

Publizierbarer Endbericht

Gilt für Studien aus der Programmlinie Forschung

A) Projektdaten

Allgemeines zum Projekt	
Kurztitel:	nonCO2farm
Langtitel:	Farm-level modelling and digital monitoring of non-CO ₂ greenhouse gas emissions in Austria
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Projekt- und KooperationspartnerIn (inkl. Bundesland):	Österreichisches Institut für Wirtschaftsforschung (WIFO), Wien LBG Consulting GmbH, Wien
Schlagwörter:	climate neutrality, methane, nitrous oxide, farm emissions, integrated assessment
Projektgesamtkosten:	298.969 €
Fördersumme:	298.969 €

Allgemeines zum Projekt	
Klimafonds-Nr:	C163291
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B) Projektübersicht

1 Kurzfassung

Global gesehen ist der Agrarsektor der größte Emittent von anthropogenen nicht-CO₂ Treibhausgasemissionen, wobei Methan (CH₄) und Lachgas (N₂O) den größten Anteil davon ausmachen. In Österreich werden in der nationalen Treibhausgasinventur rund 10 % der gesamten Treibhausgasemissionen dem Agrarsektor zugerechnet. Davon entfallen 65 % auf CH₄ und 34 % auf N₂O. Um die Klimaneutralitätsziele der Europäischen Union (EU) und Österreichs in den kommenden Jahrzehnten zu erreichen, ist eine erhebliche Reduktion der Treibhausgasemissionen erforderlich.

Gemäß des Rahmenübereinkommens der Vereinten Nationen über Klimaänderungen (UNFCCC) folgen die nationalen Treibhausgasinventuren einem international standardisierten Verfahren zur Berechnung der sektoralen Treibhausgasemissionen. Diese Berechnungen sind jedoch mit Unsicherheiten behaftet, die insbesondere auf die eingeschränkte Datenlage zu landwirtschaftlichen Aktivitäten und die Wahl der Emissionsfaktoren zurückzuführen sind. Darüber hinaus weisen jüngste Analysen darauf hin, dass das Potenzial des Agrarsektors zum Klimaschutz in der Vergangenheit möglicherweise unterschätzt wurde.

Das Monitoring von Treibhausgasemissionen auf Betriebsebene könnte bestehende Daten- und Informationslücken schließen und die gezielte und effiziente Umsetzung politischer Instrumente zum Klimaschutz unterstützen. Das Projekt nonCO₂farm widmet sich daher dem Monitoring von nicht-CO₂ Treibhausgasemissionen für landwirtschaftliche Betriebe. Dazu verfolgt es drei wesentliche Ziele:

- i) Beschreibung eines strukturierten Ablaufs (i.e. Protokoll) und Entwicklung eines Prototyps für ein digitales Treibhausgas-Emissions-Monitoring-System zur Ermittlung von nicht-CO₂ Treibhausgasemissionen (i.e. Methan und Lachgas) auf landwirtschaftlichen Betrieben;
- ii) Entwicklung und Modellierung von Mitigationsszenarien, um nicht-CO₂ THG-Emissionsreduktionspotenziale und kosteneffiziente Maßnahmen zur Reduktion von Emissionen auf landwirtschaftlichen Betrieben zu ermitteln;
- iii) Entwicklung eines Kommunikationskonzepts für ein webbasiertes Dashboard, welches nicht-CO₂ Treibhausgasemissionen aus der Landwirtschaft für verschiedene Nutzergruppen bereitstellt.

Die Projektziele wurden in drei Phasen bearbeitet. In der ersten Phase erfolgte eine Literaturrecherche zur Beschreibung des strukturierten Ablaufs (i.e. Protokoll) und zur Entwicklung des Prototyps für das digitale nicht-CO₂ Treibhausgas-Emissions-Monitoring-System. Letzteres soll insbesondere auf die Bedürfnisse der identifizierten Nutzergruppen (i.e. Landwirt:innen, Agrarexpert:innen, Wissenschaftler:innen, interessierte Öffentlichkeit) eingehen. In der zweiten Phase wurde ein bestehendes webbasiertes System erweitert, um Daten auf Betriebsebene zu erheben, die ihrerseits in die Berechnung von nicht-CO₂ Treibhausgasemissionen für landwirtschaftliche Betriebe – differenziert nach Betriebstyp und Bewirtschaftungsverfahren – einfließen. In der dritten Phase wurden mittels eines räumlich expliziten, integrierten Modellverbunds Treibhausgasemissionen und kosteneffiziente Mitigationsmaßnahmen auf Betriebsebene modelliert.

Im Rahmen des Forschungsprojektes nonCO2farm wurden das Protokoll und darauf aufbauend ein Tool für die Berechnung von nicht-CO₂ Treibhausgasemissionen entwickelt. Mittels des im Projekt erweiterten webbasierten Systems wurden Daten für 21 ausgewählte landwirtschaftliche Betriebe erhoben, die in die Berechnung ihrer jeweiligen nicht-CO₂ Treibhausgasemissionen einfließen. Der Berechnungsprozess verdeutlichte einmal mehr, dass umfangreiche und genaue Betriebsdaten für die Ergebnisse entscheidend sind. Bei der Datenerhebung war insbesondere die Abfrage von Futterrationen eine große Herausforderung.

Die Modellergebnisse zeigen eine erhebliche Heterogenität des Emissionsreduktionspotenzials und der Grenzvermeidungskosten zwischen landwirtschaftlichen Betrieben in Österreich. Dementsprechend sind maßgeschneiderte Mitigationsmaßnahmen erforderlich, die die regionalen und betrieblichen Unterschiede berücksichtigen. Der integrierte Modellverbund kann die Ex-ante-Politikanalyse unterstützen und wertvolle Erkenntnisse für eine fundierte Entscheidungsfindung liefern.

Die Ergebnisse des nonCO2farm-Projekts können als Grundlage für weitere Forschungsarbeiten zu Klimaschutz in der Landwirtschaft dienen. Nächste Schritte können sein: (i) Die Ausweitung des nicht-CO₂ Treibhausgas-Emissions-Monitoring-Systems auf CO₂-Emissionen aus der Energienutzung und aus Landnutzungsänderung sowie auf Kohlenstoffsenken würde eine umfassende Bewertung der landwirtschaftlichen Treibhausgasemissionen auf Betriebsebene ermöglichen. (ii) Die weitere Harmonisierung und Vereinfachung der Datenerhebung auf Betriebsebene ist von entscheidender Bedeutung, um eine Überlastung der Landwirt:innen zu vermeiden und ihre Beteiligung am Klimaschutz sicherzustellen. (iii) Die Modellierung von Politikszenerarien, wie zum Beispiel Düngemittelbeschränkungen und überregionaler Handel mit Gülle kann eine evidenzbasierte Entscheidungsfindung und die Entwicklung von Mitigationsmaßnahmen unterstützen.

2 Executive Summary

Brief description of the project: initial situation, targets, and methodology

Globally, the agricultural sector is the largest emitter of anthropogenic non-carbon dioxide (non-CO₂) greenhouse gas (GHG) emissions, with methane (CH₄) and nitrous oxide (N₂O) taking the largest shares. In Austria, the national GHG inventory attributes about 10% of the national GHG emissions to the agricultural sector. Thereof, CH₄ and N₂O account for 65% and 34%, respectively. A significant reduction of GHG emissions is required to achieve the European Union (EU) and national climate-neutrality targets in the next decades.

The national GHG inventories under the United Nations Framework Convention on Climate Change (UNFCCC) follow an internationally standardized procedure to calculate sectoral GHG emissions. These calculations are, however, subject to uncertainties, which arise mostly from inaccuracies and limited detail in farming activity data and the choice of emission factors. Furthermore, recent analyses suggest that the potential contribution of the agricultural sector to climate change mitigation may have been underestimated in the past. Monitoring GHG emissions at the farm level may reduce data and information gaps and support the efficient and targeted implementation of policy instruments.

Thus, the project nonCO₂farm aimed at (i) developing a protocol, i.e., a structured, reproducible approach, and a prototype of a digital non-CO₂ farm emission monitoring system (DFEMS); (ii) developing and modelling mitigation scenarios in order to identify emission reduction potentials and cost-effective mitigation measures at the farm level; (iii) developing a concept for a web-based dashboard to communicate non-CO₂ GHG emissions to different user groups.

The project was structured along five work packages (WPs), as summarised in Figure 1. A review of non-CO₂ GHG emission calculation approaches informed the development of a protocol and prototype of a DFEMS (WP2). It focused on major sources of non-CO₂ GHG emissions in agriculture, on emission factors, and on procedures and equations for calculating non-CO₂ GHG emission at the farm level, including disaggregated emission factors. This resulted in a structured overview, which allowed us to identify required farm level data, methods, and tools for developing a DFEMS that addresses the needs of different user groups. Next, non-CO₂ GHG emissions were calculated at the farm level, differentiated by farming activities and management decisions (WP3). An existing web-based farm management system was extended to collect the necessary data for applying differentiated emission factors and to test the non-CO₂ emission accounting approach for selected farms. The farmers participated voluntarily in this project and were chosen to represent the heterogeneity of the Austrian agricultural sector, e.g., in terms of farming activities and manure management. The test run and farmers' feedback provided important information about the design of the data queries as well as the suitability of the selected emission factors and non-CO₂ GHG emission accounting approach, which were considered to update the protocol (WP2) and inform the communication concept (WP5). Third, a spatially explicit integrated modelling framework was applied for farm emission and mitigation policy impact modelling (WP4). Marginal abatement costs were computed, whereby different mitigation scenarios were modelled to identify cost-efficient mitigation measures at the farm level.

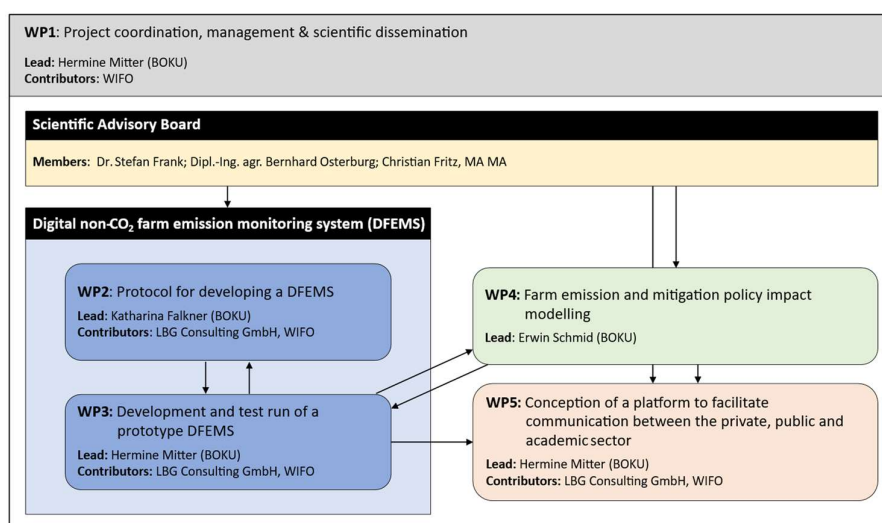


Figure 1: Project structure and interactions between work packages.

