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Executive Summary

Introduction: With increasing pressure on agriculture to reduce its environmental impacts, it has been hypothesised that mixed farming and agro-forestry systems (MiFAS), either at a farm or landscape scale, could be an option to mitigate issues of nutrient excess, the import of synthetic fertilisers or feed production. Traditionally, mixed farming was practised to provide nutrients to crops through rotation breaks and to feed livestock, however the use of synthetic fertilisers and economies of scale has led to increased specialisation.

It has been proposed that the re-integration of cropping and livestock could close nutrient cycles and reduce imports of external feed or fertiliser nutrients, improve soil quality through returns of organic matter, as well as potential socio-economic benefits; although difficulties may occur, such as a loss of more profitable crops. A further potential climate change mitigation measure is the use of agroforestry within specialised agricultural systems to provide shading, soil stabilisation, drought resistant browse material for direct grazing or cutting, as well as directly offsetting GHG emissions through sequestration of carbon through biomass and or soil organic carbon (SOC). Task 5.1 therefore aimed to assess farm survey data (Task 2.3a) from existing MiFAS (Mixed and Agroforestry Systems), to assess their environmental and economic performance, as well as link to Task 5.2 to include coverage of potential labour issues.

Methodology: The assessment of the MiFAS within Task 5.1 employed a quantitative approach to undertake an LCA-based assessment of farm practices to generate results across a wide range of environmental and economic indicators through use of the FarmLCA model that includes both Lifecycle Impact Assessment (LCIA) and the German KTBL standard costs database. As per the guidance of ISO14040 and ISO14044 (ISO, 2006), we followed the recommended four steps to conduct an LCA, including a goal and scope definition phase. Our main goal was to assess the performance of MiFAS, based on data collected through farm surveys in multiple European countries. We also aimed to improve methodologies for assessing these systems and then to make a comparison so that conclusions and recommendations could be made. In terms of scope, we would conduct single farm assessments, with flexible boundaries either at the farm gate or at a smaller scale for some systems. Interactions, such as exchanges of straw or manures were treated as external inputs or outputs to the farm boundary, as these exchanges were assessed within WP3 (D3.4).

The second step, the inventory analysis phase, comprised collection of data for each farm and was linked to Tasks 2.2 and 2.3a where the on-farm data collection was developed and supervised. The survey was conducted in each network and were undertaken either as an on-farm interview or in some countries farm management data was already accessible electronically, with a follow up interview with the farmer. In general, data collection started in autumn 2022 and final queries were completed in autumn 2023.

Collected data was utilised from 9 networks for assessment through Task 5.1. For Denmark, NW02 was organised around reducing nutrient excesses and involved exchanges of manures with biogas plants and other farms, as well as returns of digestates. Whilst in Scotland, NW04 was focussed on the trialling of winter grazing of cereals by sheep, as well as other material exchanges such as straw and manures, but the network also included mixed farms with beef cattle. The German networks comprised NW5, focussed on peatland restoration of former intensively managed land, whilst the second German network NW06, comprised three farms developing agroforestry. In Switzerland NW07 comprised farms with high-stemmed fruit trees as an agroforestry system with grazing livestock and or crops. In France two networks comprised, NW09 with a focus on outdoor pig production in an agroforestry/woodland setting, and the second French network NW10 located in the SW region, included a range of mixed, arable and specialist livestock farms collaborating with partners to improve exchanges of materials and nutrients. In the east of Europe, the Romanian NW11 comprised farms collaborating to develop agri-tourism within the region of diverse small farms, whilst in Poland NW13, a large single farm comprised a biodynamic mixed farm, linking dairy and arable production.

Following data collection, data validation was critical due to the wide range of systems studied and we focused on agronomic data, such as yield, fertiliser use, animal herd and rationing values with queries passed back to data enumerators for clarification. The assessment tool also included plausibility checks for nutrient requirements for crops or animals of a certain yield or animal type.

Each farm was modelled using the FarmLCA tool, which comprises LCA and economics modules and allows the individual nature of each farm and the management of their crops and livestock to be included. Subsequent sub-models estimating relevant emissions, such as enteric methane, nitrous oxides, or other pollutants, were based on methodologies recommended by IPCC and EMEP. The combination of on-farm data for external inputs together with outputs from the sub-models a farm specific LCA inventory was created. This is used to then calculate the impacts for different crops and livestock systems, which can be reported at various levels. Where multiple products were produced by the same plot or livestock, allocation was conducted as per ISO14040 and 14044.

The assessment of MiFAS required additional model adaptations, as by their nature, MiFAS may produce multiple products from the same land area concurrently, such as apple trees with pasture beneath them, or arable crops that provide winter grazing for sheep. The main issues included allocation of impacts between the co-products, especially when an input is not attributable to a single output. We therefore undertook specific methodological adaptations for assessing MiFAS within the MIXED project including assessing soil carbon changes and biomass with agroforestry (AF) systems. Quantifying SOC changes is scientifically challenging, and we therefore adapted the IPCC Tier 2 steady state method to include a wider variety of land uses including permanent pasture, orchards, and other trees. For agroforestry, we included a module for biomass carbon calculations and adopted a Tier 1 approach according to the meta-review by Cardinael et al. (2018), to estimate the changes in above and below ground carbon for the first 20 years following land use change. Furthermore, to increase accuracy in AF calculations we used a spatial allocation method to differentiate between trees and pasture and to account for tree size and planting density. For the economic analysis, we utilised an adapted database from the German KTBL database which allows for farms from multiple countries to be grouped together without issues of costs differing due to local situations. Gross margin calculations (partial net margins) are reported based on outputs minus inputs, which include labour.

Due to the wide diversity of farm systems within and between networks, we adopted a statistically based two-step clustering approach to group the farms from across all the networks into farm system type groups for comparison. We found that using binary variables related to the presence of AF, livestock, together with proportions of farms with permanent grassland and field crops generated four groups for comparison. To enable a statistical assessment of farm system differences, we also utilised the non-parametric Kruskall Wallis test to enable robust assessment within data that violated the normal assumptions of one-way ANOVAs.

Results: For the impact assessment phase, we presented results for each farm per network, followed by results per farm system type, as well as presented at an enterprise level for a limited number of crops and livestock. For the analysis, we adopted a number of performance indicators to characterise the farm systems, assessed their use of nitrogen as a main agricultural nutrient, estimated potential changes in carbon, environmental indicators as part of the LCIA and economic indicators for sales, costs and partial net margins.

Farm Networks: The networks assessed provided a wide variety of farm systems across a wide geographical area. The data provided about the farm systems included full farm systems through to specific areas of farms that focussed on a particular topic, e.g. agroforestry. The farms also ranged from very diverse, complex systems with crops, livestock and agroforestry through to large highly specialised units, which were included within the MIXED project due to their participation in landscape scale collaborations. These specialised systems also proved extremely valuable as comparators to the MiFAS type systems. Whilst farms within some of the networks had a common theme, such as the French NW09, others were highly diverse, such as French NW10. Livestock types were also diverse, covering all sectors except broiler chickens.

The Danish NW02 farms produced a wide range of arable crops, as well as some farms with large herds of intensively managed cattle or pig systems. Despite the transfer of nutrients via biogas plants, all of the farms had high nitrogen inputs, especially when nitrogen within feed is accounted for (up to 551kg N ha^{-1}). The intensity of farm systems therefore resulted in some very high GHG emissions, especially when livestock were kept. Whilst in Scotland NW04, most of the farms comprised cropping with or without livestock, and emissions were greatest on farms with livestock. The German NW5 farms showed that whilst emissions from the peat land have declined, the current utilisation, such as extensive beef production, was found to have very high emissions, because of the underlying peat, as well as slow growth rates. The German NW06 farms were diverse, including a free-range egg system which was very reliant on external feeds, resulting in high nitrogen related emissions, whilst the other two systems were less integrated and planted more like tree hedgerows. Whilst new agroforestry showed a potential for new carbon storage, the long-term aspects were unclear, so carbon storage on a 100-year basis was unclear.

In Switzerland, despite the NW07 farms having larger high-stemmed fruit trees as an agroforestry system, the Tier 1 methodology means that beyond 20 years of age the biomass carbon was assumed to be at equilibrium. However, the Swiss farms did demonstrate the improved circularity from using livestock manures as the primary fertiliser source, with low external nitrogen sourcing. However, when livestock are maintained with and feed imported, emissions increase, though offsetting emissions through biomass storage in new trees can be partially effective. In France NW09, despite the woodland setting for the raising of pigs, the high feed imports and stocking densities, combined with slower growth rates caused high emissions. Although comprising a significant level of woodland, the trees were generally older (around 70 years), therefore biomass carbon was assumed to be in equilibrium as per the Tier 1 guidelines. The French NW10 was a mixture of farm types, and the specialist livestock farms were generally very extensive, whilst the cropping farms were quite intensive, and emissions depended largely on their intensity and the presence of livestock. For the Romanian NW11 farms obtaining high quality data suitable for conducting an LCA was problematic, and therefore a single typical farm for the region was constructed comprising a high intensity of livestock, feeds purchased and diverse fruit trees on pasture or in orchards. The high density of livestock resulted in high emissions within this system. In Poland NW13 as a single very large biodynamic mixed farm had few external inputs, but limitations to its crop yields are a severe handicap to economic performance, as well as causing some higher-than-expected product impacts.

The interpretation phase assessed all phases of the analysis, including input data from the farms, methodological challenges, results at the network, system type and enterprise level, as well as making general conclusions from the work undertaken. We found that with such a diverse range of farms in the dataset it was difficult to come to clear conclusions about the performance of different farm system types, therefore, a single farm dataset was formed, and farms were grouped into four system types, integrated cropping and livestock (ICL), specialist arable (SA), specialist livestock (SL) and integrated cropping/livestock and agroforestry (ICLF). Ideally, we would also have liked to compare organic and conventional systems, but the dataset was too small to undertake any valid comparison.

In terms of characteristics. we found that the ICL and ICLF farm clusters were larger than the specialist systems, highlighting the focus of the farm networks. Farm areas were much greater for the ICL, SA and SL systems, whilst the ICL and SA types both had a high proportion of field cropping. However, we also observed that the more integrated system had a reasonable proportion of temporary forages, with a little grassland. The SL was dominated by permanent grassland, with similar livestock numbers for both ICL and SL, though livestock stocking density was greatest for ICLF, probably because of the French pig systems.

The main nitrogen indicators all showed significant differences between the four farm system types, whilst fertiliser application of nitrogen was lower on SA systems. Nitrogen self-sufficiency and the proportion of nitrogen applied as organic manures was always lower on SA farms, intermediate for ICL and higher on the ICLF and SL farms, as may be expected with higher livestock levels. However, nitrogen export as products was lower on SL, with ICL and SA the highest because of the higher N exported per hectare of cropland.

Whilst we found differences in revenue and costs between the farm systems, overall, there was no significant difference between the farm system types. However, when comparing environmental impacts, all environmental indicators showed significant differences between systems. For greenhouse gas (GHG) emissions we found that per hectare, the SA farms had lower emissions, with SL at an intermediate level and the two integrated systems showing the greatest impacts. Using the alternative functional unit of per kg of nitrogen exported, the results showed the greatest emissions for the SL system, likely in part due to the low productivity extensive systems, whilst the integrated systems were at an intermediate level.

In terms of fossil and nuclear energy (FNE) use, SL farms were lowest per hectare, but again, when assessed by kilogram of N exported, became the highest energy user. The cropping systems showed the greatest energy use per hectare, but SA farms were the lowest per kg nitrogen exported. In terms of mineral resource use, the SA and SL farm types had lower use per hectare, whilst per kg of N exported, SA farms had the lowest impacts, ICL was intermediate with the SL and ICLF farms the largest resource users.

Considering acidification impacts, both indicators (FA and TA) showed SL farms to have low impacts reflecting the far lower levels of N inputs per hectare, whilst for impacts per kg N exported, SA systems showed lowest impacts due to high N outputs compared to the livestock centric ICLF and SL systems. Eutrophication (FEU and MEU) results per hectare reflected the low Phosphorus inputs of the SA and SL systems, whilst for MEU, the SL system was lowest per hectare but greatest per kg N exported. The integrated systems were intermediate for both functional units.

When we assessed data at an enterprise level, we found wheat and beef to be present in many networks. In total we found 36 wheat crops, and results of comparing the underlying farming system indicated very different management between the farm types. The highest levels of mineral nitrogen were used on ICL and SA farm types who also achieved the highest yields. This probably explains why the GHGs and energy use, were lower for the ICLF and SL farm types, however due to heterogeneity within the data, for most of the environmental impact indicators there were no significant differences.

Beef animals were reared on 21 farms within the networks and included animals from both dairy and suckler cows. We found that stocking density was highest on the ICLF and ICL farms, whilst rations were not significantly different, with all systems receiving a high median level of forage. However, the environmental impacts were significantly different between farm types, with the SL farm types showing the highest impacts. Contribution analysis highlighted the greater impacts of the SL system for most impact categories, with greater GHGs likely because of enteric emissions and the greater emissions embedded within the transferred in-stock, such as weaned calves from generally higher GHG suckler cow systems.

