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Revision of the Austrian Air Emission Inventory 'OLI' for Greenhouse Gas and Ammonia Emissions in the Agricultural Sector

Überarbeitung der Oesterreichischen Luftschadstoff-Inventur 'OLI' für Treibhausgas- und Ammoniakemissionen im Agrarsektor

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Summary

Too high ammonia (NH_3) and greenhouse gas (GHG) emissions pose potential costs for agriculture due to sectoral penalty payments and for farms due to cost-intensive measures to mitigate emissions. Accurate annual monitoring and analysis methods are required to assess mitigation progress. In Austria, a major revision of the national air pollutant inventory *'OLI'* (Oesterreichische Luftschadstoff-Inventur) for the sector Agriculture was necessary to incorporate updated activity data and to align with current methodologies. The updated approach improves comparability with countries that have similar characteristics such as livestock performances and husbandry systems. Methodological adjustments, such as revised Total Ammoniacal Nitrogen (TAN) values for solid manure, a shift to Tier 2 methods for non-key animal categories or new emission factors (EFs) allow to more accurately assess mitigation efforts over time.

Keywords: CO_2-eq, N_2O, CH_4, NH_3, Emission monitoring

Zusammenfassung

Zu hohe Ammoniak- und Treibhausgas-Emissionen stellen potenzielle Kosten für die Landwirtschaft dar, da bei nationaler Zielüberschreitung einerseits Strafzahlungen drohen und andererseits kostenintensive Maßnahmen zur Emissionsminderung zu setzen sind. Eine präzise jährliche Bewertung und Analyse der Emissionen ist erforderlich, um Fortschritte bei Minderungsmaßnahmen zu beurteilen. In Österreich war eine umfassende Überarbeitung der nationalen Luftschadstoff-Inventur ‚OLI' für den Sektor Landwirtschaft notwendig, um einerseits aktualisierte Aktivitätsdaten einzubeziehen und andererseits die Methoden an den aktuellsten Stand anzugleichen. Der überarbeitete Ansatz verbessert die Vergleichbarkeit mit ähnlichen Ländern. Methodische Revisionen wie die Anpassung der Gehalte an Ammonium-Stickstoff (TAN) bei Festmist oder der Umstieg auf komplexere Tier 2-Methoden auch bei weniger relevanten Nutztierkategorien sowie neue Emissionsfaktoren ermöglichen eine präzisere Bewertung der Minderungsmaßnahmen im Zeitverlauf.

Schlagworte: CO_2-eq, N_2O, CH_4, NH_3, Emissionsmonitoring

1 Introduction

It is important to reduce GHG and air emissions (e.g., NH_3) to achieve national and international climate targets, also within the agricultural sector. Failure to achieve these targets could lead to further costs for countries and their sectors, such as agriculture, or for individual farms if payments are imposed or certificates have to purchased (Matthews, 2022) as well as specific cost-intensive reduction measures have to be taken. Austria has to reduce NH_3 emissions by 12 % by 2030 as defined in the EU Directive on the Reduction of National Emissions of Certain Atmospheric Pollutants ('NEC Directive'; 2016/2284/EU) and the Austrian Air Emissions Act 2018 (BGBl. 75/2018), with the agricultural sector accounting for 94 % of overall NH_3 emissions. The current emission levels of NH_3 in comparison to 2005 still require further actions. A similar situation applies to GHG emissions: overall, the agricultural sector currently shows only very modest reductions compared to emissions in 2005. Stronger and more substantial efforts are still needed to meet Austria's binding GHG targets. In accordance with the provisions of the EU Effort Sharing Regulation (ESR, EU 2023/857) national emissions from all non-ETS sectors, which include agriculture, must be reduced by a total of 48% by 2030. Most important emissions from the sector agriculture are biogenic. The dynamics of methane (CH_4) differ in the climate system from the major GHG CO_2, which is released from sectors like energy production and consumption, and mobility. A general reduction of all emissions is essential for meeting EU climate targets and the requirements of the NEC Directive regarding air quality. Efforts must also be undertaken in the agricultural sector to reduce emissions from livestock, their feeding systems, manure management systems (MMS) (housing, storage, yard) as well as fertilization (EP, 2016; EU regulation 2018/1999, EP, 2018). Thus, the study focuses on CH_4 and dinitrous oxide (N_2O) emissions assessed using the 100-years global warming potential (GWP_{100}), and NH_3 emissions. These gases have to be calculated and reported on a yearly basis, as provided in the National Inventory Report (NIR; Umweltbundesamt, 2024a) for GHG and the Informative Inventory Report (IIR; Umweltbundesamt, 2024b) for NH_3.