Results and conclusions of the project

The nonCO₂farm project calculated non-CO₂ GHG emissions for a total of 21 existing Austrian farms. The calculation process highlighted the need for accurate data and farmer participation. Querying feed rations was particularly challenging, and farmers were reluctant to share sensitive farm data which highlights the importance of data privacy as well as the need for intuitive, farmer-friendly data entry systems within the existing web-based farm management system *LBG Agrar System*. The model results showed heterogeneity in mitigation potentials and marginal abatement costs between Austrian farms, suggesting that mitigation measures need to be tailored to regional characteristics and farm management options. The results of the integrated modelling framework may support ex-ante policy analysis and provide valuable insights for informed decision-making.

Outlook and summary

Based on the findings of the nonCO₂farm project, we have identified three research gaps. Future research could focus on:

- (i) expanding the DFEMS to include CO₂ emissions from energy use and land use change as well as carbon sinks to provide a comprehensive assessment of the agricultural GHG emissions at the farm level. This extension is in line with the climate neutrality targets and expands knowledge on efficient mitigation measures.
- (ii) harmonizing and simplifying farm level data collection to avoid overburdening of farmers and ensure farmers' participation in climate change mitigation.
- (iii) assessing the impacts of agricultural and land use policy scenarios, such as fertilizer restrictions and trans-regional trading of manure, with integrated modelling may support evidence-based decision making and the development of targeted mitigation measures.

3 Hintergrund und Zielsetzung

Background

Globally, agriculture significantly contributes to anthropogenic greenhouse gas (GHG) emissions and climate change (Lynch et al., 2021). In 2018, the agricultural sector (excluding land use, land use change and forestry, LULUCF) emitted 5.3 Gt CO₂ equivalents (CO₂ eq; FAO, 2020), considering only GHG emissions within the farm gate. Thereby, agricultural GHG emissions are dominated by non-CO₂ gases from crop and livestock production, namely methane (CH₄) and nitrous oxide (N₂O; Mbow et al., 2019). In Austria, the agricultural sector accounted for 10.0% of the total national GHG emissions in 2022 (without LULUCF). Thereof, non-CO₂ GHG emissions from enteric fermentation and agricultural soils took the largest shares, with 5.9% and 2.4% of the total national GHG emissions, respectively (Anderl et al., 2024).

With the EU's target to become climate-neutral by 2050 (The European Green Deal, 2019) and the interim GHG emission reduction target of -55% compared to 1990 (EC, 2018), GHG emission reduction has become a key policy objective. While the climate targets for the sectors electricity and heat generation, industrial manufacturing, and aviation should be achieved via the EU Emission Trading System (EU ETS), all other sectors – including agriculture – are covered by the Effort Sharing Regulation. According to the amended Regulation (Effort Sharing Regulation, 2023), the national GHG emission reduction target for Austria is -48% by 2030, compared to the 2005 level. Even if no sectoral targets have been set to date, GHG emissions must also be reduced in the agricultural sector.

However, the mitigation potential of individual farms is uncertain and relates to farm- and site-specific characteristics, such as different crop yield potentials due to factors such as soil types, water and nutrient availability, and crop varieties as well as different livestock production intensities due to, e.g., livestock breeds, feed quality, and feeding strategies. This heterogeneity, on the one hand, leads to differing marginal abatement costs (MACs) across agricultural production regions and farming systems. On the other hand, this can result in individual farms' non-CO₂ GHG emissions deviating considerably from the national average, as provided by Austria's national GHG inventory report (Anderl et al., 2024). Therefore, we suggest that farm-level non-CO₂ GHG emission accounting may reduce uncertainties while facilitating the implementation of effective and efficient mitigation measures at the farm level.

Objectives of the research project nonCO2farm

The overall objective of this research project is to develop a non-CO₂ GHG emission accounting approach that can be applied at the farm level. This non-CO₂ GHG emission accounting approach should further be tested via a prototype of a digital non-CO₂ farm emission monitoring system (DFEMS). Thereby, the focus of the project was on developing a more differentiated and detailed application of a non-CO₂ GHG emission accounting approach in order to capture farm-specific circumstances, i.e., to focus on non-CO₂ GHG emissions arising within the farm gate. However, within the nonCO2farm project we do not emphasize to capture non-CO₂ GHG emissions resulting from the production of farm inputs and

subsequent steps in the value chain (e.g., processing of primary products). To reach this objective, the internationally standardized and accepted guidelines for national GHG inventories as provided by the Intergovernmental Panel on Climate Change (IPCC, 2006, 2019) were applied. Based on the overall objective, the following specific objectives were defined:

- i. Developing a protocol (i.e., a conceptual and structural basis) for accurately calculating non-CO₂ GHG emissions at the farm level via a DFEMS.
- ii. Developing a prototype of a DFEMS and performing a test run with a purposefully selected sample of farms.
- iii. Developing mitigation scenarios for the implementation in an integrated modelling framework (IMF) and identifying cost-efficient mitigation measures and emission reduction potentials at the farm level.
- iv. Developing a communication concept for a dashboard providing non-CO₂ GHG emissions at the farm level.

4 Projektinhalt und Ergebnisse

The project activities are described within each WP structured along the five WPs.

WP1: Project coordination, management and scientific dissemination

The following activities were performed to achieve the objectives of WP1: i) ensure project administrative reporting, ii) facilitate smooth operation of the project, iii) ensure that the WP milestones are achieved timely, iv) establish an advisory board and ensure regular exchange, and v) ensure scientific dissemination of research findings.

WP1 a) Presentation of project status to steering committee and submission of reports

The first and second interim report as well as the final report have been compiled and submitted to the funding organization on time, including supplements. Furthermore, the project was presented to the steering committee and funding organization at the Österreichische Klimatag 2023 within the ACRP quality assurance program through both an oral presentation and a poster. The WP1 leader ensured that the reviewers' feedback on the two interim reports and feedback received at the Österreichische Klimatag 2023 were addressed and considered in the further project works. The feedback was crucial for ensuring high quality of the project outputs and milestones.

WP1 b) Organization of regular meetings and a stakeholder workshop

The WP leader organized physical and online meetings during the project period to support information flow between different WPs and the completion of project milestones within the time schedule outlined. The regular meetings ensured a smooth workflow within and between the WPs, and facilitated tracking of the work progress. In addition to the regular meetings within the project team, a stakeholder workshop was organized in February 2024. This workshop proved useful for exchange between stakeholders in different initiatives and research projects within the topic of farm-level GHG emission and sustainability monitoring. The workshop aimed to provide an overview of these initiatives and projects, their specific objectives and the methods used, as well as to enable project synergies. The stakeholder workshop was organized as a hybrid event at the location of the project sub-contractor WIFO.

WP1 c) Establishment of the scientific advisory board

The WP leader established an advisory board for quality control. Exchange between the project partners and the advisory board was organized regularly to make use of the expertise of the advisory board members.

WP1 d) Development of a dissemination strategy for the project results

The WP1 leader ensured that best possible use was made of all publication opportunities for the project output. Several publication forms and pathways were covered (see section C).

WP2: Protocol for developing a digital non-CO₂ farm emission monitoring system (DFEMS)

The following activities were performed to meet the objectives of WP2: i) develop a protocol for the implementation of a DFEMS, ii) review available and identify required data, methods and tools for developing a DFEMS and iii) establish a set of emission factors and calculation procedures for deriving non-CO₂ GHG emissions at the farm level. The success of the WP2 milestones required an extensive exchange between the project partners.

WP2 a) Reviewing non-CO₂ GHG emission calculation approaches, emission factors and data requirements for calculating non-CO₂ GHG emissions at the farm level

We reviewed the non-CO₂ GHG emission calculation approaches applied in the IPCC (IPCC, 2006, 2019), in the national inventory report of Austria (Anderl et al., 2024) as well as in the reports provided by the European Environment Agency (European Environment Agency, 2023). For calculating the non-CO₂ GHG emissions at the farm level, we followed the tier 2 approach (IPCC, 2006, 2019) requiring detailed data on farming activities. In addition, we reviewed literature relevant for farm-level emission monitoring systems as well as the available emission factors (Anderl et al., 2024; Arbeitsgruppe BEK, 2021; European Environment Agency, 2023; IPCC, 2006, 2019) to be used as inputs for calculating non-CO₂ GHG emissions in the DFEMS as well as for the integrated modelling framework (WP 4). Additionally, state-of-the-art datasets such as administrative data, data from the Integrated Administration and Control System IACS and IACS-GIS, and farm survey data were reviewed to identify farm-level data that is additionally needed for calculating non-CO₂ GHG emissions at the farm level.

WP2 b) Identifying data gaps and developing a questionnaire for closing these gaps

A list of required input data for calculating non-CO₂ GHG emissions was compiled, based on the identified non-CO₂ GHG emission calculation approaches and available refinements for representing farm-specific conditions through farm-specific performance indicators and emission factors considering differences in farm management options. For contacting farmers and for collecting the required farm data, we made use of the established web-based farm management system *LBG Agrar System*. The LBG Agrar System is a product of the LBG Consulting GmbH. It supports farmers in their mandatory documentation of plant protection and fertilisation, and provides farm analyses. We compared the list of required input data to the list of data already collected via the LBG Agrar System to identify the data gaps. We then developed a questionnaire in form of a MS Excel sheet with the additionally required farm data. This questionnaire guided the implementation of additional query fields in the LBG Agrar System (WP3) comprising both direct and indirect inputs for farm-level non-CO₂ GHG emission calculations. Direct inputs

refer to the factors or data that directly feed into the equations. Indirect inputs are needed for intermediate calculation steps to finally arrive at non-CO₂ GHG emissions at the farm level.