Changes in the soil carbon were generally very small, probably due to reporting of only the passive soil pool as the more active soil pools are short term and therefore inappropriate to report within the 100 year GHG basis (GWP100). Soil carbon changes were also more limited due to the single time frame of the detailed data collection, preventing more consideration of specific management changes that may have affected SOC. One factor that became apparent within the modelling, was that in the absence of fundamental system changes, the temperature effect on soil C degradation is already apparent. As temperature increases, we see greater SOC loss under the same management and as the model uses a 20-year period for assessing SOC, the increasing temperature within the climate datasets shows SOC is generally being lost in the carbon dynamic tables.

The biomass modelling was entirely new for the project and the Tier 1 method, together with adaptations for tree size and planting density provided some insight into the potential of agroforestry. We found that there was a great difference in tree biomass potential carbon storage depending on the age structure of the trees, partly as a direct result of the modelling assumptions, i.e. no additional storage in AF systems after 20 years as most AF systems are built around early maturing trees, like fruit, nut or short-rotation coppice (SRC) trees. Furthermore, whilst the initial planting of AF trees adds new above and belowground biomass carbon storage, this is potentially at the cost of soil carbon initially and it may take up to 30 years before an increase in SOC is observed (e.g. Paul et al., 2022), however, the ecosystem services of AF go beyond carbon storage and still represents a viable climate change mitigation option.

In conclusion, we were able to assess a very diverse range of farm systems in varying geographical locations to at least partly, answer the question of whether MiFAS systems provide environmental and potentially economic benefits. The answer is sometimes and depending on the indicator and functional unit applied. The ICL and ICLF systems, as well as the SL were more self-sufficient in nitrogen supply, but SA farms had better external nitrogen utilisation. In terms of GHGs, the SA farms emitted the least at both per hectare and per kg nitrogen exported from the farm, with SL emitting the highest and the ICL and ICLF farms at an intermediate level. For the other environmental indicators, the SL farms were usually the lowest per hectare because of their extensive characteristics, whilst for the per kg nitrogen FU, SA farms were lowest and SL the highest. Economically, all farm types showed a net loss, with the low input SL farms showing the smallest loss and ICL the greatest, though these differences were not significant.

However, these results are influenced by the farms within each type, and there were clear trade-offs between per area and per product impacts. The results also showed that the impacts are very related to the specific situation on the farm and that strategies such as agroforestry alone will not solve issues, but a whole farm approach to reducing impacts through reduction and efficient use of fertilisers and feeds, combined with additional strategies will have the greatest impact. Some of the ICLF systems were situated with existing woodlands and due to its age, new carbon sequestration was unlikely, whilst the system was also supported by considerable external feed inputs, therefore the system does not appear to be a solution from an LCA impact perspective. However, the more extensive versions of this systems provided direct benefits as well as other factors such as welfare which may be much improved compared to intensive indoor production.

The results from this analysis should be viewed with caution as the systems assessed were only representative within a range of networks available within the MIXED project. Farms had specific management strategies, which may provide considerable benefits either at a local or even wider spread adoption, such as winter grazing of cereals by sheep, exchanges between farms, as well as agroforestry. However, the results could be strongly influenced by certain aspects and generalisations should not be made. From a policy perspective, the results point to variation in impacts due to the specifics of a production system and farms and policies must find a balance between productivity whilst minimising external inputs, with the potential to add agroforestry for additional benefits.

Methodologically, whilst LCA remains a good option for assessing environmental impacts, there is still much work to be undertaken to allow farm LCA assessments to fully understand the complexities of the systems. Furthermore, other ecosystem services and societal aspects are still absent from this study and most LCAs, including biodiversity and animal welfare as two major topics. Increasing crop and forage diversity, agroforestry and a more diverse landscape are all likely positives for ecosystem services, but their assessment remains challenging at a wider scale.

Abbreviations

ANOVA	Analysis of Variance
CO_2	Carbon dioxide
D	Deliverable
EC	European Commission
FAC	Freshwater acidification
FEU	Freshwater eutrophication
FNE	Fossil & nuclear energy
GHG	Greenhouse gases
ICL	Integrated crop and livestock
ICLF	Integrated crops and or livestock with agroforestry
ISO	International Standard Office
KW	Kruskal Wallis non-parametric ANOVA
LCA	Life cycle analysis
LCIA	Life cycle impacts assessment
MEU	Marine eutrophication
MiFAS	Mixed farming agroforestry systems
MRU	Mineral resource use
N	Nitrogen
N_2O	Nitrous oxide
NW	Network
PO_4	Phosphate
SA	Specialised arable
SL	Specialised livestock
SOC	Soil organic carbon
TAC	Terrestrial acidification
WP	Work Package
WT	Work Task

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1 Introduction

1.1 Background

With increasing pressure on agriculture to reduce its environmental impacts, whilst maintaining or increasing food security (Fusco et al., 2023), it has been suggested that a return to more mixed farming (Schut et al., 2021), either at a farm or landscape scale could be an option to mitigate the problems of nutrient excesses in intensively farmed livestock regions, the import of external synthetic fertilisers in cropping areas or the transfer of nutrients between continents and the issues of associated deforestation.

Mixed farming was traditionally practised to provide nutrients to crops through rotation breaks as well as feed for livestock, that generated manure and nutrients for the subsequent crops Schut et al., 2021). However, with the development of synthetic fertilisers and increased specialisation in both crop and livestock sectors, they have become less integrated (Garret et al., 2020).

The re-integration of cropping and livestock should allow for a closing of nutrient circles through the provision of manures directly or through application to cropping fields, whilst concentrate and roughage production can occur closer to the consuming livestock. The potential benefits include less imports of external feed or fertiliser nutrients, improved soil through returns of organic matter, as well as many potential socio-economic benefits including less exposure to global commodity markets, the potential to offset losses in one enterprise through increased profitability within another, as well as other potential benefits including better work balance during the year. However, difficulties may occur, such as a loss of more profitable crops to support e.g., forage provision to livestock, increased capital and or demand for labour or specialist skills.

A further mitigation measure that is receiving increased interest in temperate climates is the use of agroforestry within existing specialised agricultural systems (Jordan et al., 2020). Whilst already popular in many sub or tropical systems, the use of trees within cropping or forage-based systems is being explored by many farmers and researchers. The potential benefits include climate change impact mitigation through shading, soil stabilisation, as well as drought resistant browse material for direct grazing or cutting, as well as directly offsetting GHG emissions through sequestration of carbon through biomass and increased soil carbon. However, few examples of long-term agroforestry, especially in livestock systems exist, therefore the benefits and potential trade-offs, e.g., loss of productivity through shading or water competition are not entirely clear.

With this in mind, the MIXED project aimed to assess existing MiFAS (Mixed and Agroforestry Systems), through access to farms through the partner network.

1.2 Task 5.1 – network farms

As stated above the aim of Task 5.1 is to assess the performance of existing and newly created MiFAS. Table 1 below presents the 9 networks assessed through Task 5.1 and indicates the type of MiFAS they are operating. For some networks they have multiple levels of MiFAS, e.g. a single mixed farm that also collaborates with other farms within a region. The network farms include some that are existing systems, such as the high fruit trees within Switzerland, whilst others are just developing their MiFAS, such as the German agroforestry network, therefore their experiences and data availability could be quite variable.

Table 1 Network farms and topic

Network name	Country	Integrated crop and livestock	Integrated crop, livestock and agro-forestry	Collaborating specialist livestock and cropping system
2 AU	Denmark	X		X
4 SRUC	UK	X		X
5 ARGE	Germany	(X) organic soils		
6 IFLS	Germany		X	
7 FiBL	Switzerland		X	
9 AGROOF	France		X	
10 INRAE	France	X		X
11 ROM	Romania		X	
13 KST JUCHOW	Poland	X	(X)	

1.3 Hypothesis

The working hypothesis for the project is that MiFAS are more environmentally and economically sustainable and Deliverable 5.1 aims to try and help answer this.

2 Approach

The assessment of the MiFAS within Task 5.1 employed a quantitative approach that utilised farm data collected through Task 2.3a, to undertake an LCA-based assessment of farm practices, to generate results across a wide range of indicators, with the purpose of testing the hypothesis that MiFAS systems perform better environmentally. Furthermore, farm systems will be assessed for their economic performance through connection of a standard costs database with farm operation data.

2.1 Methodology

As per the guidance of ISO14040 and ISO14044 (ISO, 2006), we followed the recommended four steps to conduct an LCA.

2.1.1 Goal and scope definition phase

The main goal of this exercise was to assess the performance of mixed and agroforestry farm systems, base on data collected through farm surveys in multiple European countries. We also aimed to improve methodologies for assessing these systems and then to make a comparison so that conclusions and recommendations can be made. In terms of scope, we will conduct single farm assessments, with flexible boundaries either at the farm gate or at a smaller scale for some systems, for example fields associated with an agroforestry system, with other farm enterprises excluded. For As this analysis is at farm level, where farms are collaborating with each other, these will be treated as external inputs or outputs to the farm boundary, as these exchanges are being assessed within WP3 (D3.4) within the project.

2.1.2 Inventory analysis phase

2.1.2.1 Data collection

To enable a sufficient analysis, a significant quantity of data and information was required from each farm. To enable the partners from Task 5.1 were directly involved within WP2, specifically Tasks 2.2 and 2.3a whose task it was to design and supervise the on-farm data collection within the project. These tasks developed a list of key indicators and data requirements (See D2.2), and subsequently created an Excel workbook (see MS3), for use as a data collection tool by network partners.

Briefly, the data collection workbook, included sheets related to the general situation of the farm, land use that included physical as well as specific management information (e.g. seed rate, cultivations, yields, tree number and size), sheets for each livestock type and their feed rationing, as well as extra sheets related to manure. A further qualitative section included questions related to the farmers experiences of MiFAS and supply chain questions. Where necessary the workbook was translated into local languages and when completed, anonymised, and uploaded to the project Teams folders.

Due to the complexity of some questions, data collectors received training, as well as participating in the design process. The surveys were conducted in each network and were undertaken either as an on-farm interview or in some countries farm management data was already accessible electronically, with follow up via interview with the farmer. In general, data collection was started in autumn 2022 and final queries were completed in autumn 2023.

2.1.2.2 Data validation

Due to the wide range of systems studied and complex data, each workbook required data validation. Within Task 5.1 the focus was primarily upon the agronomic data, therefore key variables, such as yield, fertiliser use, animal herd and rationing values were checked for consistency. Queries were noted and passed back to data enumerators for clarification. Where it was not possible to check specific data, expert knowledge from the network or project participants was engaged to input an imputed value. The assessment tool (described next) also allows for wide ranging farm system checks to ensure consistency, e.g. nutrient requirements for crops or animals of a certain yield or animal type and productivity are estimated, livestock herd structure is checked for consistency (reconciliation), as are the rationing requirements against key parameters such as dry matter intake.

2.1.2.3 Farm system modelling for LCA

Data collected for each farm was entered into an MS Excel-based model tool, FarmLCA (Schader et al,. 2014, de Baan et al., submitted). It comprises a farm system model attached to an LCA and economics calculation module, as shown in Figure 1. The farm model provides a data entry interface, decision support functions such as fertilizer or feed nutrient requirements based on the yield or liveweight data entered. This allowed the individual nature of each farm and the management of their crops and livestock to be modelled. Based on the production data entered, subsequent sub-models estimate relevant emissions such as enteric methane, nitrous oxide or other pollutants. These sub-models are based on methodologies recommended by IPCC (2006, 2013 & 2019) and EMEP (2019). Further development of these equations, such as adding additional land uses, including residue levels, nutritional content has been added to allow further functionality of the model, such as for orchards.

The output from these equations combines with the direct farm data input for external inputs such as fertilisers to generate the farm specific LCA inventory. This is then applied to the LCA impact characterisation factors to calculate the impacts for different crops and livestock systems, which can be reported at various levels – from plot to farm level, as well as at product level after allocation is applied.

When multiple products are produced by the same plot or livestock, such as milk and meat from dairy, grain and straw from cereals, an allocation procedure is required if you wish to assign impacts between the products. As per ISO14040 and 14044 (ISO, 2006) wherever possible the inventory items are assigned directly, however for some inputs or emissions allocation must be undertaken by economic, physical or more complex methods (e.g. energy input to meat or milk as recommended by IDF 2015).

