Methane, climate change and air quality in Europe: exploring the connections

This briefing is intended to support future European Commission policy action on methane abatement at the national, EU and international levels. Such actions will contribute to innovative solutions in the industry, agriculture and food sectors.

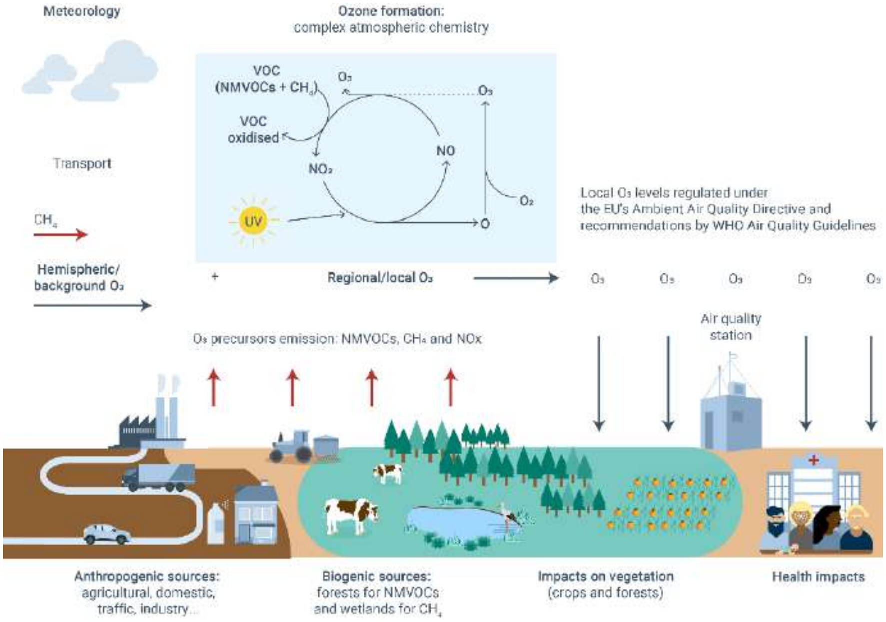
Key messages

- Methane is a potent greenhouse gas and a major contributor to ground-level ozone. Further action is needed to control and reduce methane emissions, as well as other ozone precursors, at European and international levels to mitigate climate change, improve air quality and reduce health impacts.
- Methane is responsible for 12% greenhouse gas emissions in Europe. While methane emissions are decreasing in the EU, global methane emissions and the relative contribution of methane to global warming are increasing. Global methane emissions also significantly influence ground-level ozone concentrations in Europe.
- Ground-level ozone harms human health and is linked to respiratory diseases and premature deaths. In the EU, it remains above levels recommended by the World Health Organization (WHO), with 94% of the EU’s urban population exposed to harmful levels. Staying within WHO’s Air Quality Guideline values could potentially prevent 70,000 premature deaths annually in the EU.
- Ground-level ozone also impacts ecosystems and agricultural production. It reduces growth rates and crop yields and is estimated to cause at least EUR 2 billion in damage to food crops every year in Europe.

Methane as an ozone precursor and its impacts

Methane (CH_4) is a ground-level ozone (O_3) precursor and thus has a negative impact on air quality. Ozone is a strong oxidant and can damage both human health and the environment. Ozone exposure is associated with respiratory disease and mortality both in the short- and long-term. According to the Global Methane Assessment, ozone attributable to anthropogenic methane emissions causes about half a million premature deaths every year globally (UNEP and Climate and Clean Air Coalition, 2021). The WHO Global Air Quality Guidelines (AQG) (WHO, 2021) identifies air quality levels necessary to protect public health worldwide based on the extensive scientific evidence currently available. For ozone, the latest guidelines include a short-term 8-hour averaged guideline level of $100 \mu g/m^3$. Also, a new long-term peak-season average ozone AQG level has been established at $60 \mu g/m^3$, based on new evidence on the long-term effects of ozone on total mortality and respiratory mortality. Ground-level ozone concentrations in the EU in 2022 remained above the levels recommended by WHO: 94% of those who live in the EU’s urban areas were exposed to ozone concentrations above the short-term guideline level. Reducing ozone levels below WHO’s long-term guideline level would have potentially prevented around 70,000 premature deaths in the EU in 2022 (EEA, 2024d). Apart from human health effects, ground-level ozone has significant impacts on vegetation, including agricultural crops and forests. Ozone layers reduce the growth rates and yields of crops and have negative impacts on biodiversity and ecosystem services across Europe. Due to its impact on agricultural production, ground-level ozone also causes economic losses. In 2022, almost one third of Europe's agricultural lands were exposed to ozone levels above the threshold value set for the protection of vegetation in the EU's Ambient Air Quality Directive (EU, 2008). The long-term objective was met with only 11.2% of agricultural lands (EEA, 2024c). Crop losses in 2022 due to the impact of ozone across Europe were estimated to be around 6,700 kilotons of wheat, corresponding to a value of EUR 1.3 billion, and around 3,200 kilotons of potatoes, corresponding to a value of EUR 680 million (ETC HE, 2024). Managing methane emissions can therefore have a significant impact on air quality, human health and crop productivity (ultimately impacting food security) (ETC HE, 2025).

