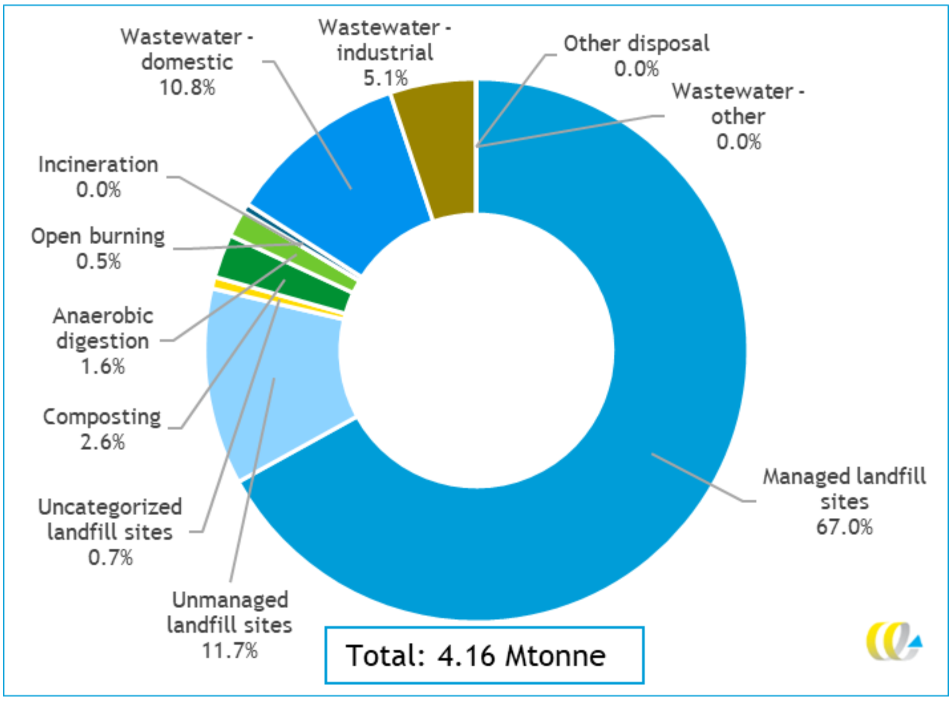
Term	Definition
Food waste	The food loss occurring at retail level and consumption levels.
Food loss	The loss of food that occurs in the food supply chain from harvest up to the retail level.
Bio-waste	Biodegradable garden and park waste, food and kitchen waste from households, restaurants, caterers and retail premises, and comparable waste from food processing plants. It does not include forestry or agricultural residues, manure, sewage sludge, or other biodegradable waste such as natural textiles, paper or processed wood.[23]
Biodegradable waste	Waste that can be easily broken down naturally by water, oxygen, the sun's rays, radiation, or microorganisms.
Organic waste	Waste that is biodegradable and comes from either a plant or an animal.

5.2 Current methane emissions

The distribution of EU waste sector methane emissions between different sources in 2019 is shown in Figure 8. The vast majority (79%) of these emissions are released at landfills. These result from anaerobic digestion processes, in which microorganisms convert organic waste to so-called landfill gas (biogas from landfills), which contains 45 to 60% methane. About 16% of the sectoral methane emissions are emitted from anaerobic digestion processes in wastewater. Finally, about 5% of sectoral emissions occur during the composting and anaerobic digestion of organic waste and open burning, incineration and other disposal of waste.

[23] European Commission, DG Environment: Biodegradable waste

Figure 8 - Shares of methane sources in the waste sector in the EU in 2019 (EEA, 2021)



5.3 Business-as-usual trend

For the business-as-usual (BAU) trend of the EU methane emissions in the waste sector, we again make use of the EU Reference Scenario 2020 (EC, 2021b). The EU Reference Scenario is a projection of the future development of the EU energy and transport system that takes into account the current EU policy regime, historical trends and likely developments of market trends. For the waste sector, the Waste Framework Directive and the Landfill Directive are included in the EU Reference Scenario.
We assume that the projected development of non-CO_2 emissions in the waste sector is similar to the development of methane emissions (which were not separately quantified in the EU Reference Scenario). By this, we arrive at a BAU trend of methane emissions in the EU waste sector of -33.1% between 2020 and 2030. This substantial reduction is expected, because the (currently active) Waste Framework Directive calls for the separate collection of biowaste, and because the 2018 amendment of the Landfill directive is foreseen to further divert municipal solid waste from landfills. The expected reduction would continue the declining methane emissions trend in the EU sector which started in 2005 (EC, 2021b).

5.4 Mitigation measures

In the waste sector, methane is generated when biodegradable waste is digested under anaerobic conditions in landfills, or during temporary storage of waste. Methane from landfills is formed and released up to several decades after dumping of the waste (Höglund-Isaksson et al., 2021).

The EU has defined the so-called ‘EU waste hierarchy’ within the Waste Framework Directive (EU, 2018), which represents the ‘optimal’ waste treatment path. At the top of the hierarchy stands prevention of waste, which is the preferred option. This is followed in order of decreasing priority by preparing for re-use, recycling, recovery, and disposal. For biodegradable waste, this hierarchy is relevant as well.

The waste sector mitigation measures in this assessment, which are treated separately below, are:
- reduction of food loss and waste;
- separation and use of organic waste;
- stabilisation of organic waste before landfilling;
- methane recovery at landfills;
- other landfill measures;
- mitigation at wastewater treatment plants (WWTPs).

Reduction of food loss and waste

About a third of all food produced is lost or wasted worldwide. In the EU, about 20% of all food produced is wasted along the food value chain, not counting food waste that is used as animal feed (EEA, 2020). Thus, the reduction of food loss and waste is a preventive methane reduction measure that could have a considerable impact.

In Europe, 51% of biodegradable waste is food waste (Trinomics, 2020). Households are the sector that contribute the most to food waste: about 61%, against 26% from the food service sector, and 13% from retail.[24] Furthermore, the Joint Research Centre indicates that 50 to 60% of food wasted by households is avoidable (Jorge et al., 2016). Assuming that this also applies to the commercial food sectors, we can calculate that 25 to 30% of biodegradable waste could be prevented through reduction of food loss and waste. If we then take into account that 79% of waste sector methane emissions occur at landfill sites (EEA, 2021), we estimate that the methane reduction potential of food loss and waste prevention is 20 to 24% of sectoral emissions.

Separation and use of organic waste

Among the different waste streams, bio-waste and paper and cardboard contribute most to methane emissions originating from landfills in the EU (Prognos & CE Delft, 2022). In order to prevent these waste streams from ending up in landfills, organic waste can be collected separately from municipal solid waste (MSW) and industrial waste, followed by utilisation of this organic waste. There are three main utilisation options, which are prioritised differently:
1. As indicated by the EU waste hierarchy, the utilisation option with the highest societal value is recycling, which for organic waste consists first and foremost of composting of organic waste, to produce a natural soil improver. A future alternative recycling option may be the use of organic waste as a feedstock in biochemistry, for example for the production of bioplastics (Guo et al., 2019).
2. The ‘next best’ utilisation option is anaerobic digestion of organic waste, with which biogas is produced, which could be upgraded to biomethane. Biogas can be used as a fuel in combined heat and power plants, while biomethane can substitute natural gas in various applications. This prevents production, transport and use of the substituted fossil fuels, and thereby the associated GHG emissions. The Waste Framework Directive calls for the encouragement of the separate collection of bio-waste ‘with a view to the composting and digestion of bio-waste’ (EU, 2018).

[24] Eufic : Food waste in Europe: statistics and facts about the problem

3. The least desirable utilisation option is the incineration of organic waste to produce electricity and/or heat. Because organic waste has a high water content, it needs to be dried before combustion, which results in a low net energy gain of the incineration process. This can still be problematic when organic waste is not separately collected but is part of the waste mix in municipal solid waste, in case of a high organic waste content. Furthermore, the combustion of MSW generates hazardous air pollutants such as particulate matter, carbon monoxide, nitrogen oxides, acid gases, and dioxins. The combustion of fossil waste also releases fossil CO_2, but methane is not generated in the waste combustion process during normal operation.

By making sure that organic waste does not end up at the landfill, landfill methane emissions are prevented. After the reduction of organic waste that is accomplished by reducing food waste and loss, the separation and use of organic waste can be seen as a logical next step in methane mitigation in the waste sector.

The reduction potential of the separation and use of organic waste is estimated using a study in which potential CO_2-eq. reductions of waste management in Europe are calculated for different waste streams (Prognos & CE Delft, 2022). We use the potential CO_2-eq. emissions reductions for bio-waste and paper and cardboard[25] from Prognos and CE Delft (2022) to calculate the total reduction potential of methane from landfills. In our estimation we assume that 100% of the methane emissions from landfills originate from organic waste.