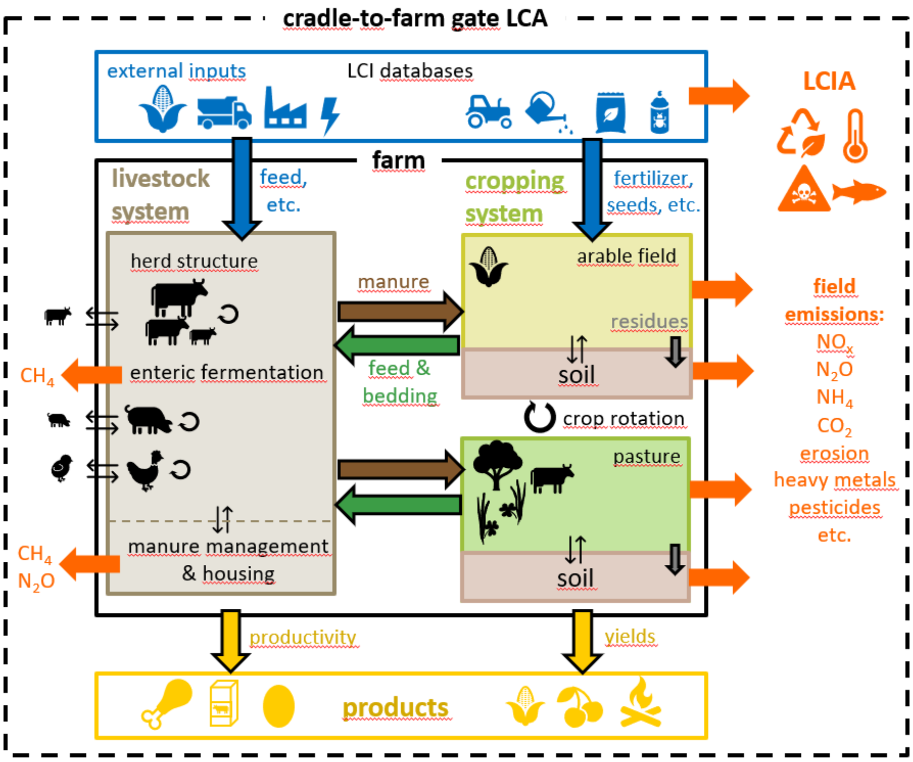


Figure 1 Graphical representation of the FarmLCA tool and the fam gate boundary approach it adopts. (from de Baan et al. (2024, submitted)

However, the assessment of MiFAS presents additional problems, as by their nature, MiFAS may produce multiple products from the same land area concurrently, such as apple trees with pasture beneath them, or arable crops that provide winter grazing for sheep. The main issues include allocation of impacts between the co-products, especially when an input is not attributable to a single output, and then allocation becomes a question of by mass, by economic value or another method, e.g. calories.

2.1.2.4 Specific developments for assessing MiFAS

Within the MIXED project Task 5.1 has worked alongside WP4 to identify and develop assessment methodologies that allow us to interpret and assess more complex farm systems such as MiFAS. Whilst our selection of methods may differ, due to different approaches to calculating LCA impacts, these discussions have allowed scientific debate in trying to improve the assessment of MiFAS.

2.1.2.5 Soil carbon changes

Within the methodological updates, soil carbon changes are increasingly of interest as a potential form of climate change mitigation. However, quantifying SOC changes is extremely challenging, particularly when sample farms are spread across a wide geographical area and contain many different farming systems. Therefore, for this assessment we adopted the IPCC Tier 2 steady state method (IPCC, 2019), with further adaptations to include a wider variety of land uses including permanent pasture, using residue and harvest index parameters from Bolinder et al., (2007 and 2020), orchards and other trees using Aguilera et al. (2015) and Gad et al. (2015).

Within the Tier 2 method three different soil pools are quantified, with algorithms to determine the quantity of crop residue carbon that is incorporated into and retained in the soil as well as decomposition rates according to temperature, water and soil management, e.g. tillage. The first two pools are very reactive to changes, whilst the passive pool reacts in a much slower context, and therefore more likely reflects longer term changes in SOC. Therefore, where soil carbon changes are stated in this report, it is only the passive pool that is reported. As a more conservative indicator, it is less likely to show rapid gains or losses, which may not be sustained on a longer-term basis.

2.1.2.6 Modelling agroforestry systems

Within the networks assessed in Task 5.1, many of the systems comprise mixed farming, but a few also utilise agroforestry to a limited degree. Therefore, to enable an assessment of the contribution of AF, the FarmLCA model was adapted to include a module for biomass carbon calculations. Whilst many assessments of AF have been undertaken in tropical regions where it is more commonly practised, especially within temperate zones little has been known about assessing the carbon changes because of for example, planting new AF systems. We therefore researched for a suitable method and after examining the latest IPCC recommendations, adopted a Tier 1 approach according to the meta-review by Cardinael et al. (2018). Under this Tier 1 approach, a specified value is applied to estimate the changes in above and below round carbon for the first 20 years following land use change. This method differentiated by type of land changed, i.e. grassland or arable land, and also specified values for temperate regions, as opposed to global values. Whilst the IPCC provides a Tier 2 method for forestry, this was very difficult to apply to AF situation as they comprise grassland or crops in the same land area, and for these types of systems timber production is not the primary goal, more likely as part of an extensive orchard or as livestock or crop shelter.

2.1.2.7 Allocating impacts of trees

A further major methodological challenge was the allocation of impacts for multiple land use types on the same plot. Whilst the biomass of the trees could be estimated using farm tree size dimensions and Cardinael et al., (2018), it did not solve the issue of multiple inputs and outputs on the same plot of land. This was particularly difficult for plots which are simultaneously used for different agricultural activities, like (i) silvo-arable or (ii) silvo-pastural systems such as the ones analysed in the MIXED project. In these specific cases, a permanent crop (e.g. a tree or bush) is combined with (i) an arable one or (ii) a permanent grassland. To add more complexity, livestock could forage in these areas and feed on products from either of the crop sources. Each element on this single plot is receiving inputs and generating outputs, also in terms of environmental impacts. This multifunctionality of MiFAS is still underrepresented in LCA literature and rather difficult to tackle methodologically (Quevedo-Cascante et al., 2023).

An example is given in Figure 2A: On a plot of permanent grassland fruit trees grow in a scattered pattern within the pasture. Both the grassland and the trees are used to produce an economic output for the farm. The grassland is mown or pastured for forage while the trees deliver fruits for food or forage for livestock. Environmental impacts include potential sequestration of carbon in the tree and root biomass, which could offset GHG emissions. In current LCA approaches an economic allocation method is frequently used (Quevedo-Cascante et al., 2023). With this approach impacts would be assigned to the products of the most important economic activity on this field (likely fruits or the derived animal products). Particularly when the impacts would be allocated to livestock, it would not be clear how much the trees contributed to their emissions. In addition, impacts from fertilisation or pesticide applications to the fruits would partially be allocated to the livestock products.

Therefore, we selected a different approach and assigned the trees to an individual plot based on the area they would influence with their crown size and management interventions. (Figure 2 B). By applying the calculation method proposed by Hemery et al. (2005) the area for each plot and tree type was estimated based on the diameter at breast height, the planting density and a tree species specific coefficient (with adoption of the most similar tree species when not directly available). In this way, tree area was modelled as a separate plot from the surrounding field and all management impacts as well as carbon estimations were allocated to the tree and closely surrounding grassland plot, while the rest of the grassland was not affected by the forestry.

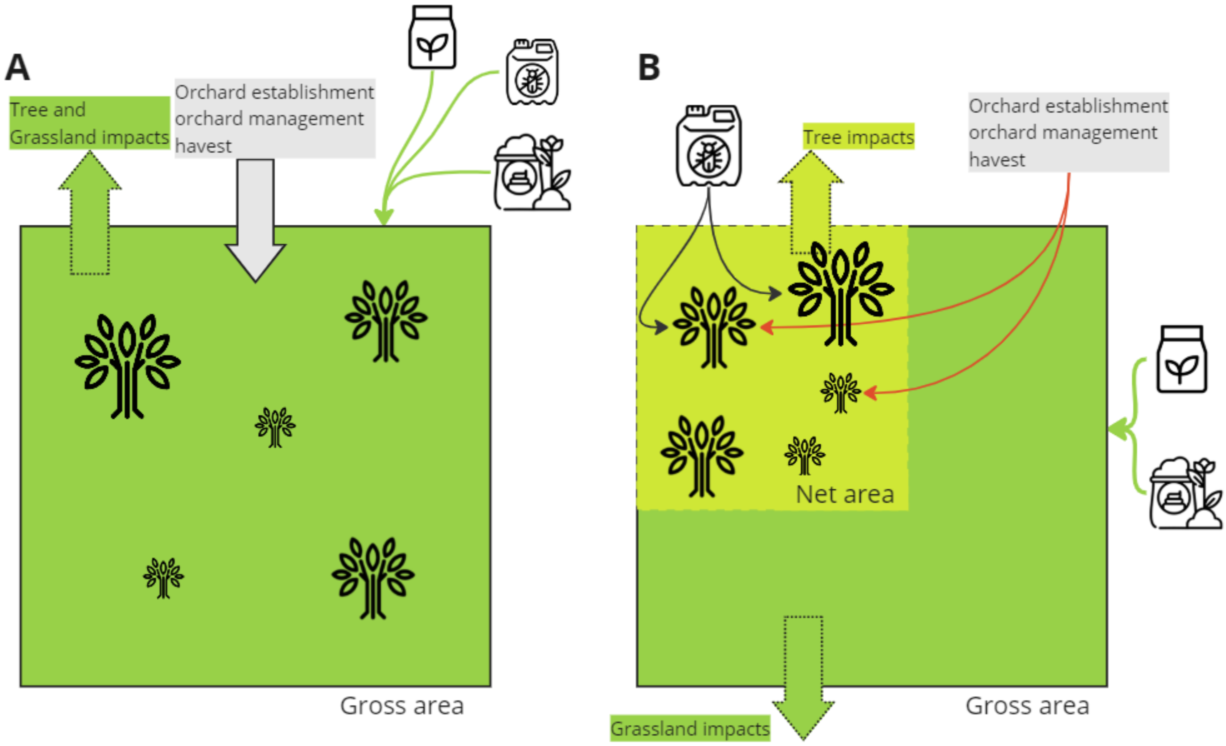


Figure 2 Allocation of environmental impacts of field management on mixed grassland and fruit trees. (A) per-plot approach: impacts are allocated physically or economically to both outputs (tree and grassland); (B) approach proposed by Hemery et al. (2005): impacts of tree-management (e.g. pesticide application) are allocated to trees only, net area of trees is calculated.

2.1.2.8 Economics

In addition to assessing the environmental impacts, the economic situation is also very important to the farmers. Therefore, to enable an assessment of the economic performance of the MiFAS, we used the economic assessment function of the FarmLCA model. It uses a background database that is aligned with the LCA input data, for example applying the costs of labour, diesel and other inputs to 1 hectare of ploughing, on the same basis as environmental impacts are applied.

The model utilises an adapted database from the German KTBL database (KTBL, 2024), which although developed for the German situation provides a reasonable representation for the majority of commercial scale farms within Europe. This approach also allows for farms from multiple counties to be grouped together without issues of costs differing due to local situations. The use of a single data source also allows for comparison beyond country or even farm specific values. This also allowed the data collection process to avoid asking the farmers economic questions which can be barriers to participation.

Gross margin calculations (partial net margins) based on outputs minus inputs were generated at a farm, plot and enterprise levels. Capital questions were avoided as these vary so considerably between farms, and these factors are considered elsewhere within the project.

2.1.2.9 Method for grouping farms for farm system comparison

As part of the task, we wished to compare the performance of different types of farm systems within the dataset. However, due to the wide diversity of farm systems between and within networks as well as geographical coverage we found that an assessment by network did not make sense. We therefore adopted a statistically based approach to cluster the farms from across all the networks into farm system type groups for comparison.

Following the analysis of farms within each network, a dataset of key characteristics and indicators for economics, environment and productivity were compiled. Within this dataset a two-step clustering procedure within IBM SPSS Statistics (Version 29) (IBM, 2023 was used, similarly to Milojevic et al., (2023), to find the natural clusters or groupings. The method allows for the use of both categorical and continuous variables and uses a combination of distance measure and clustering criterion to generate the groups (IBM, 2021). Using two binary parameters (livestock present, permanent crops present), and two continuous variables (proportion of UAA as field crops or permanent grasslands), farms were clustered.

2.1.2.10 Statistical methods for farm or enterprise level comparisons

To examine whether there are differences between the farm types represented within this dataset, each of the farms was sorted into its cluster and statistics undertaken. Initially, standard one-way ANOVA was undertaken, but tests for distribution and homogeneity of variances using Levene's test, (O'Neil & Matthews, 2002) were significant, indicating that the data may violate assumptions for ANOVA tests. To allow us to undertake comparison of clusters with these constraints, the more robust non-parametric test (Kruskall Wallis) was undertaken. This test uses a ranking method to determine differences between groups and allows both a test of significance and pairwise comparison to generate homogenous groups, as identified by the letters in subsequent tables within the results section.