Figure 1. Ozone formation mechanism and its main impacts



Ozone formation mechanism in the context of methane

As shown in Figure 1, ground-level ozone, also called tropospheric ozone, is formed when heat and light cause chemical reactions between various precursors such as nitrogen oxides (NO_x) and volatile organic compounds (VOCs). VOCs include chemical compounds that can play a role in ozone formation. When excluding methane, the term 'non methane VOC' (or NMVOC) is used. VOCs are diverse: they have different lifetimes in the atmosphere and different capacities to form ozone. They also originate from various sources. A significant contribution comes from biogenic emissions both for NMVOC (emitted by the vegetation) and methane (for instance wetlands). The report by the European Topic Centre on Human Health and the Environment (ETC HE, 2025) includes an overview of the complex formation process of ozone and the interaction of the main ozone precursors in the presence of light. Depending on the proportions between NO_x and VOCs, ozone can be accumulated or destroyed in the atmosphere, a process referred to as 'titration'. Due to the complexity of ozone formation and also depending on the local conditions, precursor emission reductions may not always lead to reductions in local ozone concentrations. Lifetime and spatial scale are particularly relevant when considering methane mitigation and its impact on ozone levels. Methane is referred to as a short-lived climate pollutant in the context of climate mitigation. This is because its lifetime in the atmosphere is about 12 years, which seems short compared to the lifetime of carbon dioxide (CO_2), which is exceeds a century (Inman, 2008). Nonetheless, in the context of air quality methane's lifetime is long compared to the lifetimes of other air pollutants (hours for NO_x, days or weeks for O_3 and other VOCs). Given its relatively long lifetime in the context of air pollution and increasing concentration in the atmosphere, methane is a significant contributor to the ground-level ozone burden. Current global methane emissions from both natural and anthropogenic sources are estimated to be responsible for about 37% of the ozone background levels in Europe (European Commission, Joint Research Centre, 2024).

Methane and its role in a changing climate

In addition to contributing to air pollution, methane contributes significantly to global warming and climate change due to its high warming potential. Of the observed net increase of 1.1°C in global temperatures, which considers the cooling effect of aerosols, 0.5°C can be attributed to methane (IPCC, 2023b). Methane is approximately 84 times more effective as a greenhouse gas than carbon dioxide when considered over a time scale of 20 years. Therefore, curbing methane emissions is an effective strategy to limit global warming in the near term (EEA, 2022). Climate change can also affect natural methane sources. For example, permafrost, peatlands, lakes, shallow seas and sediments with stored methane could become additional emission sources in a warmer climate (European Commission, Joint Research Centre, 2024). Recently, it has also been shown that increasing methane emissions from wetlands could completely offset their carbon capturing capacity (Li et al., 2024). Methane can also affect the climate through the formation of ground-level ozone, which is a potent greenhouse gas with an estimated contribution to global warming of 0.23°C in 2019 (IPCC, 2023a). Additionally, ground-level ozone may contribute to climate change due to its effects on carbon sinks. For example, the damaging effects of ozone layers on vegetation may lead to a reduced land carbon sink and therefore further increase the rate at which carbon dioxide increases in the atmosphere. The impact of climate change alone on future ozone levels in Europe is substantial and significant. This is because ozone formation is enhanced during the warm and cloud-free conditions of heatwaves. Climate change will increase the frequency and intensity of such events. By the middle of this century, the increase in the summertime daily maximum ozone concentration is expected to range from 3 to 6$\mu g/m^3$ in continental Europe under a moderate/high radiative forcing scenario (ETC HE, 2025). The Sixth Assessment Report by the United Nations' Intergovernmental Panel on Climate Change (IPCC) confirms a clear impact of climate change on ozone levels, especially in Europe (IPCC, 2023a). At the same time, future climate change could also lower episodes of particulate matter air pollution, for example through less frequent winter cold spells. As a result, the IPCC concludes that the direction of change in air pollution due to climate change is uncertain. Also, according to the European Commission's Joint Research Centre

