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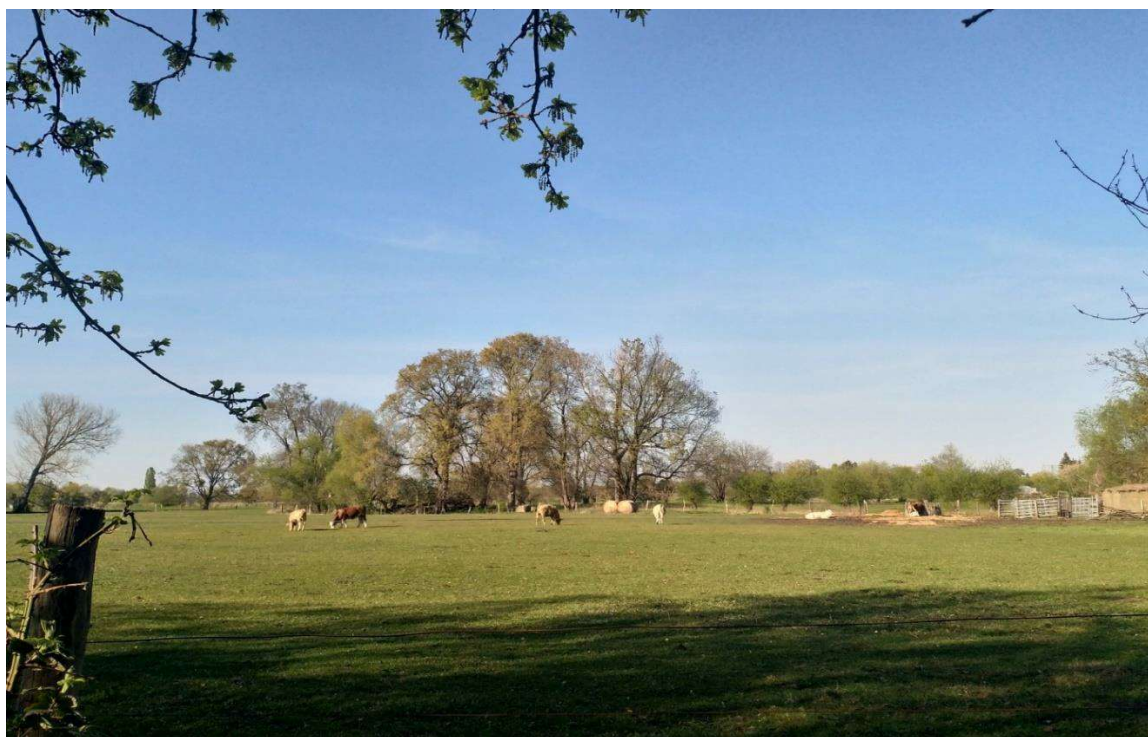
Leibniz-Institut für Agrartechnik und Bioökonomie e.V. (ATB)
2819ERA10A / 2018 Joint Call Proposal ID 39258

Mitigating greenhouse gas emissions from livestock systems (MELS)

Final Report

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Contacts:

Dr. Barbara Amon, Prof. UZ (Project coordinator):

bamon@atb-potsdam.de

Dr. Federico Dragoni (Project coordination at ATB):

eranet@atb-potsdam.de



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Summary

All countries are under pressure to reduce greenhouse gas (GHG) emissions from agriculture and to document those reductions in emission inventories. For the European Union, manure management represents the third largest source of agricultural GHG emissions after enteric fermentation and direct nitrous oxide (N₂O) emissions from soil. Nitrogen (N) in urine and dung deposited by grazing animals and in organic fertilisers contributes about one third of the latter emissions and is a major contributor to the indirect N₂O emissions. This means that about a quarter of the agricultural GHG emissions are related to animal excreta. Modifying excretal carbon (C) and N flows through manure management systems is key to reducing GHG emissions from agriculture. About 95% of ammonia (NH₃) emissions result from agriculture with manure management being the largest source. Mitigation of NH₃ emissions is key for improved N management and reduced negative environmental impact.

The MELS project built on the DATAMAN database of manure-related emissions, and collated a multitude of additional data into the database. The database was carefully checked for data quality and an emission unit conversion activity was carried out, which resulted in a marked increase in the number of available data that could be used for the further analysis. Then, the database was statistically analysed to generate functional relationships between emissions and activity/ancillary variables enabling a refinement of emission factors and the assessment of mitigation measures. On these premises, MELS assessed and recommended improvements to: i) national emission inventories, and ii) decision support systems (DSS) in relation to GHG and N emissions from live-stock production systems.

The MELS work plan was made up of 6 work packages. The ATB took care of project coordination and management including internal communication among the partners (WP1) and contributed to all WPs: from database management (WP2) to component modelling (WP3), GHG-DSS development (WP4), improvement of national emission inventories and projections (WP5), stakeholder consultation and dissemination (WP6), with particular regard to the international communication with IPCC, TFEIP, and TFRN. In particular, ATB's activity on improving emission inventories includes recommendations for improving inventory methods in partner countries and methods for maintaining transparency of Tier2+ and Tier3 emission inventories. MELS had 10 international partners and its very active advisory board allowed a global outreach.



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The data collation in MELS was aimed to increase the number of observations to be used in the statistical analysis, and also to broaden the geographical coverage of the DATAMAN database.

In detail, MELS increased the DATAMAN number of EF related to animal housing and manure storage by more than 6 times. The process took specifically care of including EF from Latin America, China, Eastern and Southern Europe, Africa, since most of the emission observations typically originated from Western countries and cooler climates before MELS. The process led to the public release of the expanded DATAMAN database and to the submission of the new EF to the EF database of the IPCC (Intergovernmental Panel on Climate Change).

As a following step, “emission factors” (EF) for the main animal housing types, manure types, and storage types were determined, key drivers influencing emissions were identified, and statistical functions describing the relationships between emissions and ancillary variables were developed. EF are key in the assessment of emissions from agriculture, as they allow calculating the emissions of a livestock system by multiplying the EF by data typically available in the national statistics. In this way, EF “embed” the complexity of the emission assessment, while the multipliers are routinely gathered by public authorities. MELS EF are designed to advance the assessment methodology providing more tailored estimates that are better able to capture the effects of mitigation measures soon in the future. However, national emission inventories must retain transparency and allow i) to compare across methods (and also across countries/regions), and ii) to validate whether results are fit for purpose. To this end, MELS correlated the EFs calculated in the project to the existing official Tier2/Tier3 methods and developed guidelines for the improvement of future inventories. Consequently, an analysis of current emission inventories of the MELS countries and other countries in the world allowed identifying a path for improving emission inventories and to assess the results of improved estimation methodologies. The MELS “traffic light systems” shows where improvements in the collation of activity data will be most effective and efficient.

The analysis was extended to farm-scale GHG DSS, as engaging the farming sector is key to promote transformative changes needed to tackle climate change. Knowledge about the emissions under different conditions, the effectiveness of mitigation measures, and their cost enables advisors and livestock farmers to choose the most affordable mitigation strategies for achieving air quality and climate change goals. Therefore, an improved prototype DSS was developed allowing emissions of livestock systems to be more accurately quantified. MELS also assessed the future demands of the farming sector on farm-scale GHG DSS, while recommending improvements to the existing systems and developing a methodology to assess farm costs of mitigation measures.



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I. Scientific results

The research work in MELS was divided in 6 work packages (WPs) led by different partners of the European consortium. WP1 dealt with project management; WP2 with the collation of data to the DATAMAN database; WP3 drew functional relationships between the emission data and the ancillary variables, aiming to derive statistical models for the emission factors, WP4 reported on existing farm-scale GHG DSS (decision-support software) and developed an improved software prototype; WP5 developed recommendations and instructions on the improvement of emission inventories, based on the outcomes of MELS; WP6 managed project communication and dissemination, including the engagement of policy advisors, policy makers and other stakeholders.

The Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB) coordinated the project (WP1), led WP5, and was involved in all other WPs. In particular, ATB contributed to data collation (WP2), to the statistical analysis of the data (WP3) and to the development of the prototype GHG DSS and the related tasks (WP4). The list of partners is reported at Table 1.

Table 1 - List of partners.

Partner organization name	Project Role	Country	Abbreviation
ATB – Leibniz Institute for Agricultural Engineering and Bioeconomy	Coordinator, WP5 leader	Germany	ATB
AgResearch	WP2 leader, major role in WP3	New Zealand	AgR
INRAE (UMR Ecosystème Prairial)	WP3 leader	France	INRAE
Agricultural University of Athens	WP4 leader	Greece	AUA
Teagasc	WP6 leader	Ireland	LU
University of Zielona Góra	Major role in WP5	Poland	UZ
INRAE (UMR Sol, Agro et hydro systèmes, Spatialisation)	Major role in WP2 and WP3	France	INRAE



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Instituto de Investigaciones Agropecuarias	Major role in WP2	Chile	INIA
Aarhus University	Major role in WP3 and WP4	Denmark	AU
Cork University Business School	Task 4.4	Ireland	CUBS

A. WP1 – Project management

WP Leader: Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB, Germany)

Partners: All MELS partners

The objectives of WP1 were: to manage MELS efficiently and effectively, to monitor project progress, to ensure timely fulfilment of the planned objectives, quality of the results, management of human and financial resources, and to optimise exploitation, dissemination of results and deal with any issues that arise during the project. WP1 was made up by three tasks:

- T1.1 - Project management and coordination
- T1.2 - Project advisory group
- T1.3 - Data management, IPR and dissemination plans

Task 1.1: The Consortium Agreement (**D1.1**) was finalized in June 2020. A project website (**D1.2**) has been published (<https://www.mels-project.eu/>): it reports information about the project, project partners, the scientific Advisory Board, the DATAMAN database and all project WPs. MELS has been managed mainly through meetings of the Project Management Committee (PMC), composed of the work package leaders and chaired by the coordinator (ATB). The coordinator invited all project partners to attend PMC meetings, in order to ease the internal communication within the Consortium and open the discussion when required. WP-dedicated meetings between the coordinator and the partners involved in each WP generally preceded each PMC meeting.

Beside the main meetings, partners of each WP have been in close and continuous contact. In particular, several bilateral meetings and WP meetings took place in WP2 (2020) and in WP3-WP5 (2021-2022). Annual Meetings were also carried out. The first and the second Annual Meeting (2020-2021) should have taken place at the RAMIRAN Conference (Cambridge, UK), where all MELS partners agreed to meet, but the conference was canceled because of the pandemic. So,



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the MELS partners met online. The third Annual Meeting was organized by the ATB (Potsdam, Germany). The Annual meetings served as management meetings, but also as workshops, where the partners discussed scientific aspects and found solutions to the problems that arose in WP2-WP5.

The coordinator took care of the communication with FACCE and participated to the networking and dissemination initiatives promoted by FACCE in the three project years, informing and involving the project partners.

In particular, the coordinator updated the contents of the FACCE-JPI Project “Wheel”, (<https://project-wheel.faccejpi.net/>) and joined the FACCE kick-off event in November 2020. In 2021, MilKey was presented at the mid-term seminar of the FACCE ERA-GAS 2018 Joint Call. In 2022, MilKey took part to a FACCE networking event.

Table 2 - Main WP1 events 2020-2023

2020	
Kick-Off Meeting (Poznan, Poland)	January 2020
PMC Meeting (online)	April 2020
PMC Meeting (online)	June 2020
1 st Annual Meeting (online)	September 2020
FACCE kick-off event (online)	November 2020
2021	
PMC Meeting (online)	March 2021
PMC Meeting (online)	June 2021
2 nd Annual Meeting (online)	November 2021
FACCE mid-term presentation (online)	December 2021
2022	
FACCE networking event	January 2022
PMC meeting	February 2022
PMC meeting	June 2022
3 rd Annual Meeting (Potsdam, Germany)	September 2022
2023	
WP3 Meeting (Potsdam, Germany)	March 2023

ATB finalized and submitted to FACCE the interim report in M21 (original deadline: M18, officially postponed by the FACCE board; see Annex). To date, the FACCE board did not inform the MilKey coordinator about the submission of a final report. **D1.5** and **D1.6** consisted of the first and the



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second year report, respectively (see Annex). **D1.7** will consist of this final report, after circulation to the Consortium and approval of the partners.

Task 1.2: In 2020, MELS established a stakeholder advisory group (see **D1.4**). This group consists of about 20 experts (farm advisors, inventory compilers, policy makers and scientists) suggested by the project partners. In 2020, the stakeholder advisory board was invited to the 1st Annual Meeting. In the figures below, information on the composition of the stakeholder advisory board of MELS is reported.

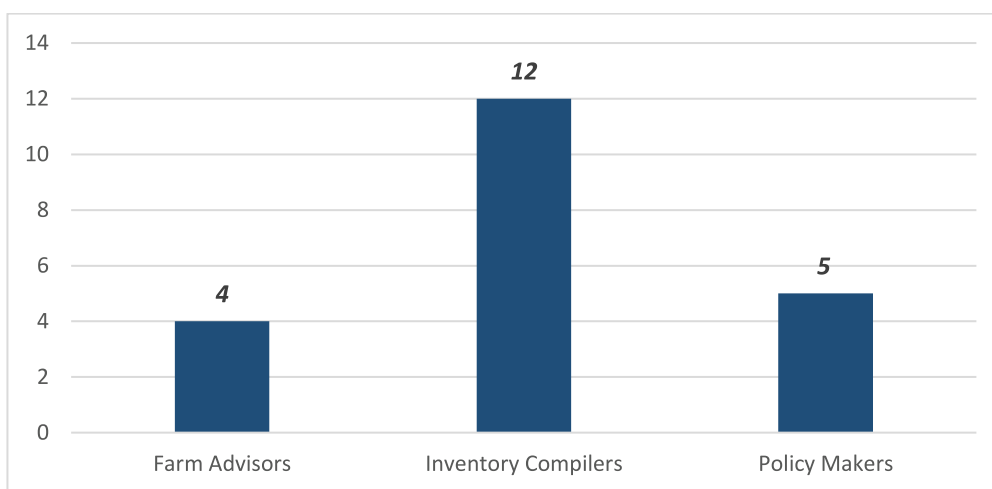


Figure 1 - Stakeholder advisory board members by category.

