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Co-mitigation of methane and ammonia emissions from agricultural sources

Summary

The present document was prepared by the Task Force on Reactive Nitrogen in cooperation with the Task Force on Techno-economic Issues in accordance with item 2.2.1 of the 2022–2023 workplan for the implementation of the Convention. It provides information on possible interactions between ammonia and methane mitigation measures and on considerations to be taken into account for simultaneous mitigation, as well as serving as a background document for future policy development.

The Working Group on Strategies and Review discussed the document at its sixty-first session (Geneva, 4–6 September 2023) and forwarded it as amended during the session to the Executive Body for adoption at its forty-third session.

I. Introduction

1. There are significant interactions between the processes and management practices that contribute to ammonia (NH_3) and methane (CH_4) emissions from agriculture. Guidance is needed to identify the effects of mitigation measures on both of these gases and potential interactions, as summarized in the present document (see paras. 13–34 below). While some measures offer synergistic benefits, there is an ongoing need to optimize practices in order to minimize trade-offs between the mitigation of the two gases. These interactions highlight the opportunity to further develop synergies.

2. The present work has been carried out under item 2.2.1 of the 2022–2023 workplan for the implementation of the Convention (ECE/EB.AIR/148/Add.1). In this context, the present document outlines the effects of CH_4 as an air pollutant and an important greenhouse gas (GHG) and the possible interactions between the mitigation of NH_3 and CH_4 emissions. This can serve to inform readers about the merits of linking measures to control CH_4 and NH_3.

II. Methane as an air pollutant and a greenhouse gas

3. While the effects of NH_3 as an air pollutant have been targeted for many years in air pollution policies, CH_4 has, until now, primarily been considered as a GHG, and the regulation of CH_4 emissions has been related to GHG reductions under UNFCCC. However, in addition to CH_4 being a powerful GHG, it also contributes to ozone (O_3) formation in the troposphere. O_3, as well as being a GHG, is an air pollutant that causes inflammation in the respiratory tract and increased premature mortality, as well as contributing to significant crop losses in the United Nations Economic Commission for Europe (ECE) region. O_3 is formed in the atmosphere via interactions between nitrogen oxides (NO_x), carbon monoxide (CO) and volatile organic compounds (VOCs), including CH_4 among others. Thus, VOCs, including CH_4, are closely linked in terms of their atmospheric chemistry.

4. The emission of O_3 precursors with a short lifetime in the atmosphere of days to weeks (NO_x and non-methane VOCs) primarily affects local and regional O_3 concentrations. In contrast, because of the longer lifetime of CH_4 in the atmosphere (approximately 10 years), CH_4 affects a much larger area (in practise, the whole northern or southern hemisphere), while the local air pollutant effect of CH_4 is minor. This means that mitigation strategies for CH_4 need to be addressed at transboundary, international scales.

III. Interactions between ammonia and methane emission mitigation

5. Most NH_3 emissions in the ECE region, and around half of anthropogenic CH_4 emissions, result from agricultural activities (see table below). In the case of CH_4, the waste and energy sectors are also major sources after agriculture.

Anthropogenic sources of emissions of methane and ammonia
(Percentage)

Source of emission	*CH_4*[a]	*NH_3*[b]
Agriculture	56	93
Livestock	45	
Livestock manure	10	74
Other	1	19
Waste (household, sewage, garden)	24	1
Energy industry and other sectors	20	6

Note: Figures from the European Union. A similar distribution would be expected for the entire ECE region.

[a] European Environment Agency (EEA), "Climate and Energy in the EU: Data", 2021 data, available at:https://climate-energy.eea.europa.eu/topics/climate-change-mitigation/greenhouse-gas-emissions-inventory/data.

[b] EEA, *European Union Emission Inventory Report 1990–2019 under the UNECE Convention on Long-range Transboundary Air Pollution (Air Convention)*, EEA Report No. 5/2021 (Copenhagen, 2021), 2019 data, available at www.eea.europa.eu//publications/lrtap-1990-2019.

6. Agricultural NH_3 emissions arise predominantly from livestock manure management, grazing and nitrogen (N) fertilizer use. By contrast, CH_4 emissions arise mainly from enteric fermentation in ruminants, with manure management as a secondary source. Rice production also gives rise to both CH_4 and NH_3 emissions, although this is only a small source of emissions in the ECE region.

7. Although there is little direct causal relationship between NH_3 and CH_4 emissions, the feed intake and the level of activity in the livestock and crop sectors affect the emission of both gases, as do specific management practices, in particular manure management.

8. Increases in the efficiency of animal production (in terms of higher output per input, e.g., a higher nitrogen use efficiency) are likely to be associated with lower emission intensities per unit product for both NH_3 and CH_4. For example, increasing the productive lifetime of a dairy cow will result in fewer replacement animals being required and therefore a lower overall NH_3 and CH_4 emission from the whole dairy system (i.e., cows and replacement animals) per litre of milk produced. However, intensification, with more manure handling and shorter grazing periods, may counterbalance this.