The example of Austria demonstrates that emission reduction targets can be met if effective incentives and measures are implemented and their effect can be assessed using the methods documented in the NIR and the IIR. A combination of technological advancements and policy frameworks has enabled Austria to take initial steps toward its targets, as evidenced by declining agricultural NH_3 and GHG emissions, the latter measured with the metric 'GWP asterisks' (GWP*; Hörtenhuber et al., 2022), but also by the GWP_{100} metric, as shown in this study's findings.

Accurate and internationally comparable assessment methods are essential for monitoring emission trends and evaluating mitigation efforts, to systematically capture technical advancements and the effects of implemented measures (IPCC, 2019). For this purpose, specific parts of the Austrian emissions calculation method within the Austrian Air Pollutant Inventory (*OLI)* have been further developed for the sector agriculture in previous studies; see among others Amon et al. (2021) and Hörtenhuber et al. (2023). However, ongoing improvements can be observed both in agricultural practices and in data collection methodologies. Thus, this study aimed to integrate updated agricultural activity data for 2023, including new information on MMS (housing, storage, yard), manure application and mitigation measures. Another primary focus was to integrate recent and more advanced methods into the *OLI* and to analyze the consequences of the improved calculation methods.

2 Material and Methods

Important characteristics and results of the Austrian *OLI* model in the sector agriculture can be found in Umweltbundesamt (2024ab), Hörtenhuber et al. (2023, 2022) or Amon et al. (2021). The most recent revision, described within this article, implemented the Tier 2 approach according to IPCC (2019) for the calculation of CH_4 emissions from enteric fermentation in non-key animal categories that contribute only marginally to total emissions (e.g., poultry, sheep, goats, or horses), resulting in country-specific values for volatile solid excretions (VS_{ex}) and nitrogen excretions (N_{ex}). Furthermore, most CH_4- and N_2O-related EFs for MMS were updated following IPCC (2019; see tables 10.17 and 10.21) to replace the previous IPCC-2006 EFs. During this revision process, NH_3-related calculations for the key sources cattle and swine were updated too. As total ammoniacal nitrogen (TAN) contents of cattle's and swine's manure in the *OLI* obtained from (BMLFUW, 2006; in: Amon et al., 2006a) appeared significantly lower than in other countries, especially for solid manure, those TAN contents were revised based on recent data measured in Austria and assessed following Kupper (2022), i.e., the method '*Agrammon*', which is used for NH_3 in the Swiss National Inventory. Specifically, the initial TAN contents of cattle and swine manure at excretion was recalculated based on data measured for stored manure at HBLFA Raumberg-Gumpenstein (Pötsch, 2019), resulting in initial TAN contents of 50 % for cattle and 65 % for swine following Kupper (2022). In a next step, the TAN contents were increased by 10 percentage points for liquid slurry and reduced to 60 % of the initial value for the addition of straw, i.e. for immobilization (-40 %), according to the procedures described in Kupper (2022). Furthermore, new data was taken from the TIHALO III study (Pöllinger et al., 2025), and expert estimates for specific previous years' activity data by Pöllinger (HBLFA Raumberg-Gumpenstein; personal communications, 25.11.2024). Data were linearly interpolated between the two survey years, 2017 and 2023. These new data include additional MMS and manure treatment options with specific EFs and correction factors (CFs), which were not specifically considered in the previous *OLI* version. Examples are slurry pits below animal confinements (with slatted floors), separation of liquid slurry or the frequency of slurry mixing per year.