2.1.3 Impact assessment phase

The impact assessment phase is presented in the results section. The results are presented for each farm per network, followed by and results by farm system type, that combines all the farm data and assigns the farms by type, for comparison. Furthermore, results are presented at an enterprise level for a limited number of crops and livestock.

2.1.3.1 Indicators to assess MiFAS performance.

To determine the performance of the MiFAS farms and enterprises studied within the networks we identified a number of key performance indicators. These key indicators include measures of farm characteristics, including aspects of nitrogen nutrient use, carbon dynamics, environmental impacts and economic performance:

- Farm characteristics:
    - Land area (farm size)
    - Type of land use, with proportions of crops, temporary forage, permanent grassland and permanent crops (orchards, biomass crops and agriculturally utilised forests)
    - Livestock units per farm, socking density and type of livestock
  - Nitrogen dynamics
    - Nitrogen inputs in the form of mineral and organic fertilisers, external feeds
    - Nitrogen outputs in the form of products
    - Overall nitrogen utilisation efficiency (NUE) as a ratio of outputs vs inputs (Oenema et al., 2015)
    - Nitrogen self-sufficiency for fertilisation (nutrient circularity)
  - Carbon dynamics

  - Soil carbon changes according to IPCC (2019) Tier 2 steady state method (only passive pool changes reported to avoid over-reporting of longer-term changes)
  - Above and below ground biomass carbon according to Cardinael et al. (2018)
- Environmental impacts based on the lifecycle impact assessment (LCIA) including selected ImpactWorld+ impact categories:
  - Climate change, short term (GWP100) as kgCO_2 equivalents
  - Fossil and nuclear energy (FNE) as MJ deprived
  - Mineral resource use (MRU) as kg deprived
  - Freshwater acidification (FAC) as kgSO_2 equivalents
  - Terrestrial acidification (TAC) as kgSO_2 equivalents
  - Freshwater eutrophication (FEU) as kgPO_4 equivalents
  - Marine eutrophication (MEU) as KgN equivalents
- Economics
  - Input costs (€)
  - Revenues (€)
  - Partial net margin (€) (Revenue minus direct costs excluding capital items)

As per current recommendations, all results are reported without the inclusion of soil carbon changes, unless explicitly mentioned, e.g. tables highlighting soil carbon dynamics.

2.1.4 Interpretation phase

The interpretation phase is presented in the subsequent discussion section. We discuss all phases of the analysis, including input data from the farms, methodological challenges, results at the network, system type and enterprise level, as well as making general conclusions from the work undertaken.

3 Results

The results section comprises the LCA impact assessment phase and is constructed to provide feedback for all farms within each network, followed by results of clustered system groups with more general analysis across the farms and networks, to enable assessment of factors related to mixed farms, such as internal nutrient flows.

3.1 Results at network level

Results for each network are presented for each network in turn, ordered as per network number within the project.

3.1.1 Network 2 (Denmark AU)

3.1.1.1 Network specifics

Within this network, multiple cropping, livestock and mixed farms are interacting to improve nutrient distribution, as well as avoiding some gaseous losses via biogas production and re-distribution of digestates.

The Danish farms were generally large and comprised of field cropping either as specialised arable farms, or with a combination of livestock, including pigs, dairy or beef (Table 2. None of the farms utilised agroforestry, except for a specialised crop of Christmas trees on one farm. Whilst the permanent grassland area was small within the farms, with only one farm comprising more than 5%, temporary grassland including forage crops was more widely utilised.

All of the farms had high nitrogen inputs, with most using a combination of mineral and organic fertilisers. Table 3 shows that Nitrogen self-sufficiency was quite varied but was also strongly influenced by the movement of manures and digestates between farms and biogas plants. Some of the farms with livestock were also importing very high amounts of nitrogen (and phosphorus) through feed. As an example, farm 1 is importing almost 428 kg of nitrogen per hectare within the pig feed imports. When the nitrogen exports and efficiency of the use of imported nitrogen, there are varying levels of performance. Farms 1, 2 and 7 show the lowest nitrogen efficiency, whilst some farms, such as farms 4 and 5 show a greater nitrogen output than external input.

Table 2 NW02 Farm characteristics

Variable	Unit	DK02_01	DK02_02	DK02_03	DK02_04	DK02_05	DK02_06	DK02_07	DK02_08	DK02_10	DK02_11	DK02_12
Farm system type		**ICL**	**ICL**	**SA**	**ICL**	**SA**	**ICL**	**ICL**	**ICL**	**ICL**	**ICL**	**ICLF**
Area	ha	848.	230.	19.5	496.4	68.4	413.2	203.4	162.3	28.6	13.1	158.7
Field crops	%	88%	69%	100%	78%	100%	87%	47%	100%	100%	98%	98%
Temporary forage	%	11%	28%	0%	4%	0%	13%	51%	0%	0%	0%	0%
Permanent grassland	%	1%	3%	0%	18%	0%	0%	1%	0%	0%	2%	1%
Permanent crops	%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
Livestock	LU	2234.48	264.09	0.00	399.48	0.00	311.32	278.19	146.50	14.47	1.55	0.00
Livestock density	LU/ha	2.63	1.15	0.00	0.80	0.00	0.75	1.37	0.90	0.51	0.12	0.00
Dairy cattle	%	0%	95%	-	85%	-	0%	97%	0%	0%	0%	-
Beef cattle	%	0%	5%	-	15%	-	0%	3%	0%	100%	100%	-
Pigs	%	100%	0%	-	0%	-	100%	0%	100%	0%	0%	-
Sheep, horses, llamas	%	0%	0%	-	0%	-	0%	0%	0%	0%	0%	-
Poultry	%	0%	0%	-	0%	-	0%	0%	0%	0%	0%	-

Table 3 NW02 Farm nitrogen dynamics

Variable	Unit	DK02_01	DK02_02	DK02_03	DK02_04	DK02_05	DK02_06	DK02_07	DK02_08	DK02_10	DK02_11	DK02_12
Nitrogen inputs (fertiliser and manure)	kg N/ha	152	203	164	75	108	134	133	149	157	167	100
N% as mineral N	%	58%	27%	100%	0%	58%	36%	42%	70%	75%	98%	63%
N% as organic N	%	42%	73%	0%	100%	42%	64%	58%	30%	25%	2%	37%
Imported fertiliser N	kg N/ha	122	201	164	53	108	89	126	129	119	163	100
Imported feed	kg N/ha	428	152	0	54	0	145	158	72	1	1	0
Nitrogen self-sufficiency	%	19%	1%	0%	30%	0%	34%	6%	13%	25%	2%	0%
Total imported N	kg N/ha	551	353	164	107	108	233	284	201	120	164	100
Crops sold	kg N/ha	99	23	148	91	146	129	16	35	91	112	101
Livestock sold	kg N/ha	106	61	0	32	0	39	75	73	1	1	0
Exported N in products	kg N/ha	205	84	148	123	146	168	91	108	92	113	101
External N utilisation	%	37%	24%	90%	115%	135%	72%	32%	53%	77%	69%	101%

3.1.1.2 Economics

All farms undertook the sale of crops, though the value of both sold and homegrown forage crops was quite variable between the farms, as shown in Table 4. Livestock costs and revenues were extremely variable between farms as some farms had no livestock, whilst others earnt most of their revenue from the livestock. The partial net margin varied from a loss of almost -€1000 up to a profit of +€1364 per hectare.

3.1.1.3 LCIA: Greenhouse gases and carbon dynamics

The results for GHGs shown in Table 5 indicate the large range in GHG impacts for the different farms. The range in emissions per hectare is extremely large and strongly influenced by the livestock on the farms. Use of the alternative functional unit of kilogram nitrogen did not change the results and showed farms 1, 2 and 7 to also have the greatest GHG emissions per kg N. The addition of soil carbon changes only increased the net emissions due to a slight soil carbon loss for all farms.

3.1.1.4 LCIA: Other environmental indicators

For the environmental impacts, Table 6 highlights that on a per hectare basis, farm number 1 created the greatest impacts for all indicators, due to its intensive use of fertiliser and especially externally sourced feed for the large pig enterprise. This farm is also the largest in the network, so these high impacts spread across a large area could cause widespread environmental damage. A second group of farms also has moderately high emissions for several indicators and comprises a mix of dairy and pig farms with cropping. The lowest emissions are from the cropping farms, and this is true whether the emissions are presented as per hectare or per kilogram of nitrogen exported from the farm.

Table 4 Economic performance for NW02

Variable	Unit	DK02_01	DK02_02	DK02_03	DK02_04	DK02_05	DK02_06	DK02_07	DK02_08	DK02_10	DK02_11	DK02_12
Revenue (sold crops)	€ ha^{-1}	1180	255	1194	2180	1093	1075	158	535	823	931	1025
Value (own use crops)	€ ha^{-1}	140	527	27	356	0	1	997	697	425	39	3
Total crop value	€ ha^{-1}	1321	781	1221	2536	1093	1076	1155	1232	1248	970	1028
Costs (crops)	€ ha^{-1}	1030	861	1198	1017	1294	1051	797	1169	888	1184	1082
Revenue (sold livestock)	€ ha^{-1}	4567	3711	0	2336	0	1673	4509	3135	64	68	0
Costs (livestock)	€ ha^{-1}	5448	3465	0	2491	0	2657	3819	3520	303	203	0
Farm partial net margin	€ ha^{-1}	-590	167	23	1364	-201	-960	1048	-322	121	-349	-54

Table 5 Environmental performance for NW02 for GHGs (GWP100) with and without soil and biomass carbon dynamics included

Dimension	Unit	DK02_01	DK02_02	DK02_03	DK02_04	DK02_05	DK02_06	DK02_07	DK02_08	DK02_10	DK02_11	DK02_12
No C dynamics	kg CO_{2e} ha^{-1}	37580	15351	3528	8987	3107	9445	16683	8821	5562	4663	2914
	kg CO_{2e} kg N^{-1}	184	182	24	73	21	56	183	82	60	41	29
With C dynamics	kg CO_{2e} ha^{-1}	37605	15435	3606	9054	3203	9549	16761	8910	5660	4754	3007
	kg CO_{2e} kg N^{-1}	184	183	24	74	22	57	184	83	61	42	30
Change with C dynamic added	%	0.07%	0.54%	2.19%	0.75%	3.00%	1.09%	0.46%	1.00%	1.74%	1.91%	3.11%

Table 6 Environmental performance for NW02 for energy (FNE), resource (MRU), acidification (FAC, TAC) and eutrophication (FEU, MEU)

IC	Unit (ha^{-1})	DK02_01	DK02_02	DK02_03	DK02_04	DK02_05	DK02_06	DK02_07	DK02_08	DK02_10	DK02_11	DK02_12
FNE	MJ dep	133780	57062	29236	39037	24781	64861	57950	52832	26894	32391	22118
MRU	kg dep	532	232	53	150	53	241	312	196	77	71	45
FAC	$kgSO_2eq$	2.1E-04	8.9E-05	3.9E-05	5.1E-05	4.7E-05	1.3E-04	7.9E-05	9.8E-05	4.0E-05	4.3E-05	3.8E-05
TAC	$kgSO_2eq$	0.29	0.16	0.05	0.09	0.09	0.20	0.13	0.15	0.05	0.05	0.07
FEU	$kgPO_4eq$	2.60	0.45	0.18	0.38	0.21	1.18	0.51	0.58	0.16	0.20	0.19
MEU	KgNeq	6.68	3.15	0.93	1.48	1.67	3.90	3.67	3.40	1.10	1.11	1.07
IC	**Unit (N^{-1})**											
FNE	MJ dep	653.81	676.61	197.23	318.53	169.59	386.21	637.20	490.96	291.75	286.96	219.50
MRU	kg dep	2.60	2.75	0.36	1.23	0.36	1.43	3.43	1.82	0.83	0.63	0.45
FAC	$kgSO_2eq$	1.0E-06	1.1E-06	2.6E-07	4.2E-07	3.2E-07	7.5E-07	8.7E-07	9.1E-07	4.3E-07	3.8E-07	3.7E-07
TAC	$kgSO_2eq$	1.4E-03	1.9E-03	3.1E-04	7.1E-04	6.2E-04	1.2E-03	1.5E-03	1.3E-03	5.3E-04	4.5E-04	6.8E-04
FEU	$kgPO_4eq$	0.013	0.005	0.001	0.003	0.001	0.007	0.006	0.005	0.002	0.002	0.002
MEU	KgNeq	0.033	0.037	0.006	0.012	0.011	0.023	0.040	0.032	0.012	0.010	0.011

FNE - Fossil and nuclear energy use, MRU - Mineral resources use, FAC - Freshwater acidification, TAC - Terrestrial acidification, FEU - Freshwater eutrophication, MEU- Marine eutrophication.

3.1.2 Network 4 (UK SRUC)

3.1.2.1 Network specifics

The UK network based in Scotland (Table 7), comprised 8 farms working within a network that was exploring collaboration through re-integration of livestock onto cropping farms. Whilst some farms already had livestock (farms 3, 6-8), others are specialist cropping system and they were testing the winter grazing of cereals by sheep. Some farms had tried this over, multiple years and were confident grazing winter crops over an extended period, others were just trialling the system, so the level of livestock integration within their system was limited, e.g. farms 4-5.