9. Similarly, improvements in dairy and beef cow fertility, reductions in the incidence of diseases and production-impairing conditions (e.g., lameness) will result in higher productivity per animal for a given input and therefore lower NH_3 and CH_4 emission intensity per unit product, and there is the opportunity/need for co-benefits and synergies with animal welfare objectives.

10. Some mitigation measures targeted at reducing NH_3 emissions will also reduce CH_4 emissions (and vice-versa), but this is not always the case. There are three possible outcomes:

(a) Measures that reduce both NH_3 and CH_4 emissions: examples include the coverage of manure stores with covers that enable CH_4 oxidation, cooling and/or acidification of the slurry. Each of these will reduce emissions of both gases. For example, acidification of slurry lowers NH_3 emissions by retaining NH_3 as ammonium in the slurry, while also inhibiting the activity of methanogens. Removing slurry from the livestock house more frequently will reduce CH_4 emission inside the livestock house, but this can be offset by increased emission downstream in external storages. When slurry is frequently removed from a below-ground pit, cleaning the storage area is desirable as it could also reduce the inoculum load. Extra measures to reduce NH_3 and CH_4 during storage are necessary to prevent pollution swapping between housing, storage and field application. For NH_3, covering the storage is sufficient but biofiltration can also be used, whereas for CH_4, more measures are needed, such as acidification, cooling or oxidation of CH_4 (biofilter or flare). The biofilter can, if not optimized, result in increased nitrous oxide (N_2O) and nitric acid (HNO_3) emissions, and flaring can increase the emission of nitrogen oxides (NO_x);

(b) Measures that reduce one pollutant but have no effect on the other: any measures aimed at reducing NH_3 emissions from N fertilizer applications or manure application to land are not expected to affect CH_4 emissions, as these are not significant sources of CH_4 emissions. Similarly, lowering protein intake for ruminants may decrease N excretion, but, without effects on diet digestibility and dry matter intake, there will be little effect on enteric CH_4 emissions. The production of biogas from slurries under specific conditions has the potential to reduce CH_4 emissions and will not affect NH_3 emissions if low-emission land-spreading techniques (e.g., injection or incorporation) are used for the liquid effluent of the digestion process, the high pH of which can otherwise increase NH_3 emissions. Aerated compost may emit less CH_4 than compost piled without physical manipulation, and composting with turning and aeration will tend to increase NH_3 emissions. Lastly, novel feed additives may selectively reduce enteric CH_4 emissions;

(c) Measures that reduce one pollutant but increase the other: some animal feeding strategies (i.e. young grass) or dietary supplements (i.e. nitrate) to lower enteric CH_4 emissions can have the effect of increasing N excretion, which will increase subsequent NH_3 emissions. Covering solid manure storages will reduce NH_3 emissions, but composting manure may lead to CH_4 emissions. Similarly, active aeration of stored manure to reduce CH_4 emissions will generally increase NH_3 emissions. These examples point to the opportunity to further refine practices to minimize such trade-offs. Increased space requirement per animal due to animal welfare considerations can increase NH_3 emissions from increased soiled surface area, and is, moreover, an example of co-benefits/trade-offs beyond the CH_4/NH_3 complex that should also be taken into account. In this context, use of more bedding materials and feed waste into the slurry are also factors that can increase CH_4 production with a negligible effect on NH_3 emissions.

IV. Principles and important considerations for simultaneous mitigation of methane and ammonia emissions

11. The combined effects of NH_3 and CH_4 mitigation measures are important to consider, especially in relation to measures targeted at the livestock sector. While there are obvious win-wins between NH_3 and CH_4 mitigation, there are also trade-offs that need to be addressed. In any evaluation, the whole agricultural production system needs to be considered in an integrated approach.

12. Based on the listed NH_3 and CH_4 air pollution interactions discussed above, and the general principles of the Guidance document on integrated sustainable nitrogen management (ECE/EB.AIR/149), the following guiding principles on the opportunity to exploit synergies with extensive environmental benefits and develop approaches that minimize the trade-offs between the control of these two gases can be derived as below.

A. Livestock

13. The primary source of agricultural CH_4 emissions is enteric fermentation in ruminants. Enteric CH_4 production is determined by total feed use in combination with a complex interaction of enteric microbiota and feed properties. Mitigation of enteric CH_4 emissions therefore focuses on suppressing the methanogenic processes in the rumen using certain feeds or feed additives and/or by increasing the efficiency with which feed is converted into products such as meat and milk.