We have used a projection from Prognos and CE Delft (2022) in which it is assumed that 6 to 8% of organic waste will go to landfills in 2035 and that 56% of bio-waste and 81% of paper cardboard is recycled. Because this projection is for 2035, we have adapted the estimated emission volumes to a value for 2030 assuming a linear trend between 2018 and 2035. This results in a (maximum) reduction potential of 56% of methane emissions from landfills. Although separate collection of organic waste is technically feasible, the costs of a separate collection system for organic waste next to MSW may be a reason for governments to refrain from, or delay, its implementation. Also, separate collection in apartment buildings is more difficult to achieve, due to lack of space and higher efforts that are required from households. Moreover, methane may be released during biogas production or during treatment of organic waste in composts (Höglund-Isaksson et al., 2021). Therefore, we set the lower value of the reduction potential at 35%. Correcting for methane reductions accomplished by reduction of food waste and loss, this leads to a methane reduction potential of 21 to 31% for the waste sector between 2020 and 2030.

Stabilisation of organic waste before landfilling

Organic waste that goes to landfills must be treated beforehand, according to the EU Landfill Directive. Material Recovery and Biological Treatment (MRBT) is a waste treatment concept that combines the recovery of useful material with the biological stabilisation of organic waste. The use of MRBT can contribute both to the increase of materials recycling and the reduction of landfill methane emissions (Zero Waste Europe, 2020).

In the recent report 'Methane Matters' on methane mitigation, a literature overview of methane reduction efficiencies of bio-stabilisation of organic waste before landfilling is given (Changing Markets et al., 2020). The efficiencies vary widely between studies, from

[25] Amongst all waste streams bio-waste and paper and cardboard have by far the highest methane emissions. The CO_2-eq. emissions of these two streams consist mostly of methane.

50% up to 95%. We adopt this range in our assessment. Correcting for methane reductions accomplished by reduction of food loss and waste and organic waste separation, this leads to a methane reduction potential of 19 to 23% for the waste sector between 2020 and 2030.

Methane recovery at landfills

Methane recovery at landfills is a curative rather than a preventive measure. It represents a set of specific measures in which landfill gas is collected and used, for example for biomethane production or electricity and heat generation, or flared. With methane flaring, the collected landfill gas is immediately burnt at the landfill site. This converts methane into CO_2, which is a less potent greenhouse gas. Landfill gas contains 45 to 60% methane. Prognos and CE Delft (2022) report that around 53% of methane emissions at EU landfill sites is currently recovered, although this is an uncertain figure given the lack of accurate measurement data on EU landfill methane emissions. In 2019 the majority of the EU waste sector methane emissions (79%) came from landfills (EEA, 2021).

It is difficult to measure or estimate methane emissions at landfills. Potential methane recovery percentages at landfills given in literature vary widely. Mønster et al., (2015) found, from studying fifteen Danish landfill sites, that methane recovery could lead to a 41 to 80% methane emissions reduction. In an EPA report on the mitigation of global non-CO_2 emissions, a reduction potential of 75 to 85% was given Quantification of methane emissions from 15 Danish landfills using the mobile tracer dispersion method (EPA, 2013). For this study, we set the theoretical recovery potential at 50 to 80%. Here we assume that current landfill gas emissions are located at landfills without recovery, and that methane recovery is implemented everywhere in the EU by 2030. Correcting for methane emissions already reduced by the previous measures, this leads to a 1 to 10% reduction potential for the waste sector between 2020 and 2030.

Other landfill measures

Two other measures that aim to reduce methane emissions from landfills are biological oxidation at landfills and landfill aeration. Both strive to reduce the formation of methane in landfills, rather than capturing it. Thus, both of these measures overlap with methane recovery and with each other: The implementation of one measure will reduce the effectiveness of the other measures. In this study, we have estimated the potential impact methane recovery, because this is a more established method which enables the utilisation of landfill gas, which generates income and may reduce the use of natural gas, thereby contributing to the reduction of both CH_4 emissions and CO_2 emissions in the energy sector. To prevent double-counting, biological oxidation at landfills and landfill aeration are not included in the assessment.

Mitigation at wastewater treatment plants (WWTPs)

Wastewater treatment plants (WWTPs) process wastewater from residential, commercial, and industrial sources. Methane is produced when organic material present in the wastewater decomposes under anaerobic conditions. WWTPs in developed countries such as in the EU use centralized aerobic wastewater treatment systems which limit methane production (EPA, 2019). In the EU in 2019, 16% of the sectoral methane emissions came from wastewater flows (EEA, 2021).

Different wastewater treatment methods lead to different methane emission levels. When domestic wastewater is centrally collected and mechanical treatment to remove larger solids is the only treatment step, the level of methane formation is relatively high. If well-managed aerobic or anaerobic treatment steps are used, methane emissions can be restricted to a negligible level (Höglund-Isaksson et al., 2021). With anaerobic treatment, methane can be recovered in the form of biogas, which generates income for the WWTP owner and can replace natural gas as a fuel. The residue of WWTPs, sewage sludge, may also emit methane if natural anaerobic digestion occurs, but the sludge can also be fed into digestion units to produce biogas.

Nisbet et al., (2020) give a literature overview of achievable methane reduction levels with different treatment steps in WWTPs. It is possible to realise a methane recovery level of over 50% using a submerged underwater bioreactor, while floating bioreactors on wastewater settling pools in agricultural settings have achieved 67% methane oxidation. Furthermore, with an up-flow anaerobic sludge blanket reactor at ambient temperatures, a methane removal efficiency of 40 to 50% was measured. The authors argue that methane removal in WWTPs 'appears to be both feasible and inexpensive' (Nisbet et al., 2020). Furthermore, the data of the elaborate work of the U.S. Environmental Protection Agency on global methane emissions and abatement give a methane reduction potential of mitigation in WWTPs of 69% (EPA, 2019).

We estimate the reduction potential of methane mitigation measures at wastewater treatment plants at 60 to 70%. Taking into account that 16% of current methane emissions in the EU waste sector originate from wastewater, we arrive at an estimated sectoral reduction potential of 10 to 11%.

5.5 Methane reduction potential

The estimations of the methane reduction potential of the different mitigation measures in the EU waste sector between 2020 and 2030, which are described in the previous section, are summarised in Table 10. In the shown values of individual measures, the effect of the implementation of other sectoral measures has been taken into account.

Table 10 – EU methane reduction potential in the waste sector between 2020 and 2030

	Estimation (low)	Estimation (high)
Individual measures*		
Reduction of food waste and loss	20%	24%
Separation and use of organic waste	21%	31%
Stabilisation of organic waste before landfilling	19%	23%
Methane recovery at landfills **	10	1%
Mitigation at wastewater treatment plants (WWTPs)	10%	11%
Sector		
Total reduction percentage	**79%**	**90%**
Total reduction volume (Mt/year)	**2.2**	**2.5**

*: Reduction potential of individual measures relative to sector emissions in 2030. Overlap between measures has been considered when estimating reduction percentages of the measures.

**: Because of the higher degree of organic waste prevention for the high estimation, the reduction percentage of methane recovery at landfills is lower than for the low estimation.

The total (theoretical) methane reduction potential of the EU waste sector is estimated at 79 to 90%. Although this range suggests that it is possible to remove most of the methane emissions from the waste sector, it must be kept in mind that it is the outcome of adding up reduction potentials of all identified mitigation measures, based on values found in literature. However, estimations from literature are uncertain, and may be measured at locations that deviate from the average European situation. Having said that, the high range indicates that waste sector methane emissions could be reduced to a high degree.

Reduction of food waste and loss, separation and use of organic waste, and stabilisation of organic waste before landfilling can all make a substantial contribution to methane reduction in the EU waste sector. The first two are preventive measures, which reduce the amount of organic waste that goes to landfills (which is where 79% of the EU waste sector methane emissions are currently released). The third is a curative measure that mitigates the methane emissions from landfilled organic waste.

Due to the large overlap between measures, the estimated reduction percentages can only be considered in interrelation. We have taken into account that the reduction of food waste and the separation and use of organic waste will lead to lower volumes of organic waste that go to landfills, which will lower the reduction potential of curative landfill-related measures.

6 Methane reduction scenarios

6.1 Introduction

In this chapter, we use the results of the effects estimation presented in Chapters 3 to 5 to compose three scenarios: A Maximum scenario, which indicates the maximum methane reduction potential in the EU between 2020 and 2030, and a Pledge Scenario and Science scenario, which indicate what mitigation measures are needed to realise a 30 and 45% methane reduction within this time period respectively.

The scenario results provide insight into the theoretical potential of methane mitigation measures, i.e., implementation barriers and limited effectiveness of policy measures (to instigate the execution of the considered measures) were not considered in the underlying estimations. Also, these estimations are subject to uncertainties, as is reflected by the indication of upper and lower values.

In the consecutive sections, we present the overall business-as-usual trend (Section 6.2), the Maximum scenario (Section 6.3), the Pledge scenario (Section 6.4), and the Science scenario (Section 6.5).

6.2 Business-as-usual trend

The business-as-usual (BAU) trends of methane emissions in the EU between 2020 and 2030 of the different sectors have been presented in the previous chapters. They are based on the EU Reference Scenario 2020. The BAU trend incorporates EU policies that have already been adopted, including the Waste Framework Directive. However policies that are still in the pipeline, such as the EC proposal on methane reduction in the energy sector, the Industrial Emissions Directive and the RePowerEU plan, are not included in the BAU trend.