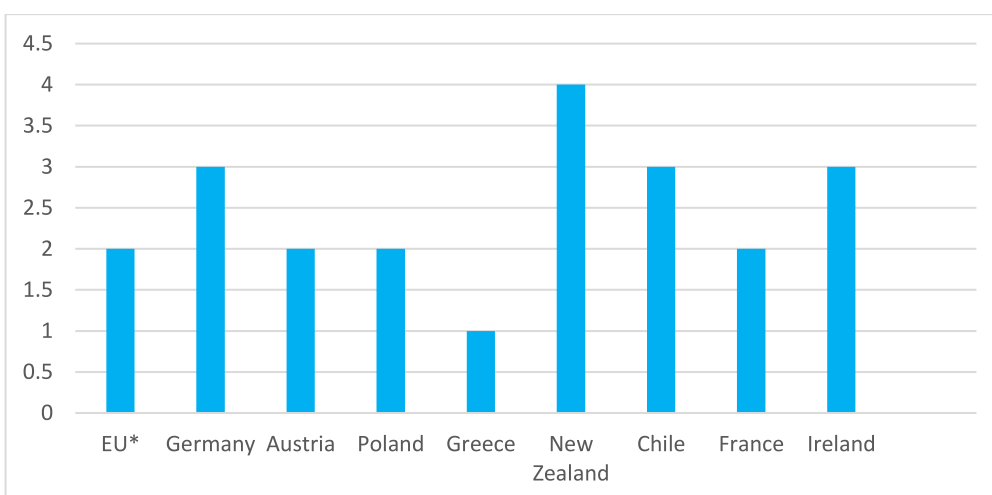


Figure 2 - Stakeholder advisory board members by country (*EU stakeholders belong to EU institutions)

The stakeholder advisory board was involved in the surveys in T4.2 and T5.3 (see Annex).



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MELS also had a scientific advisory board. The scientific advisory board of MELS was drawn outside of the MELSConsortium and was tasked with providing international experience, constructive criticism and feedback concerning the implementation of the project. The MELS Advisory Board received all the general project communication (i.e. information on project meetings, workshops and PMC meetings, meeting minutes) and was invited to join all quarterly meetings of the Consortium. The MELS Advisory Board was made up by 5 members (see Table below).

Table 3: Advisory board members of MELS

Advisory board member	Institution	Country
Karin Groenenstein	Wageningen University	The Netherlands
Paolo Balsari	University of Turin	Italy
Hongmin Dong	Chinese Academy of Agriculture Sciences	China
Vinicius Pereira	EMBRAPA	Brazil
Peter Demeyer	ILVO	Belgium

Task 1.3: The Data Management Plan (DMP) and the Dissemination Plan (DP) were discussed at the kick-off meeting. Then, the first draft was circulated in June 2020 and first approved version of the document was finalised before the 1st Annual Meeting. In June 2021 and in July 2022, updated versions of the DMP were circulated to the Consortium and approved by the partners. **D1.3** reports the updated versions of these plans (see Annex).

WP1 – List of deliverables

	Deliverable	Planned for	Status	Responsible partner
D1.1	Consortium Agreement	M1	Done	ATB
D1.2	Functional project website	M2	Done	ATB
D1.3	Data management and dissemination plans	M4	Done	ATB



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D1.4	List of Advisory Group members	M6	Done	ATB
D1.5	Progress report	M12	Done*	ATB
D1.6	Progress report	M24	Done*	ATB
D1.7	Final report	M36	Done*	ATB

* D1.5-D1.7 are the yearly reports of the coordinator.

B. WP2 – Data collation and database management

WP Leader: AgResearch (AgR, New Zealand)

Partners: ATB (Germany), AU (Denmark), AUA (Greece), Teagasc (Ireland), INRAE (France), INIA (Chile), UZ (Poland)

Objectives of WP2 were: i) to collate GHG and NH₃ emission factor data and ancillary activity data across the entire manure management chain, including direct deposition by grazing livestock, into a unified database; ii) to include data describing the effect of imposing mitigation measures, iii) to manage the database (i.e. maintain integrity of the data, avoid duplication and enable access from other work packages). WP2 was divided into three tasks:

- T2.1 - Data collation
- T2.2 - Incorporation of mitigation and abatement strategies
- T2.3 - Database management

The ATB played a major role in Tasks 2.1 and 2.2. Task 2.3 was a continuous task carried out by AgR.

Task 2.1: GHG and NH₃ emission data were collated to the DATAMAN database until the end of March 2021; quality checks were carried out until the end of October 2021. A first version of the database was iterated in September 2020 (**D2.1**). The most relevant aspects of the data collation activity are summarised as follows.

Task 2.1 was based on the “guidelines on data acceptance” prepared by AgR in 2020 (See Annex). Collated emission data were sourced from several publication typologies, such as scientific papers, monographs, chapters in monographs, conference proceedings, dissertations, research projects



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reports. Relevant information for different animal categories, manure types, livestock buildings, outdoor storage and climatic conditions were also collated. Data sources were carefully examined by researchers from ATB, AgR, UZ, INIA, INRAE and entered into the database. The geographical range of the database was widened by including data not only from MELS partner countries, but also from other countries in Latin America, Eastern and Southern Europe and from China. The ATB added data from 88 publications to the database.

Thanks to additional funding secured by the GRA (Global Research Alliance), collated housing and storage emission factors (EF) went through a unit conversion activity. This was done in order to develop a common method for deriving or estimating EF from emission rates or cumulative emissions. As a result of the unit conversion project, three type of EF values were developed:

- Supplied EF: as published in the sourcing literature (kg N/kg N excreted or stored; kg CH₄/kg VS excreted or stored);
- Derived EF: calculated using information supplied in the sourcing literature;
- Estimated EF: calculated using national/international statistics (e.g., average weight of livestock; N and VS content of manure), as the information required was not available in the sourcing literature.

The unit conversion process led to a scientific paper entitled “*Guidance on the conversion of gaseous emission units to standardized emission factors and recommendations for data reporting¹*”, published in the “Carbon Management” peer-reviewed journal (see Annex).

Task 2.2: In this task, partners have been extensively working on identifying and collating data of mitigation strategies for CH₄, N₂O and NH₃ emissions. The collation of data on relevant mitigation measures was completed by the end of March 2021. Quality checks were carried out until the end of October 2021.

Mitigation strategies have been categorized with a focus on housing and manure storage solutions. Mitigation strategies for pig and dairy cattle production systems encompassed by the DATAMAN database after MELS data collation are the following:

• ¹ <https://doi.org/10.1080/17583004.2021.1995502>



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- For cattle and swine housing
 - Floor Type;
 - Type of bedding material;
 - Rate of Bedding per Animal;
 - Type of Forced Ventilation Air Inlets;
 - Type of Forced Ventilation Air Outlets;
 - Presence of Air Scrubber;
 - Presence of Cooling System;
 - Presence of Manure Drying;
 - Removal of manure from housing;
 - Manure management in housing;
 - Duration of manure storage in housing.
- For manure storage
 - manure acidification (slurry tanks, e.g. with sulphuric acid);
 - covered storages (slurry tanks and manure heaps);
 - compaction (manure heaps);
 - composting (manure heaps);
 - aerobic treatment (slurry);
 - solid/liquid separation.

The effect of the mitigation strategies identified in T2.2 was statistically analyzed in T3.2.

Task 2.3: Activities in this task were aimed to ensure consistency of the DATAMAN database and to publicly release the data collated by the MELS project.

In February 2021, a scientific paper on “*Ammonia and nitrous oxide emission factors for excreta deposited by livestock and land-applied manure*”² was submitted to the peer-reviewed “Journal of Environmental Quality”. It was accepted for publication in June 2021 (see Annex). Additionally, in 2021 a manuscript (D2.2, see Annex) entitled “*DATAMAN: A global database of methane, nitrous oxide and ammonia emission factors for livestock housing and outdoor storage of manure*”³ was prepared. This paper summarised the overall MELS activity in WP2. The paper was submitted to

² <https://doi.org/10.1002/jeq2.20259>

³ <https://doi.org/10.1002/jeq2.20430>



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the peer-reviewed “Journal of Environmental Quality” in April 2022 and accepted for publication in October 2022.

After publication of this paper, the database was publicly released (**D2.3**). It can now be reached at <https://dataman.azurewebsites.net/>. The user can register and then browse through the data collated by the MELS partners on GHG and NH₃ emissions. Hence, DATAMAN database has now three sections: manure-related emissions from i) fields, ii) housings and iii) storages.

The final storage emissions database contains 654 NH₃ EF from 16 countries, 243 CH₄ EF from 13 countries and 421 N₂O EF from 17 countries. Across all gases, dairy cattle and swine production in temperate climate zones are the most represented animal and climate categories. In the housing database, 2024 EF were collated (63% for NH₃, 19.5% for CH₄ and 17.5% for N₂O). Overall, the number of EF for the tropical climate zone was heavily under-represented, since a substantial lack of data exists for tropical countries.

WP2 – List of deliverables

	Deliverable	Planned for	Status	Responsible partner
D2.1	First iteration of the expanded DATAMAN database	M9	Done	AgR
D2.2	Scientific paper summarizing structure and content of the expanded DATAMAN database	M18	Done	INRAE
D2.3	Public release of the database	M21	Done	AgR

C. WP3 – Component modelling

WP Leader: Research Institute for Agriculture, Food and Environment (INRAE, France)

Partners: AgR (New Zealand), AU (Denmark), ATB (Germany), Teagasc (Ireland), INIA (Chile)



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Objectives of WP3 were: i) to develop functional relationships of GHG emissions from farm components and ii) to develop mechanisms to incorporate the effectiveness of mitigation measures into the functional relationships. WP3 was divided into three tasks:

- T3.1 - Functional relationships for emissions
- T3.2 - Incorporation of mitigation measures
- T3.3 - Parameterisation of functional models

The ATB was involved in all WP3 tasks.

Task 3.1: In this task, statistical analysis of the storage and housing databases was carried out, obtaining functional relationships between emissions and activity/ancillary variables. This task was carried out by ATB, AUA, INRAE and AgR. Storage and housing emission databases were interrogated for the statistical analysis, with the workload shared between three MELS partners. The cattle and swine storage data was analysed by AgR, whilst the housing data analysis was analysed by ATB (cattle housing) and AUA and AgR (swine housing). Because different institutions led the analysis of different components of the databases, the approach and presentation of the methods and results also differ. However, we attempted to minimise these differences through a series of workshops between MELS partners conducted on-line in March-April 2020, followed by regular on-line discussion between the three institutes over the last two years.

Another challenge was the heterogeneity of details and ancillary variables provided in the different literature sources. The DATAMAN database is the most extensive and the biggest dataset on livestock emissions measurements published so far. Since the data came from many different experiments and measurements conducted under entirely different conditions, selecting a uniform range of variables was laborious. Missing data points also hindered the statistical analysis. MELS partners could proceed only by a lengthy trial and error process, studying the distribution of the data and finding solutions step by step.

A systematic approach was adopted for analysis of the Storage datasets in relation to determining NH₃, N₂O and CH₄ emissions, key drivers and functional relationships. The approach employed a four-stage process, which can be briefly summarised as follows:



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1. Based on an analysis of the data and review of the literature, manure treatments that either enhance or reduce emissions (e.g., acidification, storage covers) were excluded,
2. Emissions for main animal/manure type and storage types were determined,
3. Key drivers influencing emissions were identified,
4. Statistical functional relationships describing emissions were developed

The datasets were filtered according to a stepwise process to ensure data used for quantifying mitigation practices, identifying key drivers and developing functional relationships was “fit-for-purpose”. The remaining number of observations for determining revised EF, key drivers and functional relationships were 337 NH₃, 294 N₂O and 147 CH₄ emission values.

The analysis of the cattle housing dataset was conducted following the steps below:

1. Emissions related to dairy and beef cattle in the housing dataset were extracted,
2. Key drivers to be tested in the analysis were identified,
3. Emissions were filtered according to data availability of key drivers,
4. A datasheet of emissions and corresponding key drivers observations was prepared,
5. Statistical models describing emissions were developed.

The cattle housing database included 329 NH₃, 114 CH₄ and 101 N₂O observations of emissions for beef cattle and dairy cattle combined. Selected key drivers to be tested were: housing type, floor type, climate zones, manure type, ventilation type, barn temperature and relative humidity.

Similarly, the analysis of swine housing data was carried out following the steps below:

1. Based on the data availability, the connection to the type of emissions and the interest for national inventory compilation, a list of potential emission key drivers was developed,
2. Emissions for the main types of swine housing installations were determined,
3. Key driving variables influencing emissions for NH₃, N₂O and CH₄ were identified,
4. Statistical models describing emission values were developed.

The initial housing dataset for swine included 661 NH₃ emissions from 21 countries, 191 N₂O emissions from 10 countries and 207 CH₄ emissions from 12 countries. This dataset was filtered by: a) selecting only the emission data corresponding to a measurement duration larger than 6 days, b) removing the manure management options in house that may influence the base emissions for the house type being examined, and c) removing observations connected to treatments in house (to air and to manure) that may influence base emissions.



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Overall, this analysis allowed to identify key drivers of the emission factors and functional relationships between emissions and activity/ancillary variables, generating revised CH₄, N₂O and NH₃ emission factors

- cattle and swine slurry tanks
- cattle and swine solid manure heaps,
- cattle tied stalls, loose housings, cubicle housings and feedlots, and
- swine deep pit housing, closed housing and loose housing.

Statistically-based single and multi-variable functional relationships were drawn where sufficient data existed.

For manure **storage**, multi-variable functional relationships for different GHGs included the following key variables:

- Predicted NH₃ EF from cattle and swine slurry tanks: 3-variable model containing manure DM, manure TAN concentration, air temperature
- Predicted NH₃ EF from cattle and swine solid manure heaps: 3-variable model containing manure organic C, manure pH, manure TAN concentration
- Predicted N₂O EF from cattle and swine slurry tanks and solid manure heaps: 2-variable models containing combinations of manure DM, manure organic C, manure total N concentration, manure C:N ratio and manure temperature,
- Predicted CH₄ EF from cattle and swine slurry tanks and solid manure heaps: 2-variable models containing combinations of manure DM, manure C:N ratio, manure VS concentration, manure temperature and air temperature.

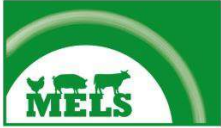
The analysis also showed that the storage **duration** has a significant effect on NH₃ and N₂O emissions, but not on CH₄ emissions. NH₃ and N₂O emission factors were estimated for different storage types for swine and cattle storage. The highest NH₃ and N₂O emissions factors were observed from manure heaps, while the lowest NH₃ emission factors were from slurry tanks for both cattle and swine. The graphs below summarize the results of NH₃ and N₂O emission factors from manure storage (Figures 1-4).