Overall, the farms were quite large with significant field cropping areas, whilst one farm also had extensive moorland grazing land (farm 7). Livestock system comprised either beef or sheep or both species, as is common in northern and western UK. Due to the size of the farms, even those with significant livestock numbers, still had relatively low stocking densities.

Table 7 NW04 Farm characteristics

Variable	Unit	UK04_01	UK04_02	UK04_03	UK04_04	UK04_05	UK04_06	UK04_07	UK04_08
Farm system type		**SA**	**SA**	**ICL**	**ICL**	**SA**	**ICL**	**SL**	**ICL**
Area	ha	286	231	402.37	378	370	364.74	6425.11	531.74
Field crops	%	100%	100%	70%	100%	100%	88%	10%	69%
Temporary forage	%	0%	0%	20%	0%	0%	8%	2%	10%
Permanent grassland	%	0%	0%	10%	0%	0%	4%	88%	22%
Permanent crops	%	0%	0%	0%	0%	0%	0%	0%	0%
Livestock	LU	0.00	0.00	231.22	5.82	0.18	104.21	711.47	310.80
Livestock density	LU/ha	0.00	0.00	0.57	0.02	0.00	0.29	0.11	0.58
Dairy cattle	%	-	-	0%	0%	0%	0%	0%	0%
Beef cattle	%	-	-	0%	0%	0%	98%	20%	99%
Pigs	%	-	-	0%	0%	0%	0%	0%	0%
Sheep, horses, llamas	%	-	-	100%	100%	100%	2%	80%	1%
Poultry	%	-	-	0%	0%	0%	0%	0%	0%

Nitrogen dynamics within the network, (Table 8), indicate quite a range (31-300kg N/ha) in nitrogen input as fertiliser. All farms used a mixture of mineral and organic fertilisers, but the mix was quite varied, with some farms also importing substantial volumes of bio-digestate (e.g. farm 4). The only farm with over 50% nitrogen self-sufficiency was the extensive farm 7, whilst 4 of the farms had imported all their nitrogen. Feed imports had little or no impact on total nitrogen imports. Whilst the quantity of nitrogen in exported product was greatest for farm 4, it's utilisation of externally sourced nitrogen was also the lowest of the group. Overall, the farm with the highest external nitrogen utilisation efficiency was the extensive farm 7, followed by farm 6. Both have significant livestock numbers and may demonstrate the value livestock have in producing nitrogen (protein) rich products from land that is otherwise of little agricultural value.

Table 8 NW04 Farm nitrogen dynamics

Variable	Unit	UK04_01	UK04_02	UK04_03	UK04_04	UK04_05	UK04_06	UK04_07	UK04_08
Nitrogen inputs (fertiliser and manure)	kg N/ha	152	146	228	300	187	120	31	146
N% as mineral N	%	82%	95%	58%	53%	85%	38%	22%	82%
N% as organic N	%	18%	5%	42%	47%	15%	62%	78%	18%
Nitrogen self-sufficiency	%	0%	0%	42%	1%	0%	14%	68%	18%
Imported fertiliser N	kg N/ha	152	146	133	298	187	104	10	120
Imported feed	kg N/ha	0	0	0	0	0	4	0	0
Total imported N	kg N/ha	152	146	133	298	187	107	10	120
Crops sold	kg N/ha	125	128	94	161	136	109	13	91
Livestock sold	kg N/ha	0	0	5	1	0	6	0	3
Exported N in products	kg N/ha	125	128	98	162	136	115	14	94
External N utilisation	%	82%	88%	74%	55%	73%	107%	136%	78%

3.1.2.2 Economics

Economically, the farms showed variable performance (Table 9), with half the farms showing a negative partial net margin, 3 breaking even, whilst farm 3 showed a very positive margin because of profits within both its cropping and livestock enterprises. Negative margins for farms 6 and 8 were due to losses within their livestock enterprises outweighing profits within the cropping enterprise.

Table 9 Economic performance for NW02

Variable	Unit	UK04_01	UK04_02	UK04_03	UK04_04	UK04_05	UK04_06	UK04_07	UK04_08
Revenue (sold crops)	€ ha^{-1}	1120	1044	984	1425	1266	1166	128	791
Value (own use crops)	€ ha^{-1}	0	0	133	7	0	154	69	159
Total crop value	€ ha^{-1}	1120	1044	1117	1431	1266	1320	197	950
Costs (crops)	€ ha^{-1}	1240	893	669	1485	1327	1055	117	771
Revenue (sold livestock)	€ ha^{-1}	0	0	1770	416	74	730	126	316
Costs (livestock)	€ ha^{-1}	0	0	1251	355	59	1244	195	783
Farm partial net margin	€ ha^{-1}	-120	151	967	8	-46	-249	10	-287

3.1.2.3 LCIA: Greenhouse gases and carbon dynamics

In terms of environmental impacts from the farming systems, Table 10 highlights the GHG emissions per hectare or per kg of nitrogen exported from the farm. The extensive cropping and hill farm 7 achieved the lowest impacts per hectare due to its significant land area, but when assessed per kg of nitrogen, the reverse was true, and its impacts were highest. Whilst the cropping farms generally had lower GHGs farm 4 had the highest overall GHGs per hectare but lower emissions per kg of nitrogen sold, in part due to livestock sales. Farms 3, 6 and 8 all had higher livestock numbers higher emissions for both functional units.

Table 10 Environmental performance for NW04 for GHGs (GWP100) with and without soil and biomass carbon dynamics included

Dimension	Unit	UK04_01	UK04_02	UK04_03	UK04_04	UK04_05	UK04_06	UK04_07	UK04_08
No C dynamics	kg CO_{2eq} ha^{-1}	3761	3555	7643	9203	4339	8343	1196	7938
	kg CO_{2eq} kg N^{-1}	30	28	78	57	32	73	88	85
With C dynamics	kg CO_{2eq} ha^{-1}	3819	3600	7703	9274	4413	8398	1211	8026
	kg CO_{2eq} kg N^{-1}	30	28	78	57	32	73	89	86
Change with C dynamic	%	1.50%	1.25%	3.70%	2.74%	2.49%	1.70%	1.24%	1.97%

3.1.2.4 LCIA: Other environmental indicators

For the non-GHG environmental impacts farm 4 had the highest values for all categories with the per hectare functional unit (Table 11). The extensive farm 7 also showed the lowest impacts per hectare, as per GHGs per hectare. The other farms all showed similar levels of fossil energy use, whilst farms 3, 6 and 8 with livestock tended to have slightly higher emissions for acidification and eutrophication impacts.

When assessed by impacts per kg nitrogen, farms 3, 4 and 8 tended to be highest whilst the cropping farms were lower.

Table 11 Environmental performance for NW04 for energy (FNE), resource (MRU), acidification (FAC, TAC) and eutrophication (FEU, MEU)

IC	Unit (ha^{-1})	UK04_01	UK04_02	UK04_03	UK04_04	UK04_05	UK04_06	UK04_07	UK04_08
FNE	MJ dep	33122	30420	31519	68086	35476	27061	3279	33403
MRU	kg dep	67	58	68	193	67	67	9	121
FAC	$kgSO_2eq$	6.0E-05	5.8E-05	8.5E-05	1.3E-04	6.7E-05	6.1E-05	7.2E-06	8.3E-05
TAC	$kgSO_2eq$	0.08	0.08	0.12	0.26	0.09	0.13	0.01	0.12
FEU	$kgPO_4eq$	0.20	0.19	0.26	0.50	0.19	0.25	0.16	0.23
MEU	KgNeq	1.43	1.51	2.24	4.32	1.65	2.01	0.21	3.01
IC	**Unit (N^{-1})**								
FNE	MJ dep	264.30	237.92	320.02	419.21	261.04	236.23	240.03	356.12
MRU	kg dep	0.54	0.45	0.69	1.19	0.49	0.58	0.64	1.29
FAC	$kgSO_2eq$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
TAC	$kgSO_2eq$	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
FEU	$kgPO_4eq$	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00
MEU	KgNeq	0.01	0.01	0.02	0.03	0.01	0.02	0.02	0.03

3.1.3 Network 5 (Germany)

3.1.3.1 Network specifics

Within this network, data for 4 farms was available for analysis (see Table 12). These farms collaborate to protect an area of peat organic soils in Germany. Formerly intensively farmed, each farm, now works together to protect the peat soils under permanent grassland. Due to the primary aim of peatland conservation, farming on the land is very extensive, and more focussed on soil protection than profits, therefore the results may be influenced by this. However, three of the farms also have non-peatland soil and grow arable and or forage crops.

Table 12 NW05 Farm characteristics

Variable	Unit	DE05_01	DE05_02	DE05_03	DE05_04
Farm system type		**ICL**	**ICL**	**SL**	**ICL**
Area	ha	31	77.5	65	107
Field crops	%	38%	46%	0%	70%
Temporary forage	%	36%	21%	0%	9%
Permanent grassland	%	26%	34%	100%	21%
Permanent crops	%	0%	0%	0%	0%
Livestock	LU	2.75	33.82	15.10	65.22
Livestock density	LU/ha	0.09	0.44	0.23	0.61
Dairy cattle	%	0%	0%	0%	0%
Beef cattle	%	0%	100%	100%	100%
Pigs	%	0%	0%	0%	0%
Sheep, horses, llamas	%	100%	0%	0%	0%
Poultry	%	0%	0%	0%	0%

Nitrogen imports were quite low within the network (Table 13), and mainly as fertiliser, with zero or very low levels of feed imports across the farms. Due to the low nitrogen imports and exports of products all farms show a nitrogen use efficiency above 100%, indicating high nitrogen use efficiency.

Table 13 NW05 Farm nitrogen dynamics

Variable	Unit	DE05_01	DE05_02	DE05_03	DE05_04
Nitrogen inputs (fertiliser and manure)	kg N/ha	73	65	23	106
N% as mineral N	%	52%	63%	0%	74%
N% as organic N	%	48%	37%	100%	26%
Nitrogen self-sufficiency	%	16%	0%	100%	26%
Imported fertiliser N	kg N/ha	61	65	0	78
Imported feed	kg N/ha	0	5	0	0
Total imported N	**kg N/ha**	**61**	**70**	**0**	**78**
Crops sold	kg N/ha	164	73	6	76
Livestock sold	kg N/ha	0	2	1	13
Exported N in products	kg N/ha	164	76	7	89
External N utilisation	**%**	**267%**	**108%**	**N/A**	**114%**

3.1.3.2 Economics

Only one of the farms showed a positive net margin (excluding any form of support payments), whilst the other three farms showed significant losses using the standardised cost data.

Table 14 Economic performance for NW05

Variable	Unit	DE05_01	DE05_02	DE05_03	DE05_04
Revenue (sold crops)	€ ha^{-1}	1007	482	12	638
Value (own use crops)	€ ha^{-1}	88	186	86	322
Total crop value	€ ha^{-1}	1094	667	98	959
Costs (crops)	€ ha^{-1}	822	536	145	879
Revenue (sold livestock)	€ ha^{-1}	0	229	90	1329
Costs (livestock)	€ ha^{-1}	0	646	408	1612
Farm partial net margin	€ ha^{-1}	185	-472	-452	-524

3.1.3.3 LCIA: Greenhouse gases and carbon dynamics

Network 5 is unique within the project as the farms assessed are focussed on reducing carbon emissions from the organic soils in their region. For this assessment, it is only possible to conduct a soil assessment using the IPCC organic soil values, which are shown in Table 15. Even under protective management nutrient rich peatlands can emit high levels of GHGs. The IPCC method used for this assessment predicts up to 740kg carbon per hectare per year can be lost as emissions to air or water, equivalent to 2.7 tonnes of CO_2per year and hectare. Furthermore, the forage products from this land have a very high emission, so any livestock products consuming this forage inherently have a high carbon footprint. This is further exacerbated when the livestock are of limited productivity and emit high levels of emissions per unit of product.

Table 15 Environmental performance for NW05 for GHGs (GWP100) with and without soil and biomass carbon dynamics included

Dimension		Unit	DE05_01	DE05_02	DE05_03	DE05_04
GHG (GWP100)	Only organic soil carbon dynamics	kg CO_{2eq} ha^{-1}	3542.90	10414.12	4469.45	7128.74
		kg CO_{2eq} kg N^{-1}	21.60	137.90	668.67	79.87

3.1.3.4 LCIA: Other environmental indicators

For the non-GHG environmental indicators (Table 16), three farms have much greater energy use, and we see a similar pattern for the other indicators per hectare. However, when the impact is assessed by the kilogram of nitrogen functional unit the low intensity farm 3 has the highest emissions, due to its very low output per hectare.