For livestock agriculture, the 3.7% emissions reduction is the net result of a small increase in animal products export volumes, a small decrease of EU consumption of animal products, and a small increase in livestock productivity. For the energy sector, the 20% reduction originates from an expected increase of renewable energy production and use and energy efficiency improvements. For the waste sector, the 33% reduction is based on the expected decline of the share of organic waste that goes to landfills, as demanded by the Waste Framework Directive. The sectoral BAU trends have been put together in Table 11, showing the overall BAU trend.

Table 11 – Business-as-usual trend of total methane emissions in the EU between 2020 and 2030

Sector	Current methane emission (Mt CH_4/year)	Methane emission in 2030 (Mt CH_4/year)	Emission trend (Mt CH_4/year)	Reduction percentage
Livestock agriculture	8.0	7.7	-0.3	3.7%
Energy	2.0	1.6	-0.4	20.0%
Waste	4.2	2.8	-1.4	33.1%
Sum of sectors	*14.2*	*12.1*	*-2.1*	
EU total	**15.2**	**13.2**	**-2.0**	**13.4%**

Note: To calculate the EU total, we applied a 10.9% methane emissions increase in industry from the EU Reference Scenario 2020, and assumed a 10% increase in mobility due to increased use of (bio)LNG (own estimation).

With current expected developments and policies, the methane emissions in the EU are estimated to come down by 13.4%. This is less than half of the reduction advocated by the Global Methane Pledge (i.e., 30%), and less than a third of the reduction that scientists state is needed (45%). This shows that without additional mitigation measures and policy efforts, the EU will not achieve these reduction targets.

For the methane emissions related to the import of fossil fuels in the energy sector, the emissions are estimated to decline from 10.4 Mt in 2020 to 9.8 Mt in 2030, a reduction percentage of 5.8%.

6.3 Maximum scenario

In the maximum scenario, all measures from the assessment are included, as shown in Table 12. This scenario thus indicates the maximum methane reduction potential that could be obtained by implementing all measures included in the assessment. This maximum reduction potential is presented in Table 13.

Here, interactions between measures of different sectors should be taken into account as well. We have identified one such interaction: Healthier consumer diets lead to a reduction of organic waste from meat consumption.[26] However, the effect of this interaction is small: About 12% of food waste is from meat, milk and egg products.[27] A rough calculation indicates that a 30 to 38% reduction of livestock volumes due to healthier consumer diets (see Section 3.4) would lead to a reduction of organic waste of 4 to 5%. This interaction would reduce the absolute methane reduction potential of mitigation measures in the waste sector in megatonnes, but also the potential methane emissions related to the organic waste volume in 2030. Because of the low effect of this interaction and the difficulty to incorporate this into the assessment, we assume here that this effect is negligible.

Table 12 - Methane reduction measures included in the Maximum scenario

Sector	Included reduction measures
Livestock agriculture	— healthier consumer diets — animal feed changes and additives — selective breeding — animal health management — anaerobic digestion of manure — other manure management
Energy	— leak detection and repair (LDAR) — replacement of existing devices — instalment of new devices — reduction of venting and flaring in oil and gas production — coal mine methane management
Waste	— reduction of food waste and loss — separation and use of organic waste — stabilisation of organic waste before landfilling — methane recovery at landfills — mitigation at wastewater treatment plants (WWTPs)

26 In our analysis we found that, due to the overconsumption of calories and nutrients in the EU, a switch to healthier consumer diets does not lead to an increase in consumption of plant-based food to compensate for reduced meat and dairy consumption. Therefore, organic waste volumes from plant-based food are estimated to remain the same.

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Table 13 – Methane reduction potential in the EU between 2020 and 2030 in the Maximum scenario

Emissions reduction	Volume (Mt)		Percentage (compared to EU total)	
	Low	High	Low	High
Livestock agriculture	3.2	5.5	21%	36%
Energy	0.7	1.0	4%	6%
Waste	3.6	3.9	23%	26%
Total reduction volume	**7.5**	**10.3**		
Total reduction percentage	**49%**	**68%**		

A positive value stands for an emissions reduction. For each sector, the sectoral business-as-usual trend is incorporated along with the reduction percentages of the considered sectoral mitigation measures.

The estimated maximum methane reduction potential in the EU between 2020 and 2030 is 49 to 68%. This is higher than the methane reduction target of 45% which is needed according to science. Thus, our estimation results show that a 45% methane reduction within the coming decade is achievable in the European Union, which is in line with the conclusion from the Global Methane Assessment for the entire world.

The uncertainty range is large, because there are uncertainties about the size of current EU methane emissions, the impact so far of already introduced EU directives, the effectiveness and feasibility of measures (as indicated by the ranges found in literature), and the extent to which overlaps and interactions between measures are accurately accounted for in the estimation. However, the lower value of 49% is above the 45%, which allows for some margin of error.

The maximum EU methane reduction potential that could be achieved through measures in the livestock agriculture sector is estimated at 21 to 36%. Thus, perhaps not surprisingly, the sector with the highest methane emissions can also make the highest contribution to methane mitigation. The estimated contribution that the waste sector can make of 23 to 26% is close the sector’s share in current EU methane emissions, which is about 27%. This reflects the relatively high estimated sectoral methane reduction in the analysis of 79 to 90%.

According to the GMA report, the largest methane reduction potential in Europe is in the waste sector (UNEP & CCAC, 2021). Our results indicate that the largest reduction potential in the EU lies in the agriculture sector (although the intra-sectoral reduction in the waste sector is found to be higher than in livestock agriculture).

6.4 Pledge scenario

We have composed a Pledge scenario by selecting a combination of feasible and impactful methane reduction measures, with which an EU methane reduction of 30% between 2020 and 2030 can be realised, following the Global Methane Pledge. We have included measures from all three sectors, to spread out the required efforts and the risks of disappointing methane reduction results:

- In livestock agriculture, we selected two measures that are technologically advanced and could be implemented before 2030: anaerobic digestion of manure and other

manure management. The measure of healthier diets is included because of its high theoretical impact. In this scenario we assume that only 10% of this potential is met.[28]
— Regarding the energy sector, the three measures that are covered by the EC proposal for methane reduction in the energy sector are selected (see Table 14), as these measures will likely be carried out when this proposal is implemented (depending on the negotiation process with the Parliament and Council).
— We selected two measures from the waste sector. Separation and use of organic waste is a key measure that is covered by the EU Waste Framework Directive. Mitigation at WWTPs is an impactful measure that aims to abate methane emissions from a different waste stream, i.e. wastewater.

The measures included in the Pledge scenario are listed in Table 14, and the methane reduction potential in the Pledge scenario is shown in Table 15.

Table 14 – Methane reduction measures included in the Pledge scenario

Sector	Included reduction measures
Livestock agriculture	— healthier consumer diets, with 10% of EU consumers making the switch — anaerobic digestion of manure — other manure management
Energy	— leak detection and repair (LDAR) — reduction of venting and flaring in oil and gas production — coal mine methane management
Waste	— separation and use of organic waste — mitigation at wastewater treatment plants (WWTPs)

Table 15 – Methane reduction potential in the EU between 2020 and 2030 in the Pledge scenario

Emissions reduction	Volume (Mt)		Percentage (compared to EU total)	
	Low	High	Low	High
Livestock agriculture	1.0	1.4	6%	9%
Energy	0.6	0.9	4%	6%
Waste	2.4	2.9	16%	19%
Total reduction volume	4.0	5.2		
Total reduction percentage	***26%***	***34%***		

A positive value stands for an emissions reduction. For each sector, the sectoral business-as-usual trend is incorporated along with the reduction percentages of the considered sectoral mitigation measures.

The potential reduction volumes of the included measures add up to a total EU methane reduction between 2020 and 2030 in the Pledge scenario of 26 to 34%, which means that the Global Methane Pledge target of 30% would likely be reached in the EU. In this scenario, the contribution of the waste sector of 16 to 19% is larger than the sum of the contributions of the livestock agriculture and waste sector.

The Pledge scenario illustrates that multiple measures in each of the three methane emission-intensive sectors are likely to be needed to achieve this reduction target. Although it is possible to reach 30% methane reduction by reaping the full potential of all measures in

[28] An EU methane reduction target of 30% could also be met by a higher adoption rate of healthier consumer diets in combination with fewer other mitigation measures. The Pledge scenario should be seen as one of many possible combinations of measures with which 30% methane reduction could be achieved.

the energy and waste sectors (this leads to a 28 to 32% reduction), this probably is not the most feasible and cost-effective way to reduce methane emissions. It is unlikely that the full theoretical potential of all those measures is met. Given the uncertainty of the impact of technical measures in the livestock agriculture sector and the high potential impact of dietary change, it is important to take policy actions to start up the transition to healthier consumer diets in the EU (see Section 7.2).