The results for the updated method were compared to previous national submission (see Umweltbundesamt, 2023), and data from selected European countries, whose official GHG submissions (data and reports) can be downloaded under the United Nations Climate Change webpage (https://unfccc.int/reports), e.g., the Swiss National Inventory (FOEN, 2024a), and whose official submissions on air emissions (e.g. NH_3) can be found at EMEP-CEIP (2024; https://www.ceip.at/status-of-reporting-and-review-results). Further details on NH_3 can be accessed in the Informative Inventory Reports (IIR), for example, the Swiss IIR (FOEN, 2024b).

3 Results and Discussion

3.1 Total Ammoniacal Nitrogen (TAN) contents and emission factors per head

The new Austrian TAN values for cattle and swine align well with those reported in other countries such as the UK, Germany, and Switzerland (Table 1). This also holds true for the comparison of indirectly derived 'implied' emission factors (IEF) for NH_3 emissions across these countries for the last available submissions 2024 (latest reporting year 2022; Figure 1).

In addition to Austrian measured values, the updated OLI's TAN values rely on the methodological approach of *Agrammon*, which is based on emission measurement data from Switzerland. As a result, the updated NH_3-IEFs of sector 3.B Manure Management (housing, storage, yard) align more closely with Swiss results compared to previous IEFs. Many livestock characteristics, such as average milk yields, are similar between Austria and Switzerland with, e.g., 7,250 and 7,074 kg per dairy cow and year, respectively, in 2022.

In Germany (UBA Germany, 2024), Denmark (Nielsen et al., 2024) and the Netherlands (Wever et al., 2024), the NH_3-IEFs are substantially lower – by around 30% for cattle (based on the average of dairy and other cattle across the three countries) and by approximately 60% for swine. This is mainly due to massive N-reduced feeding especially in the pig sector and in general the higher use of technical measures to mitigate NH_3 emissions, e.g., biogas digestion, slurry injection at application, or slurry acidification at storage or at least at application. As an example, in Denmark and

Table 1. Comparison of Total Ammoniacal Nitrogen (TAN) contents for calculations of the year 2022.

	Previous *OLI*		Updated *OLI*		Switzerland		Germany		UK	
	Solid manure	Liquid slurry	Solid manure	Liquid slurry	Solid manure	Liquid slurry	Solid manure	Liquid slurry	Solid manure	Liquid slurry
	TAN contents for 2022									
Cattle	0.15	0.50	0.30	0.50	$0.55 - f_{imm}$ [a]	0.55	0.47	0.67	$0.60- f_{imm}$	0.60
Pigs	0.15	0.60	0.40	0.75	$0.70 - f_{imm}$ [a]	0.70	0.71[b]		$0.70 - f_{imm}$	0.70

[a] according to the description in Kupper (2020) for Agrammon, the factor f_{imm} for immobilization due to straw reduces the TAN content by 40 %