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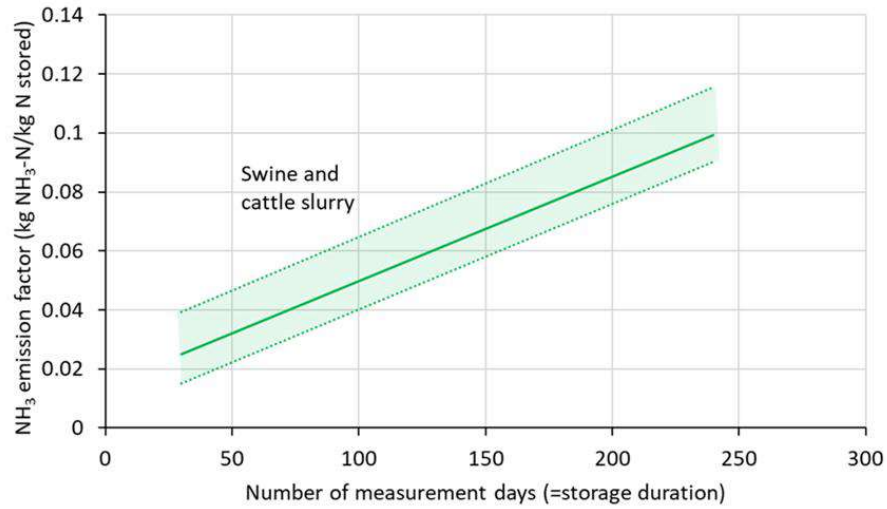


Figure 3 - The effect of storage duration on NH₃ emission factors.

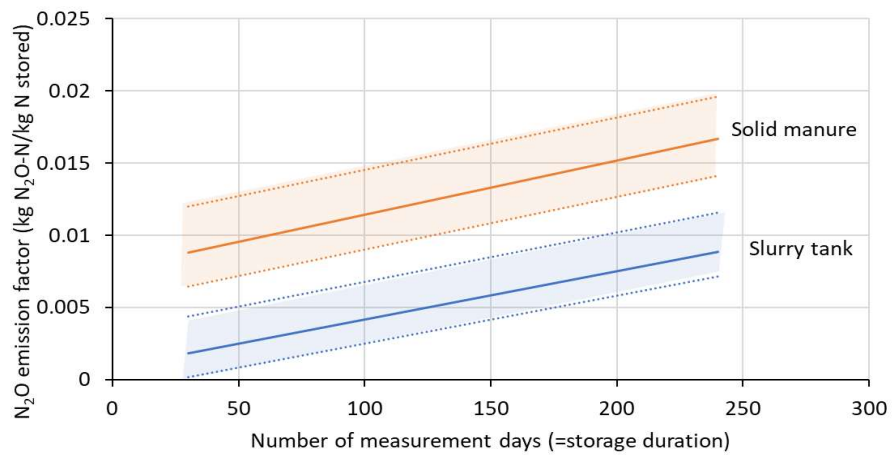
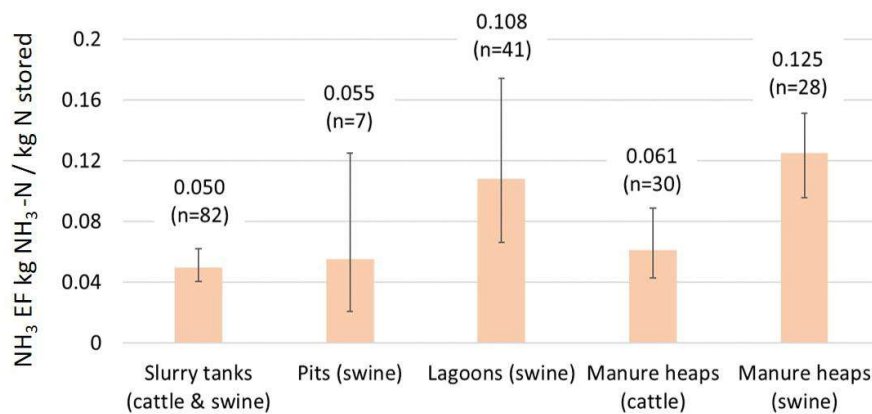


Figure 4 - The effect of storage duration on N₂O emission factors.



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Figure 5 - NH₃ emission factors for different storage types.

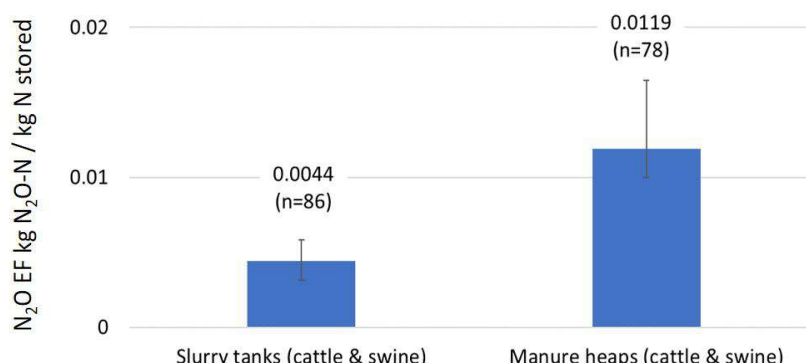


Figure 6 - N₂O emission factors for different storage types.

“Storage type” rather than “manure type” was selected for classifying emission values from the storage emissions dataset, as this was considered to be a more robust variable for grouping the data. Using storage type also aligns with the IPCC classification of storage-based GHG emissions. Five storage types were assessed, with slurry tanks initially split into cattle and swine slurry. The analysis showed there was no significant difference in the NH₃, N₂O and CH₄ emissions between the two animal types ($p > 0.05$), therefore these were combined into a single group (cattle and swine slurry stored in slurry tanks). A similar comparison was conducted on mean NH₃ emissions for cattle manure heaps and swine manure heaps; however, these two groups were found to be significantly different ($p < 0.05$) and therefore animal type was retained as an explanatory variable (Table 3).

Table 4: Revised mean NH₃, N₂O and CH₄ EF values for different manure storage types. Number of observations shown in brackets

Storage type	Manure type	Livestock type	mean NH ₃ EF (kg NH ₃ -N/kg N stored)	mean N ₂ O EF (kg N ₂ O-N/kg N stored)	mean CH ₄ EF (kg CH ₄ /kg N stored)
Slurry tanks	slurry	Cattle & swine	0.0497 (82)	0.0044 (86)	0.0691 (41)
Manure heaps	solid	Cattle & swine	-	0.0119 (78)	0.0250 (26)
Manure heaps	solid	Cattle	0.061 (30)	-	-
Manure heaps	solid	Swine	0.125 (28)	-	-



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Lagoons	slurry	Swine	0.108 (41)	-	-
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For **cattle housing**, no multi-variable models were identified, while a single-variable functional relationships to predict NH₃ EF from all housing types based on indoor temperature was found. The analysis of categorical variables for cattle housing emissions considered housing and floor type combinations, in order to take into account the nested effect of floor types within housing types and to be able to compare the effect of different floor types for one housing type. There were not enough data in the database to investigate the effect of Manure TAN and Manure total N content on the N₂O and NH₃ EFs. Analogously, manure VS content did not show a significant effect on CH₄ EFs, which was probably due to insufficient VS data in the database. Three categorical variables showed a significant effect on NH₃ EFs: housing and floor type combinations, climate zones, ventilation types. The only highly significant key driver of N₂O EFs was the climate zone, while for CH₄ EFs only the ventilation type showed significant effects.

For **swine housing**, multi-variable functional relationships for different GHGs included the following key variables:

- Predicted NH₃ EF from closed housings and loose housings (generating solid manure): 2- and 3-variable models containing combinations of live weight gain per day, housing type, ventilation system, type of bedding material
- Predicted N₂O EF from closed housings and loose housings (generating solid manure): 2- and 3-variable models containing combinations of live weight gain per day, housing type, type of bedding material.
- Predicted CH₄ EF from deep pit housings (generating slurry): 2-variable model containing type of forced air inlet and feed conversion ratio.
- Predicted CH₄ EF from closed housings and loose housings (generating solid manure): 2-variable model containing live weight gain per day and type of bedding material

The analysis of categorical variables suggested a significant difference ($p < 0.05$) of the NH₃ EFs between closed house and loose housing. NH₃ EFs are also presented for the different swine sub-categories, significant differences ($p < 0.05$) of the NH₃ EFs between swine sub-categories were also noticed. In the case of N₂O, there is a statistically non-significant difference ($p > 0.05$) between



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closed house and loose housing. Significant differences were highlighted between solid manure and slurry, likely due to higher available C and increased aeration, stimulating N₂O production. This could also be the reason for weaners showing higher N₂O EF than growers/finishers in solid manure systems. No difference in CH₄ EF between swine categories was found, apart from sows in slurry-based systems (deep pit house). In general, higher CH₄ from slurry-based system is expected due to the anaerobic conditions.

A summary of mean EF values for key cattle and swine housing categories is provided in Tables 4-5.

Table 5: Mean NH₃, N₂O and CH₄ EF values for different cattle housing types. Number of observations shown in brackets.

Housing type	Manure type	mean NH ₃ EF (kg NH ₃ -N/kg N excreted)	mean N ₂ O EF (kg N ₂ O-N/kg N excreted)	mean CH ₄ EF (kg CH ₄ /kg VS excreted)
Tied stalls	Slurry	0.0323 (69)	0.0015 (24)	0.0749 (107)
Loose housing	Solid	0.0633 (52)	0.0021 (19)	
Cubicle housing	Solid	0.0750 (135)	0.0018 (44)	
Feedlot	Solid	0.2936 (29)	0.0123 (10)	

Table 6: Mean NH₃, N₂O and CH₄ EF values for different swine housing types, disaggregated into swine sub-categories. Number of observations shown in brackets.

Housing type	Manure type	Swine sub-category	mean NH ₃ EF (kg NH ₃ -N/kg N excreted)	mean N ₂ O EF (kg N ₂ O-N/kg N excreted)	mean CH ₄ EF (kg CH ₄ /kg VS excreted)
Deep pit house	Slurry (& unsure)	Growing swine (growers & finishers)	0.1762 (341)	0.0101 (53)	0.047 (73)
		Growing swine (weaners)	0.1117 (27)	0.0022 (9)	0.032 (10)
		Breeding sows	0.0921 (19)	0.0029 (13)	0.142 (24)
Closed house	Solid	Growing swine (growers & finishers)	0.2633 (57)	0.0271 (43)	0.026 (42)
		Growing swine (weaners)	0.1285 (16)	0.0684 (16)	0.015 (16)
		Breeding sows	0.1454 (7)	0.0529 (7)	0.020 (7)



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Loose housing	Solid	Growing swine (growers & finishers)	0.1163 (27)	0.0267 (21)	-
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Full detail on the results obtained in Task 3.1 is given in the “*Report on functional relationships for emission to be integrated in on-farm accounting tools and national inventories*” (D3.1).

Task 3.2: In this task, a statistical analysis of the data collated in the Housing and Storage datasets of the DATAMAN database was carried out aiming to examine if there is a statistically significant relationship between the emission factors of NH₃, N₂O and CH₄ and variables in the database which are associated with a mitigation effect (thus defined as “mitigation variables”). This activity was carried out by AUA in collaboration with ATB, AgR and INRAE.

To determine the impact of these variables on **housing emissions**, the study examined the differences between the mean EF values associated with the treatment scenario and a reference (control) scenario. The effect of mitigation variables was analyzed separately by animal category and manure type. The analysis was conducted at two levels:

1. the level of common countries, analyzing data country by country where values for the tested variable (including the control) were available for a given emission type;
2. the level of common experiments, analyzing data of experiments within each country where values for the tested variable (including the control) were available for a given emission type

Of these two levels, the most reliable for evaluating treatment effects is at experimental level, as this reduces the influence of other variables on results. In comparison, an analysis based on data sourced from common countries will be less robust as the dataset may contain studies where either the control or the treatment was included, but not both control and treatment. However, this needs to be tempered with the number of experiments and observations available, as there was a decreasing number of observations from ‘common countries’ to ‘common experiments’. In some cases, there was insufficient data for a formal analysis. We also acknowledge that at the experiment level there may be other experimental conditions which could affect the results.

Regarding **pig housing**, for liquid manure management systems significant changes in CH₄ emissions were only observed when modifying the type of forced ventilation inlets in swine houses (i.e. from porous ceiling to lateral or frontal), at both the common countries and common experiments level. In particular, this resulted in an increase in mean EFCH₄ of 5.5 times and of 11 times compared to porous ceiling at the levels of common countries and common experiments,



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respectively. However, the number of EFCH₄ observations at both analysis levels can be considered low (especially for porous ceiling forced ventilation air inlets type the observations are based on one country and one experiment) to infer that the lateral or frontal forced ventilation air inlets type is connected to a higher EFCH₄ in comparison to the porous ceiling type.

For solid pig manure, significant emission reductions were observed when modifying the type of bedding material from straw to sawdust in swine houses and when reducing the rate of bedding per animal from >30 kg of bedding per pig per month to <10 kg of bedding per pig per month at the level of common experiments. In particular, sawdust bedding in swine housing was found to significantly reduce mean EFCH₄ in comparison to straw bedding, with a mean reduction of 46% at the level of common experiments (analysis was based on 4 experiments conducted in 2 countries). Regarding the rate of bedding per animal at the level of common countries, a 53% reduction in mean EFCH₄ was observed when reducing the amount of bedding per pig.

Table 7: Effect of treatments on methane emission factor for swine housing.

Source of data	Control EF ¹ (Number of observations)	Treatment EF ¹ (Number of observations)	P value	% Change in EF (rounded)		
				Mean	Upper 95% CI limit	Lower 95% CI limit
Modification of the type of the forced ventilation air inlets; S*, GSGF* and GSW*; slurry						
Limited to common countries (C: 2)	0.008 (Porous ceiling: 4)	0.049 (Lateral or frontal: 14) 0.018 (Duct: 4)	0.018 ; 0.268	545 ; 130	572 ; 257	490 ; 57
Limited to common experiments (C: 1, E: 1)	0.008 (Porous ceiling: 4)	0.091 (Lateral or frontal: 6)	0.002	1084	1129	992
Modification of the type of bedding material; S, GSGF* and GSW*; solid manure						
Limited to common countries (C: 3)	0.024 (Straw: 50)	0.019 (Sawdust: 18); 0.021 (None: 1)	0.059; 0.99	-23; -14	-52; 3	5; -27
Limited to common experiments (C:2, E: 4)	0.017 (Straw: 14)	0.009 (Sawdust: 11); 0.021 (None: 1)	0.009 ; 0.814	-46 ; 23	-49 ; 61	-45 ; -3
Modification of the rate of bedding per animal**; S and GSGF; solid manure						
Limited to common countries (C: 1)	0.045 (> 30]: 5)	0.021 (< 10]: 4)	0.0002	-53	-58	-47



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S: Sows; GSGF: Growing swine (growers & finishers); GSW: Growing swine (weaners); C: Number of countries involved; E: Number of experiments involved. Bold characters denote statistically significant differences for the respective pairwise comparisons between control EF and treatment EF.

¹ The mean methane emission factor is expressed in kg CH₄ per kg VS excreted in housing.