WP2 c) Developing a protocol that summarizes required data, methods, and emission factors for a DFEMS including application examples from Austria

We have summarized our findings from activities WP2 a) and b) in a protocol, i.e., a structured, comprehensive and freely available overview on farm-level data requirements, existing methods for calculating non-CO₂ GHG emissions at the farm level, and emission factors. Where necessary, expert knowledge complemented these findings to provide a thorough understanding. The protocol highlights Austrian-specific values and includes information on default values that can be used if farm-level data is not available in the level of detail required. The protocol may serve as a guide for farmers, interested stakeholders and the general public to calculate the non-CO₂ GHG emission from enteric fermentation, manure management and agricultural soils at the farm level. Together with the calculation tool (WP3) it has been reviewed by one advisory board member and five experts with complementary expertise from different organizations. The reviewers were instructed to provide feedback on (i) the applicability for end users (protocol and Excel calculation tool), (ii) the accuracy and transparency of assumptions and sources for emission factors, and on (iii) data requirements (e.g., feasibility of data collection at farm level; awareness of alternative data sources). The detailed and comprehensive reviewer comments have been taken into account and ensure high quality, applicability and user-friendliness of the protocol and the calculation tool (WP3). The protocol was published as an open access discussion paper in English; a German version is planned.

WP3: Development and test run of a prototype DFEMS

The following activities were performed in order to meet the objectives of WP3: i) extend an existing web-based farm management system for collecting missing but relevant data for calculating non-CO₂ GHG emissions at the farm level, ii) develop a prototype DFEMS, iii) identify a sample of farms for testing the DFEMS, iv) calculate the non-CO₂ GHG emissions for the test farms, and v) update the protocol (see WP2) and the DFEMS based on external feedback, internal review and the conducted non-CO₂ GHG emission calculations.

WP3 a) Extending a web-based farm management system for querying identified farm data gaps

Based on the questionnaire for farm data collection developed in WP2 b), the web-based LBG Agrar System was extended by data queries. Additional query fields were added in the LBG Agrar System. While most of the data queries could be implemented quickly, numerous feedback loops both between project partners and with farmers were necessary for querying feed rations. The prototype for the feed ration query developed in MS Excel. The currently implemented feed ration query provides farmers with as much flexibility as possible, i.e., feed rations can be

entered in dry and fresh matter shares as well as in weight units. As some farmers raised the problem of limited information on feed rations and the respective nutrient composition, a range of pre-defined feed rations (160 in total) has been stored in the database of the web-based farm management system. The pre-defined feed rations are based on established feed rations, as provided in the literature and are described in more detail in the protocol. The feed rations account for differences between livestock sub-categories and for differences in nutrient requirements (e.g., energy and crude protein demand) resulting from livestock performance and output type (e.g., milk, meat). The pre-defined feed rations should provide farmers with a reference for specifying their own feed rations. Once selected and allocated to a livestock sub-category, the specifications of a feed ration are automatically loaded in the LBG Agrar System. However, farmers may individually modify and adapt these feed rations by changing the share of individual feed components or removing and adding feed components. For this purpose, a total of 278 feed components for the livestock categories cattle, swine, and poultry were developed and stored in the database of the LBG Agrar System and have been linked to nutritional information available from feed tables during the project (LfL, 2021b, 2021a, e.g., 2023; LK Oberösterreich, 2020). However, if farmers have sufficient information, they can also add and save additional feed components and nutritional information from feed analysis as well as define individual feed rations without relying on the pre-defined ones.

WP3 b) Identifying test farms and collecting the relevant farm data for application in the DFEMS

The farm selection was based on prior support contacts and the extent to already available farm data in the LBG LBG Agrar System. About 40 farmers were contacted for participation by telephone. A follow-up e-mail with project details was sent, and non-responding were contacted again. In total, 21 farmers agreed to participate as test farms in the project. Participating farmers received a bonus of € 150 as an incentive and compensation for the time spent on data entering. Farm data were collected between December 2023 and April 2024. The time required for data entry varied greatly between farms, ranging from 90 minutes to four hours, depending on the farm type, farm size, farmers' personal interest on agronomic records and the project, and their technical understanding. However, the majority of farmers did not have all required records and information readily available in the required level of detail during the first meeting which made further interactions necessary. The greatest effort was required for querying additional information on animal characteristics, feeding strategies and feed rations. The process was particularly challenging for farms with multiple livestock sub-categories requiring data of several feed rations. In addition, the majority of the participating farmers did not have records of feeding quantities. Instead, the farmers often base feeding on individual experience and implicit knowledge. The extensive support also allowed to clarify ambiguities on the relevance and scope of the data and facilitated plausibility checks. Plausibility checks included for instance, checks of queried manure application methods, incorporation time, the

use of harvested products and straw removal, as well as fertilizer application and harvesting measures. However, despite great effort to support farmers with data entering, many requested data queries remained unanswered. After data entry, the farm datasets were exported from the LBG Agrar System for further processing and analysis.

WP3 c) Developing a prototype DFEMS and calculating non-CO₂ GHG emissions for the test farms

A prototype of the DFEMS was developed in MS Excel, applying the documented non-CO₂ GHG emission calculation steps in the developed protocol (WP2). For each farm type covered in the protocol, i.e., cattle, swine, poultry, and arable farms, a separate MS Excel file was developed. The prototype of the DFEMS was tested with the data collected in WP3 b for the test farms. Missing farm data were replaced with default values for calculating non-CO₂ GHG emissions. Since these assumptions can lead to over- or underestimation of the emission results, they are explicitly stated in the final factsheets provided to the test farms. Therefore, the non-CO₂ GHG emission results should be interpreted with caution; the same accounts for the farm mitigation potential. Fictive calculation examples from the DFEMS were added to the protocol in order to facilitate its comprehensibility and applicability. In summary, the LBG Agrar System was used for data collection, whereas the quantification of non-CO₂ GHG emissions and the modelling tasks were carried out independently, i.e., external to the LBG Agrar System.

WP3 d) Updating the protocol and the prototype DFEMS

Project internal reflections on data collection as well as feedback of the participating farmers informed the protocol (WP2) and the prototype of the DFEMS. For instance, farm data were not always available in the required level of detail which made the importance of providing default values in the DFEMS clear. In addition, links to farm data collected for other purposes or to automatically recorded data were suggested to be established in the DFEMS where possible.

WP4: Climate change and mitigation policy impact modelling

Several activities were necessary to achieve the objectives of WP4. In particular, management options for climate change mitigation and adaptation were defined, the bio-economic optimization model BiomAT, as well as the farm optimization model FAMOS were updated and an emission accounting tool was incorporated (Schmid, 2004b), and N₂O emissions were modelled for Austria by applying an integrated modelling framework (IMF).

WP5: Conception of a platform to facilitate communication between the private, public and academic sector

Several activities were performed to meet the objectives of WP5: i) ensure effective communication of the research results to farmers, agricultural experts

and the interested public and ii) develop a concept of a platform (dashboard) for communicating farm-level GHG emissions.

WP5 a) Communication of research results to farmers

Communication material was developed for participating farms to provide them with a concise, one-page factsheet summarizing the non-CO₂ GHG emissions of their farms. The factsheet aims to present the data in a clear and accessible manner, enabling farmers to easily understand how to interpret the results as well as to take informed actions towards lowering their GHG emissions. The assumptions underlying the calculations are provided, in particular if the farm-specific data were incomplete.

WP5 b) Conceptual development of a platform for communicating farm-level GHG emissions

Various formats and information channels are available for communicating complex concepts, information about the historical trends, current situation and hypothetical developments with multiple data dimensions (Eckerson, 2011). Interactive web-platforms (also called dashboards, performance dashboards or scoreboards) are one such format. They are widely used to communicate and visualize a range of socio-economic and environmental indicators in a comprehensive and structured way, being a “visual display of the most important information needed to achieve one or more objectives that has been consolidated on a single computer screen so it can be monitored and understood at a glance.” (Few, 2012, p. 30). Ideally, (interactive) web-platforms support users in decision-making or achieving goals by focusing on the presentation of a limited number of key data and indicators. This requires an informed choice of a suitable data basis and a suitable presentation format, both influencing the speed at which information is perceived and processed (Janes et al., 2013). For nonCO₂farm, we have identified the potential target groups, their key information requirements and suitable data bases for the development of a web-platform. The developed prototype DFEMS in form of an MS Excel tool is intended to provide the basis for developing a new or extending an existing web-platform within a follow-up project. Already implemented applications that can serve as a reference are the online gross margin calculator (Bundesanstalt für Agrarwirtschaft und Bergbauernfragen (BAB), 2022) or the climate-check ([Klima-Check Landwirtschaft](#)) implemented and released by the LfL. The web-platform concept was designed to allow users to easily visualize their farms’ non-CO₂ GHG emissions under different management options. The Excel tools allow testing different layout and data visualization approaches before developing a fully functional online platform. An additional workshop held at the BAB was used to understand the information needs of farmers, agricultural experts and the interested public (e.g., type of information, level of detail). The exchange with representatives of related projects also ensured to reduce overlaps and avoid duplications. This improved the conceptual development of a web-platform for communicating farm-level non-CO₂ GHG

emissions. The realization and implementation of such a fully functional online platform is beyond the scope of this project.

Following the descriptions of the WP activities, the results are provided structured along the five WPs.

WP1: Project coordination, management and scientific dissemination

WP1 a) Presentation of project status to steering committee and submission of reports

The presentations at the Österreichischer Klimatag 2023 within the ACRP quality assurance program are provided in **Fehler! Verweisquelle konnte nicht gefunden werden.** and **Fehler! Verweisquelle konnte nicht gefunden werden..** The feedback led to separate reporting of a farm's ammonia emissions (NH₃) instead of combining them with the overall N₂O emissions. This may improve the practical relevance of the DFEMS. In addition, this feedback was considered in the model applications and analyses.

WP1 b) Organization of a stakeholder workshop at WIFO

The organized stakeholder workshop lasted a total of 3.5 hours with participants from science, administration and policy, consulting and food industry. The online keynote speech by Cathal Buckley from Teagasc in Ireland broadened the thematic scope of the workshop and gave an overview on the National Farm Survey Sustainability Report for Irish farms. Ireland is the first European country publishing a report on economic, environmental and social sustainability as well as indicators on innovation and technology adoption based on farm-level data. The plenary discussion was followed by a group discussion, focusing on the (i) relevance and consequences of farm-level sustainability and GHG monitoring from the perspective of different stakeholders (interest groups, food industry & associations, public sector, farms) and (ii) lessons learnt from previous work to plan possible next steps. Due to the positive feedback and the high resonance, the stakeholder workshop in February 2024 resulted in a follow-up workshop in October 2024.