[b] average for solid manure and mainly liquid slurry systems

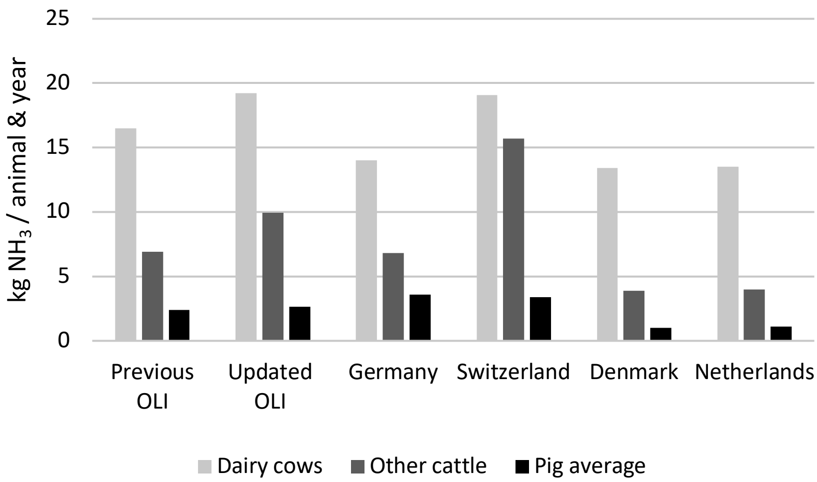

Figure 1. A comparison of average Implied Emission Factors (IEFs) of sector 3.B Manure Management (housing, storage, yard) for ammonia (NH_3) between the previous and the updated (current) OLI, Germany, Switzerland, Denmark and the Netherlands.

the Netherlands, the NH_3-IEFs for average swine have decreased by a remarkable 67 % and 69 %, respectively, since 1990. In Germany, this reduction has been 21 %, whereas we assessed only 12 % in the updated OLI for the Austrian average swine's NH_3-IEF. In Austria, average farms are much smaller and family-run, thus investments in advanced emission-reducing technologies are less common. However, in Austrian swine production, feeding practices have already been adapted to reduced crude protein- and N-levels to a broad extent (see study *MiNutE*; Hörtenhuber et al., 2023). These developments have resulted in lower, but still notable reductions in NH_3 emissions even without extensive adoption of additional technical mitigation measures.

Comparative data for N_2O from MMS was found for Denmark. Similarly to NH_3, the Austrian N_2O-IEFs of 3.B Manure Management for average swine in 1990 and 2005 were still comparable to those of Danish swine (0.14 vs. 0.12 and 0.12 vs. 0.11 kg N_2O per swine and year in 1990 and 2005 for Austria and Denmark, respectively). However, the Austrian value for 2022 was at 0.09 kg N_2O, whereas the Danish value has decreased to just 0.05 kg N_2O per swine and year due to a mix of effective mitigation measures. In Austria, the N_2O-IEFs for other cattle and swine are higher than those from Denmark by 16 % and 75 %, respectively. This difference can primarily be attributed to a higher proportion of straw-based systems in Austria (see results from the updated OLI and Nielsen et al., 2024). Conversely, the CH_4-IEFs from MMS are lower in Austria compared to Denmark for both cattle and swine. This is mainly due to the higher proportion of solid manure systems as well as the lower national CH_4 emission factor for liquid slurry measured in Amon et al. (2006b) in Austria. Nevertheless, for cattle in Austria, the CH_4-IEFs from MMS have more than doubled between 1990 and 2022, primarily due to the increased use of liquid manure systems. The NH_3-, N_2O- and CH_4-IEFs of sector 3.B Manure Management for Austrian cattle and swine according to the updated OLI version are presented in Table 2.

Table 2. Updated Austrian Implied Emission Factors (IEFs) of sector 3.B Manure Management for ammonia (NH_3), nitrous oxide (N_2O) and methane (CH_4) for cattle and swine for the year 2022.

	NH_3-IEF	N_2O-IEF	CH_4-IEF
Dairy cows	19.2	0.70	20.9
Other cattle	10.0	0.47	9.0
Swine	2.7	0.09	1.8

3.2 Overall cattle- and swine related emissions in Austria

The results from this *OLI* update reflect recent science for NH_3 emissions from solid and liquid manure (e.g., following Kupper, 2022), and are in accordance with the results of other countries. Figure 2 illustrates the changes in total NH_3 and GHG emissions (CO_2-eq) in the Austrian agricultural sector for both the previous and the updated OLI versions. According to the updated OLI, emissions from cattle's and swine' MMS (sector 3.B Manure Management except emissions from spreading) were reduced by 7,7 % for NH_3, 38 % for N_2O, and increased by 15 % for CH_4 between 1990 and 2022. For the period 2005 to 2022, the changes account for +0,1 % for NH_3, -26 % for N_2O, and +44 % for CH_4 from this source. The most important source of Austria´s CH_4 emissions as well as in many other countries is enteric fermentation (mainly from cattle). These emissions were not updated during this study, however, they contribute the main component in total GHG emissions in Figure 2 (black lines; 57 % according to the updated *OLI* method and 59 % according to the previous *OLI*). Austrian enteric CH_4 declined by 15 % between 1990 and 2022 and by 3 % between 2005 and 2022.