* Swine sub-category existing at both analysis levels

** Rate of bedding per animal expressed in kg of bedding per animal per month

Regarding N₂O emissions, the only significant variable found was air scrubbing, which resulted in an increase in the EFN₂O (58% increase in mean EF) in comparison to the non-presence (same results for both analysis levels). However, the number of EFN₂O observations for the presence of air scrubber was very low, suggesting caution when inferring concerning the effect of this treatment. Concerning EFN₂O and solid manure, modification of the type of bedding material and the rate of bedding per animal showed significant effects but only at the level of common countries and not for all pairwise comparisons. Regarding the type of bedding material, the EFN₂O was significantly increased (112% increase in mean EF) when changing from straw to sawdust. Concerning the rate of bedding per animal, a significant increase in the mean EFN₂O (+519%) was observed when decreasing the rate of bedding from 20-30 kg per pig per month to <10 kg per pig per month.

Table 8: Effect of treatments on nitrous oxide emission factor for swine housing.

Source data	of	Control EF ¹ (Number of observations)	Treatment EF ¹ (Number of observations)	P value	% Change in EF (rounded)		
					Mean	Lower 95% CI limit	Upper 95% CI limit
Presence of air scrubber; GSGF; slurry							
Limited common countries	to (C: 1)	0.013 (No: 12)	0.021 (Yes: 4)	<0.001	58	44	68
Limited common experiments	to (C: 1; E: 2)	0.013 (No: 12)	0.021 (Yes: 4)	<0.001	58	44	68
Modification of the type of bedding material; S, GSGF* and GSW*; solid manure							
Limited common countries	to (C: 2)	0.026 (Straw: 43)	0.056 (Sawdust: 26); 0.023 (Woodchips: 2)	0.038 ; 0.992	112 ; - 14	77 ; -25	139 ; -9
Limited common experiments	to (C: 2; E: 4)	0.020 (Straw: 13)	0.062 (Sawdust: 19); 0.023 (Woodchips: 2)	0.081; 0.912	216; 15	247; 48	207; -1
Modification of the rate of bedding per animal**; S and GSGF*; solid manure							
Limited common countries	to (C: 2)	0.013 ([20-30]: 10)	0.082 ([< 10]: 4); 0.007 ([10-20]: 4);	<0.0001 ; 0.22; 0.876	519 ; - 49; 46	510 ; -70; 4	556 ; -47; 83



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		0.019 ([> 30]: 7)				
Limited to common experiments (C: 1; E: 1)	0.013 ([20-30]: 10)	0.007 ([10-20]: 4); 0.01 ([> 30]: 2)	0.158; 0.849	-49; - 29	-70; -7	-47; -44

S: Sows; GSGF: Growing swine (growers & finishers); GSW: Growing swine (weaners); C: Number of countries involved; E: Number of experiments involved. Bold characters denote statistically significant differences for the respective pairwise comparisons between control EF and treatment EF.

¹ The mean nitrous oxide EF is expressed in kg N₂O-N/kg N excreted in housing.

* Swine sub-category existing at both analysis levels

** Rate of bedding per animal expressed in kg of bedding per animal per month. The classes of rate of bedding per animal corresponding to the modified rates are: [< 10], [10-20], [20-30] and [> 30]. Only the classes with available observations are presented in the table.

Regarding NH₃ emissions, modifying the floor type in swine houses from fully slatted to partially slatted, significantly reduced the mean EFNH₃ (23%) only at the level of common countries. At the level of common experiments, there was again a reduction in the mean EFNH₃ (24%) for the same modification, although statistically non-significant. Changing from porous ceiling to lateral or frontal forced ventilation air inlets type resulted in a significant increase in EFNH₃ (35%) only at the level of common countries. A slight non-significant increase (2%) for the same change was also noticed at the level of common experiments, owing to a very low number of EFNH₃ observations.

Air scrubbing resulted in a significant decrease in the mean EFNH₃ at both analysis levels (23 and 20% at levels of common countries and common experiments, respectively).

In the case of solid manure type, a significant decrease in mean EFNH₃ was observed when changing from solid to fully slatted floor type (73%). This was however only for a dataset limited to common countries and the analysis was accompanied by a very low number of EFNH₃ observations for fully slatted floor type. Thus, caution would be necessary when inferring that fully slatted floor is connected to a significantly lower mean EFNH₃ in comparison to solid floor for grower and finisher pigs and solid manure systems. A change from straw bedding to sawdust bedding led to a significant decrease in mean EFNH₃ (45%) at the level of common countries and to a statistically non-significant decrease (32%) at the level of common experiments. For the dataset limited to common countries, a decrease in the monthly rate of bedding per pig from 20-30 kg to 10-20 kg was connected to a statistically significant increase in the mean EFNH₃ (-152% and -169% respectively). However, at the level of common countries an increase to > 30 kg had the same effect. In addition, changing the forced ventilation air inlets type from lateral or frontal to chimney significantly increased the mean EFNH₃ (+100%) while changing to porous ceiling significantly decreased it (-75%).



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Table 9: Effect of treatments on ammonia emission factor for swine housing.

Source data	of	Control EF ¹ (Number of observations)	Treatment EF ¹ (Number of observations)	P value	% Change in EF (rounded)		
					Mean	Lower 95% CI limit	Upper 95% CI limit
Modification of floor type; S*, G, GSGF* and GSW*; slurry							
Limited to common countries (C: 12)	to	0.184 (Fully slatted: 333)	0.142 (Partially slatted: 138); 0.291 (Solid: 2)	0.0004 ; 0.369	-23; 58	-27; 59	-20; 57
Limited to common experiments (C: 8; E: 21)	to	0.223 (Fully slatted: 32)	0.169 (Partially slatted: 35)	0.080	-24	-20	-28
Modification of the type of the forced ventilation air inlets; S*, G, GSGF* and GSW*; slurry							
Limited to common countries (C: 7)	to	0.17 (Porous ceiling: 188)	0.231 (Lateral or frontal: 26); 0.157 (Duct: 9)	0.012 ; 0.938	35 ; -8	21 ; -27	49 ; 10
Limited to common experiments (C: 3; E: 4)	to	0.177 (Porous ceiling: 4)	0.181 (Lateral or frontal: 7); 0.123 (Duct: 2)	0.996; 0.647	2; -31	-3; -18	2; -42
Presence of air scrubber; GSGF; slurry							
Limited to common countries (C: 3)	to	0.206 (No: 24)	0.158 (Yes: 27)	0.011	-23	-21	-27
Limited to common experiments (C: 3; E: 6)	to	0.196 (No: 23)	0.156 (Yes: 21)	0.027	-20	-22	-21
Modification of the floor type; GSGF; solid manure							
Limited to common countries (C: 1)	to	0.199 (Solid: 33)	0.053 (Slatted: 4)	0.009	-73	-80	-70
Modification of the type of bedding material; S, GSGF* and GSW*; solid manure							
Limited to common countries (C: 2)	to	0.262 (Straw: 51)	0.145 (Sawdust: 27); 0.124 (Woodchips: 2)	0.0001 ; 0.215	-45 ; - 53	-54 ; -72	-37 ; -37
Limited to common experiments (C: 2; E: 5)	to	0.204 (Straw: 20)	0.139 (Sawdust: 22) 0.124 (Woodchips: 2)	0.125; 0.567	-32; - 39	-39; -60	-26; -26
Modification of the rate of bedding per animal**; S and GSGF*; solid manure							
Limited to common countries (C: 1)	to	0.111 ([20-30]: 11)	0.174 ([< 10]: 5); 0.279	0.732; 0.013 ; 0.007	57; 152 ; 169	72; 165 ; 209	38; 146 ; 141

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3)		0.298 ([10-20]: 9); (> 30]: 8)				
Limited to common experiments (C: 2; E: 2)	0.111 ([20-30]: 11)	0.068 (< 10]: 1); 0.159 ([10-20]: 5); 0.205 (> 30]: 3)	0.966; 0.738; 0.384	-39; 44; 85	-0.7; 46; - 24	-55; 42; 134
Modification of the type of the forced ventilation air inlets; S, GSGF and GSW; Solid manure						
Limited to common countries (C: 3)	0.214 (Lateral or frontal: 50)	0.428 (Chimney: 4); 0.337 (Duct: 4); 0.054 (Porous ceiling: 4)	0.004 ; 0.186; 0.049	100 ; 58; -75	105 ; 37; - 82	96 ; 72; - 71

S: Sows; G: Gilts; GSGF: Growing swine (growers & finishers); GSW: Growing swine (weaners); C: Number of countries involved; E: Number of experiments involved. Bold characters denote statistically significant differences for the respective pairwise comparisons between control EF and treatment EF.

¹ The mean ammonia EF is expressed in kg NH₃-N/kg N excreted in housing.

* Swine sub-category existing at both analysis levels

** Rate of bedding per animal expressed in kg of bedding per animal per month

Regarding **cattle housing**, no significant mitigation variable were found in the CH₄ emissions dataset. However, modifying the floor type from solid to fully slatted significantly increased (p=0.006) the N₂O emissions (186%) at common countries level, while the increase in N₂O emission (26%) at common experiment level was not statistically significant (p=0.372). Similarly, the modification of the type of the forced ventilation air inlets from lateral/frontal to duct type significantly increased (p=0.0001) the N₂O emission (143%) at common countries level.

Access of cattle to the outdoor areas slightly increased the N₂O emissions (37%) but the results were not statistically significant (p=0.363). Changing the manure removal technique from scraper to flushing significantly (p=0.0003) increased the N₂O emission (313%) at the common countries level while the values were not significantly different (p=0.303) at common experiment level. In addition, the management of manure in housing by using additives and chemicals significantly (p=0.036) increased the emission of N₂O (254%) in both level of analysis. The change in the duration of manure storage in the housing had no significant effect on the emission of N₂O.

Regarding ammonia, modifying the floor type from solid to earthen significantly (p<0.0001) increased the NH₃ emission (280%) at common countries level analysis, while no significant (p=0.48) effect on NH₃ emission was observed at common experiment level. Analysis regarding the bedding material showed that changing the bedding material from straw to woodchips significantly (p<0.0001) decreased the emission of NH₃ (58%) from cattle housing, while removing all type of bedding material significantly (p=0.0006) increased the NH₃ emission (144%) at common



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countries level. Results regarding the modification of the type of the force ventilation air inlets from lateral/frontal to duct type significantly ($p=0.012$) reduced the NH_3 emission (49%) while modification of air inlet from lateral/frontal to porous ceiling type showed non-significant effect ($p=0.386$). Similarly, the modification of the type of forced ventilation air outlets from wall/pit fans to chimney with fans significantly ($p=0.039$) reduced the emission of NH_3 (46%). The presence of air scrubbers reduced the NH_3 emission up to 78% but the results were not statistically significant ($p=0.259$) at both analysis levels.

Access of animals to the outdoor areas reduced the NH_3 emission (49%) significantly ($p<0.0001$) at common countries level analysis. On the other hand, the change in the duration of manure storage in the housing (0.666-1 days vs <0.333 days) increased the NH_3 emission (356% and 464%) significantly at common countries level ($p=0.003$), while the results were non-significant at common experiments level analysis.

Table 11: Effect of treatments on nitrous oxide emission factor for cattle housing.

Source of data	Control EF ¹ (Number of observations)	Treatment EF ¹ (Number of observations)	P value	% Change in EF (rounded)		
				Mean	Lower 95% CI limit	Upper 95% CI limit
Modification of floor type; Milking cows*, steers < 2yrs; Slurry*, solid manure*						
Limited to common countries (C: 3)	0.007 (Solid: 23)	0.014 (Fully slatted: 27); 0.021 (Earthen: 14)	0.192; 0.006	86; 186	113; 233	66; 154
Limited to common experiments (C: 2; E: 2)	0.005 (Solid: 19)	0.006 (Fully slatted: 21)	0.372	26	31	26
Modification of the type of the forced ventilation air inlets; Milking cows, steers < 2yrs; Slurry, solid manure						
Limited to common countries (C: 1)	0.016 (Lateral or frontal: 4)	0.040 (Duct: 6)	0.0001	143	126	157
Modification of the practice for removal of manure from housing; Milking cows; Slurry*, solid manure*						
Limited to common countries (C: 2)	0.009 (Removal via scraper: 25)	0.038 (Removal via flushing: 4); 0.008 (Removal via vacuum: 3)	0.0003 ; 0.993	313 ; -19	581 ; -3	180 ; -38
Limited to common experiments (C: 1; E: 1)	0.005 (Removal via scraper: 15)	0.008 (Removal via vacuum: 3)	0.303	38	34	28
Modification of the practice of manure management in housing; Milking cows; Slurry						



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Limited to common countries (C: 1)	0.005 (Other: 10)	0.017 (Additives-chemical: 2); 0.008 (Additives-unknown: 1)	0.036; 0.641	254; 74	417; 211	189; 19
Limited to common experiments (C: 1; E: 1)	0.005 (Other: 10)	0.017 (Additives-chemical: 2); 0.008 (Additives-unknown: 1)	0.036; 0.641	254; 74	417; 211	189; 19

¹ Mean EF is expressed in kg N₂O-N/kg N excreted in housing.

* Cattle sub-category existing at both analysis levels

** Duration of manure storage in housing expressed in days; The manure storage duration classes corresponding to the modified manure storage duration were: [0.333-0.666], [0.666-1], [1-30], [30-60], [60-90], [90-120], [120-150], [150-180] and [> 180]. Only the classes with available observations are presented in the table.



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Table 12: Effect of treatments on ammonia emission factor for cattle housing.