WP1 c) Exchange with the scientific advisory board

Dr. Stefan Frank from the International Institute for Applied Systems Analysis (IIASA), Dipl.-Ing. agr. Bernhard Osterburg from the Johan Heinrich von Thünen Institute, and Christian Fritz, MA MA from the Agricultural Research and Education Centre Raumberg-Gumpenstein formed the international scientific advisory board. The advisory board supported the project e.g., by providing input and feedback on the methods and project results, by facilitating access to relevant research networks and to agricultural stakeholders, and by reviewing the protocol (WP2). Regular exchange with other experts, e.g., experts from BOKU specialized in animal science and nutrition (e.g., Stefan Hörtenhuber, Martin Seiringer, Martin Gierus), has proven useful within the project. Advice was, for instance, provided

on methods and important factors applicable for the conversion of metabolizable energy demand of swine and poultry to gross energy demand and dry matter intake. This information is highly relevant for applying a tier 2 but not available from the emission accounting standards provided by IPCC (2006, 2019) and the National Inventory Report (Anderl et al., 2024).

WP1 d) Development of a dissemination strategy for the project results

The dissemination activities are summarized in section C).

WP 2: Protocol for developing a digital non-CO₂ farm emission monitoring system (DFEMS)

WP2 a) Required data and questionnaire for closing identified data gaps for calculating non-CO₂ emissions at the farm level

The developed questionnaire, i.e., required data, specifies the identified data gaps by livestock (sub-)category and the type of questions for querying these data. Open questions are, e.g., suggested for performance data such as daily weight gain and milk and egg mass production, whereby daily weight gain is only relevant for growing livestock sub-categories (e.g., fattening pigs) and the daily egg mass production needs to be queried for laying hens only. Closed questions are used to collect farm-level data based on available emission accounting methods and emission factors specific to farm management practices (e.g., type of manure storage and cover, manure application method, crop type). For the closed questions, the selection options for some newly implemented queries dependent on other answers. For instance, the list of housing systems or animal breeds that can be selected by the farmer depends on the previously selected livestock sub-category.

WP2 b) Protocol summarizing required data, methods, and emission factors for a DFEMS including application examples from Austria

The protocol provides a structured overview and reproducible documentation for farm-level non-CO₂ GHG emission accounting including (i) the IPCC guidelines for non-CO₂ GHG emission accounting, (ii) calculation approaches and emission factors for CH₄ emissions from enteric fermentation, CH₄ and N₂O emissions from manure management, N₂O emissions from managed agricultural soils, and ammonia (NH₃) emissions from manure management, livestock housing and soils; and (iii) data requirements for farm-level non-CO₂ GHG emission accounting. In addition, we give examples of how we have implemented the suggested approach for Austrian farms, using the data queried in WP3. The protocol focuses on the farming activities within the farm gate, neither accounting for GHG emissions resulting from the production of farm inputs nor from subsequent steps in the value chain. It addresses the livestock categories cattle, swine, and poultry, which are responsible for the largest share of the non-CO₂ GHG emissions in the agricultural sector in Austria. For a broad applicability, default values are provided

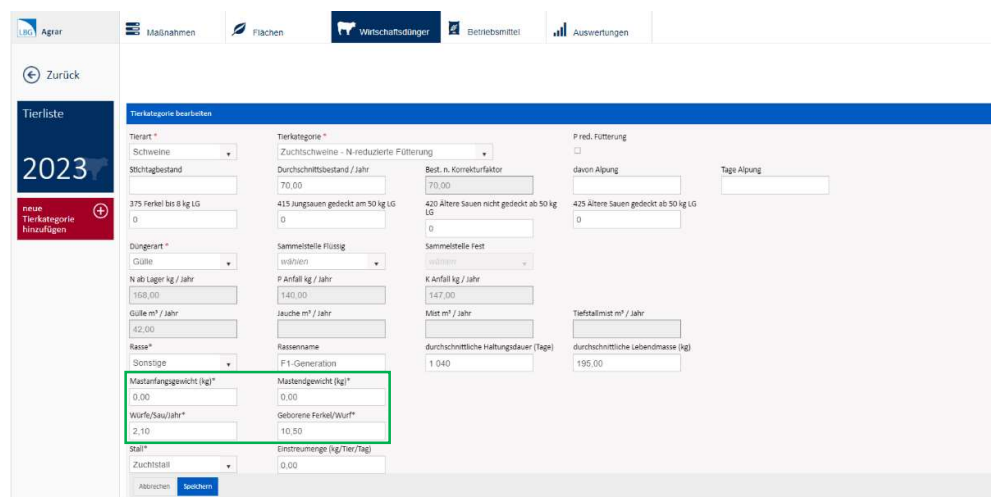
where available, e.g., for average daily weight gain of a typical animal per livestock (sub-)category. They can be applied in the equations if farm-specific data is not available.

WP3: Development and test run of a prototype DFEMS

WP3 a) *Extended web-based farm management system*

New query fields were added to the LBG Agrar System to close the identified data gaps between data that is not yet being collected in the query tool but needed for non-CO₂ GHG emission calculations at the farm level.

Figure 2 provides an example for newly implemented data query fields.



The screenshot shows the 'Tierliste' (Livestock List) interface for the year 2023. The main form is titled 'Tierkategorie bearbeiten' (Edit Livestock Category). It contains several input fields for different categories of livestock. Two fields are highlighted with green boxes: 'Mastanfängergewicht (kg)*' (Starting weight in kg) and 'Mastendgewicht (kg)*' (Ending weight in kg). Other fields include 'Tierart' (Species), 'Tierkategorie' (Livestock Category), 'Durchschnittsbestand / Jahr' (Average stock / year), 'Best. n. Korrekturfaktor' (Estimated correction factor), 'P. red. Fütterung' (Reduced feeding), 'davon Alping' (Of which Alping), 'Tage Alping' (Days Alping), '420 Ältere Sauen nicht gedeckt ab 50 kg LG' (420 Old sows not mated from 50 kg LG), '425 Ältere Sauen gedeckt ab 50 kg LG' (425 Old sows mated from 50 kg LG), 'Düngerart' (Fertilizer type), 'Gülle' (Manure), 'N ab Lager kg / Jahr' (N from storage kg / year), 'P Anteil kg / Jahr' (P share kg / year), 'K Anteil kg / Jahr' (K share kg / year), 'Mist m³ / Jahr' (Slurry m³ / year), 'Tiefstallmist m³ / Jahr' (Deep stall slurry m³ / year), 'Rasse' (Breed), 'Sonstige' (Other), 'Rassenname' (Breed name), 'F1-Generation' (F1 generation), 'Wurfe/Sau/Jahr*' (Litters/sow/year*), 'Geborene Ferkel/Wurf*' (Born piglets/litter*), 'Stall*' (Stall*), 'Zuchtschil' (Breeding shed), 'Abtreiben' (Abort), and 'Speichern' (Save).

Figure 2: Example for data queries on livestock characteristics for breeding sows (green boxes), newly implemented in the LBG Agrar System.

The main advantages of extending an existing system compared to a new query system or directly sending out questionnaires to farmers are that:

- The farmers are already familiar with the system and can provide additional data within a web-based application they have used before.

- Data that has already been queried for other accounting purposes are directly used for calculating non-CO₂ GHG emissions which reduces the effort for farmers to provide data.
- The project team expected a higher participation rate of because farmers trust the existing LBG Agrar System resulting from previous experiences gained through regular personal exchanges with project members from LBG Consulting GmbH.

The project team could build on a broad knowledge base as well as already implemented and extensively tested routines for data queries and plausibility checks. The basic three-module structure of the LBG Agrar System was retained for the extensions. All new data fields can be activated in the setting. LBG Agrar newly collects data on manure storage system covers, feed rations, livestock performance characteristics. For the extension, balancing between data needs for non-CO₂ GHG emission accounting and the usability and comprehensibility of the extension for a wide range of farmers operating in different production regions, following different farming activities, and applying different management strategies and practices was important.

WP3 b) Dataset with farm-level data from test farms

In total, 21 farmers agreed to provide additional farm-level data within the project.

Table provides an overview on the main characteristics of the test farms.

Table 1: Overview on the main characteristics of the test farms.

Farm ID	Farm type	Livestock (sub-) categories	Main/secondary occupation	Organic farming
1	Crop	Poultry (for own consumption)	Main	yes
2	Cattle	Fattening cattle	Secondary	no
3	Crop	NA	Main	no
4	Poultry	Laying hens	Main	no
5	Swine	Fattening pigs, breeding pigs	Main	no
6	Crop	NA	Main	no
7	Closed swine	Swine	Main	no
8	Swine	Breeding pigs	Main	no
9	Swine	Laying hens, Fattening pigs	Main	no
10	Swine	Fattening pigs	Main	no
11	Crop	NA	Main	yes
12	Crop	Suckling cows	Main	no
13	Crop	Horses	Secondary	no

14	Crop	NA	Main	no
15	Crop	NA	Main	yes
16	Crop	Poultry (for own consumption)	Secondary	yes
17	Crop	NA	NA	yes
18	Cattle	Fattening cattle	Main	no
19	Crop	NA	Secondary	yes
20	Crop, livestock	Fattening cattle, Fattening pigs	Main	yes
21	Crop	NA	Secondary	no

WP3 c) *Prototype of a DFEMS*

The prototype of a DFEMS is available for each farm type covered in the project, i.e., separate applications in the form of MS Excel calculation tools. The general structure of the applications is identical, with differences arising only from the specific data needs and the stored livestock (sub-)category specific formulas and parameters (i.e., default values and emission factors). Besides one spreadsheet containing basic information and guidelines on how the tool is to be applied, the prototype consists of two spreadsheets for entering farm specific data – one focusing on livestock-related information (excluded in the application for crop farms) and the other one on crop related data. The MS Excel calculation tools follow the protocol developed in WP2.