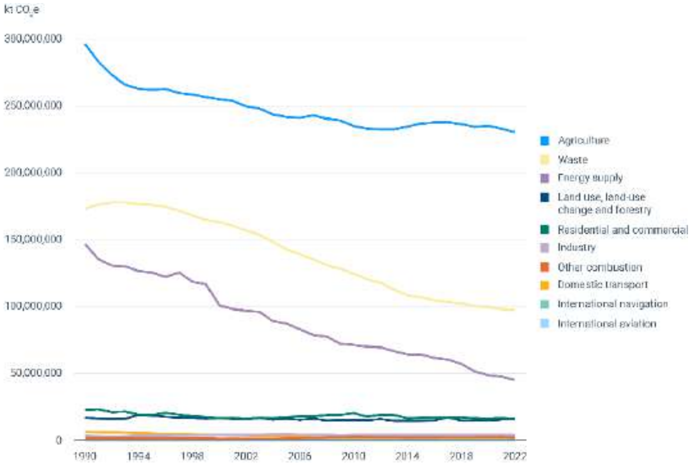
(JRC), the interplay of ozone, climate change, carbon dioxide and climate change adaptation is very complex and is still not fully understood (European Commission, Joint Research Centre, 2024).

Methane emissions and concentrations in the EU and globally

Methane emissions

Methane is emitted from natural and anthropogenic sources. According to the International Energy Agency (IEA), annual global methane emissions are about 14.5 billion tones CO_2e (IEA, 2024). Around 40% of these emissions are from natural sources and 60% from human activities. Wetlands are the main natural methane source. In Europe, anthropogenic methane emissions amounted to around 410 million tones CO_2e in 2022 (EEA, 2025), which corresponds to a reduction of about 38% since 1990 (see Figure 2). The agriculture, waste and energy sectors are the largest sources of anthropogenic methane emissions in Europe.

Figure 2. Methane emission trends by sector in the EU-27, 1990-2022



Emissions from livestock management

The agricultural sector is the biggest methane emitter in Europe with around 230 million tones CO_2e of methane emissions in 2022 (EU, 2024c). This accounts for about 56% of the EU's methane emissions. The largest source of methane from agriculture is enteric fermentation, i.e. the digestion process in ruminants (e.g. cows and sheep). Enteric fermentation from cattle alone accounted for 67% of the sector's methane emissions in the EU in 2020. Another large source is the management of livestock manure. Enteric fermentation and manure management together accounted for around 98 % of the methane emissions in the agriculture sector in 2022 (European Union, 2024). Methane emissions from the agriculture sector are projected to decrease by 3% by 2050 (EEA, 2023). Between 1990 and the early 2000s, methane emissions from the agricultural sector decreased, but since 2010 they have stagnated (Figure 2). Methane emissions from enteric fermentation in dairy cattle decreased substantially in the EU between 1990 and 2010 (-27.9Mt CO_2e) after which the decrease has been slower. However, emissions per liter of milk declined by 17% between 2000 and 2019 due to changes in dairy cattle management practices, such as livestock diet optimization (ETC CME, 2021). In addition to the manipulation and supplementation of livestock feed, methane emissions can also be reduced through optimized manure processing, such as by reducing storage temperatures (FAO, 2023). Another practice that has contributed to methane emission reductions in the agriculture sector is the production of biogas and biomethane from manure in anaerobic digesters and then using these products to produce heat and electricity in the energy sector (FAO, 2023). In addition to changed agricultural practices, other potential actions can contribute to reducing methane emissions including dietary changes, such as balancing the consumption of meat and dairy, which can also support healthier diets (Willett et al., 2019).