Table 16 Environmental performance for NW05 for energy (FNE), resource (MRU), acidification (FAC, TAC) and eutrophication (FEU, MEU)

Variable	Unit (x ha^{-1})	DE05_01	DE05_02	DE05_03	DE05_04
Fossil and nuclear energy use	MJ deprived	27533	26779	6602	33743
Mineral resources use	kg deprived	162	147	41	122
Freshwater acidification	kg SO_{2eq}	5.6E-05	5.0E-05	9.3E-06	5.1E-05
Terrestrial acidification	kg SO_{2eq}	0.08	0.07	0.01	0.06
Freshwater eutrophication	kg PO_{4eq}	0.45	0.39	0.15	0.34
Marine eutrophication	kg N_{eq}	1.27	1.13	0.14	1.41

Variable	Unit (x N^{-1})				
Fossil and nuclear energy use	MJ deprived	167.89	354.60	987.75	378.03
Mineral resources use	kg deprived	0.99	1.95	6.16	1.37
Freshwater acidification	kg SO_{2eq}	3.4E-07	6.6E-07	1.4E-06	5.8E-07
Terrestrial acidification	kg SO_{2eq}	4.8E-04	9.1E-04	1.4E-03	7.2E-04
Freshwater eutrophication	kg PO_{4eq}	0.00	0.01	0.02	0.00
Marine eutrophication	kg N_{eq}	0.01	0.01	0.02	0.02

3.1.4 Network 6 (Germany)

3.1.4.1 Network specifics

Data from three farms was collected in NW6. In terms of farm structure, the commonalities found in Table 17 were at least a small area covered by permanent crops (trees) and grassland. Farms 1 and 3 both have livestock: farm 1 keeps chicken with a rather high stocking density of 2.4 LU ha^{-1} while farm 3 has extensive dairy and beef cattle (0.8 LU ha^{-1}). The latter two are both growing field crops too, which are sold or used as feed for livestock on-farm.

Farm 2 is the smallest farm out of the three and is dominated by permanent grassland with orchard areas. At data collection times the trees were too young to yield any fruits yet. To assess the potential of the farm with biomass and orchard more adequately, however, we assumed the trees to already be older and yielding first fruits, even though still in low amounts.

Table 17 NW06 farm characteristics.

Variable	Unit	DE06_01	DE06_02	DE06_03
Farm system type		**ICLF**	**SA**	**ICLF**
Area	ha	10.0	4.0	141.1
Field crops	%	15.0	0.0	42.5
Temporary forage	%	60.0	0.0	32.6
Permanent grassland	%	14.3	99.9	23.8
Permanent crops	%	10.7	0.1	1.1
Livestock	LU	24.00	0.00	112.76
Livestock density	LU ha^{-1}	2.40	0.00	0.80
Dairy cattle	%	0	N/A	88
Beef cattle	%	0	N/A	12
Pigs	%	0	N/A	0
Sheep, horses, llamas	%	0	N/A	0
Poultry	%	100	N/A	0

In terms of nitrogen farms 1 and 3 differ considerably (Table 18). Farm 3 is fully self-sufficient for fertilisers since it only distributes manure from the dairy and beef herd. In addition, the farm can feed most of its livestock with on-farm forage (e.g. maize silage, grassland or legume crops). This is not the case for farm 1 which relies on external mineral fertilisers for field crops (pumpkin) but even more does not grow any crops than can be used as concentrate feed for the chicken herd. However, since the farms is rather productive it can still use 36% of the imported nitrogen directly for exported products. However, the risk of losses to the environment particularly through the chicken manure are rather high.

On the other hand, farm 3 risks to deplete its own nitrogen reserves, re-exporting more than 6 times as much nitrogen in products, as is imported.

For farm 2 no NUE could be calculated as there are no external imports of nitrogen in the current state. The exported nitrogen in the crops is, however, quite high and can be explained by the legume-based silage that is produced on farm and exported.

Table 18 NW06 nitrogen dynamics.

Variable	Unit	DE06_01	DE06_02	DE06_03
Nitrogen inputs (fertiliser and manure)	kg N ha^{-1}	14	0	36
N% as mineral N	%	63	N/A	0
N% as organic N	%	38	N/A	100
Nitrogen self-sufficiency	**%**	**0**	**N/A**	**100**
Imported fertiliser N	kg N ha^{-1}	14	N/A	0
Imported feed	kg N ha^{-1}	289	0	4
Total imported N	**kg N ha^{-1}**	**303**	**N/A**	**4**
Crops sold	kg N ha^{-1}	20	197	12
Livestock sold	kg N ha^{-1}	89	0	30
Exported N in products	**kg N ha^{-1}**	**109**	**197**	**42**
External N utilisation	**%**	**36**	**N/A**	**944**

3.1.4.2 Economics

Both farms 6 1 and 3 reach a positive net margin with 307 and 805 € ha^{-1} (Table 19). Farm one has high revenues but even higher costs from the chicken system. These stem mainly from the feed and bedding imports, followed by the costs for stall and infrastructure and costs of purchasing the young chicks. However, the farm is able to remediate these losses with income from sold permanent crops. It is to be stressed that the yields for these energy crops are estimates since currently the trees are too young and have not yet been harvested.

For farm 3 has a different livestock system and an overly efficient nutrient management with risk of mining and depleting on-farm resources. However, with the current productivity these low external inputs pay off and the farm can have positive margins for both the livestock as well as the crop sector.

Farm 2 manages to also have a positive partial net margin. Without significant imports the costs of the crop production are lower than the estimated revenues, leaving the farm with 61 € ha^{-1} margin per year.

Table 19 Economic performance for NW06

Variable	Unit	DE06_01	DE06_02	DE06_03
Value (sold crops)	€ ha^{-1}	286	205	272
Value (own use crops)	€ ha^{-1}	421	0	746
Total crop value	€ ha^{-1}	708	207	1019
Costs (crops)	€ ha^{-1}	203	144	524
Revenue (sold livestock)	€ ha^{-1}	6595	0	2063
Costs (livestock)	€ ha^{-1}	6792	0	1752
Farm partial net margin	€ ha^{-1}	307	61	805

3.1.4.3 LCIA: Greenhouse gases and carbon dynamics

When looking at the environmental performance in terms of GHG emissions the farms 1 and 3 have quite different results per hectare but very similar emission levels per kg N in exported products (Table 20). The first aspect is easily explained through the differing farm sizes – farm 1 is 14 times smaller than farm 3 and these total emissions are “concentrated” on the available 10 hectares. On the other hand, farm 1 has a higher productivity with regards to exported nitrogen per hectare. Therefore, less emissions occur per single kg of nitrogen exported (dilution effect).

Carbon estimations for farm 2 would not really affect the environmental performance. The rather low productivity, missing C inputs and few and young trees are not affecting the total GHG emissions.

Table 20 Environmental performance for NW06 for GHGs (GWP100) with and without soil and biomass carbon dynamics included

Dimension	Unit	DE06_01	DE06_02	DE06_03
No carbon dynamics	kg CO_{2eq} ha^{-1}	15345	581	5777
	kg CO_{2eq} kg N^{-1}	141	3	137
With carbon dynamics	kg CO_{2eq} ha^{-1}	14146	581	5595
	kg CO_{2eq} kg N^{-1}	130	3	133
Change with C dynamic	%	-8.47%	0.14%	-3.25%

Farm 1 could benefit from the carbon storage estimations. These could offset 7.8% of the GHG emissions without the inclusion of soil and biomass carbon storages. When looking at more detail it becomes clear that most positive changes in carbon are due to the temporary accumulation in tree biomass (+337.05 kg C a^{-1}). On the other hand, soil carbon changes only very little to even decrease by 15 kg C ha^{-1} in farm 3. This is due to the low inputs and yields from the grasslands and maize silage. Only the on-farm wheat and protein forage crops are able to build up some soil carbon and compensate for the losses of the other plots.

3.1.4.4 LCIA: Other environmental indicators

Looking further, substantial differences can be found in other impact categories (Table 21. These are seen particularly for mineral resource use and eutrophication related indicators, where farm 1 has clearly higher emissions than farm 3 both per hectare and per kg exported nitrogen. These differences can mostly be explained by the animal density on farm 1 and the very high imports and connected indirect emissions of feedstuff.

Being livestock-free farm 2 has clearly the lowest emissions throughout the network. Minor inputs and machinery processes for crop planting and harvesting are mainly responsible for the energy and mineral resource consumption.

Table 21 Environmental performance for NW06 for energy (FNE), resource (MRU), acidification (FAC, TAC) and eutrophication (FEU, MEU)

Variable	Unit (x ha^{-1})	DE06_01	DE06_02	DE06_03
Fossil and nuclear energy use	MJ deprived	110332	4670	18605
Mineral resources use	kg deprived	631	23	98
Freshwater acidification	kg SO_{2eq}	1.90E-04	4.80E-06	2.82E-05
Terrestrial acidification	kg SO_{2eq}	2.39E-01	4.06E-03	3.47E-02
Freshwater eutrophication	kg PO_{4eq}	4.48	1.38E-01	2.07E-01
Marine eutrophication	kg N_{eq}	4.23	5.83E-02	0.88

Variable	Unit (x N^{-1})	DE06_01	DE06_02	DE06_03
Fossil and nuclear energy use	MJ deprived	1012	24	441
Mineral resources use	kg deprived	5.79	1.18E-01	2.34
Freshwater acidification	kg SO_{2eq}	1.74E-06	2.44E-08	6.69E-07
Terrestrial acidification	kg SO_{2eq}	2.19E-03	2.06E-05	8.22E-04
Freshwater eutrophication	kg PO_{4eq}	4.11E-02	7.01E-04	4.90E-03
Marine eutrophication	kg N_{eq}	3.88E-02	2.96E-04	2.09E-02

3.1.5 Network 7 (Switzerland)

3.1.5.1 Network specifics

For network CH_07 seven case-study farms from Switzerland were available. All of them are part of a network growing high-stem fruit trees (see “Permanent crops” in Table 22), even though the degree of intensity and area coverage would vary greatly. Further heterogeneity was given from the practiced farming systems with farm 3 and 8 being organically certified, 5 and 6 not having any livestock on farm, while the other farms differ in animal type kept (mostly beef cattle, otherwise dairy cattle or pig). Another important characteristic is the share of arable land with field crops or temporary forage, which differs between farms with percentage cover ranging from 0% (farms 1, 4, 5) to 68% (farm 6).

Table 22 NW07 Farm characteristics.

Variable	Unit	CH07_02	CH07_03	CH07_04	CH07_05	CH07_06	CH07_07	CH07_08
Farm system type		ICLF	ICLF	ICLF	ICLF	ICLF	ICLF	ICLF
Area	ha	14.6	33.17	24.2	7.595	34.04	29.9	20.43
Field crops	%	0	29	0	0	53	46	26
Temporary forage	%	0	27	0	0	15	5	13
Permanent grassland	%	94	39	98	24	30	27	56
Permanent crops	%	6	6	2	76	2	22	5
Livestock	LU	44.07	21.00	63.63	0.00	0.00	29.11	21.89
Livestock density	LU ha^{-1}	3.02	0.63	2.63	0.00	0.00	0.97	1.07
Dairy cattle	%	0	0	65	N/A	N/A	0	0
Beef cattle	%	100	100	6	N/A	N/A	100	100
Pigs	%	0	0	29	N/A	N/A	0	0

With regards to nitrogen use and dynamics again a wide range of values can be observed between the network farms. Only the organic farms 3 and 8 do not apply any mineral fertiliser (Table 23).

However, the proportion of mineral fertiliser out of total fertilisers applied varies from a maximum of 81% (farm 6) to 4% (farm 5). The rest is covered by various types of organic N which can be both from on-farm livestock or external sources.

Table 23 NW07 Farm nitrogen dynamics

Variable	Unit	CH07_02	CH07_03	CH07_04	CH07_05	CH07_06	CH07_07	CH07_08
Nitrogen inputs (fertiliser and manure)	kg N ha^{-1}	86	35	264	104	176	120	123
N% as mineral N	%	15	0	31	4	81	17	0
N% as organic N	%	85	100	69	96	19	83	100
Fertiliser N self-sufficiency	%	85	94	69	0	5	83	89
Imported fertiliser N	kg N ha^{-1}	13	2	81	104	168	21	13
Imported feed	kg N ha^{-1}	84	4	200	0	0	0	0
Total imported N	kg N ha^{-1}	97	6	281	104	168	21	13
Crops sold	kg N ha^{-1}	2	19	0	36	92	28	15
Livestock sold	kg N ha^{-1}	9	5	128	0	0	5	4
Exported N in products	**kg N ha^{-1}**	**11**	**24**	**129**	**36**	**92**	**33**	**19**
External N utilisation	%	16	427	46	35	55	159	141

The presence of livestock increased the nitrogen self-sufficiency for fertilisation to well above 70%, whereas it does not seem to be correlated with the stocking density (Figure 3). Another important aspect was the nitrogen found in feedstuff, which contributes to the farm nitrogen use efficiency (external N utilisation). Farms 2-4 are the only ones importing feed, with farm 4 being the highest. This is due to the high livestock density including dairy and beef cattle herd and pigs as well as the availability of only grass forage, which may require the import of more concentrated feed. Despite these high imports the NUE of the farm is 46%, farm 2 and farm 5 being clearly lower with 11% and 35% respectively. Products from livestock are denser in nutrients, particularly N-containing proteins. Farm 4 has the highest production and export of these products of all farms and can thus re-export a fair amount of imported nitrogen, while farms 2 and 5 have low or no (livestock) product exports and cannot use the imported N very efficiently.