WP4: Farm emission and mitigation policy impact modelling

WP4 a) *Model results on fertilizer scenario impact analysis on Austrian farmland*

Model results suggest most pronounced changes in yields and land use with the dry and wet climate change scenarios. Comparing the historic reference and the future period, yield increases are projected for soybeans (4-17%), alpine pastures (~5%), intensively managed grassland (15-29%) and winter wheat (~5%). Cropland and extensively managed grassland area are expected to decrease, while intensively managed grassland areas increase due to cropland conversion. Largest extensively managed grassland areas are projected for the climate change scenario with dry conditions and strong forcing (i.e., IPSL85). In terms of irrigated area, model results suggest an increase from 1% of Austrian agricultural land in the historic reference period to approximately 5% for the climate change scenario with dry conditions and moderate forcing (i.e., MOHC45) in the future period. Regarding economic implications, total net benefits of crop and grassland production are expected to increase by 20-64% across all climate change scenarios and when comparing the historic reference to the future period under reference

fertilization. For the fertilizer scenario f20 of uniform reductions in fertilizer inputs, reductions in net benefits are modelled, while net benefits in the combined scenario (fcm) increase slightly. The analysis of N loss reduction suggests a total decrease in future N losses (-8.4% and -0.3%) for the two climate change scenarios of moderate forcing (i.e., MOHC45, ICHEC45) and N loss increases (+0.1% and +9%) for the climate change scenarios of strong forcing (i.e., ICHEC85, IPSL85) compared to the historic reference. Results for the fertilizer scenarios f20 and fcm suggest overall reductions in N losses of 1.3-1.9% and 7.4-8.5% respectively with large regional variations. We use correlation analysis to test for the relationship between N losses and several environmental indicators, such as N-fertilization intensity, terrain slope, maximum temperatures, mean annual precipitation as well as soil-related indicators being topsoil organic carbon contents, bulk densities, pH-values, and clay contents. Overall, the model results highlight the complex interactions between climate change, fertilization, agricultural productivity with strong regional variability in outcomes. The study indicates that fertilization restrictions as proposed in the F2F strategy will likely lead to a decrease in crop production (by 6-9%), which is in line with other studies suggesting reductions between 7-15%. N loss reductions are suggested by the IMF results, yet fall short of the intended 50% reduction target. Both fertilization scenarios are likely to have beneficial environmental effects, whereas larger for fcm than for f20. N loss reductions are highest for water and air, which might yield positive effects on water quality, soil biodiversity or for the prevention of soil acidification. Climate change mitigation through decreased fertilizer production might be an indirect beneficial effect of imposed F2F measures. Our results further highlight that N loss reduction potentials differ according to regional soil and climate conditions as well as regionally prevalent agricultural farming systems. The IMF reveals potential impacts of the F2F strategy on Austrian agricultural production and N losses. The study highlights the need for targeted policy measures to achieve F2F goals. It suggests that uniform national policy implementation may be an inadequate approach to reach set targets cost-effectively and that tailored, region-specific strategies are necessary. The full publication (Jost et al., 2025) can be found in **Fehler! Verweisquelle konnte nicht gefunden werden..**

WP4 b) *Model results on climate change scenario impact on agricultural mitigation and adaptation in Austrian farmland*

The model results indicate synergies between adaptation and mitigation in Austrian agriculture. Both, adaptation and mitigation result in an extensification of agricultural land. With increasing MAC, the extensification of grassland is more pronounced whereas intensively used grassland shows a relative decrease in area. Another synergy between adaptation and mitigation can be observed in the adoption of mitigation measures depending strongly on the climate change scenario, i.e., irrigation. Model results give the marginal N₂O emission reductions in t CO₂e for incremental MAC levels ranging from 30-300 € (t CO₂e)⁻¹ across the climate change scenarios (ICHEC45, MOHC45, ICHEC85 and IPSL85). The reference N₂O emissions range from 1,128,242 t CO₂e (MOHC45) to 1,338,865 t CO₂e (ICHEC85). Magnitudes of marginal N₂O emission reductions differ among the climate change scenarios. With increasing MAC, N₂O emissions steadily decrease across all climate change scenarios, with the highest absolute reductions observed under the strong forcing IPSL85 (227,052 t CO₂e) and the lowest under the moderate forcing MOHC45 (131,417 t CO₂e) at MAC of 300 € (t CO₂e)⁻¹. The

model results may inform the development of the Austrian agricultural and climate policies and support the transition of the sector towards the climate neutrality goal.

WP4 c) *Focus analyses on marginal abatement costs, feed rations and mitigation scenarios*

The model results of the first master thesis (Alkier, 2021) show that the conventional farm system emits around 1,002 kg CO₂-eq./ha and the organic farm system around 375 kg CO₂-eq./ha in the baseline scenario. The conventional farm system can be optimized to abate up to 52% of N₂O emissions at marginal abatement costs of 4.5 €/kg CO₂-eq. and total abatement costs of 403 €/ha. The organic farm system can be optimized to abate up to 23% of N₂O emissions at marginal abatement costs of 3.4 €/kg CO₂-eq and total abatement costs of 210 €/ha. Both the conventional and the organic farm system start to abate N₂O emissions by incorporating crops that require less N-fertilizer into the crop mix. As a next measure, the N-fertilizer amount per crop is reduced. Then, the farm systems switch to more efficient fertilizer application techniques, such as trailing hose application or injection of fertilizer. The model results of the second master thesis (Seiringer, 2021) show clear differences in environmental impacts between the examined feedstuffs. Roughage and by-products that do not require artificial drying have lower environmental impacts per MJ of metabolizable energy. An increase in milk yield leads to a decrease in GWP per kg milk, while LU per kg milk remains relatively constant. Optimizing the feed ration for GWP resulted in the highest LMA in the comparison of the scenarios. LMA increases with the milk yield. Optimizing LMA can reduce the LMA to zero while GWP per kg milk slightly increases, regardless of the milk yield level. The model results of the third master thesis (Lienhart, 2025) show that initial emission reductions were achieved primarily through land use changes and increased concentrate feed inclusion to the feed rations. However, higher reduction targets required structural changes, such as herd size reduction, which diminished the cost-effectiveness of management-based measures alone. The intensification scenarios showed higher relative net return losses under stricter reduction targets, but also achieved significantly lower per product emissions of milk production than the baseline scenario. The study underscores the need for balanced mitigation strategies that ensure both emission reductions and economic sustainability, with future research suggested on broader environmental impacts under expanded system boundaries.

WP5: Conception of a platform to facilitate communication between the private, public and academic sector

WP5 a) *Communication of research results to farmers*

We send a one-page factsheet containing the calculation results on non-CO₂ GHG emissions as well as information on assumptions and interpretability of these results to each participating farmer. We offer the option to discuss the results with the project members. An important aspect in providing such results is to highlight the limitations as well as the uncertainties they come with. For instance, missing farm data were replaced with default values and as such, the result may not fully capture the farm-specific non-CO₂ GHG emissions.

WP5 b) Conceptual development of a platform for communicating farm-level GHG emissions

First, the target groups of a potential interactive web-platform were specified: farmers, decision-makers in policy, consulting, administration, scientists, interested societies, and consumers (Figure 3).

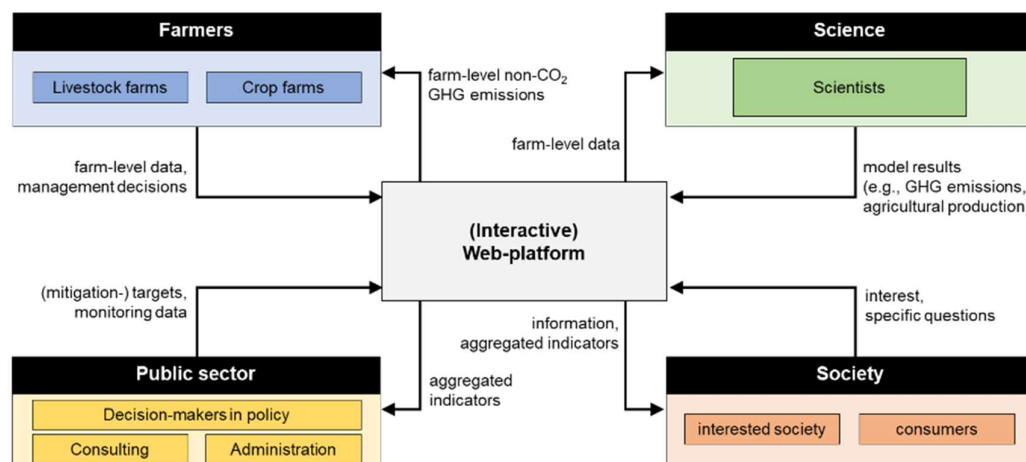


Figure 3: Identified target groups of the intended web-platform and important information flows (own representation based on Schneider et al., 2019).

Second, the information to be provided by the web-platform was structured along the description provided by Janes et al. (2013), Table 2. Structured information is particularly important as the indicators resulting from the non-CO₂ GHG emission calculations are only useful and usable for the defined target groups if the respective context for the interpretation is provided. For example, to assess whether a farm's non-CO₂ GHG emissions are "low" or "high" requires an option to compare this information with, e.g., regional averages, or the average of a certain farm type.

Table 2: Information requirements for the selection of a suitable data basis for developing a (interactive) web-platform (based on Janes et al., 2013).

Conceptional basis (Janes et al., 2013)	Transference to the intended web-platform
Objective:	
1. <i>What?</i> Definition of the object that is in the focus of the analysis.	Farm-level non-CO ₂ GHG emissions resulting from farm management decisions.

2. <i>Why?</i> Reason(s) for analyzing this objective.	To increase transparency by documenting GHG emission calculated by following a publicly accessible protocol
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Defining the questions to be answered:

Definition of the relevant characteristics (indicators) of the object to be analyzed.	• How high are non-CO₂ (i.e., CH₄, N₂O, NH₃) GHG emissions at the farm level? • What is the influence of selected management options on non-CO₂ GHG emissions? • What is the impact of changes in management on farm-level non-CO₂ GHG emissions? • What impact do changes in management have on crop yields, costs, revenue etc.?
→ A basic principle for indicator selection is that they should represent the information that is decisive for the decision-making process (Han et al., 2014).	→ Further relevant indicators are derived from farmers' feedback.