Waste sector emissions

The waste sector is the second largest methane emitter in Europe, with approximately 97Mt CO_2e of methane emitted in 2022 (EEA, 2025). The largest contributor to methane emissions in this sector is solid waste disposal (primarily landfills), which accounts for about 80% of the sector's methane emissions. Based on the Member States projections of greenhouse gas emissions, methane emissions from the waste sector will decrease by 52% by 2050 (EEA, 2023). Since 1990, methane emissions from solid waste disposal and wastewater treatment have decreased due to the increased separate collection, recycling, and pre-treatment of waste, and by diverting waste to biological treatment and waste energy recovery. Methane emissions are reduced further through improved landfill gas capture and recovery. In the EU, the Waste Framework Directive, the Landfill Directive and circular economy policies and actions have contributed to reducing methane emissions from the waste management sector (EEA, 2024a). The proposed EU targets for preventing food waste will contribute to reducing one of the root causes of methane emissions (European Commission, 2024). The Biomethane Action Plan, launched in May 2022 as part of the REPowerEU plan, is another pillar of EU actions to curb methane emissions (European Commission, 2023). The strategy aims at expanding the production of biomethane by promoting industrial partnerships, accelerating investments and reducing production costs. According to a recent report, the improved collection of biowaste has an untapped potential for producing 2-4bn m^3 of biomethane in the EU (Biobased Industries Consortium, 2024).

Energy sector emissions

The third largest methane emitter in Europe is the energy sector with approximately 65Mt CO_2e of methane emissions in 2022. Fugitive emissions from coal mining and handling account for 36% of these emissions, whereas natural gas operations and biomass combustion in the residential sector account for 24% and for 14%, respectively (EEA, 2022). Methane emissions from the energy sector are projected to decrease by 8% by 2050 (EEA, 2023). The new EU Methane Regulation (EU, 2024b) places further obligations on the fossil gas, oil, and coal industry in Europe to control their methane emissions. It prohibits avoidable and routine flaring and reduces flaring and venting to exceptional situations such as emergencies or technical malfunctions.

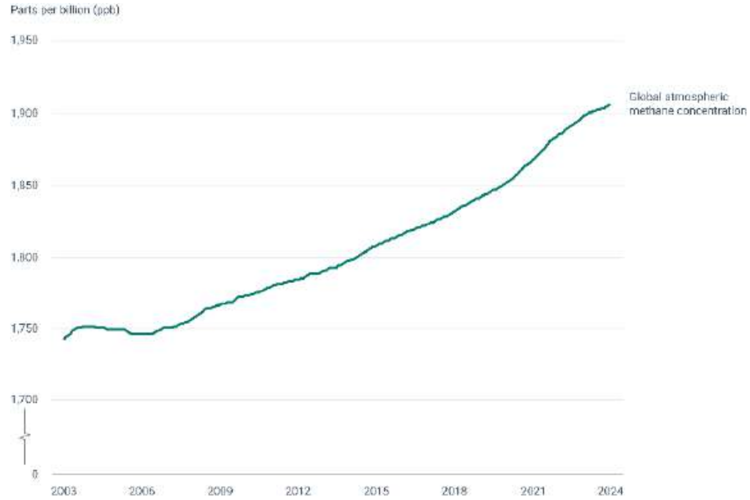
Reducing emissions creates benefits across sectors

Policies aiming to reduce methane emissions in one sector can additionally lead to reduced emissions in another sector. For example, biogas produced from manure management in agriculture can be used to produce heat and electricity in the energy sector, where the recovered methane can replace a part of the imported natural gas. Therefore, it is estimated that almost 50% of methane emissions from the energy sector globally can be mitigated at negative marginal costs (European Commission, Joint Research Centre, 2024). Measures to increase the sustainability of the food system in Europe, which include technical solutions as well as changes to production and consumption patterns, can also lead to reductions in methane emissions, lower energy demands and reduced waste generation. Furthermore, cutting methane emissions through reduced fossil fuel consumption can contribute to improved long-term energy security in Europe.

International contribution to methane and ground-level ozone levels

Despite the emission reductions in Europe, methane concentration in the atmosphere is increasing and is now around 1,925ppb (Figure 3), which is over two-and-a-half times greater than pre-industrial levels (722ppb). Although increasing fossil fuel use, and methane emissions from agriculture, waste and natural wetlands are identified as contributing factors, the atmospheric methane growth rate remains a subject of research. The atmospheric chemistry of methane is complex and involves both anthropogenic and natural sources and sinks that may counteract each other and be affected by weather and climate (Peng et al., 2022).