6.5 Science scenario

We have composed a Science scenario by selecting a combination of feasible and impactful methane reduction measures, with which an EU methane reduction of 45% between 2020 and 2030 can be realised, following the level of reduction that is needed according to science. The measures included in the Science scenario are listed in Table 16, and the methane reduction potential in this scenario is shown in Table 17.

The selection of measures in the Science scenario is made by adding two methane reduction measures from the waste sector to the measures included in the Pledge scenario: reduction of food waste and loss and stabilisation of organic waste before landfilling. These are two measures with a high impact that can further reduce methane emissions from organic waste compared to enhanced separation and use: by reducing the organic waste volumes and by lowering the methane emission rate from organic waste. Furthermore, we assume that in this scenario 50% of the full theoretical potential of the measure of healthier consumer diets is realised, i.e., 50% of EU consumers switch to an advised diet based on national dietary health guidelines.

Table 16 – Methane reduction measures included in the Science scenario

Sector	Included reduction measures
Livestock agriculture	— Healthier consumer diets, with 50% of EU consumers making the switch — Anaerobic digestion of manure — Other manure management
Energy	— Leak detection and repair (LDAR) — Reduction of venting and flaring in oil and gas production — Coal mine methane management
Waste	— Reduction of food waste and loss* — Separation and use of organic waste — Stabilisation of organic waste before landfilling* — Mitigation at wastewater treatment plants (WWTPs)

*: These reduction measures are only included in the Science scenario, not in the Pledge scenario.

Table 17 – Methane reduction potential in the EU between 2020 and 2030 in the Science scenario

Emissions reduction	Volume (Mt/yr)		Percentage (compared to EU total)	
	Low	High	Low	High
Livestock agriculture	1.8	2.4	12%	16%
Energy	0.6	0.9	4%	6%
Waste	3.3	3.9	22%	25%
Total reduction volume	5.7	7.2		
Total reduction percentage	38%	47%		

A positive value stands for an emissions reduction. For each sector, the sectoral business-as-usual trend is incorporated along with the reduction percentages of the considered sectoral mitigation measures.

In the Science scenario, an EU methane reduction potential between 2020 and 2030 is estimated between 38 and 47%, which means an EU reduction target of 45% is achievable. The effect of adding healthier consumer diets and reduction of food loss and waste becomes clear when comparing the results of the Science scenario and the Pledge scenario. The range of 38 and 47% from the Science scenario is substantially higher than the 26 to 34% from the Pledge scenario. The two additional waste sector measures and the higher share of consumers switching to a healthier diet both make a large contribution to this. For healthier consumer diets the question remains whether policies will be put in place to encourage EU citizens to move towards an advised diet with lower meat and dairy consumption (which we will discuss in Section 7.2), whether citizens will act upon these policies, and whether reduced animal products production for the EU will not be (partially) substituted by increased production for the export market.

7 Implications for methane reduction policy

7.1 Introduction

In Chapter 6 three different methane reduction scenarios were composed, combining different mitigation measures in the livestock, energy and waste sectors estimated in Chapters 3 to 5. In this chapter, we discuss what is needed in terms of EU policy to realise the Pledge and Science scenarios, which correspond to an EU methane reduction between 2020 and 2030 of 30 and 45%, respectively.

In Section 7.2 we discuss the required sectoral methane reduction policy for each of the investigated sectors. In Section 7.3 we briefly discuss cross-sectoral and general GHG emission reduction policy measures. These measures are not directed at specific sources of methane emissions and were therefore not included in the assessment, but can also contribute to methane emission reductions in the EU. Finally, in Section 7.4 we discuss possible co-benefits and adverse effects associated with the methane reduction measures.

7.2 EU sectoral methane reduction policy

Livestock agriculture

In livestock agriculture, both the EU Farm to Fork strategy (EC, 2020a) and the EU Methane strategy (EC, 2020b) are roadmaps, and therefore do not propose any concrete methane reduction measures. However, a recent EC proposal for the revision of the Industrial Emissions Directive (IED) does cover the livestock agriculture sector and methane emissions. Where the current IED targets about 20,000 large poultry and pig farms, the proposal targets all cattle, pig and poultry farms in the EU with over 150 livestock units. Together, these farms are responsible for 43% of sectoral methane emissions. With the revised IED, emissions prevention and control will continue to be based on a 'Best Available Technique' (BAT) permitting process, involving emission limit values for methane and other emission types. The EC expects that an annual methane reduction in livestock agriculture of 265 kilotonnes per year is realised with the IED revision.
The policy approach with emission limits considering Best Available Techniques appears to link best to technology-related and proven measures such as anaerobic digestion of manure and other manure management, although animal feeding measures are covered as well[29]. However, according to the EC proposal, an implementing act on livestock farms is not expected before the end of 2027 (EC, 2022). Assuming that 43% of livestock methane is covered by the revised IED and that the full reduction potential of anaerobic digestion of manure and other manure management are realised before 2030[30], the revised IED would result in a sectoral methane emissions reduction of 2 to 4% (1 to 2% of total EU emissions).

[29] https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/JRC107189_IRPP_Bref_2017_published.pdf

[30] Although the REPowerEU plan does aim for the growth of biomethane production capacity in the EU well before 2027, it is unlikely that the full potential of other manure management will be realised in three years' time. Thus, we estimate a theoretical maximum reduction here.

Although EU citizens are becoming increasingly aware of the environmental problems associated with the consumption of meat and dairy products, the consumption of these products is not declining, despite the emergence of plant-based alternatives. EU policy action is needed to influence consumers to switch from animal-sourced to plant-based food. There are many policy instruments that could be deployed for this purpose.
Governments could try to influence people's attitude by implementing nationally advised dietary guidelines, or by starting a national debate on the effect of overconsumption of animal-sourced products on health, the environment and animal welfare (Chatham House, 2015). They could also try to provide financial incentives, such as increasing the VAT on meat and reducing the VAT on vegetables and fruits. Furthermore, consumers could be nudged to make healthier choices by means of a smarter design of food environments[31], for example by offering healthier options in school canteens and other public institutions. However, the effectiveness of these kinds of policy measures are difficult to assess, due to the scarcity of research data on these measures.
A concern is that the effectiveness of campaigns and 'nudging' may be too low to cause significant change in people's consumption patterns. Buckwell & Nadeu (2018) notice that the negative effects of livestock agriculture have not yet had a 'Blue Planet' moment, referring to the 2017 BBC Programme series which showed the impact of plastics on ocean life, which led to a large increase in public awareness and rapid introduction of EU legislation (the Directive on single-use plastics). They argue that EU and Member State policy makers should focus public attention on negative effects of livestock agriculture and the need for change. One way to draw attention to the need for change could be to develop a European dietary health guideline, which could also incorporate principles for sustainable diets.[32]

Although our results show that 30% methane reduction is achievable when *all* measures in the energy and waste sectors in our assessment are carried out (this leads to a 28 to 32% reduction), this probably is not the most feasible and cost-effective way to reduce methane emissions. It is unlikely that the full theoretical potential of all those measures is met. Therefore, it is important to take policy actions that result in methane abatement in livestock agriculture. Furthermore, the adoption of healthier consumer diets has by far the largest theoretical methane reduction potential of all mitigation measures. This measure alone could reduce EU methane emissions by 15 to 19%, if all EU consumers would switch from their current diets with a high consumption of meat and dairy to advised diets. It could be a key measure in the legislative framework for sustainable food systems[33], which the EC will adopt by the end of 2023. Thus, healthier consumer diets could make a significant contribution to a methane reduction target of 45%.

These points make clear that the livestock agriculture sector has an important role to play in the reduction of EU methane emissions and that policymakers should target this sector in methane reduction policy.

Energy

The recent EC proposal on methane reduction in the energy sector includes obligations in the oil and gas sectors on the measurement, reporting and verification (MRV) of methane

[31] Food environments are the physical, economic, political and socio-cultural contexts in which people engage with the food system to make their decisions about acquiring, preparing and consuming food (EPHA: What are 'food environments'?).

[32] EPHA: Dietary guidelines for co-benefits: a case for European action

[33] https://ec.europa.eu/food/horizontal-topics/farm-fork-strategy/legislative-framework_en

emissions (including from inactive wells), on methane leak detection and repair (LDAR), and on the limitation of venting and flaring (EC, 2021c). Furthermore, the proposal contains a general obligation to minimise methane emissions. For the coal sector, MRV and a ban on venting and flaring are proposed for operating mines, and for abandoned mines. Also, Member States should draw up a methane emissions mitigation plan.

Therefore, the adoption of the EC proposal would cover the majority of the measures identified in Section 4.4 directed at reducing domestic EU methane emissions in the energy sector. Our analysis indicates that the implementation of the EC proposal could cause a methane reduction in the EU energy sector of 11 to 26% between 2020 and 2030, or 1.4 to 3.4% of total (domestic) EU methane emissions.[34] The technical abatement measures of replacing existing devices (for instance electric devices instead of pneumatic ones) and installing new devices (to capture methane that would otherwise be released) are not included in the Commission’s proposal. If these two measures are also taken, the reduction potential in the energy sector increases to 13 to 29%, or 2 to 4% of EU methane emissions.