Source of data	Control EF ¹ (Number of observations)	Treatment EF ¹ (Number of observations)	P value	% Change in EF (rounded)		
				Mean	Lower 95% CI limit	Upper 95% CI limit
Modification of floor type; Milking cows*, dry cows*, heifers < 2yrs, steers < 2yrs; Slurry*, solid manure*, unsure						
Limited to common countries (C: 8)	0.084 (Solid: 130)	0.083 (Fully slatted: 81); 0.319 (Earthen: 17)	0.366; <0.0001	-1; 280	0.5; 289	-2; 266
Limited to common experiments (C: 4; E: 9)	0.085 (Solid: 30)	0.1 (Fully slatted: 30)	0.48	17	13	21
Modification of the type of bedding material; Milking cows*, heifers < 2yrs*, steers < 2yrs; Slurry*, solid manure*, unsure*						
Limited to common countries (C: 4)	0.081 (Straw: 32)	0.197 (None: 4); 0.034 (Woodchips: 49)	0.0006 ; <0.0001	144; -58	92; -53	163; -63
Limited to common experiments (C: 3; E: 4)	0.120 (Straw: 4)	0.197 (None: 4); 0.032 (Woodchips: 5)	0.313; 0.261	64; -73	188; -31	40; -82
Modification of the type of the forced ventilation air inlets; Milking cows, steers < 2yrs; Slurry, solid manure						
Limited to common countries (C: 3)	0.11 (Lateral or frontal: 24)	0.056 (Duct: 22); 0.13 (Porous ceiling: 13)	0.012 ; 0.386	-49; 18	-43; 30	-53; 9
Modification of the type of forced ventilation air outlets; Milking cows, dry cows, steers < 2yrs; Slurry, solid manure, unsure						
Limited to common countries (C: 2)	0.155 (Wall or pit fans: 13)	0.084 (Chimney with fans: 30)	0.039	-46	-34	-51
Outdoor access of cattle; Milking cows*, heifers < 2yrs, steers < 2yrs*; Slurry*, solid manure*, unsure						
Limited to common countries (C: 4)	0.134 (No: 94)	0.068 (Yes: 54)	<0.0001	-49	-56	-42
Limited to common experiments (C: 3; E: 3)	0.067 (No: 7)	0.092 (Yes: 4)	0.171	38	-1	74
Modification of the duration of manure storage in housing***; Milking cows*, steers < 2yrs*; Slurry*, solid manure*, unsure						
Limited to common countries (C: 5)	0.017 ([0.333-0.666]: 8)	0.076 ([0.666-1]:16); 0.094 ([<0.333]: 5);	0.003 ; 0.003 ; 0.382; 0.201;	356 ; 464 ; 161; 256;	352 ; 498 ; 140; 209; 294	347 ; 464 ; 202; 328; 110

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		0.044 ([1-30]: 5); 0.059 ([150-180]: 3); 0.046 ([30-60]: 1)	0.818	177		
Limited to common experiments (C: 3; E: 3)	0.086 ([0.666-1]: 4)	0.094 (<0.333]: 5); 0.049 ([1-30]: 3); 0.059 ([150-180]: 3); 0.046 ([30-60]: 1)	0.998; 0.761; 0.906; 0.901	9; -43; -31; -47	109; -31; 8; 38	-6; -33; -27; -64

¹ Mean EF is expressed in kg NH₃-N/kg N excreted in housing.

* Cattle sub-category existing at both analysis levels

** Rate of bedding per animal is expressed in kg of bedding per animal per month; The classes of rate of bedding per animal corresponding to the modified rates are: [< 60], [120-180], [180-240] and [> 240]. Only the classes with available observations are presented in the table.

*** Duration of manure storage in housing expressed in days; The manure storage duration classes corresponding to the modified manure storage duration were: [0.333-0.666], [0.666-1], [1-30], [30-60], [60-90], [90-120], [120-150], [150-180] and [> 180]. Only the classes with available observations are presented in the table.

Regarding **manure storage emissions**, no significant differences were found between cattle and swine, so they were analyzed together. Prior to this analysis, the datasets were filtered according to a stepwise process to ensure data used for quantifying mitigation practices were ‘fit-for-purpose’. As part of the data filtering process, EF outliers were identified and excluded from the dataset. Manure types were grouped into slurry (dirty water, separated liquid, slurry) and solid manure (solid manure, separated solid), with other types (e.g. digestates, chicken manure) excluded as these may influence the determination of revised EFs even though there were relatively low numbers of such observations.

Identification of manure treatments to be analysed was based on a combination of statistical analysis, appreciation of first principles influencing emissions and review of relevant individual studies where data had been collated in the database. An example of first principles is the reduction in NH₃ from slurry following acidification due to the NH₄⁺:NH₃ equilibrium favouring NH₄⁺. Once again, the statistical analysis of manure treatments was conducted at 2 different levels:

1. data limited to common countries,
2. data limited to common experiments.

Acidification, aerobic treatment and covers were analysed by comparing the treatment data against no treatment (i.e. treatment = ‘none’). Swine and cattle data was pooled, as was slurry and solid data. There was evidence of acidification reducing CH₄ emissions (when data is limited to common experiments, however number of observations is very low at 6 for treatment and 4 for control).



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Results of analysis at the experiment-level suggest covers have no effect on EF CH₄, although the less-robust analysis at the country-level did suggest a significant increase in EF CH₄.

There was insufficient data to assess aerobic treatments.

Table 13. Comparison of CH₄ EF values (kg CH₄ kg⁻¹ volatile solids (VS) stored) for CH₄ sources untreated (Control) or treated. The dataset used (i) limited to data from common countries and (iii) limited to data from common experiments. Data includes swine and cattle data, and slurry and solid manures. Not restricted to a specific storage type.

Source of data	Control (# of observation; mean EF shown if significant effect)	Treatment (# of observations; mean EF shown if significant effect)	P value	Change in EF (%)
Acidification (slurry)				
Limited to common countries	(6)	(8)	0.074	nil
Limited to common experiments	(6) 0.0370	(4) 0.0068	0.0006	82%
Aerobic treatment (slurry)				
Limited to common countries	(1)	(7)	N/A - insufficient data	N/A - insufficient data
Limited to common experiments	(1)	(1)	N/A - insufficient data	N/A - insufficient data
Covered (slurry)				
Limited to common countries	(22) 0.0251	(14) 0.0929	<0.0001	370%
Limited to common experiments	(8)	(6)	0.871	nil

Covers, composting and compaction were analysed by comparing the treatment data against no treatment (i.e. treatment = 'none'). The results of the analysis at the experiment level showed covers, composting and compaction had no significant effect on N₂O emissions, when compared with none. For composting, while there were indications of a significant result at the country-level, with swine manure showing an increase in EF and cattle manure a decrease in EF with composting, the number of observations was extremely limited. When the composting data was restricted to common experiments, either no significant difference between composting and control treatments was observed or there was insufficient data.



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Table 14. Comparison of N₂O EF values (kg N₂O kg⁻¹ N stored) for N₂O sources that were either untreated (Control) or treated. The dataset used was (i) limited to data from common countries and (iii) limited to data from common experiments. Data includes swine and cattle data, and slurry and solid manures.

Source of data	Control (# of observation; mean EF shown if significant effect)	Treatment (# of observations; mean EF shown if significant effect)	P value	Change in EF (%)
Covered (slurry tanks); Swine only				
Limited common countries	to (22)	(23)	0.868	nil
Limited common experiments	to (22)	(20)	0.979	nil
Covered (slurry tanks); Cattle only				
Limited common countries	to (15)	(14)	0.584	nil
Limited common experiments	to (2)	(2)	0.860	nil
Covered (slurry tanks); Swine and Cattle				
Limited common countries	to (39)	(39)	0.624	nil
Limited common experiments	to (24)	(22)	0.979	nil
Covered (manure heaps); Cattle only				
Limited common countries	to (5)	(8)	0.600	nil
Limited common experiments	to -	-	N/A insufficient data	N/A - insufficient data
Composted (manure heaps); Cattle only				
Limited common countries	to (12) 0.00361	(10) 0.00993	0.0406	275%
Limited common experiments	to (5)	(7)	0.705	nil



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Composted (manure heaps); Swine only							
Limited common countries	to	(1)	0.02820	(6)	0.00832	0.0255	70%
Limited common experiments	to	-	-	-	-	N/A insufficient data	N/A - insufficient data
Composted (manure heaps); Cattle and Swine only							
Limited common countries	to	(7)		(15)		0.112	nil
Limited common experiments	to	(5)		(7)		0.705	nil
Compacted (manure heaps); Cattle only							
Limited common countries	to	(5)		(6)		0.422	nil
Limited common experiments	to	(5)		(5)		0.968	nil

Acidification substantially reduced NH_3 by ~70%, however this was not significant ($P = 0.12$). It is important to note the very low number of observations (3). Compaction also showed substantial reductions in NH_3 EF (50-70%) although again this was not significant (P values varied between 0.16 [common countries] and 0.56 [common experiments]) and the number of observations was very low. There is good evidence of compaction + covering reducing NH_3 , however, there is little evidence of compaction alone having a significant effect. Given compaction may influence EF but the driver(s) may not be included as one of those under investigation, we opted to omit compaction data from the dataset used for determining EF values and drivers. Covering significantly reduced EF NH_3 ($P < 0.05$). The number of observations at the experiment level was low (between 4 and 6 per treatment), however the results obtained from the country-level analysis supported the results obtained at the experiment-level. Solid separation on both solid and liquid fractions could not be sufficiently assessed due to limited data and no common experiments.

Table 15. Comparison of NH_3 EF values ($\text{kg NH}_3\text{-N kg}^{-1}$ N stored) for NH_3 sources untreated (Control) or treated. The dataset used was (i) limited to data from common countries and (ii) limited to data from common experiments. Data includes swine and cattle data, and slurry and solid manures.

Source of data	Control (# of observation; mean EF	Treatment (# of observations;	P value	Change in EF (rounded %)
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	shown if significant effect)	mean shown if significant effect)	EF if	
Acidification (slurry tanks); Cattle only				
Limited to common countries	(3)	(3)	0.1203	70%
Limited to common experiments	(3)	(3)	0.1203	70%
Compacted (manure heaps); Cattle only				
Limited to common countries	(6)	(4)	0.155	70%
Limited to common experiments	(4)	(4)	0.5621	50%
Composted (manure heaps); Cattle and swine				
Limited to common countries	(9)	(4)	0.0742	300%
Limited to common experiments	(4)	(4)	0.2713	200%
Covered (slurry tanks); Swine only				
Limited to common countries	(14) 0.0773	(38) 0.0299	0.0010	60%
Limited to common experiments	(6) 0.0963	(6) 0.0268	0.0290	70%
Covered (slurry tanks); Cattle only				
Limited to common countries	(13)	(20)	0.0784	30%
Limited to common experiments	-	-	N/A insufficient data	N/A - insufficient data
Covered (manure heaps); Cattle and swine				
Limited to common countries	(7)	(5)	0.205	50%
Limited to common experiments	(4) 0.0895	(4) 0.0272	0.0101	65%
Solid separation – liquid fraction (slurry); Cattle only				
Limited to common countries	(6) 0.2880	(3) 0.0556	0.0001	81%
Limited to common experiments			NA	
Solid separation – solid fraction (solid manure); Cattle only				
Limited to common countries	(17) 0.1530	(6) 0.0311	0.0005	80%
Limited to common experiments			NA	



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A scientific paper on mitigation of pig and cattle housing emissions entitled “*Quantification of decreasing and increasing effects of greenhouse gas and ammonia emissions from manure using the global DATAMAN database for livestock housing*” is in preparation by AUA, ATB, INRAE and AgR and will be submitted to a peer-reviewed journal by September 2023 (see **D3.2**). A scientific paper on mitigation of manure storage emissions is also planned. Full detail on the results of T3.2 analysis is given in **D3.2**.

Task 3.3: In this task, we considered the processes driving emissions of N₂O, CH₄ and NH₃, how these are reflected nowadays in the IPCC guidelines and UNECE guidebook, and how emission factors and functional relationships drawn in T3.1 could potentially be included in national inventories. To this end, the functional relationships drawn in T3.1 were checked against the usual approach to the construction of emission inventories, assessing how the levels of detail in functional relationships map onto the Tier level organization of IPCC (N₂O, CH₄) and UNECE (NH₃). Furthermore, a qualitative assessment of the availability of activity data of relevance for the new functional relationships drawn in T3.1 was carried out. More specifically, we assessed whether a variable (i.e a typology of activity data) is easy to obtain with acceptable accuracy, more difficult or very difficult, at the farm level and at national scales.

T3.3 was carried out mostly by AU, in collaboration with ATB and AgR. The activities in this task led to produce a report on the feasibility to integrate new functional relationships in accounting tools and national inventories (see **D3.3**).

WP3 – List of deliverables

	Deliverable	Planned for	Status	Responsible partner
D3.1	Report on functional relationships for emission to be integrated in on-farm accounting tools and national inventories.	M21	Done	AgR
D3.2	Scientific paper submitted on most relevant mitigation option and mechanism to be represented in models in order	M24	Done	AUA



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	to effectively assess GHG sources, product efficiencies, and farm-scale management.			
D3.3	Report on the feasibility to integrate new functional relationships in accounting tools and national.	M24	Done	AU

D. WP4 - Farm-scale GHG decision support

WP Leader: Agricultural University of Athens (AUA, Greece)

Partners: Teagasc, CUBS (Ireland), ATB (Germany), INIA (Chile), INRAE (France), AU (Denmark)

The objectives of WP4 were: i) to review and characterise existing farm-scale GHG DSSs according to emissions included and factors determining them; ii) to recommend improvements to GHG and cost calculations in existing farm-scale GHG DSSs; iii) to produce a flexible prototype farm-scale GHG DSS for countries without an existing DSS and iv) to assess the future demands on farm-scale GHG DSSs, including the future role for ICT and sensor technologies. WP4 was made up by five tasks:

- T4.1 Survey and characterize existing farm-scale GHG DSSs
- T4.2 Current and future demands on farm-scale GHG DSSs
- T4.3 Assess the potential for improving emission estimates in farm-scale GHG DSSs
- T4.4 Farm-scale Mitigation Costs
- T4.5 Prototype generic farm-scale GHG DSS

The ATB is directly involved in all WP4 tasks.

Task 4.1: The aim of this task was to survey and characterize the range of currently available farm-scale GHG DSSs available, describing their user-friendliness, their capabilities and the extent to which these tools are freely available and openly documented. In order to compare the surveyed tools, the most frequently used input and output categories were identified and checklists regarding the consideration or not of these parameters were drawn.



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Activities in this task started at the beginning of the project. A first draft of **D4.1** (Survey of existing farm-scale GHG DSS) was finalised in November 2020 and the information regarding the available DSS tools was circulated to the project members for comments and revisions. The final version was delivered in December 2021.

Overall, 15 DSS tools were evaluated with respect to aspects related to the GHG emissions, their user interface, their functions and their inputs and outputs. Four of them (i.e. Cool Farm Tool v2.0, SAFA, HOLOS and EX-ACT) were selected by AUA, the rest were proposed by the other partners. Input on existing DSSs from all the partners was received. The ATB directly contributed by submitting to AUA (task leader) information about 6 DSSs from Germany or of interest for German agriculture, released between 2008 and 2016.

The tools were divided in two categories: tools that are mainly “emission calculators” and tools providing indicators for more than one sustainability pillar (“multi-pillar tools”). It was ascertained that the majority of the existing emission calculators can be freely and easily accessed, although the user requires in most cases to be registered. However, this is not the case of the majority of the multi-pillar sustainability assessment tools, since they cannot be freely accessed and information about the structure of these tools is not available. For instance, a major difference between “emission calculators” and “multi-pillar tools” is that results of multi-pillar tools are typically presented as sustainability scores, whose underlying calculations are not openly accessible. This points out the great topicality and urgency of research and open publications on multi-pillar sustainability assessment tools. Results on emissions from “emission calculators” were fully quantitative, while “multi-pillar” tools provided scores or partially quantitative emission assessments. Some tools showed characteristics of both categories. Almost half of the emission calculators examined were found to be suitable for inexperienced users. Table 2 shows the main outcomes of the classification of the surveyed tools:

Table 16. Classification of the DSS tools based on the sustainability indicators assessed.