Total Austrian NH_3 emissions (updated version) are primarily influenced by N_{ex} (Figure 3). However, since 2005, NH_3 emissions have begun to diverge from N_{ex} trends, showing a stronger increase. This trend can be attributed, among other factors, to rising N_{ex} levels excreted in liquid slurry systems (in yards and inside animal houses), particularly for cattle, but also for swine. In recent years, however, the two curves have converged again, largely due to NH_3 reduction measures such as low-emission slurry application techniques (trailing hoses, trailing shoes or injection), and – to a lesser extent – due to slurry separation, incorporation of applied manure, slurry dilution, or optimized timing and weather conditions for application. Additionally, there have been countervailing trends, such as a slight decline in the proportion of covered slurry stores and a corresponding increase in open slurry pits with their higher NH_3 losses from storage (Table 3). However, permanent natural crusts have been emphasized and are often present in such cases.

Similar trends and effects can be observed for total GHG emissions (Figure 4): The effects of N_{ex} and VS_{ex} are dominant, causing that the curve of total CO_2-eq from cattle and swine follows a similar trend. However, the increasing share of excretions in liquid manure systems, particularly pit storage below animal confinements, counteracts the generally declining N and VS excretion activities over time with higher emissions. In recent years, mitigation options for CH_4 and N_2O emissions, for example, a modest increase of the proportion of excreta on pasture, enabled a parallel development of N_{ex} and VS_{ex} and GHGs.

Table 3 provides the developments of selected MMS and mitigation measures since 1990 for average cattle and swine, weighted by N_{ex}, and their qualitatively estimated impact on NH_3 and CO_2-eq.

Reducing emissions and meeting targets not only protects nations, their sectors or individual farms from penalty payments, costs and environmental damage. A reduction of NH_3 losses can also be interesting from farms' economic perspective due to decreased demand for external fertilizers, leading to a potentially cost-neutral emission mitigation, especially at rising prices of energy-intensive N fertilizers. Research highlights that current worldwide ammonia production alone contributes to 1 % of global CO_2 emissions

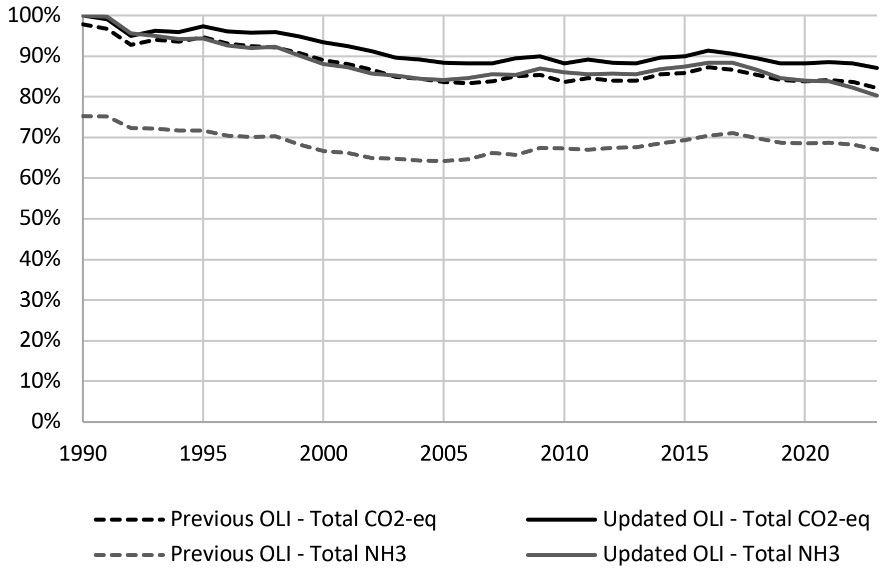

Figure 2. Trends of total ammonia (NH_3)- and greenhouse gas emissions (CO_2-eq) from the sector Agriculture as relative changes compared to the maximum emission values (which were found in the updated *OLI* version for 1990).