Thus, the implementation of the EC proposal would in principle deliver the methane emission reduction for energy estimated in the Pledge and Science scenarios. Points of attention are that the proposal should not be eroded during negotiations between the EU’s co-legislators and that sufficient enforcement assurances should be put in place.
To tackle import-related energy emissions, which were not included in the scenarios, firstly an extension of the MRV obligation to include importers of fossil fuels could be considered. This goes beyond the general information obligation proposed by the Commission (EC, 2021c). A full-fledged MRV is a precondition for any further measures imposed on importers. However, whether these measures take the form of a methane standard related to the production of fossil fuels or the obligation to apply specific measures such as LDAR, in both cases they will probably face significant compliance challenges.

To guarantee a level playing field, the same standard should also apply in the EU domestically. However, the effectiveness of such a standard within the EU is limited, as methane emission intensities in the EU are already significantly lower than in most exporting countries. Also the combination of a methane emission standard and an obligation to implement technical measures and a venting or flaring ban is not recommendable from a policymaking point of view, as it could force companies to reduce their emissions in a way that is not the most cost-effective. This would probably cause fierce resistance from the sectors involved, which is not conducive for achieving effective methane-reducing policies on the short term.

An advantage of imposing a methane emissions standard to importers of oil and gas would be that importers are free to choose the technical measures by which they want to meet the standard. Depending on the required emission level, which might be gradually lowered, a methane emission intensity standard could be an effective measure to reduce the methane emissions associated with the imports of oil and gas into the EU. We do not deem it realistic or desirable for the EU to impose specific measures such as LDAR or a ban on venting on oil and gas producing countries outside Europe through its import regulations[35].

[34] The BAU trend has not been included in this estimation, as the methane reduction in the EU Reference Scenario 2020 is the result of increase in renewable energy use and energy efficiency improvements.

[35] This is also in line with general EU policy on import regulations. There may be examples of import requirements that demand certain specific measures, but this is often in a different context. In the case of F-gases there is an international agreement (Montreal Protocol and its Kigali amendment) to reduce the use of F-gases rather than EU policy. Building on this example, a ban on venting in export countries would rather require an international treaty than EU obligations as part of import regulations.

Waste

The EU Waste Framework Directive stipulates that ‘bio-waste is either separated and recycled at source, or is collected separately and is not mixed with other types of waste’ (EU, 2018). Furthermore the EU Landfill Directive (EC, 1999) obliges EU countries to minimize the bio-waste that goes to landfills, and requires that EU countries implement a national strategy to progressively reduce the amount of organic waste that goes to landfills. With these current EU policies, important preventive technical methane reduction measures in the waste sector are already in place.

Our analysis results show that with the separation and use of organic waste (which is already included in the Waste Framework Directive), a sectoral methane reduction of 18 to 30% could be obtained, or a reduction of 5 to 8% in the EU as a whole. It should be noted that, if the measure of reduction of food waste and loss is adopted as well, the relative reduction potential of separation and use of organic waste will shrink.
Enforcement of the EU’s waste legislation is a challenge, as several EU countries do not fully comply with its provisions. A pan-European measurement and control system of landfill methane emissions and stringent enforcement may need to be introduced to improve compliance to legislation.

A behavioural change that is more difficult to influence by policy measures is the reduction of food loss and waste. However, the potential methane reduction that could be realised by this behavioural change is large, while it would also reduce CO_2 emissions and negative environmental effects related to food production.
The Global Methane Assessment lists various detailed measures that could be taken with the purpose to reduce food loss and waste. Along the food supply chain level, the cold-storage food chain could be improved, storage at market places could be improved, food date labelling at stores could be altered, and personnel could be trained in reducing food loss. At the consumption side, leftovers at hotels and restaurants could be donated and educational campaigns could raise awareness on the impact of food waste and teach good practices to minimise food waste (UNEP & CCAC, 2021). Thus, in order to reap the full methane reduction potential of food loss and waste reduction, a lot of detailed policy measures are needed, which actually change consumer and business behaviour.

7.3 Cross-sectoral and non-methane-specific policy measures

So far we have considered policy measures directed specifically at the reduction of methane emissions in a specific sector. Apart from these, cross-sectoral measures and climate measures that are not directed specifically at methane emissions can contribute to the reduction of methane emissions as well.

Cross-sectoral measures

A cross-sectoral measure that was already briefly referred to in our discussion on a Methane Border Adjustment Mechanism (MBAM, Section 4.5) is the creation of a EU methane emission certificates market. This is a precondition for an MBAM to be acceptable under WTO rules, but such a market may function as a methane reduction measure on its own as well.
A methane emission certificates market could be realised by either introducing a separate emissions trading system for methane or by including methane into the existing EU ETS[36].

[36] Depending on the design, this could also lead to a single price for ETS allowances, where CO_2 and CH_4 emissions are combined to represent CO_2-equivalent emissions instead of (the currently applied) CO_2 emissions.

The latter has been proposed by several parties, for instance in the context of waste-to-energy technologies (ESWET, 2022). However, there are practical difficulties to overcome as methane emissions originate from different sectors (not coinciding with the scope of the current EU ETS), and as creating a functional single methane certificates market may prove very complex.

Another possible cross-sectoral measure is the introduction of an EU-wide methane emissions reduction target analogous to the existing climate targets. However, the overall climate targets of the EU (at least 55% reduction in 2030 compared to 1990 and climate neutrality in 2050) already include all greenhouse gases, including methane. Since the global warming potential of methane is especially strong on the short term (86 times as potent as CO_2 on a 20-year timescale, compared to 28 times as strong on a 100-year timescale), it could be argued that a separate methane reduction target is effective if it forces methane emissions to decrease much faster than under the existing overall GHG reduction targets. At the same time, in this report we have seen that the anthropogenic sources of methane are very different in character than those of CO_2, as are the proposed reduction measures. The variety of methane sources makes it difficult to pursue a cross-sectoral methane reduction target by means of cross-sectoral measures. Just setting a cross-sectoral target also bears the risk that challenging measures that require more policy efforts, for instance in livestock agriculture, are being postponed in favour of measures that are easier to implement. Therefore, a cross-sectoral methane reduction target can only be successful if the focus of the reduction effort is actually on the sectoral level, for instance by setting binding sub-targets or mandatory measures for each sector. This will create a much stronger impetus for actual reduction efforts than a general, cross-sectoral target. Moreover, EU member states contribute to EU methane emissions to a different extent, because their share in livestock farming and fossil energy production varies strongly (EEA, 2021). This implies that an EU-wide methane reduction target would probably induce a political debate on breaking down the overall target in national targets for Member States. While this is not a bad thing in itself, it would consume considerable amounts of time and effort, which may be better spent on strengthening the sectoral approach.

Lastly, a global methane tax has been suggested in the GMA (UNEP & CCAC, 2021). This could be considered as a geographic extension of the idea of an EU methane price and would make an MBAM redundant, as a single tax rate would apply globally. Although a global methane tax could potentially play a major role in reducing emissions, the feasibility of the measure on the short term should be seriously doubted. Currently, global taxes do not exist in any policy field and no international organisation is in place to implement such an instrument. Efforts are underway, though, to connect various geographically separate ETS systems for CO_2, with the aim to ultimately create a global carbon market. Although this objective is still far from being reached, experience gained in geographically extending carbon markets may be used in the future to launch similar initiatives for methane.

Non-methane specific policy measures

EU climate policies that are not specifically directed at methane emissions can still contribute to their reduction. This holds for the EU GHG reduction targets for 2030 and 2050. Another important instrument is the Effort Sharing Regulation (ESR). This regulation establishes binding national greenhouse gas emission reduction targets for the EU Member States in sectors that are not subject to the EU ETS: transport, agriculture, the built environment, waste and small industries. The ESR explicitly includes methane emissions, but it does not prescribe sub-targets for specific sectors or greenhouse gases, and does not include specific mitigation measures. The distribution of the national reduction target over the different sectors is entirely up to the Member State, which also can decide independently how the GHG reduction should be achieved, including what level of contribution of methane mitigation is foreseen. Thus, it is uncertain to what degree Member States will realise methane emissions reductions in the context of the ESR.

As part of the revision of the Land use, land use change and forestry (LULUCF) Regulation, the Commission has recently proposed to include non-CO_2 emissions from the agricultural sector in this regulation, and to set a joint climate-neutrality target for agriculture, forestry and land used for the year 2035.[37] This target would enter into force as of 2031, but methane-reducing strategies in EU livestock agriculture would need to be initiated well before 2030 in order to meet this ambitious target. Having said that, it is uncertain to what extent the prospect of this target would induce additional sectoral efforts and create additional methane reduction in livestock agriculture between 2020 and 2030.

In the energy sector, all EU policies directed at reducing the use of fossil fuels, such as energy efficiency improvements, renewable energy stimulation and fuel switching, also contribute to the reduction of methane emissions.[38] These reductions will materialise for a large part in the import-related emissions.