Figure 3. Atmospheric methane measured in ppb (as dry-air mole fraction)

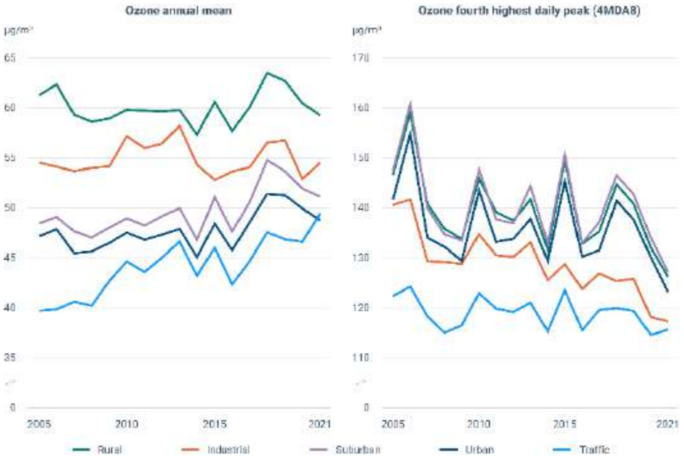


Due to the global transport of methane and the intercontinental transport of ozone, methane -along with other precursors- should be considered in the context of a broader intercontinental approach to reduce background ozone concentrations in Europe. As global methane concentrations increase, its importance as an ozone precursor is also expected to increase (UNEP and Climate and Clean Air Coalition, 2021).The required global efforts in methane mitigation are recognized in the Global Methane Pledge (GMP), which is a collective voluntary commitment to reduce global anthropogenic methane emissions across all sectors by at least 30% below 2020 levels by 2030. The pledge was launched at COP26 by the EU and the United States (Climate and Clean Air Coalition, 2025).

Ground-level ozone levels in the EU

The long-term evolution of ground-level ozone concentrations in Europe is mainly driven by three factors: short-lived precursor (NO_x/VOC) emissions from Europe; the long-range background contribution, including non-European precursors and methane; and the year-to-year meteorological variation. In contrast to other air pollutants, the observed ozone levels do not follow the same trends as the reported precursor emissions. While NO_x and VOC emissions in Europe declined between 2005 and 2021 by about 50% and 30%, respectively, the annual average concentration of ozone increased by 3% at background stations in the 27 EU Member States (EU-27) and ozone peaks decreased by 8%. The reduction of NO_x emissions, especially at traffic and urban sites, is mainly responsible for the increase in the annual mean ozone values due to the titration effect of ozone. Figure 4 illustrates how ozone peaks in the EU-27 have been declining in the last few decades, while the trend in annual mean ozone concentration has been flat or even increasing. There is a strong geographical variability in ozone concentrations over Europe, with Mediterranean countries and Central Europe being typically exposed to higher levels.

Figure 4. Ozone levels in the EU-27 between 2005 and 2021, representing the ozone annual mean (left) and the fourth highest daily peak (4MDA8, right)



Achieving the European air quality standards for ground-level ozone

The ambient air quality directives (2004/107/EC and 2008/50/EC) set standards to protect both human health and vegetation from air pollution, including both target values and long-term objectives for ozone. The newly revised EU Ambient Air Quality Directive