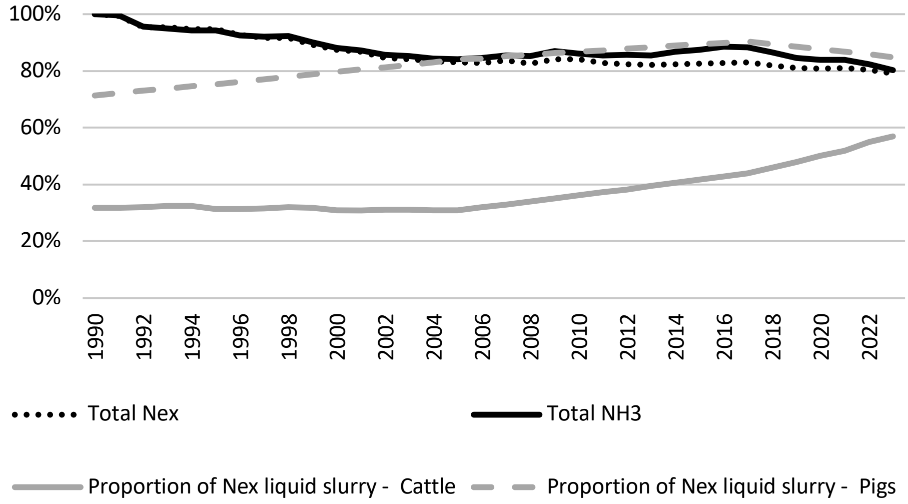

Figure 3. Trends of total ammonia (NH_3) emissions from sector Agriculture and total Nitrogen excretion (N_{ex}) as relative changes compared to the maximum emission values (updated *OLI* version for 1990) as well as cattle's and swine's proportions of N_{ex} in liquid slurry systems.

due to its energy-intensive processes (Mingolla et al., 2024), emphasizing the potential economic and environmental benefits of efficient nitrogen management.

4 Conclusions and Outlook

The continuous improvement of inventories and the collection of new data is labor-intensive but necessary. Without such updates of assessment methods, it is difficult to promote sustainable development. In the future, Austrian producer associations for milk, swine/pork, eggs, and poultry meat aim to continuously collect high-quality farm data to further improve emission modeling. With the revision described herein, incorporating the latest activity data for 2023, the update of cattle's and swine's TAN contents for solid and liquid manure, the application of the revised IPCC (2019) EFs and Tier 2 methods for non-key animal categories, more accurate emission results and trends are now derived. This allows for better quantification of the emission levels, the mitigation progress, and deviations from targets. Furthermore, updated inventory methods are useful to in-