7.4 Co-benefits and adverse effects

The Global Methane Assessment (GMA) stresses the importance of global methane emissions reduction to help prevent climate tipping points, which could lead to more extreme weather events, desertification, heat stress and other climate effects. Moreover, the GMA estimates that every million tonne of methane reduced (UNEP & CCAC, 2021):
- prevents approximately 1,430 annual premature deaths thanks to reduced ozone exposure;
- reduces approximately 4,000 asthma-related accident and emergency department visits and 90 hospitalizations thanks to reduced ozone exposure;
- avoids 145,000 tonnes of losses of wheat, soybeans, maize and rice thanks to more favourable cultivation climates;
- avoids the annual loss of up to 400 million hours of work thanks to the reduced occurrence of extreme heat.

Livestock agriculture

The following co-benefits of methane reduction measures in livestock agriculture have been identified:
- Livestock reduction, which results from consumers switching to healthier diets or from animal health management, will free up large areas of land, both from animal husbandry and from animal feed production. This land could then be used for the cultivation of food crops for human consumption. As the production of plant-based food requires much less land than the production of animal-sourced food, this could make an important contribution to feeding the growing world population. The Food and Agriculture Organization of the United Nations has estimated that roughly 50% more food must be produced worldwide by 2050 (FAO, 2017). However, under such land use change, environmental damage from intensive agriculture must be prevented, among

[37] https://www.europarl.europa.eu/RegData/etudes/BRIE/2021/698843/EPRS_BRI(2021)698843_EN.pdf, accessed June 2022.

[38] These developments have been taken into account in the BAU trend for the energy sector (see Section 4.3), but this does not go beyond expected developments under current and proposed policies.

others by using sustainable production methods with lower use of fertilisers and pesticides. Alternatively, the freed up land could be used for reforestation, rewilding and other nature-based solutions to climate change.
- Livestock reduction also prevents deforestation for the purpose of animal husbandry and animal feed production. About 82% of tropical forest carbon loss is at some stages associated with agricultural activities, including animal feed production (Feng et al., 2022). A modelling study has shown that the substitution of 20% of per-capita ruminant meat consumption with cultured meat and fermentation-derived microbial protein globally by 2050 can reduce annual deforestation and related CO_2 emissions by 50% (Humpenöder et al., 2022).
- Livestock reduction will also reduce the scope of animal welfare problems, through the potential to reduce intensive animal farming.
- The reduction of meat consumption that results from the adoption of healthier consumer diets will lead to lower human health risks. This is especially true for reduced consumption of red and processed meat. A high and long-term intake of red and processed meat can increase the risk of all-cause mortality, cardiovascular disease, colorectal cancer and type 2 diabetes (EPHA, 2021).
- Through the anaerobic digestion of manure, biogas/biomethane can be produced, which substitutes natural gas. Therefore, this measure may not only reduce the methane emissions from manure, but also diminish methane emissions from natural gas production and transport.
- The solid-liquid separation of animal excrements, which is one of the sub-measures under the ‘other manure management’ measure, not only reduces the emission of methane, but also of N_2O, which is another potent greenhouse gas, and of ammonia, which can cause soil acidification and loss of biodiversity.

The following adverse effects of methane reduction measures in livestock agriculture have been identified:
- The implementation of technical methane mitigations measures that influence the living conditions of ruminants in animal farms, i.e. animal feed changes and additives, selective breeding and animal health management, may reduce animal welfare.
- For feed additives to be effective, livestock need to be fed regularly. This is most effectively implemented in combination with intensive animal farming. However, intensive animal farming often conflicts with the objective of more organic farming practices, which is advocated in the EC’s Farm to Fork Strategy (EC, 2020a).
- Feed changes that lead to lower methane emissions from enteric fermentation, may at the same time create more emissions of other greenhouse gases or other environmental impacts. Examples of this are higher nitrous oxide emissions from feeding younger grass and the higher loss of organic matter in soil when producing maize instead of grass as animal feed (Vellinga et al., 2018).
- Feed changes and additives which focus on the reduction of methane formation from enteric fermentation may lead to a reduced productivity of dairy cattle due to reduced animal welfare or diminished feed digestibility (Hristov et al., 2013) , and thereby to a higher needed livestock volume. This effects would dampen the overall methane reduction effect of this measure.

Energy

In the energy sector, the methane reduction measures are aimed directly at reducing methane emissions along the energy supply chain. Such technical measures do not have many co-benefits. One co-benefit of the reduction of gas flaring is that this also reduces the emission of other gases that are released during the combustion process which have a negative impact on air quality and health, such as nitrogen oxides (NO_x).

Regarding methane reduction measures related to imported fossil fuels (which do not count towards an EU methane reduction target), imposing mandatory reduction measures on fossil fuel importers is challenging. Both measures proposed above (MRV and a methane emission standard) bear the risk that exporters are not willing to comply because of the associated costs and reduce their exports to the EU, leading to a reduced security of supply of fossil fuels in the EU. In the view of recent geopolitical developments, the EC and Member State governments may be hesitant to impose obligations on fossil fuel importers that may negatively affect security of supply.

Waste

The following co-benefits of methane reduction measures in the waste sector have been identified:

- An important co-benefit of the reduction of food loss and waste is that less food needs to be produced to meet the same demand. Therefore, less land and energy is needed to produce and deliver food for EU citizens, which will result in lower greenhouse gas emissions from fossil fuel use during agricultural production and food distribution and less negative environmental effects of intensive agriculture on soil, water and biodiversity.
- The reduction of food loss and waste increases food availability, which may also lead to lower food prices.
- The separation of organic waste through separate collection of this waste at households and food service companies, followed by recycling of this organic waste as animal feed, fertiliser or feedstock for the biochemistry, will substitute their conventional counterparts. Hereby the production of those conventional products will decrease, along with the associated GHG emissions and other negative environmental effects. The use of separated organic waste to produce electricity, heat and/or biogas substitutes the use of fossil fuels, which results in lower CO_2 and CH_4 emissions from fossil fuel production, transport and distribution.
- The anaerobic digestion of organic waste from households and industrial companies and of organic matter from wastewater generates biogas, which could be upgraded to biomethane. This may substitute natural gas in various applications, including LNG as a fuel for trucks and ships.

An adverse effect of incineration of organic waste (along with municipal solid waste) is that fossil CO_2 emissions are released, as well as hazardous air pollutants such as particulate matter, carbon monoxide, nitrogen oxides, acid gases, and dioxins.

8 Conclusions

The reduction of methane is an essential part of greenhouse gas mitigation and has been identified by scientists as one of the most important climate actions we can take in this decade to slow down the rate of global warming. According to IPCC analysis, global methane emissions must be reduced by 40 to 45% by 2030 to limit global warming to 1.5°C in this century in a cost-effective way (UNEP & CCAC, 2021). In the European Union, the livestock agriculture sector has the largest share in the total EU methane emissions of 15.2 megatonne per year (53%), followed by the waste sector (27%) and the energy sector (13%). The share of the energy sector is relatively low, because most of the fossil fuels that are consumed in the EU are imported, which means that most of the methane emissions associated with EU energy consumption are released outside the EU and do not count as EU emissions. There are large differences in absolute methane emissions and relative sector contributions between EU countries.

Business-as-usual trend

In order to estimate the potential methane reduction in the EU between 2020 and 2030 through various measures, the business-as-usual (BAU) trend serves as a starting point. This BAU trend includes current EU policy, but not proposed policies such as the EC proposal on methane reduction in the energy sector. We arrive at an estimated EU methane emissions reduction between 2020 and 2030 under the current policy regime of 13.4%. The sectoral reduction is highest in the waste sector (33%) due to already implemented EU waste policies, whereas the estimated reduction in livestock agriculture is only 3.7%, as the consumption and export of animal-sources products are not expected to change much.

Methane reduction scenarios

By means of a literature study and own calculations, main methane reduction measures in the livestock agriculture, energy and waste sectors have been identified, and their (theoretical) reduction potential has been estimated in the form of a sectoral methane reduction percentage between 2020 and 2030. Overlaps between measures have been considered when estimating the reduction percentages, and uncertainties are reflected by lower and upper values. The Maximum scenario indicates the maximum methane reduction potential that could emerge if all considered reduction measures are carried out: 49 to 68% reduction in the EU between 2020 and 2030. Given that a 45% methane reduction is needed globally according to science, this indicates it is possible to achieve a 45% methane reduction target in the EU.

We also explored what a policy package that is necessary to realise 30 and 45% methane reduction in the EU between 2020 and 2030 may look like, by composing a Pledge scenario and a Science scenario, respectively. In the Pledge Scenario, a reduction of 26 to 34% is found to be achievable by means of various methane mitigation measures distributed among the sectors, including 10% of EU consumers switching to an advised diet based on national dietary health guidelines. In the Science Scenario, a reduction of 38 to 47% is found to be feasible if the policy package from the Pledge scenario is complemented by two additional waste sector measures and if the share of EU consumers switching to an advised diet rises to 50%. The measures included in each of the scenarios are shown in Table 18. Especially the shift of EU consumers to advised diets with lower meat and dairy consumption could make a large contribution to methane reduction, if policies are put in place to drive this change and consumers act upon these.