Measurement/Measured values

Definition of the data that must be collected to answer the questions in a (quantitative) way.	<i>Selected examples (see WP2 for more details):</i> Management-specific emission factors, cultivated crops, fertilizer application levels, applied technologies, livestock numbers, type of manure storage system and cover, variable costs, subsidies (e.g., policy premiums)
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Third, the preferred presentation mode of farmers as the main target group was identified. Farmers should have the opportunity to directly track and evaluate the influence of their management decisions on non-CO₂ GHG emissions. Furthermore, farmers would acknowledge a benchmarking system to compare their farm-level results (e.g., annual non-CO₂ GHG emissions, crop yields, net return) with aggregated key figures (e.g., for the region or farm type). This could support decision-making processes on farm management as well as increase the emission efficiency of farms by identifying promising mitigation measures. Furthermore, the provided information could be used, e.g., for access to product labeling. Finally, the technical implementation of a web-platform is beyond this project. However, the prototype DFEMS (i.e., MS Excel calculation tools) provides a basis for this next step.

WP5 c) *Participation in a stakeholder workshop held at the BAB*

Following the success of the stakeholder workshop organized within nonCO2farm in February 2024, a follow-up workshop was initiated entitled "Bottom-up Berechnung von Nachhaltigkeitsindikatoren der österreichischen Landwirtschaft". The activities and results of nonCO2farm were also presented and discussed with the participating scientists and representatives of administration, policy-making, consulting and the food industry. This networking event improved the information flow between ongoing projects in the agricultural sector related to the climate neutrality target.

5 Schlussfolgerungen und Empfehlungen

Three key findings from the project can be summarized:

First, transparent and accurate non-CO₂ GHG emission calculations at the farm level heavily rely on standardized procedures and the availability and quality of farm data. We have developed and published a protocol for calculating non-CO₂ GHG at the farm level, which is widely applicable (e.g., to different farm types and different levels of available data at hand) and ensures full reproducibility of the calculation process and results. The protocol also outlines the data needs from farmers to increase the accuracy of the results, e.g., compared to the national GHG emission inventory. An existing and broadly trusted web-based tool – the LBG Agrar System – was extended with queries to satisfy the respective data needs. The queries were revised and simplified based on farmers’ and experts’ feedback. However, the farmers participating in the project did not provide all necessary data (i.e., missing values) even though guided through the data queries by members of the project team. This demonstrates that (i) attaining a complete data set requires significant resources (both from the farmers and the researchers), (ii) the level of accuracy of the calculations needs to be balanced with the data collection efforts to ensure that farmers are willing to share high quality data, and (iii) data protection and communication with farmers is key to increase trust and dispel farmers’ concerns about being perceived or judged negatively by the researcher or the general public.

Second, a prototype DFEMS was developed by implementing the procedures summarized in the protocol in MS Excel calculation tools. The calculation tools were tested by agricultural experts working on GHG emissions and proved useful in this “pilot phase”. In particular, adjustments to the layout and functions could improve the user-friendliness and clarity of the tool. The formatting could be improved to better highlight key elements, especially in the info sheet. It would also be useful to clarify whether all fields highlighted must be filled or whether certain values can be pre-defined. Another aspect that could enhance the useability is to make the tool more dynamic, e.g., existing values are automatically deleted if the number of animals is set to zero or when converting from grassland to arable land, some combinations are still possible that are only relevant for grassland. It would be helpful if selecting a land use type would automatically remove incompatible entries or replace them with default values. Otherwise, users might overlook necessary updates, which would lead to inaccuracies. The testing of the tool by experts was highly valuable in order to improve the clarity, usability and overall efficiency of the tool for users, especially for those who are not familiar with all the underlying data requirements. The calculation tools are freely available and are planned to be used in follow-up projects. Farmers may use the calculation tools to inform management decisions and, in the long run, proof the changes in GHG emissions through implemented mitigation measures.

Third, the model results revealed that non-CO₂ GHG emissions including the potential to mitigate them are heterogenous across the Austrian agricultural landscape. We find that reductions in mineral fertilizer application by 20 % do not

suffice to reach the intended reduction target of 50 % nutrient losses. Cropland production, especially cereal and forage crop production, are reduced whereas grassland extent and production increases as a combined effect of fertilizer and climate change scenarios. Our analysis confirms the partial effectiveness of F2F measures targeted at mineral fertilizer in order to reduce N losses in air, water and through soil sediment transport. Yet, it shows that both cost-effectiveness and N loss reduction potentials depend on the regional context of prevalent farming systems, bio-physical conditions including climate change and the pollutant category. We further see a limited effectiveness of measures targeting only mineral fertilizers for the alpine, mostly grassland-dominated regions in Austria. The regional heterogeneity of our model results supports the conclusion that policies with uniform restrictions at national level fall short to attain policy targets cost-effectively. Tailored measures need to be elaborated by taking climate change as well as regional heterogeneity of prevalent farming systems and bio-physical conditions into account.

In addition, model results on agricultural adaptation to climate change show an increase in total N fertilizer use, whereas the total N₂O emissions from agricultural land decrease. This indicates an improved N use efficiency, leading to lower N₂O emission even if N fertilizer input increases. The N₂O emissions decrease by increasing MAC levels. However, the rate of reduction declines, indicating that additional incentives or more targeted policies might be needed to maintain the efficiency of N₂O emission reductions at higher MAC levels. A relative decrease of cropland area was modelled across all climate change scenarios suggesting that land use category changes serve as a key adaptation strategy, i.e., conversion from cropland to grassland. Within the grassland category, intensively managed grassland expands, whereas extensively managed grassland and alpine pastures show a relative decline when comparing the future periods to the historic reference period. The introduction of the climate policy, i.e., MAC levels between 30-300 € (t CO₂e)⁻¹, reverses this trend, i.e., leads to an extensification of grassland; both extensively used grassland as well as alpine pastures show a relative increase in area across all climate change scenarios. The results highlight key synergies between agricultural adaptation and mitigation. Grassland extensification at higher MAC levels does not only enhance soil carbon storage, but also increases resilience to climate variability. Fertilizer management improvements mitigate climate change by reducing N₂O emissions from agricultural soils, while at the same time enhancing N use efficiency, a key adaptation strategy.

The provided integrated modelling framework serves as the adequate tool to support ex-ante policy analysis by making trade-offs of policy outcomes visible in order to inform the development of targeted policy measures.

Based on the results obtained, we foresee the following next steps:

First, the protocol for calculating non-CO₂ GHG emissions at the farm level is developed as a dynamic document and framework. The applicability of the protocol is highly tied to the continuous integration of advancements in research, e.g.,

updated emission factors or other key parameters. Maintenance of the protocol is crucial as its reliability and accuracy in producing valid emission calculations depends on keeping up with the latest developments regarding emission factors, methods, and data requirements.

Second, the LBG Agrar System may be improved and extended in two ways: (i) The farm data collection process needs to be further simplified and potentially restructured and refined to ensure complete data sets for calculating non-CO₂ GHG emissions. This refers to a more intuitive data entry process while acknowledging the extensive data needs as well as to easy and efficient updates of data, where applicable. (ii) The developed protocol and potential revisions can be implemented in the LBG Agrar System to enable system-internal calculations of the non-CO₂ GHG emissions. System internal calculations could provide quick feedback to farmers, with insights into their farm's performance regarding non-CO₂ GHG emissions and the impact of various farm management options on non-CO₂ GHG emissions. System-internal calculations could also stimulate the interest of farmers in the topic and encourage extensive testing because the farmers would receive the results in real time.

Third, the LBG Agrar System is well prepared for collecting new variables within the farm sustainability data network (FSDN) survey ([European Commission, 2024](#)). The data queries implemented during the nonCO₂farm project serve as a valuable basis for this European initiative and may even serve as a guidance for the new data collection requirements in other EU countries. In particular, the newly implemented variables on manure storage covers, livestock housing systems, and farm management systems now inform EU policy via the FSDN survey.

Fourth, communication with farmers on the need to reduce GHG emissions within the agricultural sector and beyond needs to be improved. This became obvious in the recruiting process of potential project participants. Many concerns related, e.g., to data protection, bureaucratic burden, negative societal attitudes towards farming and steadily increasing environmental standards were raised. They need to be taken seriously and addressed consciously in order to increase farmers' trust as well as their willingness to contribute to climate change mitigation.

In the stakeholder workshops, it became evident that the GHG emission accounting is a critical topic across various fields and organizational levels. Several target groups can draw valuable conclusions from the project results:

- **Farmers:** As key decision-makers at the farm level, farmers can use the project results to make informed decisions about adopting mitigation measures. The project results highlight that non-CO₂ GHG emissions at the farm level often stem from natural processes, meaning achieving zero emissions is unrealistic. The results may also help farmers to identify and prioritize cost-efficient mitigation strategies tailored to their farm structure and characteristics.

- **Agricultural consultants and extension services:** The project results provide useful information for raising awareness among agricultural consultants about the different levels of non-CO₂ GHG emissions resulting from the various farm operations. Understanding the heterogeneity in non-CO₂ GHG emissions resulting from farm types and farm management – as well as the related costs – can improve the quality and customization of advisory services.
- **Policy makers:** The findings of the project may serve as a basis for the development of targeted and informed policy measures supporting the adoption of mitigation measures at the farm level. Recognizing that mitigation efforts vary in cost and effectiveness across the Austrian agricultural landscape can enhance the design of support programs that address these differences, ensuring the efficient allocation of resources.
- **Agribusinesses:** Companies, e.g., dairy companies, aiming to include farm-level emissions in their carbon portfolio can benefit from the project results, particularly the protocol providing a basis for calculating non-CO₂ GHG emissions. These insights may support corporate sustainability strategies, supply chain management and efforts to meet GHG emission reduction targets.
- **Science:** The project results are a good basis for scientific projects including the GHGfarm project. nonCO₂farm allows to calculate non-CO₂ GHG emissions at the farm level. Based on that, the GHGfarm project will employ a data envelopment analysis to develop a benchmarking system for comparing farming efficiency and for identifying efficient farms (i.e., peers). The calculated farm mitigation potential as well as the marginal abatement costs within the nonCO₂farm project will also be used by the GHGfarm project for analysing and representing trade-offs between economic and GHG efficiency, and thus, between food security and climate change. The GHGfarm project goes beyond the nonCO₂farm project such that it employs statistical and qualitative research methods. A regression analysis is used to determine the relationship between structural factors, e.g., farm size, farm type or farm manager characteristics, and the efficiency of MACs. Interviews and workshops are used to investigate farmers' goals and (intrinsic) values/ moral concepts and to which extent they are conflicting or synergistic with GHG emission reduction.

C) Projektdetails

6 Methodik

Several activities were necessary to achieve the objectives of the research project. With respect to WP4, management options for climate change mitigation and adaptation were defined, the bio-economic optimization model BiomAT as well as the farm optimization model FAMOS (Schmid, 2004b) were updated and an emission accounting tool was incorporated, and N₂O emissions were modelled for Austria by applying an integrated modelling framework (IMF).