DS tool	Emission calculators	Indicators for all pillars of sustainability	Indicators for 2 pillars of sustainability (environmental + economic)
Cool Farm Tool v2.0	Yes	No	Yes
FarmAC	Yes	No	No
Overseer	Yes	No	Yes
Carbon Navigator - Beef	Yes	No	Yes
Carbon Navigator - Dairy	Yes	No	Yes
KSNL - Kriteriensystem Nachhaltige Landwirtschaft	Yes	Yes	No



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SMART - Sustainability Monitoring and Assessment RouTine	No	Yes	No
SAFA	No	Yes	No
RISE 3.0 - Response-Inducing Sustainability Evaluation	Yes	Yes	No
BEK - Berechnungsstandard für einzelbetriebliche Klimabilanzen in der Landwirtschaft	Yes	No	No
AgBalance®	Yes	Yes	No
DLG-Nachhaltigkeitsstandard (based on REPRO)	No	Yes	No
HOLOS	Yes	No	Yes
EX-ACT (version 8.0)	Yes	No	No
GLEAM 2.0 (GLEAM-I)	Yes	No	No

AgBalance, EX-ACT, Cool Farm Tool, BEK, and GLEAM follow a Life Cycle Assessment (LCA) approach in the estimation of the indicators provided.

The coverage of eight tools (i.e. Cool Farm Tool, FarmAC, RISE, SMART, SAFA, GLEAM, AgBalance and EX-ACT) is global. The validity of the rest seems to be related to their countries of origin. The multi-pillar tools had all global geographic scope, except the DLG tool; same for the emission-calculating tools, apart from KSNL. The majority of the DS tools examined can be used in English (13 out of 15). KSNL and BEK were found to be available only in German; Cool Farm Tool, FarmAC, RISE and EX-ACT are multi-lingual tools.

Full results of this assessment are given in **D4.1**. Based on the results of this task, a scientific paper entitled “*Decision Support Systems Based on Gaseous Emissions and their impact on the Sustainability Assessment at the Farm Level: An Evaluation from the User’s Side*” is being prepared by AUA for submission to a peer-reviewed journal.

Task 4.2: The activities in this task started in M12. The deadline of D4.2, originally set to M9, was extended to M30, mostly due to the need for a longer time for stakeholder involvement caused by the pandemic. In addition, the Consortium agreed to start investigations in T4.2 only after completing the first draft of D4.1. This did not prevent the timely finalisation of other tasks, as work proceeded in parallel to T4.3 and T4.5.

The aim of the activities was to assess the current and future demands on farm-scale GHG DSS. To this end, a list of stakeholders possibly interested in the use of farm scale GHG DSS was circulated between the project partners. This allowed to map the stakeholders to be surveyed. Questionnaires to collect the opinions of stakeholders about decision support tools were developed. To analyse current and future demands on farm-scale GHG DSSs, two categories of questions were defined:



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- Questions about the awareness about DSS tools;
- Questions about the interest in DSS tools and the willingness to participate in DSS development.

The principles followed when developing the tailor-made questionnaires were the following:

- Completion of the questionnaire in a short amount of time, in order to avoid receiving incomplete questionnaires or no questionnaires answered;
- Use of easily comprehensible and direct language, targeting all educational levels and avoiding misunderstandings;
- Taking into account the time limitation, the questions need to perfectly fit the research objectives;
- Use of questions about other types of farm-scale DSS tools (e.g. livestock management tools), in order to differentiate between these tools and the GHG tools of interest.
- Preparation of tailored questions' list for each stakeholder group.

The questionnaires were developed by AUA in collaboration with ATB. The considered stakeholder categories were the following:

- Livestock farmers
- Livestock farmer advisors
- National inventory compilers
- Authorities and policy makers

The questionnaires were developed in English and circulated to the partners in November 2021 for translation, in order to be circulated in the first quarter of 2022. Questionnaires for farmers and farmer advisors were translated into the different national languages by each MELS partner. The German and English versions of these questionnaires are reported in the Annex.

Livestock farmers' advisors comprised the largest group of respondents (73 out of 109 answers), followed by livestock farmers (23 answers), inventory compilers (9 answers) and authority officials / policy makers (4 answers). It is important to notice that the level of interest in GHG DSS tools of livestock farmers and livestock farmer advisors showed a good correlation with the education level. Especially for the livestock farmers, this increases the chances of successful adoption of emerging technologies such as software-based decision-support tools.

Most of the responding stakeholders (88 out of 109) knew about DSS tools. Nevertheless, the DSS users were only 33 out of 88 answers. Even fewer are those who use DSS tools estimating GHG and NH₃ emissions at farm level. However, improvement of environmental performance of livestock farms highly concerns livestock farmers advisors, who tend to provide advice for reduction of GHG



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and NH₃ emissions, without actually having sufficient guidance in estimating such emissions. Furthermore, the answers from the livestock farmers showed that they are aware of GHG and NH₃ emitted from their farms, while most of the inventory compilers reported that farmers are generally unaware. Overall, the survey confirmed that in all considered countries there is a need for further education on GHG and NH₃ sources in agriculture, as well as on software-based decision support tools estimating such emissions and their mitigation. Detailed results of the survey are given in **D4.2**.

Task 4.3: Farm-scale GHG tools or models quantify emissions and removals from the major sources and sink within an agricultural system, attempting to represent the complex interrelationships among GHG sources and sinks in a system, which are often challenging to measure on site. This feature of farm-scale models can be particularly useful in identifying practices that decrease specific emissions from a given target within livestock systems, but increase emissions from other non-target sources, potentially causing a net increase in the livestock farm. Several tools already exist to quantify emissions from livestock farming systems with some providing decision support systems (DSSs), so that a developed community of users can be identified and surveyed. In this task, a survey was prepared by Teagasc in collaboration with AUA and circulated to all the partners to assess DSS tool user experiences (see Annex). Compared with the survey prepared in T4.2, this survey was addressed to experienced DSS and GHG model users, asking them how existing tools can be improved – and in particular where emission estimates in current farm-scale GHG DSSs can be improved – from their point of view.

The feedback from this survey, along with the findings from WP3 and T4.1-T4.2, provided a basis to formulate recommendations for priority technical improvement of existing DSSs, to be taken up by T4.5. The activities in this task started in M12 and were carried out until M30, when the first draft of **D4.3** was finalized. Revisions were carried out until M36. ATB answered the T4.3 survey internally, involving experts not taking part to the MELS project, then circulated the survey to external experts from the German community of GHG DSS developers, such as the BEK (“Berechnungsstandard für einzelbetriebliche Klimabilanzen in der Landwirtschaft”) developers (see T4.1).

Regarding the capacity in which DSS were used, the majority of respondents utilised such tools for research with less (1-2) end users using them for advisory and/or policy also. The main strengths identified in the survey for current DSSs were:



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- The tools can simulate effects of mitigation measures on livestock production and can capture knock-on environmental effects in terms of emissions.
- A life cycle approach for multiple livestock categories is often followed;
- The emission calculation and the nitrogen and carbon flows are generally transparent;
- In general, Tier 2 methodologies to describe flows in livestock and manure management and Tier 3 methodologies for crops and soil are used.
- Agro ecological zonation is used in the estimations.
- Some tools provide long-term C and N balances;
- Including missing crops is possible;

Table 37. Gaseous emissions and modelling methods for selected farm-scale greenhouse gas (GHG) decision support systems.

Name	Classification	Gaseous Emissions	Modelling Method
Cool Farm Tool v2.0	Bi-pillar sustainability model	N ₂ O, CH ₄ , CO ₂ , CO ₂ eq	IPCC method 2006
FarmAC	Emission calculator	NH ₃ and N ₂ O, CH ₄ , CO ₂ , CO ₂ eq	IPCC method 2006
Overseer	Bi-pillar sustainability model	N ₂ O, CH ₄ , CO ₂ , CO ₂ eq	IPCC method 2006
Carbon Navigator – Beef	Bi-pillar sustainability model	N ₂ O, CH ₄ , CO ₂ , CO ₂ eq	IPCC method 2006
Carbon Navigator – Dairy	Bi-pillar sustainability model	N ₂ O, CH ₄ , CO ₂ , CO ₂ eq	IPCC method 2006
KSNL - Kriteriensystem Nachhaltige Landwirtschaft	All-pillar sustainability model	NH ₃ and N ₂ O, CH ₄ , CO ₂ , CO ₂ eq	IPCC method 2006
SMART - Sustainability Monitoring and Assessment RouTine SAFA	All-pillar sustainability model	No applicable	FAO Guidance (SAFA guidance)
	All-pillar sustainability model	Not applicable	FAO Guidance (SAFA guidance)
RISE 3.0 - Response-Inducing Sustainability Evaluation	All-pillar sustainability model	N ₂ O, CH ₄ , CO ₂ , CO ₂ eq	IPCC method 2006
BEK - Berechnungsstandard für einzelbetriebliche Klimabilanzen in der Landwirtschaft	Emission calculator	NH ₃ , N ₂ O, CH ₄ , CO ₂ , CO ₂ eq	
AgBalance®	All-pillar sustainability model	NH ₃ , N ₂ O, CH ₄ , CO ₂ , CO ₂ eq	IPCC method
DLG-Nachhaltigkeitsstandard (based on REPRO)	All-pillar sustainability model	Not applicable	DLG method
HOLOS	Bi-pillar sustainability model	N ₂ O, CH ₄ , CO ₂ , CO ₂ eq	IPCC method 2006
EX-ACT	Emission calculator	N ₂ O, CH ₄ , CO ₂ , CO ₂ eq	IPCC 2006 method
GLEAM I	Emission calculator	N ₂ O, CH ₄ , CO ₂ , CO ₂ eq	IPCC 2006 method



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Name	Classification	Gaseous Emissions	Modelling Method
CAP'2ER	Bi-pillar sustainability model	NH ₃ , N ₂ O, CH ₄ , CO ₂ , CO _{2eq}	IPCC method 2006

The main weaknesses highlighted for existing DSSs were:

- Poor flexibility in dealing with crop rotations;
- Generalized lack of estimations of emissions per unit of saleable product (e.g. milk);
- Grasslands and grassland management is not so well represented;
- Some tools do not incorporate enough mitigation strategies;
- Good flexibility comes at the price of complexity;
- Economic and social dimensions of sustainability not often taken into account;
- The interfaces of the tools are sometimes not user-friendly, making them not always proper for inexperienced users.

Survey respondents provided the following suggestions to overcome current weaknesses in farm-level GHG DSSs:

- Add capabilities to account for soil C storage;
- Incorporate GHG mitigation measures in tools;
- Keep up to date with GHG estimation methodologies based on new research results (e.g. the implementation of revised models from the 2019 refinement of the IPCC 2006 Guidelines for GHG emissions' estimation and of the EMEP/EEA 2019 Guidebook for other gaseous emissions' estimation is still not implemented in most cases);
- Ensure user friendliness (i.e. interface, documentation and user guidance, options to compare results between years/farms/croppingsystems).

The results of the survey were included in the guidance document produced in this task (see **D4.3**), along with a detailed technical description of the emission accounting methodologies adopted in the considered tools.



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Table 18. Measures for mitigating emissions in farm-scale greenhouse gas (GHG) decision support systems by source category.

Name	Animal	Manure	Soils	Plants	Machinery/Energy
Cool Farm Tool v2.0	x	x	✓	✓	x
FarmAC	✓	✓	✓	✓	✓
Overseer	✓	✓	✓	✓	x
Carbon Navigator – Beef	✓	✓	✓	✓	x
Carbon Navigator – Dairy	✓	✓	✓	✓	✓
KSNL - Kriteriensystem Nachhaltige Landwirtschaft	-	-	-	-	-
SMART - Sustainability Monitoring and Assessment RouTine	x	x	x	x	x
SAFA	x	✓	✓	✓	x
RISE 3.0 - Response-Inducing Sustainability Evaluation	✓	✓	✓	✓	✓
AgBalance®	x	X	✓	✓	✓
DLG-Nachhaltigkeitsstandard (based on REPRO)	-	-	-	-	-
HOLOS	✓	✓	✓	✓	x
EX-ACT	✓	✓	✓	✓	✓
GLEAM I	✓	✓	x	✓	x
CAP'2ER	✓	✓	✓	✓	✓

Task 4.4: In this task, a generic method for estimating the costs and savings associated with implementing mitigation measures at the farm scale was developed, using Ireland as a case study and linking with T5.2 (“Quantifying the costs and benefits of mitigation measures in national inventories”). This task was carried out by Teagasc and CUBS in collaboration with ATB. The activities in this task started in M24 and were finalized in M36.

Briefly, the study carried out in T4.4 created a farm-level method to assess the financial implications of mitigation measures for gaseous emissions from livestock systems. The method was tested on an average of Irish dairy farms, representing the top, middle, and bottom one-third of producers. The study found that over half of the greenhouse gas (GHG) abatement potential was realized with cost-beneficial measures, and most of the ammonia (NH₃) abatement potential was also cost-beneficial. Animal and feed-related measures that increased efficiency drove the abatement of GHG emissions. Low emission slurry spreading was important for the bottom and middle one-third of farms, while protected urea and reducing N use accounted for most of the NH₃ abatement potential for the top one-third. The study also found that combining measures increased GHG and NH₃ mitigation, but their abatement potentials were not additive due to interactions.



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A scientific paper entitled “*Mitigation of gaseous emissions from livestock systems: A farm-level method to examine the financial implications*“ is in preparation by Teagasc, CUBS and ATB and will be submitted to “*Journal of Environmental Science and Policy*” by September 2023 (see **D4.4**).

Task 4.5: This task worked closely with WP3 and T4.3 to the finalization of a farm-scale GHG DSS prototype tool. This prototype was developed basing on an existing tool which was improved with enhanced GHG estimation capabilities. A discussion on core GHG accounting functions to be developed was carried out in the MELS Consortium starting from March 2021, in line with the project schedule. At that time, the task leader (AUA) agreed with the coordinator (ATB) on the main features of the prototype:

- easily accessible online;
- it will provide detailed guidance for its use;
- it will be transparent about the methodology adopted.

After brief consideration of the “GLEAM” tool from FAO as a basis tool to be further developed by MELS, the “FarmAC” model⁴ was finally selected, owing to its higher suitability to model single cattle and pig farms. The FarmAC model was previously developed by the EU AnimalChange project. It can be used to model GHG emissions and C and N flows under a variety of farm management conditions and cropping systems.