Table 18 – Methane reduction measures and methane reduction potential in the EU between 2020 and 2030 of the considered scenarios

	Maximum scenario	Pledge scenario	Science scenario
Livestock agriculture			
Healthier consumer diets (share of EU consumers that switch)	100%	10%	50%
Animal feed changes and additives	x		
Selective breeding	x		
Animal health management	x		
Anaerobic digestion of manure	x	x	x
Other manure management	x	x	x
Energy sector			
Leak detection and repair (LDAR)	x	x	x
Replacement of existing devices	x		
Instalment of new devices	x		
Reduction of venting and flaring in oil and gas production	x	x	x
Coal mine methane management	x	x	x
Waste sector			
Reduction of food waste and loss	x		x
Separation and use of organic waste	x	x	x
Stabilisation of organic waste before landfilling	x		x
Methane recovery at landfills	x		
Mitigation at wastewater treatment plants (WWTPs)	x	x	x
EU methane reduction potential (Mt/year)	**7.5-10.3**	**4.0-5.2**	**5.7-7.2**
EU methane reduction potential (%)	**49-68%**	**26-34%**	**38-47%**

Note: The 'x' sign indicates that the measure is included in the scenario.

Policy recommendation

Our results show that an EU methane reduction target of 30% and of 45% between 2020 and 2030 cannot be realised without taking behavioural and technical measures in the livestock agriculture sector. The adoption of healthier consumer diets alone could reduce EU methane emissions by 15 to 19%, if new policy initiatives would influence all EU citizens to switch to an advised diet based on national dietary health guidelines with lower meat and dairy consumption. This makes clear that the livestock agriculture sector has an important role to play in the reduction of EU methane emissions. At the same time, EU policy initiatives on methane reduction are least advanced and least concrete in the livestock agriculture sector. It is therefore recommended that EU policymakers increase efforts to implement policies that will result in dietary changes with lower production and consumption levels of meat and dairy and the adoption of technical measures by livestock farmers, such as manure management.

References

Abernethy, S. & Jackson, R. B., 2022. Global temperature goals should determine the time horizons for greenhouse gas emission metrics. *Environmental Research Letters,* 17, 024019.

ABLE. 2016. *Flaring Regulations for the European Union* [Online] https://able.co.uk/2016/flaring-regulations-european-union/. April 2022

Behrens, P., Kiefte-de Jong, J. C., Bosker, T., Rodrigues, J. F., De Koning, A. & Tukker, A., 2017. Evaluating the environmental impacts of dietary recommendations. *Proceedings of the National Academy of Sciences,* 114, 13412-13417.

Brémond, U., Bertrandias, A., Steyer, J.-P., Bernet, N. & Carrere, H., 2021. A vision of European biogas sector development towards 2030: Trends and challenges. *Journal of Cleaner Production,* 287, 125065.

Buckwell, A. & Nadeu, E., 2018.*What is the Safe Operating Space for EU Livestock?,* Brussels: RISE Foundation

Cassidy, E. 2022. Mapping Methane Emissions from Fossil Fuel Exploitation. Available: https://nasadaacs.eos.nasa.gov/learn/articles/methane-fossil-fuel-exploitation [Accessed January 25].

Changing Markets, EIA & GAIA. 2020. *Methane Matters: A comprehensive approach to methane mitigation* [Online] https://eia-international.org/wp-content/uploads/CM-WEB-FINAL-REPORT-SINGLE-PAGE-METHANE-MATTERS-.pdf.

Chatham House, 2015.*Changing Climate, Changing Diets: Pathways to Lower Meat Consumption*: Chatham House, The Royal Institute of International Affairs

de Haas, Y., Veerkamp, R. F., de Jong, G. & Aldridge, M. N., 2021. Selective breeding as a mitigation tool for methane emissions from dairy cattle. *Animal,* 15 Suppl 1, 100294.

Dijkstra, J., Bannink, A., France, J., Kebreab, E. & van Gastelen, S., 2018. Short communication: Antimethanogenic effects of 3-nitrooxypropanol depend on supplementation dose, dietary fiber content, and cattle type. *Journal of Dairy Science,* 101, 9041-9047.

EC, 1999. Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste. *Offical Journal of the European Union,* L182, 1-19.

EC. 2020a. *Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions : A Farm to Fork Strategy for a fair, healthy and environmentally- friendly food system, COM (2020)381 final* [Online] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52020DC0381.

EC, 2020b.*Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on an EU strategy to reduce methane emissions COM(2020) 663 final*, Brussels: European Commission (EC)

EC, 2020c.*Inception impact assessment of Proposal for a legislative act to reduce methane emissions in the oil, gas and coal sectors*, Brussels: European Commission (EC)

EC, 2021a.*EU Agricultural Outlook: For markets, income and environment 2021 - 2031*, Luxembourg: Publications Office of the European Union

EC. 2021b. *EU Reference Scenario 2020 Report* [Online] https://op.europa.eu/en/publication-detail/-/publication/96c2ca82-e85e-11eb-93a8-01aa75ed71a1/language-en/format-PDF/source-219903975. March/2022

EC. 2021c. *Proposal for a regulation of the European Parliament and of the Council on methane emissions reduction in the energy sector and amending Regulation (EU)*

2019/942, COM(2021) 805 (final) [Online] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=COM%3A2021%3A805%3AFIN.

EC. 2021d. *Proposal of a Regulation of the European Parlement and of the Council establishing a carbon border adjustment mechanism, COM(2021) 564* [Online] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52021PC0564&from=EN.

EC, 2022.*Proposal for a Directive of the European Parliament and of the Council amending amending Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions (integrated pollution prevention and control) and Council Directive 1999/31/EC of 26 April 1999 on the landfill of waste COM/2022/156 final*, Brussels: European Commission (EC)

Eckard, R. J., Grainger, C. & de Klein, C. A. M., 2010. Options for the abatement of methane and nitrous oxide from ruminant production: A review. *Livestock Science,* 130, 47-56.

EEA, 2020.*Bio-waste in Europe - turning challenges into opportunities*, Luxemburg: Publications Office of the EU

EEA. 2021. *National emissions reported to the UNFCCC and to the EU Greenhouse Gas Monitoring Mechanism* [Online] https://www.eea.europa.eu/data-and-maps/data/national-emissions-reported-to-the-unfccc-and-to-the-eu-greenhouse-gas-monitoring-mechanism-17.

EPA, 2013.*Global Mitigation of Non-CO2 Greenhouse Gases: 2010-2030*, Washington: United States Environmental Protection Agency (EPA)

EPA, 2019.*Global non-CO2 GHG emission projections and mitigation 2015-2050*, Washington DC: US Environmental Protection Agency (EPA)

EPHA, 2021.*Meat Production & Consumption (in Europe) and Public Health: An exploration*, Brussels: European Public Health Alliance (EPHA)

ESWET. 2022 *ESWET's reaction to the proposed inclusion of Waste-to-Energy in the EU ETS* [Online] https://eswet.eu/eswet-inclusion-waste-to-energy-eu-ets/. April 2022

EU, 2018. Directive (EU) 2018/851 of the European Parliament and of the Council of 30 May 2018 amending Directive 2008/98/EC on waste. *Official Journal of the European Union,* L150, 109-140.

Euractiv. 2019. *Only eight EU countries plan to phase out coal by 2030* [Online] https://www.euractiv.com/section/climate-environment/news/only-eight-eu-countries-plan-to-phase-out-coal-by-2030/.

Eurostat. 2022. *EU imports of energy products - recent developments* [Online] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=EU_imports_of_energy_products_-_recent_developments#Main_suppliers_of_natural_gas_and_petroleum_oils_to_the_EU. March/2022

FAO, 2016.*Plates, pyramids and planets : Developments in national healthy and sustainable dietary guidelines : a state of play assessment*, Oxford (UK): The Food and Agriculture Organization of the United Nations and The Food Climate Research Network

FAO, 2017.*Global Livestock Environmental Assessment Model (GLEAM)*:

Feng, Y., Zeng, Z., Searchinger, T. D., Ziegler, A. D., Wu, J., Wang, D., He, X., Elsen, P. R., Ciais, P., Xu, R., et al., 2022. Doubling of annual forest carbon loss over the tropics during the early twenty-first century. *Nature Sustainability,* 5, 444-451.

Global Methane Initiative. 2015. *Global Methane Emissions and Mitigation Opportunities* [Online] https://www.globalmethane.org/documents/gmi-mitigation-factsheet.pdf.

Grossi, G., Goglio, P., Vitali, A. & Williams, A. G., 2018. Livestock and climate change: impact of livestock on climate and mitigation strategies. *Animal frontiers : the review magazine of animal agriculture,* 9, 69-76.