Data gathering and processing for integrated modelling

The data necessary for updating and expanding the FAMOS model were collected and processed. The most recent data from the Farm Structural Survey 2020 (FSS; Statistik Austria, 2022) and the Integrated Administration and Control System (IACS; BMLFUW, 2017) were requested from the Federal Ministry of Agriculture, Forestry, Regions and Water Management and a data usage agreement was signed. These datasets provide extensive information on farm resource endowments and the participation in Austria's agri-environmental programme (ÖPUL) as well as received subsidies within the Common Agricultural Policy (CAP). Data on crop yields, livestock production and related variable production costs differentiated, e.g., by production region, product quality, fertilizer type, or soil management practices, were gathered from the standard gross margin catalogue by the Federal Institute of Agricultural Economics, Rural and Mountain Research (Bundesanstalt für Agrarwirtschaft und Bergbauernfragen (BAB), 2022). Information on market prices was taken from the OECD and FAO Outlook and processed by the project team for its application in FAMOS.

Adapting the models coupled in the integrated modelling framework

Mitigation scenarios

The Shared Socio-Economic Pathways for European agriculture and food systems (Mitter et al., 2020) were downscaled for Austria in collaboration with the research project [SALBES](#). The newly developed AT-Agri-SSPs are a set of five plausible scenarios that are characterized by varying challenges for climate change mitigation and adaptation. The quantified scenario elements can serve as a direct input into integrated models (Karner et al., 2024).

The farm optimization model FAMOS and the bottom-up agricultural land use optimization model BiomAT

The two bottom-up economic models FAMOS (Schmid, 2004a) and BiomAT (Karner et al., 2019) were updated for application in the project. Both models are programmed in GAMS (General Algebraic Modelling Systems; GAMS Development, 2019). **BiomAT** is a non-linear bottom-up, spatially explicit agricultural land use optimization model that maximizes total net benefits of crop and grassland production subject to agricultural land endowments at 1 km grid resolution in Austria. BiomAT was used within the IMF to assess impacts of fertilizer and mitigation scenarios on N losses from agricultural soils, i.e., in form of N₂O, ammonia (NH₃) and ammonium NH₄⁺. **FAMOS** is a mixed-integer, linear farm optimization model extended with a non-CO₂ GHG emission accounting module. The model maximizes farm net returns subject to farm resource endowments (e.g., land, livestock housing capacity, labor), agronomic production relationships (e.g., crop rotations, fertilizer and feed balance) and legal compliances (e.g., CAP measures and payments). Updating the model focused on utilizing most recent input data and representing the policy measures from the 1st and 2nd pillar of the CAP. The model baseline is defined as the year 2020 because the FSS is available as a full survey covering all Austrian farms. Accordingly, the represented scheme of direct payments is from 2020 and the represented ÖPUL measures are from the 2015-2022 period.

Model extension focused on including a non-CO₂ GHG emission accounting module. This module follows the guidelines for national GHG inventories as provided by the IPCC (2006, 2019), covering the non-CO₂ GHG emission sources summarized in

Table 3. For the livestock categories cattle, swine, and poultry, a farm-specific CH₄ emission factor was derived (IPCC, 2019) and applied for CH₄ emissions from enteric fermentation. For the other livestock categories represented in the model (e.g., horses, deer), we apply CH₄ emission factors provided in the Austrian inventory report (Anderl et al., 2024).

Table 3: Overview on the non-CO₂ GHG emission sources considered in FAMOS.

Non-CO₂ GHG emission source	Farm activity data	Representation in FAMOS
CH ₄ from enteric fermentation ^a	Feed energy intake	Feeding balance, livestock category and numbers
CH ₄ from manure management ^a	Feed energy intake	Feeding balance, livestock category and numbers
N ₂ O from manure management	Animal numbers	Livestock category and numbers

N ₂ O from agricultural soils ^b	N inputs from different sources to soils	Crop area, grassland, crop mix, animal numbers, commercial fertilizer, intensity levels
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^a Disaggregated by livestock categories (i.e., cattle, swine, poultry) and according to age, performance, and sex.

^b Disaggregated by nitrogen input sources and considering direct and indirect N₂O emissions.

Mitigation measures to be modelled in FAMOS were selected based on their mitigative effect (e.g., Smith et al., 2008), their mitigation potential (e.g., Herrero et al., 2016), the suggestions in the AT-Agri-SSPs (Karner et al. 2024), and the availability of data and emission factors for specific farming activities. The following mitigation measures are explicitly represented in FAMOS: various livestock production intensities (e.g., livestock daily weight gain, milk yield, egg mass production), feed rations, manure storage systems and cover types, timing and incorporation machinery of livestock manure application, and fertilizer intensities. To calculate the marginal abatement costs per ton of CO₂ equivalent, both the baseline, i.e., reference situation, and the mitigation scenario are modelled for Austrian farms using FAMOS. We calculate the difference in farm net return and non-CO₂ GHG emissions between the reference situation and the mitigation scenarios for each modelled farm.

The integrated modelling framework (IMF)

The IMF consists of three models: the crop rotation model CropRota (Schönhart et al., 2011a), the bio-physical process model EPIC (Izaauralde et al., 2006, version EPIC0810; 2017; Williams, 1995), and spatially explicit bottom-up economic land use optimization model BiomAT (Karner et al., 2019). CropRota models typical crop rotations on municipal level in Austria, using observed land use data and agronomic suitability scores. EPIC simulates bio-physical processes such as evapotranspiration, surface and subsurface runoff, percolation, erosion as well as nutrient dynamics of N and P (phosphorous) at 1 km grid resolution. For this project, the outputs on annual crop yields, N losses (in particular, NH₃-N and N₂O-N to the atmosphere, N_{min} (NO₃⁻-N, NH₄⁺-N) loss to surface and groundwater, and N_{org} lost through sediment transport in soil) are considered.

Application of the IMF: a focus analysis of fertilizer scenarios for Austrian farmland

A focus analysis was performed for Austrian crop- and grassland to derive the potential effects of two fertilizer reduction scenarios and four climate change scenarios on land use, nitrogen losses, and agricultural output in Austria for a future period of 30 years (2041-2070). This analysis was placed in the context of

the European Farm to Fork (F2F) strategy (European Commission, 2020) as a central component of the European Commission’s Green Deal (The European Green Deal, 2019). The F2F strategy contains key quantitative and qualitative targets, including the reduction of nutrient losses by 50% and fertilizer use by 20% until 2030 compared to a three-year baseline averaged over 2015 to 2017. Fertilizer input in agriculture is closely linked to N₂O emissions, making it a crucial factor for emission reductions from agricultural soils. For this focus analysis, the IMF was applied. Based on N balance data, two fertilizer scenarios reflecting the F2F strategy targets are modelled for a future period (2041-2070): a uniform 20% reduction in mineral fertilizer (f20) and a scenario with combined fertilizer restrictions (fcm), i.e., -20% mineral N fertilizer application combined with a maximum application amount of 175 kg N ha⁻¹ on cropland, except for temporary grassland (BMLRT, 2022) and no mineral N fertilizer application on permanent grassland. In order to address uncertainties in future climate conditions, the fertilizer scenarios are combined with four climate change scenarios from the ÖKS15 data set, representing conditions of moderate (ICHEC45, ICHEC85), dry (MOHC45), and wet (IPSL85) climate as well as moderate (RCP4.5: MOCH45, ICHEC45) and strong (RCP8.5: ICHEC85, IPSL85) climate forcing in Austria (Chimani et al., 2016). The IMF outputs are compared for a historical reference (1981-2010) and a future (2041-2070) period and provide results for the Austrian agricultural production regions (Wagner, 1990a, 1990b).

Application of the IMF: a focus analysis of climate change scenario impact on agricultural mitigation and adaptation in Austrian farmland

This focus analysis focusses on the N₂O emissions from mineral and organic fertilizer applications in the use and management of cropland and grassland in Austria. The IMF is employed to assess the climate change scenario impacts on agricultural mitigation and adaptation in Austria. N-balance calculations for more than 2000 municipalities serve as reference and alternatives of crop and regional specific fertilization management practices. Marginal abatement costs are computed spatially explicit using four different climate change scenarios with a moderate (RCP4.5) and strong (RCP8.5) climate forcing for Austria. In Table 4Table , the implemented management practices in the model are summarized.

Table 4: Overview on characteristics and data sources of implemented management practices.

Management practices	Characteristics	Sources
<i>Fertilizer management options</i>		

refm (reference management) and refi with irrigation	Crop-specific N fertilizer application based on livestock production, yield potentials and fertilization recommendations	(BMLRT, 2017; Loishandl-Weisz et al., 2020; Statistik Austria, 2023)
rf20 (uniform measure) and if20 with irrigation	Uniform 20% reduction of mineral N fertilizer application	Own calculation (BMLRT, 2017)
rfcm (combined measures) and ifcm with irrigation	20% reduction of mineral N fertilizer application - Maximum application of 175 kg N ha⁻¹ on crops, except for temporary grassland - No mineral N fertilizer application on permanent grassland	Own calculation (BMLRT, 2017)

Tillage

cTill	Conventional tillage
rTill	Reduced tillage
cTcov	Conventional tillage with cover crops

Irrigation

- With irrigation
- Without irrigation

Crop rotations

- Crop rotations accounting for 23 crops: winter and spring cereals, forage crops, grain legumes, roots crops, oilseeds
- Typical for Austrian municipalities

CropRota (Schönhart et al., 2011b)

Mowing frequency

- Extensive use, i.e., single cut
- Intensive use, i.e., three or more cuts

Development and application of optimization models: focus analyses on marginal abatement costs, feed rations and mitigation scenarios

Three master theses with relevance for the project were conducted. The first master thesis (Alkier, 2021) focused on modelling conventional and organic arable farm systems in Central Upper Austria and identifying their N₂O emission abatement potentials and abatement costs. The modelled farm systems maximize

net revenues from arable production. N₂O emission price scenarios are used to assess the N₂O emission abatement potential and N₂O emission abatement costs. The data for the model analysis are taken from the literature. The N₂O emissions are calculated for the two farm systems according to the 2006 IPCC guidelines. The farm system models are programmed in the GAMS software. The nitrogen fertilizer amount, the application technique and the crop mix affect the N₂O emissions and sales revenues, as well as costs. In the second master thesis (Seiringer, 2021), a life cycle assessment of 28 feedstuffs was conducted and a non-linear model was developed to optimize dairy cow feed rations with respect to global warming potential (GWP), land use and food expenditure (in form of both protein and energy). The optimization was performed for three different milk yield levels, i.e., 5000, 7000, 9000 kg per lactation. The third master thesis focused on modelling the impacts of three mitigation scenarios on the agricultural production and non-CO₂ GHG emissions of an Austrian grassland-based farm (Lienhart, 2025).