The IT development of the tool (AUA, AU) started in November 2021 and was finalized in November 2022 (M33). Upgrades for the tool were the following:

- Update in estimation methodology;
- Use of methodologies apart from IPCC 2006(2019) if it is possible and functional until the deadline;
- Friendly design with guidance (e.g. pop-ups on the tool interface) for the user;
- Addition of GHG and NH₃ mitigation effects from WP3, as a separate option of the tool;
- Better error management of FarmAC;
- Comparison of several scenarios (same interface);
- Development of an automate register/login template;
- Better presentation of results;
- Automated estimation of the results while inserting the inputs.

⁴ <https://www.farmac.dk/>



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In March 2023, the software was publicly uploaded by AUA to the following public repository: <https://github.com/mike1821/MELS/tree/master>. Full instructions on the tool are given at the same address. At the same time, a guidebook on the software was delivered by AUA. In particular, the document lists the IT requirements of the software, gives guidance on the installation procedure, on the software configuration and on the preparation of the input file to run the assessment. Video instructions have also been provided and can be accessed at <https://github.com/mike1821/MELS/blob/phase1/MELS%20software%20user's%20guide%20presentation.mp4>. Full details on the features of the prototype and the guidance document are provided in **D4.5**.

WP4 – List of deliverables

	Deliverable	Planned for	Status	Responsible partner
D4.1	Report on Survey of Capability of Existing Farm-Scale GHG DSS.	M9	Done	AUA
D4.2	Report on Stakeholder Consultation on Requirements of GHG DSS for Incentivisation and Marketing Improved Farm Carbon Efficiency and GHG Reductions.	M24	Done	AUA
D4.3	Guidance Document on Priority Technical Improvements to Existing GHG DSS to Improve Sensitivity to Regional Factors.	M27	Done	Teagasc
D4.4	Factors Explaining Variation in GHG Mitigation Cost.	M36	Done	Teagasc



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D4.5	Prototype Generic Farm-Scale GHG DSS Software.	M36	Done	AUA
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E. WP5 - Improving national emission inventories and projections

WP Leader: Leibniz Institute for Agricultural Engineering and Bioeconomy (ATB, Germany)

Partners: AgR (New Zealand), INRAE (France), Teagasc (Ireland), AU (Denmark), INIA (Chile), UZ (Poland)

The objective of WP5 was to improve accuracy & reportability of agricultural GHG emissions and of effect of mitigation measures in national inventory reporting, reducing the cost of collecting activity data. WP5 was divided into 4 tasks which are:

- T5.1 - Recommendations to improve inventory methodologies in partner countries
- T5.2 - Quantifying the costs and benefits of mitigation measures in national inventories
- T5.3 - Methods to obtain activity data to support emission inventories
- T5.4 - Retaining transparency in Tier 2+ and Tier 3 inventories

WP5 tasks were carried out mainly by ATB (leading T5.1 and T5.3) and by UZ (leading T5.2 and T5.4). A provisional planning of WP5 was introduced by the ATB during the Annual Meeting 2020, then agreed with the partners during the PMC meeting in March 2021.

Task 5.1: The aim of this task was to develop recommendations to improve inventory methodologies in partner countries. These recommendations could be developed considering the results of the statistical analysis in WP3, relating emission factors to ancillary variables in the DATAMAN database, and the emission mitigation measures identified in WP2. What could be ideally assessed for emission inventorying (WP3) was compared with the inventorying activity currently carried out in selected countries, including all MELS partner countries. To this end, activities in this task, and thus in WP5, were started by ATB in January 2021 with the preparation of an overview on national inventory methodologies on the status of GHG and NH₃ emission estimation methods for manure management systems and managed soils. This information was gathered from:

- GHG emission inventory reports 2020 of selected countries;
- The “Annual European Union GHG Inventory report 2020”;



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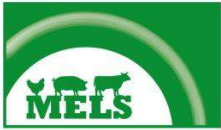
- The “JRC Technical report of Methodological overview on the calculations of air pollutant and GHG emissions from agricultural activities 2020”

Fourteen countries, namely Germany, France, Greece, Denmark, Ireland, Poland, Austria, Netherlands, Italy, Belgium, New Zealand, Chile, China, Brazil were included in the overview. The Advisory Board of MELS actively contributed to T5.1. Results of this study are summarized in Table 19.

Table 19. Number of countries using different tier methodologies for emission estimations

Emission source	# of countries using T2	# of countries using T1	# of countries using T3 or CS
Manure management-CH ₄ emissions from cattle	14		
Manure management-CH ₄ emissions from swine	10	4	
Manure management N ₂ O emissions from cattle	13	1	
Manure management N ₂ O emissions from swine	10	3	
Urine and Dung Deposited by Grazing Animals	3	10	
NH ₃ from manure management	6	2	1 T3, 2 T3/T2 2 CS
NH ₃ from agricultural soils	2 T2	1 T1 4 T1/T2	2 T3 2 T1/T2/T3 1 CS

The IPCC provides ‘Tiers’ of methodology for use by different groups of countries depending on their ability to produce their own empirical data. Tier 1 (T1) is the simplest method and uses default values for EF and equations for each animal subcategory while Tier 2 (T2) is a more detailed



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approach requires country specific information on livestock and manure management (IPCC 2006). Tier 3 (T3) introduced with the 2006 IPCC guidelines, enables countries to do the most sophisticated analysis and modelling.

Next steps in T5.1 were taken after receiving input from WP3 on functional relationships and mitigation options (M27). The key factor analysis in WP3 gave information on which are the most relevant factors to be considered in refined emission inventories. The “Guidance document on recommendation for future inventory improvement” (D5.1) was delivered by ATB in February 2023, since the final recommendations depended on the data analysis activity, which was extended to the whole 2022.

A publication on “Inventory reporting on livestock emissions: the impact of the IPCC 1996 and 2006 Guidelines” was published by the ATB in the journal “Environmental Research Letters” (IF 6.096) in June 2021 ([DOI:10.1088/1748-9326/ac0848](https://doi.org/10.1088/1748-9326/ac0848), see Annex). The paper investigates the effects of moving from the 1996 IPCC Guidelines for National Greenhouse Gas Inventories to the 2006 IPCC Guidelines on the emission estimates from the livestock sector.

Task 5.2: In this task, UZ and ATB developed a template to collate mitigation costs data, which includes the mitigation options identified in the DATAMAN database in WP2 and assessed in WP3. This task was started in 2021, while the template was circulated to the MELS Consortium in the first quarter of 2022. The assessed costs and benefits of emission abatement strategies were originated from different sources, including the publicly available data from the GAINS model (<http://gains.iiasa.ac.at>). Both national emission reduction potentials and costs were compared with national data when available. Therefore, the information on mitigation and costs was collected and elaborated by UZ: Owing to the quality and quantity of available information, T5.2 specifically focused on NH₃ emissions, allowing to deliver robust results in terms of 1) the most cost-effective feeding strategies from cattle and pigs 2) structural conditions influencing cost estimations in the different countries. In fact, large differences appear between the result of individual countries, also in comparison with model results that are generally better harmonized between countries. One of the main outcomes of the study is that different system boundaries in cost assessments affect perceived and real cost differences. This makes currently difficult to distinguish further cost-efficient solutions. Identifying and addressing this difficulty is key for further and more consistent assessments needed to improve the evaluation base for other abatement options, especially those that are newly being developed. This study on the transnational comparison of cost-effectiveness estimations of NH₃ mitigation was submitted to the peer-reviewed journal “Journal of Environmental



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Management” as a scientific paper entitled “*Costs and benefits of measures to reduce ammonia emissions from pig and cattle production: A comparison of country-specific estimations and model calculations* “ (see **D5.2**), and it is currently under the second round of revisions.

Task 5.3: The aim of this task is to review methods to obtain activity data to support national emission inventories and to give suggestions for their future optimisation. In this task, ATB created an overview on national activities to collect activity data. For this purpose, ATB developed a template to collect high-resolution activity data, which was filled by partners (see Annex). The template included questions about:

- how activity data is collated
- animal category/number information availability
- diet composition information availability
- feed Intake information availability
- “Nex” values calculation/information availability
- VS excretions calculations/information availability
- manure Management/waste management Systems information
- availability of information on manure management/distribution
- animal housing information availability

Answers for these questions were provided by partners and other experts in Greece, France, New Zealand, Denmark, Ireland, Austria, Poland and Germany, and good quality of the collected data was achieved. The information collected showed relevant differences in level of detail of activity data used in the different countries.

The assessment of the current status in the abovementioned countries was coupled with suggestions for improvement of future inventories. These suggestions were drawn from intensive consultation with inventory compilers and experts in agricultural emissions. For instance, MELS collaborated for T5.3 with the ALFAMI project (Ammonia Losses from Field-Applied Slurry: a Model-Based Approach for Emissions Inventories), which is about the application of an advanced model for NH₃ emission estimation for inventory calculation. As final consultation step, MELS joined the EAGER Workshop held in Wageningen in November 2022 (see Annex). EAGER is a group of emission inventory compilers and emission experts specifically aimed to the improvement of emission inventories.



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The outcomes of the surveying activity and the consultation allowed ATB to prepare a guidance document on methods to obtain activity data to support emission inventories (see **D5.3**).

Task 5.4: In this task, some theoretical foundations that describe the added value provided by the functional models developed in WP3 were provided, analyzing the available options to retain transparency in the emission inventories, to allow comparison across methods (and also across regions, using benchmarking approaches), and to validate whether results are fit for purpose.

The main, underlying question is to which extent Tier 2 or Tier 3 methodologies are able to provide improved responses to the estimation of the emission quantity or the other purposes (e.g. assessing emission patterns, emission mitigation and mitigation costs). Here, full transparency is needed whether or not a higher Tier methodology provides the same or a different response than the lower tier result. Facilitating such transparency requires to systematically reorganize output of emission models so that they can be directly compared to Tier 1 results.

To this end, an analysis of the prospects for maintaining the transparency of emission inventories was carried out. Activities in this task started rather late in the project (M27), as specified in the interim reports, since the main body of the data analysis in WP3 had to be completed and preliminary activities in T5.1 and T5.3 had to be carried out before the “Guidance document on maintain transparency in higher Tier inventories” could be developed (see **D5.4**). This document was prepared by UZ in collaboration with ATB, AgR and INRAE.

WP5 – List of deliverables

	Deliverable	Planned for	Status	Responsible partner
D5.1	Guidance document on recommendation for future inventory improvement.	M27	Done	ATB
D5.2	Scientific paper on the costs and benefits of mitigation measures.	M36	Done	UZ
D5.3	Guidance document on methods to obtain activity data	M33	Done	ATB



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	to support emission inventories.			
D5.4	Guidance document on maintaining transparency in higher Tier inventories.	M36	Done	UZ

F. WP6 – Consultation and dissemination

WP Leader: Teagasc (Ireland)

Partners: ATB (Germany), AgR (New Zealand), INRAE (France), AU (Denmark), INIA (Chile), UZ (Poland).

The objectives of WP6 were: i) to ensure views of main stakeholders in relation to implementation of MELS are taken into account and ii) to disseminate project’s outcomes to stakeholders and coordinate activities. WP6 was made up of three tasks:

- T6.1 - Transnational stakeholder consultation
- T6.2 - Dissemination to national bodies and farmers
- T6.3 - Wider International Dissemination

MELS aimed to enable substantial progress in mitigating emissions from livestock agriculture. In order to achieve long-lasting impact, an active outreach program engaged farmers, advisors, scientists, stakeholders and policy-makers. For this reason, consultations with farmer’s organizations, IPCC and inventory stakeholders occurred since the project began.

The ATB is the main contributor to all WP6 tasks together with Teagasc. In addition to the researchers, three categories of stakeholders are being addressed:

1. Inventory compilers;
2. Policy makers;
3. Farmers, farmer organizations and advisory services.



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Task 6.1: The main goals of T6.1 were:

- To raise awareness among international stakeholders regarding the activities undertaken in MELS to support the livestock industry mitigate emissions;
- To plan and arrange consultations between MELS partners and relevant transnational farmer, industry and policy organisations;
- To take the thoughts and opinions of a broad range of representative stakeholders into account during the implementation of MELS;
- To describe transnational stakeholders expectations and/or demands for current and future farm-scale GHG DSSs.

The views, opinions and hands-on experience of a broad selection of stakeholders helped to shape project deliverables while improving the quality and relevance of research outputs. Throughout the Mitigating Emission from Livestock System (MELS) project, transnational stakeholders were consulted with respect to a number of the primary objectives of MELS. Teagasc, in conjunction with ATB and project partners, organised consultations with major transnational stakeholders in Europe and South America, and took their views regarding the implementation of the project and operation of farm-level GHG tools into consideration. This type of multi-actor approach was also aimed to improve farmer and industry understanding of gaseous emission accounting systems.

The process to consult with stakeholders consisted of five phases:

1. Map international bodies that represent stakeholders with an interest in mitigating gaseous emissions from livestock production systems.
2. Select relevant transnational organisations by leveraging existing linkages with partners in the MELS consortium.
3. Develop communication tools to circulate to representatives in selected bodies.
4. Organise and arrange format of consultations with contact points in transnational farm, industry and policy organisations.
5. Summarise outcomes of transnational stakeholder consultations.

For the initial phase of the consultation, transnational stakeholders were mapped with project partners and advisory members. The first mapping exercise was conducted at the kick off meeting in Poznan where project partners verbally identified key stakeholders and divided them into three cohorts representing primary producers (i.e. farmers), industry and policymakers. The partners of MELS were subsequently invited to add further stakeholders to the nominated categories via email and through stakeholder templates.



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The detailed outcomes of the mapping activity in T6.1 are reported in detail in **D6.1**. Briefly, Teagasc and ATB screened the list of international organisations mapped by the MELS Consortium. Key transnational organisations were retained for each of the abovementioned cohorts of stakeholders, based on their engagement with environmental challenges and their activities regarding monitoring, mitigating and reporting emissions. The final consultation list included the following transnational stakeholders and organisations:

- Farm stakeholders - COPA COGECA (European Farmers and Agri-Cooperatives).
- Industry stakeholders - SAI platform, Sustainable Dairy Partnership, Nestle and Fepale.
- Policy stakeholders - UN TFRN, UN TFEIP and IPCC technical secretariat.

A flyer outlining the context, ambitions and expected benefits of MELS was prepared by Teagasc and ATB (see Annex). Questions on what MELS aimed to learn from stakeholder consultations were included in leaflets:

1. How can industry/farmer organizations interact with the MELS project and inventory compiling?
2. How can different mitigation measures and production improvements be evaluated and implemented by the farmers minimizing their negative impacts while maximizing efficacy?
3. How can industry/farmer organizations base their interaction with EU and national policy makers on GHG mitigation targets on existing knowledge about mitigation measures, their effects and their costs?