Gudmundsson, E., Fredenslund, A., Falk, J. M., Scheutz, C., Mønster, J., Hinge, J. & Petersen, S., 2021.*Målrettet indsats for at mindske metantab fra danske biogasanlæg*, Copenhagen: Rambøll

Guo, Z., Yan, N. & Lapkin, A. A., 2019. Towards circular economy: integration of bio-waste into chemical supply chain. *Current Opinion in Chemical Engineering*, 26, 148-156.

Haque, M. N., 2018. Dietary manipulation: A sustainable way to mitigate methane emissions from ruminants. *Journal of Animal Science and Technology*, 60.

Hegarty, R., Cortez Passetti, R., Dittmer, K., Wang, Y., Shelton, S., Emmet-Booth, J., Wollenberg, E., McAllister, T., Leahy, S., Beauchemin, K., et al., 2021.*An evaluation of emerging feed additives to reduce methane emissions from livestock.*: CGIAR Research Program on Climate Change, Agriculture and Food Security (CCAFS)

Hilhorst, M. A., Melse, R. W., Willers, H. C., Groenestein, C. M. & Monteny, G. J., 2002, *Reduction of methane emissions from manure. Non-CO2 greenhouse gases: scientific understanding, control options and policy aspects,*

Höglund-Isaksson, L., Winiwarter, W., Purohit, P., Gomez-Sanabria, A., Rafaj, P., Warnecke, L. & Schöpp, W., 2021.*Non-CO2 greenhouse gas emissions in the EU27 from 2005 to 2070 with mitigation potentials and costs - GAINS model methodology*, Laxenburg: International Institute for Applied Systems Analysis (IIASA)

Honan, M., Feng, X., Tricarico, J. M. & Kebreab, E., 2021. Feed additives as a strategic approach to reduce enteric methane production in cattle: modes of action, effectiveness and safety. *Animal Production Science*.

Hristov, A., Oh, J., Lee, C.-C., Meinen, R., Montes, F., Ott, T., Firkins, J., Rotz, C. A., Dell, C., Adesogan, A., et al., 2013. *Mitigation of greenhouse gas emissions in livestock production-a review of technical options for non-CO2 emissions*, Rome, FAO.

Humpenöder, F., Bodirsky, B. L., Weindl, I., Lotze-Campen, H., Linder, T. & Popp, A., 2022. Projected environmental benefits of replacing beef with microbial protein. *Nature*, 605, 90-96.

IEA. *Methane Emissions form Oil and Gas* [Online] https://www.iea.org/reports/methane-emissions-from-oil-and-gas. mei 2022

IEA. 2020. *Coal 2020 : Report extract* [Online] https://www.iea.org/reports/coal-2020/supply.

IEA. 2021. *Flaring Emissions* [Online] https://www.iea.org/reports/flaring-emissions. April 2022

IEA. 2022a. *Global Methane Tracker 2022 Overview* [Online] https://www.iea.org/reports/global-methane-tracker-2022/overview. April/2022

IEA. 2022b. *Global Methane Tracker 2022. Strategies to reduce emissions from fossil fuel operations* [Online] https://www.iea.org/reports/global-methane-tracker-2022/strategies-to-reduce-emissions-from-fossil-fuel-operations.

IEA. 2022c. *Methane emissions from imported oil and gas in selected countries and regions, 2020* [Online] https://www.iea.org/data-and-statistics/charts/methane-emissions-of-imported-oil-and-gas-in-selected-countries-and-regions-2020.

IEA. 2022d. *Methane Tracker Data Explorer* [Online] https://www.iea.org/articles/methane-tracker-data-explorer.

IEA Bioenergy, 2017.*Methane emissions from biogas plants. Methods for measurement, results and effect on greenhouse gas balance of electricity produced*: IEA Bioenergy

IPCC, 2022.*Climate Change 2022: Mitigation of Climate Change - Summary for Policymakers* Intergovernmental Panel on Climate Change (IPCC)

Jorge, C. G., Marta, V., Michele, G., Cristina, T. D. M. & Simone, M., 2016.*Prevention of Waste in the Circular Economy: Analysis of Strategies and Identification of Sustainable Targets - The food waste example*, Luxembourg: Publications Office of the European Union

Klop, G., 2016.*Low Emission Feed : Using feed additives to decrease methane production in dairy cows*, Wageningen: Wageningen University
Limb, L. 2022. *Flooded and forgotten: how Europe's disused coal mines could help heat our homes* [Online] https://www.euronews.com/green/2022/02/14/flooded-and-forgotten-how-europe-s-disused-coal-mines-could-help-heat-our-homes. April 2022
Llonch, P., Haskell, M. J., Dewhurst, R. J. & Turner, S. P., 2017. Current available strategies to mitigate greenhouse gas emissions in livestock systems: an animal welfare perspective. *Animal*, 11, 274-284.
Mønster, J., Samuelsson, J., Kjeldsen, P. & Scheutz, C., 2015. Quantification of methane emissions from 15 Danish landfills using the mobile tracer dispersion method. *Waste Management*, 35, 177-186.
Nisbet, E. G., Fisher, R. E., Lowry, D., France, J. L., Allen, G., Bakkaloglu, S., Broderick, T. J., Cain, M., Coleman, M., Fernandez, J., et al., 2020. Methane Mitigation: Methods to Reduce Emissions, on the Path to the Paris Agreement. *Reviews of Geophysics*, 58, e2019RG000675.
Plumer, B. & Friedman, L. 2021. Over 40 Countries Pledge at UN Climate Summit to End Use of Coal Power. *New York Times*, November 4 2021.
Prognos & CE Delft, 2022.*CO_2 reduction potential in European waste management*, Berlin/Düsseldorf/ Delft: Prognos
Scherer, L., Behrens, P. & Tukker, A., 2019. Opportunity for a dietary win-win-win in nutrition, environment, and animal welfare. *One Earth*, 1, 349-360.
Townsend, M. 2021. *The EU's Carbon Border Adjustment Mechanism and a WTO Challenge* [Online] https://www.allenovery.com/en-gb/global/blogs/countdown-to-cop/the-eus-carbon-border-adjustment-mechanism-and-a-wto-challenge. April/2022
Trinomics, 2020.*Emerging challenges of waste management in Europe : Limits of Recycling, final report*, Rotterdam: Trinomics B.V.
UNEP & CCAC, 2021.*Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions*, Nairobi: United Nations Environment Programme (UNEP)
US EPA. 2016. *Background Technical Support Document for the Final New Source Performance Standards* [Online] https://www.regulations.gov/document/EPA-HQ-OAR-2010-0505-7631. May 2022
van Gastelen, S., Dijkstra, J., Heck, J. M. L., Kindermann, M., Klop, A., de Mol, R., Rijnders, D., Walker, N. & Bannink, A., 2022. Methane mitigation potential of 3-nitrooxypropanol in lactating cows is influenced by basal diet composition. *J Dairy Sci*.
VanderZaag, A. C., Baldé, H., Crolla, A., Gordon, R. J., Ngwabie, N. M., Wagner-Riddle, C., Desjardins, R. & MacDonald, J. D., 2018. Potential methane emission reductions for two manure treatment technologies. *Environ Technol*, 39, 851-858.
Vellinga, T. V., Reijs, J. W., Lesschen, J. P. & van Kernebeek, H. R., 2018.*Lange termijn opties voor reductie van broeikasgassen uit de Nederlandse landbouw: Een verkenning*, Wageningen: Wageningen Livestock Research
Westbroek, H., Lesschen, J. P., Leip, A. & Rood, G. A., 2016.*Nitrogen on the table: the influence of food choices on nitrogen emissions and the European environment*, Edingburgh: Centre for Ecology & Hydrology
Willett, W., Rockström, J., Loken, B., Springmann, M., Lang, T., Vermeulen, S., Garnett, T., Tilman, D., DeClerck, F., Wood, A., et al., 2019. Food in the Anthropocene: the EAT-Lancet Commission on healthy diets from sustainable food systems. *Lancet*, 393, 447-492.
World Bank. ongoing. *Zero Routine Flaring by 2030 (ZRF) initiative* [Online] https://www.worldbank.org/en/programs/zero-routine-flaring-by-2030/about.
Yáñez-Ruiz, D. R., Morgavi, D., Misselbrook, T., Melle, M., Dreijere, S., Aes, O. & Sekowski, M. 2017. *Mini-paper - Feeding strategies to reduce methane and ammonia emissions* [Online]

https://ec.europa.eu/eip/agriculture/sites/default/files/fg18_mp_feeding_strategies_2017_en.pdf.

Zero Waste Europe, 2020.*Building a bridge strategy for residual waste: Material Recovery and Biological Treatment to manage residual waste within a circular economy*, Brussels: Zero Waste Europe

Zubieta, Á. S., Savian, J. V., de Souza Filho, W., Wallau, M. O., Gómez, A. M., Bindelle, J., Bonnet, O. J. F. & de Faccio Carvalho, P. C., 2021. Does grazing management provide opportunities to mitigate methane emissions by ruminants in pastoral ecosystems? *Science of the Total Environment*, 754**,** 142029.