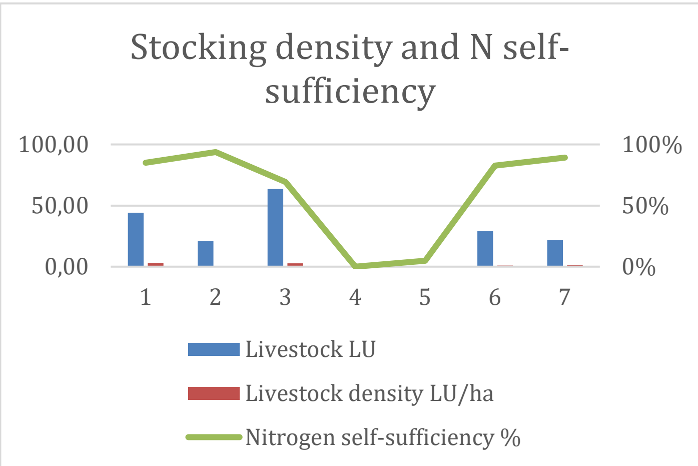


Figure 3 Livestock units, livestock density and nitrogen self-sufficiency as recorded on the seven network farms in NW07.

3.1.5.2 Economics

In terms of economic performance, the heterogeneity of the farms in the network prevails (Table 24). Partial net margins range from -1632 to 2607 € ha^{-1}. Reasons for this variability do not necessarily lie in the type of enterprise (revenue from sold crops or livestock), the farm size or previously presented resource efficiency indicators. They seem rather a farm-specific phenomenon which results from a combination of all the before mentioned factors. Farm 4 has the highest revenues from livestock, but these seem to be widely outweighed by the costs which are due to housing costs and substantial feed imports for dairy cattle, beef cattle and pigs on farm. At the same time the farm does not sell many crop products, whilst farms 5 and 6 do not have any livestock, but their management and intensity of the crop and orchard production differ in a way that make farm 5 the most profitable farm, while farm 6 is amongst the lowest performing ones. In this case the type of produced fruits (mixed stone fruits in 5 and walnuts and stone fruits in 6) as well as the yields per tree are important factors (farm 5 has the highest yields in the network).

Table 24 Economic performance for NW07

Variable	Unit	CH07_02	CH07_03	CH07_04	CH07_05	CH07_06	CH07_07	CH07_08
Revenue (sold crops)	€ ha^{-1}	300	1543	35	4286	856	1663	378
Value (own use crops)	€ ha^{-1}	587	561	522	9	0	1347	456
Total crop value	€ ha^{-1}	886	2104	556	4295	856	3010	834
Costs (crops)	€ ha^{-1}	234	430	367	1688	971	2273	344
Revenue (sold livestock)	€ ha^{-1}	1339	610	6863	0	0	560	525
Costs (livestock)	€ ha^{-1}	3623	1215	6666	0	0	465	258
Farm partial net margin	€ ha^{-1}	-1632	1070	386	2607	-115	832	757

3.1.5.3 LCIA: Greenhouse gases and carbon dynamics

Once more, the farms' performance was heterogeneous also with regards to the climate change impact (GWP100) as calculated in the life cycle impact assessment (LCIA) and shown on Table 25. Carbon estimations for farm 2 would not really affect the environmental performance. The rather low productivity, missing C inputs and few and young trees are not affecting the total GHG emissions. The results can be shown both including the organic carbon storage in (tree) biomass and soil and without these carbon dynamics. This representation shows potential carbon offsets through accumulation of carbon in biomass and soil.

Without the inclusion of carbon dynamics, farms 2 and 4 have the highest GHG emissions per ha with over 70% higher emissions than farm 3, which is third ranked. This is due to the high livestock density, particularly for dairy and beef cattle on this farm. When looking at the emissions per kg of nitrogen in exported product, the results change a little bit. While farm 2 leads far off with 1721 kg CO_{2eq} kg N^{-1} farms 3, 4, 7 and 8 are quite close with emissions between 232-350 kg CO_{2eq} kg N^{-1}. Farms 5 and 6 have no livestock and, thus, the lowest emissions both per area and per product.

Table 25 Environmental performance for NW07 for GHGs (GWP100) with and without soil and biomass carbon dynamics included

Variable	Unit	CH07_02	CH07_03	CH07_04	CH07_05	CH07_06	CH07_07	CH07_08
no carbon dynamics	kg CO_{2eq} ha^{-1}	27216	8583	30265	1689	3643	8237	5972
	kg CO_{2eq} kg N^{-1}	1752	352	235	47	39	250	318
with carbon dynamics	kg CO_{2eq} ha^{-1}	26738	8538	29979	-8022	3242	7647	5379
	kg CO_{2eq} kg N^{-1}	1721	350	233	-224	35	232	287
Change with C dynamic	%	-1.8%	-0.5%	-0.95%	-121%	-12.4%	-7.7%	-11.0%

The carbon dynamics add some more variability to the results. The stored carbon in both trees and soils can compensate the GHG emissions to various degrees ranging from 1-121% of emissions compensated. The median reduction of emissions through carbon storage accumulation is 7.2%.

This value fits for most farms, while farm 5 is a clear outlier in the network. The farm has no livestock and a more intensive high stem orchard system. The biomass accumulated in though trees is assumed to be particularly high for trees up to 20 years.

When looking at the soil dynamics in more detail the carbon inputs of various crop types can be analysed. Compared to the biomass, the long-term carbon storage is quite static and only small changes are seen, for example for temporary grassland in farms 3, 6 and 7, where 2-3 kg C are lost per hectare and year. Farm 5 has an overall negative farm soil C balance, where on average 15 kg C per year and hectare are lost. Extensively managed and low-yielding grassland can easily lose carbon and result in a negative balance.

3.1.5.4 LCIA: Other environmental indicators

With regards to the performance of the farms for other environmental indicators, results are shown per hectare and per kg of exported nitrogen (Table 26). The main categories where farms would create environmental impacts on a per hectare unit are “Fossil and nuclear energy use”, “Mineral resource use” and “Marine eutrophication”. Smaller impacts were also estimated for “Freshwater acidification”, “Terrestrial acidification” and “Freshwater eutrophication”, whereas farms 4 and 7 would have the highest impacts. This could be due to the higher livestock density in farm 4 and the mechanical harvest that was used in farm 7.

Table 26 Environmental performance for NW07 for energy (FNE), resource (MRU), acidification (FAC, TAC) and eutrophication (FEU, MEU)

Variable	Unit (x ha^{-1})	CH07_02	CH07_03	CH07_04	CH07_05	CH07_06	CH07_07	CH07_08
Fossil and nuclear energy use	MJ deprived	57634	15927	90169	9101	27188	22189	14516
Mineral resources use	kg deprived	346	86	452	21	81	114	89
Freshwater acidification	kg SO_{2eq}	2.09E-02	2.99E-05	1.95E-04	1.21E-03	3.25E-03	5.24E-01	2.39E-05
Terrestrial acidification	kg SO_{2eq}	1.49E-01	4.09E-02	2.82E-01	4.11E-02	1.44E-01	6.13E-01	3.00E-02
Freshwater eutrophication	kg PO_{4eq}	4.47E-01	2.23E-01	1.54E+00	1.71E-01	1.66E-01	1.84E-01	1.76E-01
Marine eutrophication	kg N_{eq}	3.91	1.11	6.06	0.57	3.28	1.71	0.70

Variable	Unit (x N^{-1})	CH07_02	CH07_03	CH07_04	CH07_05	CH07_06	CH07_07	CH07_08
Fossil and nuclear energy use	MJ deprived	3709.06	652.37	699.78	254.59	294.80	672.59	773.15
Mineral resources use	kg deprived	22.25	3.52	3.51	0.58	0.88	3.47	4.77
Freshwater acidification	kg SO_{2eq}	1.34E-03	1.23E-06	1.51E-06	3.39E-05	3.52E-05	1.59E-02	1.27E-06
Terrestrial acidification	kg SO_{2eq}	9.60E-03	1.67E-03	2.19E-03	1.15E-03	1.56E-03	1.86E-02	1.60E-03
Freshwater eutrophication	kg PO_{4eq}	2.88E-02	9.12E-03	1.19E-02	4.79E-03	1.80E-03	5.58E-03	9.40E-03
Marine eutrophication	kg N_{eq}	0.25	0.05	0.05	0.02	0.04	0.05	0.04

Amongst the main drivers for the fossil fuel consumption was the livestock density (Figure 4). The smaller spike in farm 6 can be explained with the comparably high mineral fertiliser import, which has a high energy demand for production. The latter is also reflected in the mineral resource use, which is fourfold the impact of the also livestock-free farm 5.

When looking at the impacts per product slightly different results can be seen. The differences for most impact categories are less pronounced. A rather clear distinction can be made between mixed farms with and without livestock. An outlier in this category is farm 2. The farm has clearly the highest impacts due to the comparably higher intensity of beef cattle farming. No crop products for export are produced on farm. The rather low productivity leads to higher impacts per kg of N in exported products.

Another aspect of interest is the environmental performance of organic farms within the network. Farm 3 and 8 have lower impact levels than comparable enterprises like farm 2, 4 or 8 for most categories. Less external imports of livestock feed, mineral fertilisers, no pesticide application and ideally a better nutrient management would be the key drivers for this result.

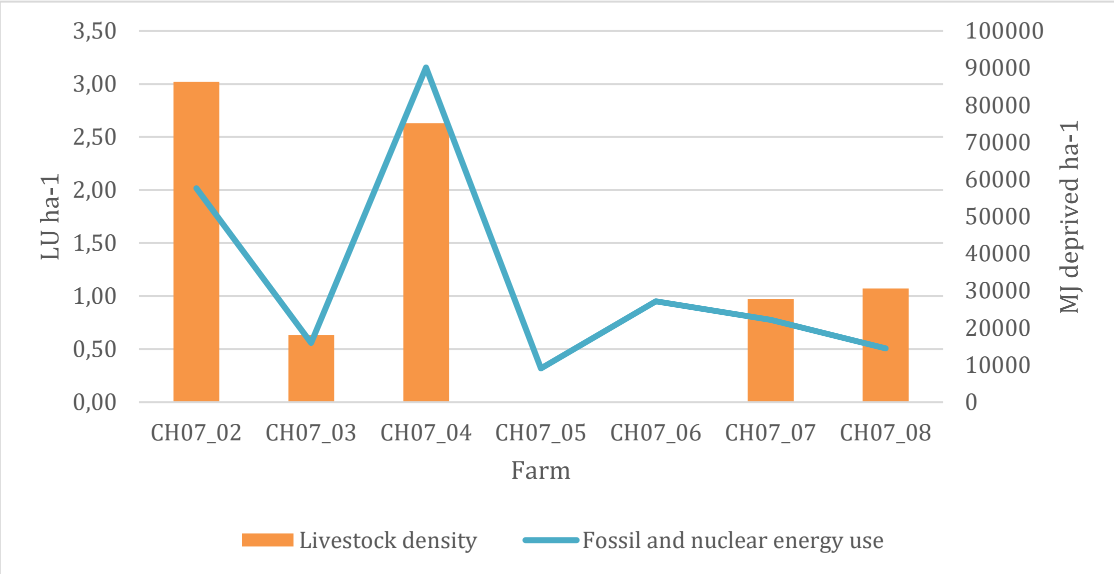


Figure 4 The livestock density (orange bars) and impact category “Fossil and nuclear energy use” (blue line) are plotted together to highlight possible relationships.

3.1.6 Network 9 (France)

3.1.6.1 Network specifics

For the French network 9 (NW9) data from seven farms was collected. They all had a free-range pig system in common (see livestock section of Table 27), where the animals would roam freely on pasture and forests and partially feed on the forest products (i.e. acorns). The farms have an area of forest and grassland (permanent crops) which covers 1-100% of the farm’s areas. What is not covered by tree areas is mostly permanent grassland, which can also be used as pasture. An exception within the network is farm 5 which has a high area coverage of arable crops (89%).

While all farms have only pigs as livestock in the modelled system the stocking density varies considerably between 0.07-2.89 LU ha^{-1}.

Farms 1, 3, 5 and 7 are certified organic, which is another aspect of interest for later discussions.

Table 27 NW09 Farm characteristics.