7 Arbeits- und Zeitplan

Below, we present the final updated work and time schedule (Figure 4).

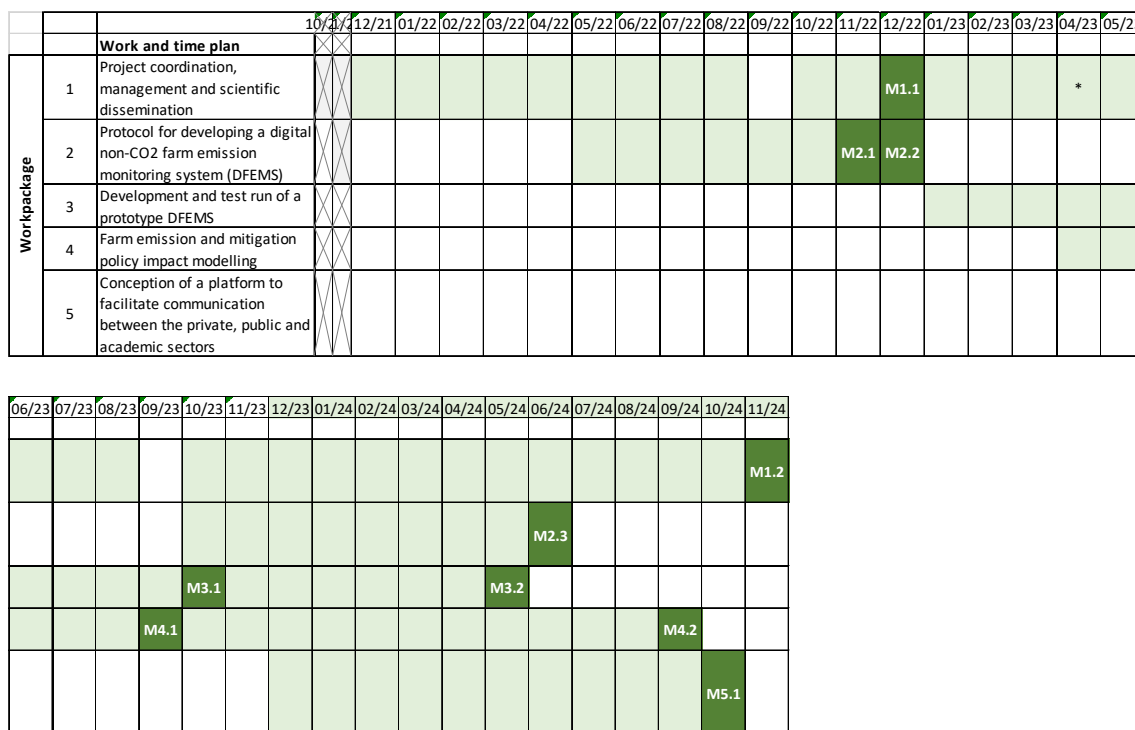


Figure 4: Final work and time schedule of the project.

Milestones:

M1.1 Interim report finished and submitted

M1.2 Final report finished and submitted

M2.1 Protocol that summarizes required data, methods, and emission factors for a DFEMS

M2.2 Data gaps at farm-level identified and activities to be surveyed via the DFEMS defined

M2.3 Protocol updated according to results from WP3

M3.1 Web-based farm management application extended such that data gaps can be closed

M3.2 Farm-level non-CO2 emissions for test farms available

M4.1 Data reviewed, collected, and prepared for their application in the quantitative models

M4.2 Models successfully adapted, outputs generated and validated for a baseline and for scenarios

M5.1 Concept for a digital communication platform for the results of DFEMS available

* Österreichischer Klimatag 2023

8 Publikationen und Disseminierungsaktivitäten

A major project outputs is a protocol entitled "Calculating non-CO₂ greenhouse gas emissions at the farm level: Methods, emission factors, and data requirements with application examples from Austria" (Kroener et al., 2025). The protocol shall be published as an open access discussion paper and provided with supplementary materials on pre-defined feed rations and considered feed components.

Below, the publication and dissemination activities that acknowledge the nonCO₂farm project are listed. The publication and dissemination activities include peer-reviewed articles, presentations at international and national conferences and at stakeholder workshops as well as three master and two doctoral theses related to the nonCO₂farm project.

Articles in peer-reviewed journals

- Jost, E., Schönhart, M., Mitter, H., Zoboli, O., & Schmid, E. (2025). Integrated modelling of fertilizer and climate change scenario impacts on agricultural production and nitrogen losses in Austria. *Ecological Economics*, 227, 108398. <https://doi.org/10.1016/j.ecolecon.2024.108398>
- Karner, K., Mitter, H., Sinabell, F., Schönhart, M. (2024). Participatory development of Shared Socioeconomic Pathways for Austria's agriculture and food systems. *Land Use Policy* 142, 107183. <https://doi.org/10.1016/j.landusepol.2024.107183>
- Loacker, A., Schmid, E., Mitter, H. (2025). Actors' frames and advocacy coalitions in the CAP reform process 2013 in Austria's agricultural media. *Agric Hum Values*. <https://doi.org/10.1007/s10460-024-10689-7>

Presentations at national and international conferences

- Mitter H, Falkner K, Kröner V, Lienhart B, Sinabell F, Fensl F, et al. Farm-level modelling and digital monitoring of non-CO₂ greenhouse gas emissions in Austria. In: CCCA Climate Change Centre Austria, editor. Tagungsband 23. Klimatag Ressourcen im Wandel [Internet]. 2023. Available from: https://ccca.ac.at/fileadmin/00_DokumenteHauptmenue/03_Aktivitaeten/Dialogveranstaltungen/OEsterreichischer_Klimatag/2023_Tagungsband_fin_al.pdf
- Kröner V, Falkner K, Schmid E, Fensl F, Koch J, Schuster F, et al. Modelling non-CO₂ greenhouse gas emissions and mitigation potentials of typical farms in Austria. In: Österreichische Gesellschaft für Agrarökonomie ÖGA, editor. Agrar- und Ernährungssysteme im Wandel: Chancen und Herausforderungen für Landwirtschaft und ländliche Räume [Internet]. 2023. Available from: https://oega.boku.ac.at/fileadmin/user_upload/tagungsband_2023_mit_Seitenangaben.pdf
- Mitter H, Falkner K, Kröner V, Lienhart B, Sinabell F, Fensl F, et al. Modelling non-CO₂ greenhouse gas emissions and mitigation potentials of Austrian farms. In: CCCA Climate Change Centre Austria. 24. Klimatag Stadt und Land im Fluss [Internet]. 2023. Available from:

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Kröner V, Falkner K, Schmid E, Mitter H. Modeling the emission reduction potentials of non-CO₂ mitigation measures for Austrian farms. In: European A, Mediterranean A, editors. 188th EAAE Seminar: "Reorienting agri-food chains to hinder climate change and food security threats". Book of Abstracts. [Internet]. EAAE; 2024. Available from: <http://188eaae.maich.gr/img/book-of-abstracts-188-EAAE-seminar.pdf>

Kröner, V., Falkner, K., Mitter, H., and Schmid, E.: Modeling of farm-specific marginal abatement costs of non-CO₂ greenhouse gas mitigation measures in Austria, EGU General Assembly 2024, Vienna, Austria, 14–19 Apr 2024, EGU24-8911, <https://doi.org/10.5194/egusphere-egu24-8911>

Stakeholder workshops

Organization of a stakeholder workshop on "Stand und Ausblick des Treibhausgas- und Nachhaltigkeitsmonitorings in der Landwirtschaft in Österreich" at WIFO on 21 February 2024.

Participation in a stakeholder workshop on "Bottom-up Berechnung von Nachhaltigkeitsindikatoren der österreichischen Landwirtschaft" at the Bundesanstalt für Agrarwirtschaft und Bergbauernfragen (BAB) on 31 October 2024.

Master theses

Alkier, S. (2021). Optimising conventional and organic arable farm systems with respect to N₂O emission abatement potentials and costs in Central Upper Austria. Master / Diploma Thesis - Institut für Nachhaltige Wirtschaftsentwicklung, BOKU University, pp 87.

Seiringer-Gaubinger, M. (2021). Reduktion des Treibhauspotentials versus Lebensmittelkonkurrenz in der Milchkuhfütterung. Eine Analyse auf Basis von Modellrechnungen. Diplomarbeit / Masterarbeit - Institut für Nutztierwissenschaften (NUWI), BOKU University, pp 40.

Lienhart, B. (2025). Modelling the effect of varying production intensities under different mitigation targets on non-CO₂ greenhouse gas emissions on an Austrian grassland-based dairy farm. Master / Diploma Thesis - Institut für Nachhaltige Wirtschaftsentwicklung, BOKU University

Doctoral theses

Jost, E. (2025). Integrated modelling of sustainable carbon and nitrogen management options in Austrian agri-food systems under global change. Doctoral Thesis – Institute for Sustainable Economic Development, BOKU University.

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Diese Projektbeschreibung wurde von der Fördernehmerin/dem Fördernehmer erstellt. Für die Richtigkeit, Vollständigkeit und Aktualität der Inhalte sowie die barrierefreie Gestaltung der Projektbeschreibung, übernimmt der Klima- und Energiefonds keine Haftung.

Die Fördernehmerin/der Fördernehmer erklärt mit Übermittlung der Projektbeschreibung ausdrücklich über die Rechte am bereitgestellten Bildmaterial frei zu verfügen und dem Klima- und Energiefonds das unentgeltliche, nicht exklusive, zeitlich und örtlich unbeschränkte sowie unwiderrufliche Recht einräumen zu können, das Bildmaterial auf jede bekannte und zukünftig bekanntwerdende Verwertungsart zu nutzen. Für den Fall einer Inanspruchnahme des Klima- und Energiefonds durch Dritte, die die Rechteinhaberschaft am Bildmaterial behaupten, verpflichtet sich die Fördernehmerin/der Fördernehmer den Klima- und Energiefonds vollumfänglich schad- und klaglos zu halten.