Contact points with transnational stakeholder were identified and pursued by Teagasc, ATB and INIA. The MELS flyer, contact information and website details were shared with these organisations, and their representatives were invited to attend introductory meetings, followed by dedicated workshops.

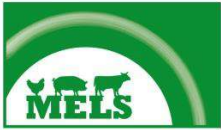
In detail, Teagasc and ATB engaged with **COPA COGECA** through their representatives in the Irish co-operative organisation society (ICOS). An introductory online meeting was held with Irish COPA COGECA members in February 2020. Following the introductory call, additional MELS project information was shared with the member organisations of the COPA COGECA, and specifically sent to members of the livestock, climate change and environment committees. The representatives on the environment committee discussed the merits of the MELS project and agreed to a consultation in July 2021. Policy officers in COPA COGECA placed the consultation



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on the working party agenda and hosted the meeting remotely with translation services. In-person consultation was not possible due to COVID-19 restrictions. The minutes of the consultation were recorded and the views of stakeholders were gathered on the KUDO platform by COPA COGECA officials (see **D6.1**).

For transnational industry bodies, consultation were initiated by Teagasc through their industry contacts within the **Sustainable Dairy Partnership (SDP)**. Similar to the approach adopted with the COPA COGECA, an initial call was held with Irish members of the SDP in June 2021 where the project context, goals and expected benefits were outlined. The MELS project was presented to the livestock directors of the SAI platform in July 2021. A plan was developed for consulting with member organisations in the SAI platform after further discussions with the organisation's livestock and dairy directors in October 2021. European and Latin American (Nestle, Fepale) companies in the livestock working group were contacted by directors in the SAI platform and by INIA. Then, they were invited to join a MELS industry workshop on the 12th April 2022. Detailed information on this activity is reported in **D6.1**.

Regarding transnational policy advisory bodies, ATB, UZ and AU regularly interacted with policy stakeholders in IPCC and UN Task Forces (TFRN – Task Force on Reactive Nitrogen⁵; TFEIP – Task Force on Emission Inventories and Projections⁶) and planned consultations with these bodies, in particular in connection with T3.3 and all tasks in WP5.

In particular, the **Task Force on Reactive Nitrogen (TFRN)** has the long-term goal of developing technical and scientific information and options to be used for strategy development across the UNECE to coordinate air pollution policies on nitrogen. The TFRN works within the CLRTAP (Convention on Long-range Transboundary Air Pollution⁷), an international treaty signed by 51 out of 56 UNECE countries. The transboundary strategy development of TFRN may be used by other bodies outside the Convention in consideration of other control measures. TFRN conducts the technical work necessary to develop a better understanding of the integrated, multi-pollutant nature of reactive nitrogen, in the context of the nitrogen cycle, considering how this work would complement the work of other subsidiary bodies of the CLRTAP, such as the TFEIP.

⁵ <https://www.clrtap-tfrn.org/>

⁶ <https://www.tfeip-secretariat.org/>

⁷ https://unece.org/fileadmin/DAM/press/pr2009/09env_p29e.htm



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The **Task Force on Emission Inventories and Projections (TFEIP)** is also a group established under the UNECE Convention on Long-range Transboundary Air Pollution. The main role of TFEIP is to support Parties in the reporting of air pollutant emissions and projections data to the Convention. This includes having responsibility for the development and technical content of the EMEP/EEA Emission Inventory Guidebook used for the estimation and reporting of national emissions. The TFEIP also works as expert network to harmonise emission factors, establish methodologies for the evaluation of emission data and projections and identify problems related to emissions reporting.

In addition, MELS established close links with other international bodies and working groups such as IPCC (Intergovernmental Panel on Climate Change⁸), EPNB (Expert Panel on Nitrogen Budgets⁹), EPMAN (Expert Panel on Mitigating Agricultural Nitrogen¹⁰), RAMIRAN (Research Network on Recycling of Agricultural and Industrial Residues in Agriculture¹¹), GRA MMN (Manure Management Network of the Global Research Alliance¹²).

In 2020 the MELS project took part to the TFEIP annual meeting. This meeting was held jointly with the EIONET network of the EEA network and focused on the issues around emissions reporting under the CLRTAP. The MELS project team presented their findings on the collation of data to the DATAMAN database and contributed to the discussions on updating the Emission Inventory Guideline for compliance with the CLRTAP. Still in 2020, MELS presented results at the 2020 meeting of the Manure Management Network of the Global Research Alliance (GRA MMN).

In 2021, MELS participated in the 15th annual meeting of the Task Force on Reactive Nitrogen (February 2021), where B. Amon chaired the Expert Panel on the Mitigation of Nitrogen from Agricultural Sources (EPMAN). MELS contributed to emission inventory methodology developments and to the update of the Gothenburg protocol in the joint meeting of TFEIP and EIONET in May 2021. MELS also contributed to the TAIEX EPPA "Online Regional Workshop on emissions of certain atmospheric pollutants" and to the TAIEX-EIR "Multi-country Workshop on Ammonia reducing technology and measures" in February and November 2021 respectively.

In May 2022, MELS results on the analysis of the emission data contributed to the revision process of emission inventory methodology at the 19th meeting of the EPNB (Expert Panel on Nitrogen

⁸ <https://www.ipcc.ch/>

⁹ <https://www.clrtap-tfrn.org/epnb>

¹⁰ <https://www.clrtap-tfrn.org/epman>

¹¹ <http://ramiran.uvlf.sk/>

¹² <https://globalresearchalliance.org/research/livestock/networks/manure-management-network/>



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Budgets) and the meeting of the Agriculture and Nature Panel (chaired by B. Amon) of the TFEIP. The MELS results were also presented at the annual meetings of the TFEIP and TFRN, held in June and October 2022 respectively.

Detailed information on these activities is reported in **D6.1** and in **Section V** of this report.

Task 6.2: ATB coordinated the efforts of the partners in reaching national stakeholders in the farming sector. At the beginning of the project, Teagasc circulated a template to collect concrete ideas of events and initiatives for MELS dissemination from the partners. Workshops with farm organizations were planned in each partner country. However, farmer events had to be planned for 2021, and then postponed to 2022 due to the persisting difficulties related to the pandemic. In 2022, MELS partners joined events such as the Teagasc Beef Open Day (Ireland), the EuroTier fair in Hannover (Germany), the Agrotechnica fair in Thessaloniki (Greece), other open days in Poland. Detailed information on the MELS dissemination to national stakeholders from the farming sector are given in **D6.2** and in **Section V** of this report.

Task 6.3: This task is more specifically related to the dissemination of project results to the international scientific community. Interim results were disseminated to various conferences and workshops from the beginning of the project. The main scientific outcomes are summarized by the following papers published in peer-reviewed journals:

- Under WP2
 - A scientific paper describing the field database was published by the “Journal of Environmental Quality”: “*DATAMAN: A global database of nitrous oxide and ammonia emission factors for excreta deposited by livestock and land-applied manure*”.
 - A scientific paper on “*Ammonia and nitrous oxide emission factors for excreta deposited by livestock and land-applied manure*” was also published by the “Journal of Environmental Quality”.
 - The additional “unit conversion project” funded by GRA (see T2.1) led to the publication entitled “*Guidance on the conversion of gaseous emission units to standardized emission factors and recommendations for data reporting*” in “Carbon Management”.



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- The paper entitled “*DATAMAN: A global database of methane, nitrous oxide and ammonia emission factors for livestock housing and outdoor storage of manure*” was published in 2022 by the “Journal of Environmental Quality”.
- Under WP3
 - a publication on “*The simulated environmental impact of incorporating white clover into pasture-based dairy production systems*” was in the “Journal of Dairy Science”.
 - a publication on “*Influence of key factors on ammonia and nitrous oxide emission factors for excreta deposited by livestock and land-applied manure*” was published by the journal “Science of the Total Environment”.
- Under WP4
 - a paper on “*Farm-Scale Greenhouse Gas Emissions’ Decision Support Systems*”, published by the journal “Engineering Proceedings”.
- Under WP5
 - a paper on “*Inventory reporting of livestock emissions: the impact of the IPCC 1996 and 2006 Guidelines*” was published in “*Environmental Research Letters*” (Special Issue on `Focus on Reactive Nitrogen and the UN Sustainable Development Goals`).

Other papers have been submitted to peer-reviewed journals or are in preparation. The full list of scientific papers is provided at **Section IV** of this report. Other dissemination activities (i.e. presentations to conferences, workshops, international meetings) are listed in **Section V**.

This task also took care of the final delivery of revised emission factors and statistical models relating emissions to ancillary variables to the **EFDB** (Emission Factor Database¹³) of the IPCC. The EFDB is a library of emission factors/parameters and other relevant data maintained by the IPCC. The EFDB mainly consists of default values from IPCC guidelines, data from peer-reviewed scientific papers and data from other publications such as industry studies and government reports. Since its development, EFDB evolves dynamically through data proposals e.g., voluntary submission of data by researchers and inventory compilers and data collection efforts from expert networks and meetings. The database is open to any kind of data proposals and the inclusion of proposed data into the EFDB is decided by the editorial board after careful

¹³ <https://www.ipcc-nggip.iges.or.jp/EFDB/main.php>



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consideration of selection criteria. The Editorial Board of the EFDB is composed of experts recommended by the IPCC member states. The EFDB is available online and offline. The offline application of EFDB can be downloaded by using the following link (<https://www.ipcc-nggip.iges.or.jp/EFDB/downloads.php>). Details of the delivery of MELS results to the EFDB are provided in **D6.3**.

WP6 – List of deliverables

	Deliverable	Planned for	Status	Responsible partner
D6.1	Report on the outcomes of transnational stakeholder consultations.	M36	Done	Teagasc
D6.2	Report on the outcomes of the national stakeholder workshops on the implications for agricultural inventories.	M36	Done	Teagasc
D6.3	Database of emission factors publicly accessible and submission to IPCC and TFEIP.	M36	Done	ATB



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II. Relevant third-party results

To date, we did not find any recently published information that would make the MELS main hypotheses obsolete. The research topic is still very topical and we expect continuous contributions from research groups active in this field. The specificity of the approach adopted, the extensiveness of the data collation from many sources to a single database and the close collaboration with those who developed it and continuously maintain it (AgR) lead us to believe that the contribution of MELS will remain highly original for years. This is proven by the number of innovative, peer reviewed papers published and conference talks given within the MELS context.

III. Comparison of actual project status with original planning

The MELS project ran smoothly and without delays. Data analysis (WP3) and stakeholders surveys (WP4) were slowed down in the second year (2021) due to persisting restrictions caused by the pandemic. These delays have not been fully overcome until the last project year. Delays in other workpackages were minimized already during 2021 and did not have any effect on the project.

For these reasons, some papers could not be submitted by the end of the project (i.e., D3.2, D4.4), although they are close to be finalized. Nonetheless, additional papers were submitted, also under WP3 and WP4 (see T6.3 and Annex), while others exceeded the requirements of the original Description of Work (i.e., D2.2 already published; D5.2 under the second round of revisions).

1.1 Contribution of the results to the BMEL policy goals

MELS contributes mostly to the objective 2.3 („Tiergesundheit, Tierschutz und nachhaltig gestaltete Erzeugung tierischer Produkte“) of the “Zukunft nachhaltig gestalten - Forschungsfelder des Bundesministeriums für Ernährung und Landwirtschaft“ document from 2014. In particular, MELS contributed to the development of sustainable livestock systems, with specific regard to cattle and pigs. MELS contributed to the knowledge of the mechanisms of N₂O, CH₄ and NH₃ emissions and how to assess them in emission inventory reports, including the effect of mitigation measures. Thus, MELS contributed to the development of low-emission livestock systems. MELS contributed also to the project funding areas of BLE on i) sustainable livestock farming and ii) emission mitigation



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and adaptation to climate change, in line with the objectives of the Bundesprogramm Nutztierhaltung and with the topic “Für mehr Nachhaltigkeit” of the BMEL Innovationsförderung.

1.2 Appropriateness of effort and time

Effort and time were appropriate. For the realization of the project, the ATB required an additional doctoral position for the entire project duration of 36 months. A junior researcher was hired, to take care of the data collation to the DATAMAN database, the statistical analysis of the data, the development of guidance to improve emission inventories. Personnel funds were used also to partially fund a PostDoc position. The PostDoc supported the project in all WPs, supporting project coordination and helping in project dissemination and publication of the findings in peer-reviewed journals. Travel funds supported project dissemination (i.e. conferences). Other funds supported project management (i.e. final project meeting in 2022 and WP3 meeting in 2023, organized by ATB) and project dissemination (i.e. open access publication fees and editorial services).

1.3 Work that did not lead to a solution

No work was carried out that did not lead to a solution.

1.4 Appropriateness of use of federal funds causal for the achievement of the planned project objectives

MELS objectives would not have been reached without federal funds. Thanks to the funding of the BLE, it was possible to hire staff and consumables, thus making sampling campaign, experiments, data collection and data analysis possible. Federal funds also substantially contributed to the dissemination of project results. This research would not have been carried out without these financial resources.



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1.5 Scientific connection to a possible next phase

The factors known to drive NH_3 , N_2O and CH_4 emissions could only explain part of the observed variation in emissions, and we suspect that this was due to non-measured factors. Therefore, having more measurements from studies that include all key factors will improve our understanding of the underlying processes influencing emissions, and thus help to refine emission factors.

Improved EF values can be used by inventory compilers to improve the accuracy of national inventories and quantify the effectiveness of mitigation strategies where country-specific EFs do not exist. However, there are persisting knowledge gaps, with some regions poorly represented despite all the MELS efforts to broaden the geographical coverage of DATAMAN (e.g., Asia, Africa, South America). We hope that in time, data will become more representative as we continue to include additional studies within the DATAMAN database from a wide range of climates and regions.

It was shown that there is a strong relationship between emission inventory methodology and mitigation options, as the mitigation measures will only be effective for meeting emission reduction targets if their effectiveness can be demonstrated. Therefore, it is very much in the interest of the agricultural sector to report detailed and transparent inventories, moving from lower Tiers to advanced methodologies. Such improvements are worth the effort for policy makers, because inventory reports are a potent tool to implement mitigation measures and thus reflect improvements in the emission of the agricultural sector. This effort can by no means be considered concluded and future research should contribute to propose emission assessment methods that can refer to activity data that realistically can be accessed by inventory compilers.

In this respect, the capability of acquiring data should also be improved. It is necessary to relate agricultural practices to farm emissions more rigorously, as modelling emissions remains a source of large uncertainties. On farm measurements, and in particular barn measurements and the creation of a EU level database of barn emissions are necessary for the future development of more reliable emission models. Widespread farm measurements would allow the farmers to obtain a better insight of the effects of management practices on emission levels, increasing their awareness and creating possibilities for further improvement.



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