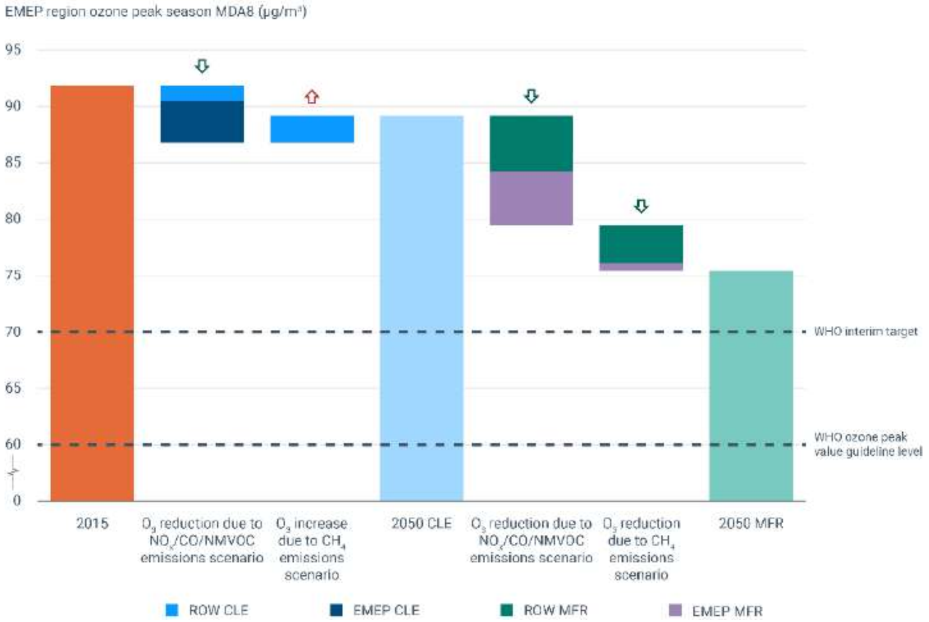
(EU, 2024a) aims to align EU air quality standards more closely with the latest WHO guidelines and sets new air quality standards to be attained by 2030. It also includes measures to improve air quality monitoring, modelling and management. This directive has aligned the long-term objective for human protection with WHO's short-term guideline value for ozone to be attained in 2050. It also requires that air quality plans are established when these target values are exceeded to keep the exceedance period as short as possible. Nonetheless, an exception is allowed if measures are considered to have disproportionate costs. In this directive, methane was introduced in the list of relevant ozone precursors that may be monitored at air quality stations as it can also be a relevant regional or local precursor in some areas. To achieve ozone air quality standards in Europe, it is crucial to understand ozone formation and to implement appropriate measures for the relevant precursors in each air quality zone and region. For this, further studies are needed at the regional level to better understand ozone formation. Studies should especially identify the specific role of individual VOCs from both anthropogenic and natural sources. This is also needed to develop better modelling tools for local ozone concentrations (European Commission, Joint Research Centre, 2024). Methane is critical for the hemispheric ozone contribution, but local volatile organic compounds (VOC) and nitrogen oxides (NOx) play an important role during ozone episodes (ETC HE, 2025). Therefore, global action on methane and other ozone precursors is required to reach ozone air quality standards.

The role of methane abatement in air quality management

The interplay of ozone precursors with diverse origins and different atmospheric lifetimes poses specific challenges to ozone air quality management. Different VOCs have significantly different potentials to produce ozone. Thus, the identification of the relevant VOCs at the regional or local levels and measures taken are key for actions with effective impacts on ozone levels. While reducing NO_x levels can reduce ozone production, another challenge is that in some circumstances it can also have the opposite effect due to ozone titration, leading to increased ozone levels. This happens typically in rural areas with low NO_x levels. Finally, the correlation between atmospheric lifetime and the spatial scale at which emission reduction strategies are implemented is key: while it makes sense to target point sources of short-lived VOCs, longer lived gases, such as methane, must be targeted in a coordinated manner at a much broader spatial scale. The relative impact of methane mitigation compared to other ozone precursors (NO_x and NMVOC) was assessed by the European Monitoring and Evaluation Program (EMEP) in the framework of the Revision of the Gothenburg Protocol (EMEP, 2023)(van Caspel et al., 2024). Based on these projections (Figure 5), the current legislation scenario would only result in a minor reduction in ozone levels by 2050. This is because the reductions in NO_x and NMVOC emissions would be counteracted by the increasing global methane emissions. On the contrary, a substantial reduction in ozone levels is projected under the maximum feasible scenario. This scenario is based on significant reductions in methane, NO_x and NMVOC emissions simultaneously, both in Europe and globally.

Although this scenario would take Europe closer to the WHO guidelines, the levels would not be reached by 2050, partially due to the lifetime of methane.

Figure 5. Estimation of ozone exposure in Europe in 2015 and for two scenarios in 2050



Methane emission reductions in Europe alone would only lead to a limited reduction in ozone levels in Europe (Belis and Van Dingenen, 2023). Under the current legislation scenario, the mortality associated with ozone exposure in the United Nations Economic Commission for Europe (UNECE) region grows steadily from 2020 to 2050, mainly due to the increasing impact of methane emissions from the rest of the world (Belis and Van Dingenen, 2023). Thus, to reduce ozone levels in Europe and globally, international efforts in methane abatement are needed. Potential policy options and technical solutions to mitigate methane emissions have been identified within the frame of the UNECE Air Convention (UNECE, 2023, 2024). A recent JRC report highlighted that Europe was responsible for about 5% of global methane emissions, and the mortality burden attributed to these emissions was about 10% of the global health impact associated with methane. Therefore, while the European share of emissions appears limited, Europe would benefit more from global methane mitigation compared with other regions due to a specific population density, age distribution and higher ozone response to methane emissions.