14. Good animal health improves feed use efficiency at the level of the individual animal and the herd, and this helps to mitigate both NH_3 and CH_4 emissions at the scale of the production system. Lower feed use requires less feed production and related emissions; higher feed use efficiency implies less nutrients in manure storage and application-related emissions.

15. Higher-productivity ruminant livestock tend to have lower enteric CH_4 and NH_3 emissions per unit of meat and/or milk, due to a larger share of the carbon (C) and N metabolism spent on growth or milk production compared to animal maintenance. However, an increase in health issues may be encountered with very highly productive livestock, resulting in welfare problems and reduced herd-level feed use efficiency (see para. 14 above).

16. Supplementing cattle diets with 3-Nitrooxypropanol (3-NOP) has been shown to reduce enteric CH_4 emission by around 30 per cent, without a significant impact on production. Because 3-NOP quickly breaks down in the rumen (within hours), efficacy drops when cattle are not fed the supplement frequently (e.g., during grazing). An effect on NH_3 emission from excreta will then not occur.

17. Supplementing cattle diets with other compounds (e.g., fats, nitrate) has been shown to reduce enteric CH_4 to a lesser extent. If not corrected with diet formulation, adding fat may increase CH_4 from manure storage, and adding nitrate may increase NH_3 emissions by increasing the N content of excreta.

18. Frequent flushing of slurry from animal housing reduces CH_4 emissions in climates where the temperature outdoors is significantly lower than indoors, i.e. in winter and in colder climates, in particular for pig production. Reduction in NH_3 would also be expected, especially where NH_3 mitigation measures (e.g., covering, lowering the emitting surface and adaptation of the indoor slurry pit) are implemented for the outside storage but not in the livestock housing.

19. The cooling of slurry in animal housing is an accepted method to reduce NH_3 emissions. Cooling also reduces CH_4 emissions but some compensatory emission may occur when this slurry is transferred to outside storage. Cooling should not result in increased use of fossil energy.

B. Manure storage

20. In general, low pH and low temperature reduces the risk of both CH_4 and NH_3 emissions from manure storage, but air/oxygen reduces CH_4 while increasing NH_3 emissions. CH_4 emission from manure storage results from microbial decomposition of manure organic matter under anaerobic or low-oxygen conditions. The growth of the micro-organisms involved is reduced at low pH, low temperature and by the presence of oxygen, or removal of degradable organic matter.

21. Urea is a key compound in animal excreta and in some mineral fertilizers. The microbial enzyme urease can start converting urea into NH_3 within a few hours. NH_3 can be lost to the air if it is at or near the surface, pH is high, and/or temperature and air velocity are high. In case of application to soil, incorporation, use of urease inhibitors or rainfall help to minimize NH_3 losses. NH_3 is soluble in water, especially once it can dissociate into ammonium ions (NH_4^+) at low pH (high acidity). In oxic zones, it may be converted into nitrate via nitrification, or alternatively undergo other microbial conversions.

22. An important difference between emission of CH_4 and NH_3 is how the gases are exchanged with the atmosphere. NH_3 emission (flux) is mainly controlled by factors affecting the interface between the surface and the gas layer above the manure surface. These include total ammoniacal N concentration in the manure, pH, temperature and air exchange, which controls the concentration gradients. CH_4, on the other hand, is produced by microorganisms and released from the bulk of the manure and is controlled by the availability of degradable organic matter, the presence of methanogenic microorganisms, temperature, presence of inhibiting factors like volatile fatty acids, hydrogen sulfide, and electron acceptors such as oxygen, nitrate and sulfate. The release can be by diffusion over the interface or by ebullition (effervescence/bubbling).

23. If NH_3 and CH_4 emissions from manure in housing are prevented, more N and C are retained, and NH_3 and CH_4 can be emitted further down the chain of farming operations unless mitigation practices are employed. Mitigating measures including incorporation are therefore also needed during storage (CH_4 and NH_3) and application (NH_3) of manure to the

field. This should also consider leaching to water bodies of any nitrate that has been converted from ammonium (see para. 21 above).

24. In agriculture, emissions of NH_3 result from manure handling, including storage and application of manure and related substrates such as biogas digestate or compost. Also, application of mineral fertilizers (urea or NH_3 compounds) may lead to the release of NH_3 (see para. 21 above). As a consequence of its properties, losses from urea are minimized by applying urease inhibitors to slow down NH_3 formation, by maximizing solubility at low temperatures or maintaining moisture by keeping ventilation/air speed/exposure times low, and by incorporating substrates into the soil instead of allowing surface exposure. Due to the chemical equilibrium between NH_3 and NH_4^+, the rate of NH_3 release can further be reduced at a low pH (see also para. 20 above regarding the interactions with CH_4 emissions).

25. Acidification of slurry has primarily been used to reduce NH_3 emissions from animal housing, manure storage and field-applied slurry. However, acidification has also been shown to reduce CH_4 emissions from stored slurry. The acid dose necessary to reduce CH_4 is lower than that normally used for mitigation of NH_3 emissions but some reduction of NH_3 would still occur.