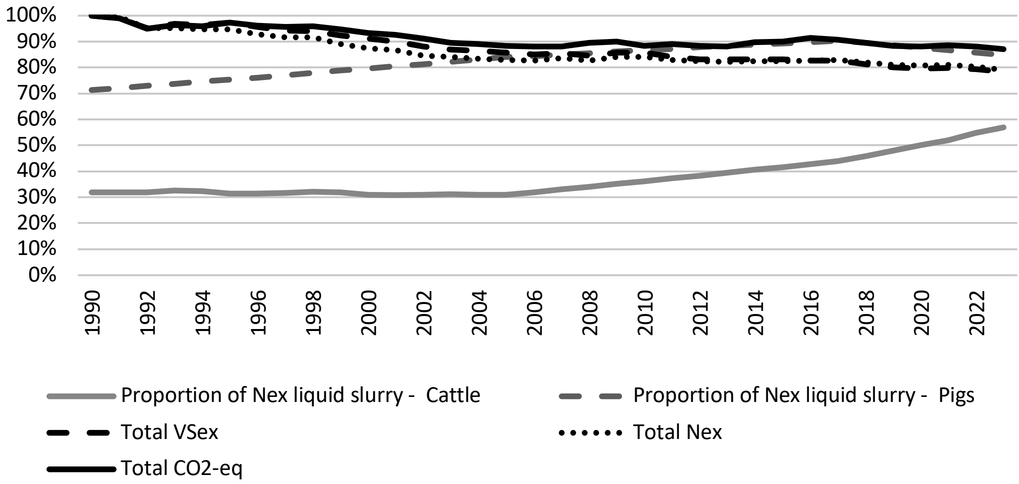

Figure 4. Trends of total greenhouse gas emissions (CO_2-eq) from sector Agriculture and total Volatile Solids excretion (VS_{ex}) and total Nitrogen excretion (N_{ex}) as relative changes compared to the maximum emission values (updated *OLI* version for 1990) as well as cattle's and swine's proportions of N_{ex} in liquid slurry systems.

Table 3. The occurrence and development of selected manure management systems (%) for cattle and pigs and their impact on total Austrian Ammonia (NH_3) and greenhouse gas emissions (CO_2-eq) under the updated *OLI* version.

Year	1990		2005		2022		Impact on…[a]	
	Cattle	Pigs	Cattle	Pigs	Cattle	Pigs	NH_3	CO_2-eq
Pasture[b] (%)	10.4	0	5.9	0	8.2	0	-1	-1
Slurry systems[b] (%)	31.1	71.3	30.1	84.0	53.5	90.4	+1	+1
Slurry stored with solid cover (%)	62.5	69.8	56.0	65.7	49.0	48.7	-2	-1
Slurry stored with tent, plastic film, hexa-cover, straw or natural crust cover[c] (%)	5.0	5.8	4.5	5.9	16.0	25.4	-1	-1 to +1
Slurry in pit storage below animal confinement[c] (%)	17.0	8.6	21.9	10.4	17.6	14.3	0	+1
Separated slurry[c] (%)	0.0	0.0	0.0	0.0	8.5	1.3	0 to -1	-1 to +1
Slurry digested in biogas plants[c] (%)	0.0	0.0	1.1	1.8	2.4	0.8	0 to -1	-1 to -2
Broadcast application[d] (%)	91.3	97.2	86.6	94.3	83.8	48.3		
Bandspreading[d] (trailing hose and shoe, injection; %)	3.8	2.8	7.6	5.7	16.2	51.7	-1 to -2	0

[a] between -2 for strong reduction and +2 for a strong increase of emissions
[b] percentage of N_{ex} not only for excretions inside animal houses, but also including those on pasture
[c] percentage of N_{ex} excreted in MMS (excluding pasture)
[d] percentage of N_{ex} in liquid slurry applied to land

vestigate the emission status and mitigation potentials for specific production systems in research projects (Ogle et al., 2013) or for web applications to analyze sustainable development in real-life farms.

In connection with (productive) livestock and fertilized soils, which are important to ensure the production of food with internationally comparably low climate and environmental impacts, extensive reductions are challenging. However, Farm Information Management Systems and Decision Support Systems are expected to accelerate the adoption of sustainable practices, resulting in reduced impacts on environment. Per unit of product and in comparison to other countries, Austria is already on the track towards environment- and climate-friendly food production (see, for example, Hörtenhuber et al., 2023). This study aims to identify further key areas with the greatest potential for national improvement regarding NH_3 and GHG emissions.

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Disclaimer

The new Austrian emission values (so-called 'updated OLI') provided in this paper are considered as preliminary data and might slightly differ from the emissions that are and will be reported officially in Austria´s submissions 2025.

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