26. Covering slurry storage with a semi-porous organic or inorganic material capable of supporting microorganisms can encourage the growth of CH_4-oxidizing microbes. These microbes convert CH_4 into carbon dioxide (CO_2) and water. Such natural crusts or covers also effectively reduce NH_3 emission. However, development of cracks should be avoided because this impairs the effect.

27. Covering slurry storage with an impervious cover is commonly used to reduce NH_3 emissions. It is possible that this might increase slurry temperature and thus CH_4 emissions but this has not been investigated. The use of a gas-tight cover would permit the use of flaring or biofilters to convert CH_4 to CO_2.

C. Anaerobic digestion

28. The emission of CH_4 is reduced by using animal manure in biogas production via anaerobic digestion, provided that the CH_4 generated is efficiently collected and used for energy or industrial purposes. Efficient collection means that leakage from the biogas reactor must be minimized and losses from post-digestion storage prevented, either by gas capture or chemical means. Anaerobic digestion converts much of the organic N into NH_4^+, which improves its efficiency for fertilization of crops. However, the higher NH_4^+ concentration and pH of the biogas digestate compared to untreated manure means that biogas production can increase NH_3 emissions. This can be addressed by ensuring covered storage, acidification and low-emission application technology for biogas digestate considering the environmental conditions during and following application. The principle can also be exploited to allow recovery of NH_3 for reuse in "white ammonia" fertilizer production. Application of this principle therefore means that biogas production with action to reduce/recover NH_3 and terminate CH_4 release offers a major opportunity for mitigation of both CH_4 and NH_3. In summary, anaerobic digestion can reduce CH_4 emissions through biogas production and collection, and the resulting digestate can be applied to soils as an organic fertilizer to reduce NH_3 emissions when substituting mineral fertilizers.

D. Aeration of slurry

29. Aeration of slurry in storage is sometimes used to reduce the amount of N by encouraging nitrification and denitrification. This method is mainly used in areas where the production of manure N exceeds utilization capacity of the land (see definition in the European Union Nitrates Directive).[1] This aeration is also likely to reduce CH_4 emission from

[1] Council Directive of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources, *Official Journal of the European Communities*, L 375 (1991), pp. 1–13.

the slurry. However, the deliberate loss of N contradicts the principles of the circular bioeconomy and is also likely to increase NH_3 emissions.

E. Pastures

30. Livestock excreta deposited onto pastures during grazing emit less NH_3 and CH_4 compared to excreta stored and applied to fields, as soil incorporation of urine is rapid (short exposure time) and oxygen access is relatively high. However, livestock productivity and feed use efficiency can sometimes be lower in grazing livestock, and it is harder to achieve an optimal diet composition for grazing livestock, underlining the challenge of low quality forage on pastures, and the positive effect of good forage quality. Extending grazing beyond the end of the growing season reduces the efficiency with which mineral N in the soil is used for production and can increase N losses to the air and aquatic systems.

F. Integrated nutrient management

31. To minimize N and CH_4 losses from crop and livestock production, the factors that define crop growth and livestock productivity have to be addressed at the system (farm) scale, to identify trade-offs and synergies. For example, in livestock production, within the limits set by welfare considerations, increasing the rate of maturation reduces the period during which the livestock are emitting CH_4 and excreting N. For NH_3 emission, ensuring that the N saved by mitigation measures is used efficiently will avoid pollution swapping and reduce the amount of synthetic N fertilizers required.

32. The individual measures for which there are significant synergies between mitigation of CH_4 and NH_3 can generally be ranked in the following order in terms of cost effectiveness, applicability across agricultural systems of different size and type, and speed of implementation in practise: optimization of animal diets and nutrient management > manure treatment and storage > animal housing. However, the ranking is also true for the difficulty in enforcing the measures and the difficulty with which measures can be documented for inclusion in national emission inventories. In this context in particular, the measures related to manure management are available for implementation.

33. The optimum combination of measures appropriate for a given Party to the Convention will vary considerably, depending on a wide range of factors, including the structure of the agricultural industry, climate, market conditions for product prices, the extent to which mitigation measures are already implemented (maturity level) and the constraints on management imposed by existing legislation (e.g., related to nitrate leaching).

34. While both NH_3 and CH_4 have an impact on the chemical composition of the atmosphere, contributing to fine particulate matter ($PM_{2.5}$) and/or tropospheric O_3 formation, CH_4 moreover is a GHG. Measures to reduce CH_4 cannot therefore be treated independently from other GHGs, especially emissions/sequestration of CO_2 in soils and vegetation, and emissions of N_2O that also are intrinsically connected with the same substrates (fertilizers and manure) that are key in the release of NH_3.