Variable	**Unit**	**FR09_01**	**FR09_02**	**FR09_03**	**FR09_04**	**FR09_05**	**FR09_06**	**FR09_07**
Farm system type		**ICLF**	**ICLF**	**ICLF**	**ICLF**	**ICLF**	**ICLF**	**ICLF**
Area	ha	5.0	6.8	6.5	3.5	27.3	11	6.0
Field crops	%	0	0	0	0	83	91	0

Temporary forage	%	0	0	0	0	0	0	0
Permanent grassland	%	20	78	0	0	0	0	83
Permanent crops	%	80	22	100	100	17	9	17
Livestock	LU	13.23	14.00	11.40	10.11	3.70	7.22	10.11
Livestock density	LU ha^{-1}	2.65	2.07	1.75	2.89	0.14	0.66	1.69
Dairy cattle	%	0	0	0	0	0	0	0
Beef cattle	%	0	0	0	0	0	0	0
Pigs	%	100	100	100	100	100	100	100
Sheep, horses, llamas	%	0	0	0	0	0	0	0
Poultry	%	0	0	0	0	0	0	0

Details on the nitrogen management of the network farms is shown on Table 28 below. All farms are self-sufficient in terms of nitrogen fertiliser which they retrieve from their livestock. The amount of distributed nitrogen varies and seems related to the stocking density, as fields are only fertilised through direct deposition by the animals during pasture.

All nitrogen imports for the farms stem from the pig feed which all farms retrieve from similar providers in the area. Farms 5 and 6 are the only ones with arable area where they grow cereals and legumes as feed. Surplus farm-grown feed was assumed to be sold and which is reflected in the nitrogen use efficiency, even though it might not necessarily reflect the reality of the farms, since feed could for example be stored for subsequent years. However, farms 5 and 6 were the most efficient in terms of nitrogen management, since they relied on little external inputs. Due to the extended farm size and share of arable area they were still able to produce a significant amount of on-farm feed to cover the needs of the pigs.

In contrast farms 1-4, which all have a very similar profile in terms of size, land use, stocking density and feed import, could not use the imported nitrogen in feed very efficiently, with only 13.5% of the imported nitrogen exported again in livestock products. These farms do not produce any crop products for export.

Table 28 NW09 Nitrogen dynamics.

Variable	**Unit**	**FR09_01**	**FR09_02**	**FR09_03**	**FR09_04**	**FR09_05**	**FR09_06**	**FR09_07**
Nitrogen inputs (fertiliser and manure)	kg N ha^{-1}	165	141	141	162	11	37	94
N% as mineral N	%	0	0	0	0	0	0	0
N% as organic N	%	100	100	100	100	100	100	100
Fertiliser N self-sufficiency	%	100	100	100	100	100	100	100
Imported fertiliser N	kg N ha^{-1}	0	0	0	0	0	0	0
Imported feed	kg N ha^{-1}	411	329	309	434	5	62	258
Total imported N	kg N ha^{-1}	411	329	309	434	5	62	258
Crops sold	kg N ha^{-1}	0	0	0	0	31	20	0
Livestock sold	kg N ha^{-1}	66	50	39	61	3	13	41
Exported N in products	**kg N ha^{-1}**	**66**	**50**	**39**	**61**	**34**	**33**	**41**
External N utilisation	%	16	15	13	14	653	53	16

3.1.6.2 Economics

In economic terms the farms in NW9 perform quite differently, with partial net margins ranging from -5631 to 28 € ha^{-1} (Table 29). Due to decisions taken at data collection stages, farm specific economic data was not collected. Thus, the revenues from sold pig meat here follows the standard values used throughout all modelled networks. However, it is to be assumed, that extensive free-range system, linked to a cooperative marketing society, such as NW9 would have higher revenues from sold products, which would benefit the margins of more intensive farms like 1-4. The main result from the economics is the potential of on-farm feed with regards to the achievable margin. Particularly for organic farms, where feed prices are assumed to be higher than the conventional ones, being independent of these inputs can make a difference. For example, farm 5 has the highest margin. The second important cost point for livestock is housing and infrastructure, which on average makes 20% of total costs for the present pig systems.

Table 29 Economic performance for NW09

Variable	Unit	FR09_01	FR09_02	FR09_03	FR09_04	FR09_05	FR09_06	FR09_07
Revenue (sold crops)	€ ha^{-1}	80	22	25	23	374	178	4
Value (own use crops)	€ ha^{-1}	113	68	92	141	259	654	148
Total crop value	€ ha^{-1}	193	91	116	164	632	832	152
Costs (crops)	€ ha^{-1}	90	24	45	42	493	571	3990
Revenue (sold livestock)	€ ha^{-1}	6341	2125	3637	2621	270	618	71
Costs (livestock)	€ ha^{-1}	11835	5906	8864	8373	381	2754	7741
Farm partial net margin	€ ha^{-1}	-5391	-3714	-5155	-5631	28	-1969	-3670

3.1.6.3 LCIA: Greenhouse gases and carbon dynamics

The results for the main performance indicator, GHG emissions, highlights the potential for mixed crop and livestock farms, with lower stocking densities and some crop production for the overall farm emissions, but also for the emissions per kg of N in products (Table 30). Farms 5 and 6 all export both crop and livestock products, whereas farms 1-4 and 7 are mainly relying on livestock products for income.

Table 30 Environmental performance for NW09 for GHGs (GWP100) with and without soil and biomass carbon dynamics included

Dimension	Unit	FR09_01	FR09_02	FR09_03	FR09_04	FR09_05	FR09_06	FR09_07
No carbon dynamics	kg CO_{2eq} ha^{-1}	15526	14641	11319	22240	884	4166	8892
	kg CO_{2eq} kg N^{-1}	234	295	292	365	26	126	215
With carbon dynamics	kg CO_{2eq} ha^{-1}	15468	14655	11298	20332	877	3907	8651
	kg CO_{2eq} kg N^{-1}	233	295	291	333	26	119	209
Change with C dynamic	%	-0.37%	0.09%	-0.19%	-9.38%	-0.83%	-6.63%	-2.79%

In terms of organic carbon storage the farms' performances do not differ a lot when comparing net GHG emissions with and without on-farm carbon calculations. On one hand, the conservative approach taken for soil carbon Tier 2 estimations allows for some C storage change due to management and crop residues, but it is always marginal when compared to the emissions from the import-dependent livestock system.

On the other hand, the biomass estimations (Tier 1) account for biomass accumulation of trees particularly in their first 20 years. Since most forest pastures in NW9 had been established up to 75 years ago, it is assumed that not much more biomass carbon will be added on a yearly basis anymore. The only exception in this network is farm 4 where the average tree age is around 8 years and leads to potential yearly biomass storage increase of 514.5 kg of carbon. This would offset 8.6% of yearly GHG emissions of the farm.

3.1.6.4 LCIA: Other environmental indicators

The livestock system is responsible for most of the differences between the farms and similar observations as with the GHG emissions can be made: The more extensive and self-sufficient farms 5 and 6 have clearly better performances in all environmental impact categories in Table 31.

Table 31 Environmental performance for NW09 for energy (FNE), resource (MRU), acidification (FAC, TAC) and eutrophication (FEU, MEU)

Variable	Unit (x ha^{-1})	FR09_01	FR09_02	FR09_03	FR09_04	FR09_05	FR09_06	FR09_07
Fossil and nuclear energy use	MJ deprived	153374	146041	111263	224447	9312	36426	75164
Mineral resources use	kg deprived	674	566	444	815	41	189	546
Freshwater acidification	kg SO_{2eq}	4.76E-04	3.17E-04	3.66E-04	4.57E-04	1.76E-05	7.26E-05	2.30E-04
Terrestrial acidification	kg SO_{2eq}	6.81E-01	4.09E-01	5.23E-01	5.74E-01	2.33E-02	1.00E-01	3.37E-01
Freshwater eutrophication	kg PO_{4eq}	2.58E+00	2.02E+00	1.80E+00	2.82E+00	1.58E-01	7.44E-01	2.06E+00
Marine eutrophication	kg N_{eq}	9.83	6.14	7.58	8.53	0.35	1.61	5.05

Variable	Unit (x N^{-1})	FR09_01	FR09_02	FR09_03	FR09_04	FR09_05	FR09_06	FR09_07
Fossil and nuclear energy use	MJ deprived	2311.88	2940.30	2868.25	3678.85	272.75	1105.01	1814.75
Mineral resources use	kg deprived	10.17	11.39	11.44	13.36	1.20	5.72	13.18
Freshwater acidification	kg SO_{2eq}	7.18E-06	6.37E-06	9.43E-06	7.49E-06	5.17E-07	2.20E-06	5.56E-06
Terrestrial acidification	kg SO_{2eq}	1.03E-02	8.24E-03	1.35E-02	9.41E-03	6.82E-04	3.04E-03	8.13E-03
Freshwater eutrophication	kg PO_{4eq}	3.89E-02	4.06E-02	4.63E-02	4.62E-02	4.63E-03	2.26E-02	4.98E-02
Marine eutrophication	kg N_{eq}	0.15	0.12	0.20	0.14	0.01	0.05	0.12

Interesting is a comparison between Farm 3 and 7 which have a similar stocking density but different pig and feeding system in place. While farm 3 has a sow and finishing pig system, farm 7 has only finishing pig system. Further, feeding regimes are rather different both in terms of daily amount fed as also the composition of the feed. For GHG and fossil energy use farm 7 performs clearly better and seems to be more efficient also in economic terms. However, farm 3 has a lower mineral resource usage and performs a little better in the impact category of freshwater eutrophication. This heterogeneity highlights the potential to improve the environmental performance of an enterprise by various structural and management changes which at first sight do not always seem obvious in such assessments.

3.1.7 Network 10 (France)

3.1.7.1 Network specifics

Within this network, data for 7 farms was available for analysis (see Table 32). The farms were selected as they form part of a farm network that is engaged in exchanges of materials between farms, however for the analysis in WP5, each farm is assessed as an individual unit.

The farms were quite variable, ranging from 100% cropping farms (specialist arable – SA) without livestock, such as farms 5 and 7, through to upland livestock farms with mainly permanent pasture such as farms 2, 3 and 4 (specialist livestock – SL). Only one farm type was mixed (integrated crops and livestock – ICL). The most common livestock type was cattle, with farm 4 also keeping sheep, whilst farm 6 collaborated with a livestock farm to provide winter crop grazing.

Table 32 NW10 Farm characteristics

Variable	**Unit**	**FR10_01**	**FR10_02**	**FR10_03**	**FR10_04**	**FR10_05**	**FR10_06**	**FR10_07**
Farm system type		**ICL**	**SL**	**SL**	**SL**	**SA**	**SA**	**SA**
Area	ha	298.98	254.63	193.26	174.2	124.46	222.85	135.55
Field crops	%	41	0	0	0	55	88	100
Temporary forage	%	23	2	0	0	41	11	0
Permanent grassland	%	36	98	100	100	5	1	0
Permanent crops	%	0	0	0	0	0	0	0
Livestock	LU	154.83	57.87	102.56	140.34	0.00	1.21	0.00
Livestock density	LU/ha	0.52	0.23	0.53	0.81	0.00	0.01	0.00
Dairy cattle	%	47	0	0	0	N/A	0	N/A
Beef cattle	%	53	100	100	30	N/A	0	N/A
Pigs	%	0	0	0	0	N/A	0	N/A
Sheep, horses, llamas	%	0	0	0	70	N/A	100	N/A
Poultry	%	0	0	0	0	N/A	0	N/A

Within the network, nitrogen imports and dynamics were high variable between the farms due to their differing nature. The SA farms mainly relied on external mineral nitrogen inputs, whilst the SL farms relied mainly on nitrogen from manures. Farms 1 and 5 utilised more of a mix, either from their own livestock manure or imported organic nitrogen. The livestock farms imported some or all of their nitrogen via externally sourced feeds. When looking at the nitrogen exports the highest nitrogen exports per hectare were achieved by cropping systems, with low nitrogen exports on the extensive specialist livestock farms. The efficiency of the use of externally sourced nitrogen is assessed as a ratio of nitrogen exported to nitrogen imported.

Table 33 NW10 Farm nitrogen dynamics

Variable	**Unit**	**FR10_01**	**FR10_02**	**FR10_03**	**FR10_04**	**FR10_05**	**FR10_06**	**FR10_07**
Nitrogen inputs (fertiliser and manure)	kg N/ha	107	8	24	43	91	132	167
N% as mineral N	%	62	0	0	0	73	100	100
N% as organic N	%	38	100	100	100	27	0	0
Nitrogen self-sufficiency	%	38	100	100	100	27	0	0
Imported fertiliser N	kg N/ha	66	0	0	0	67	132	167
Imported feed	kg N/ha	21	3	53	10	0	0	0
Total imported N	kg N/ha	87	3	53	10	67	132	167
Crops sold	kg N/ha	23	0	0	0	122	60	98
Livestock sold	kg N/ha	12	1	3	3	0	1	0
Exported N in products	**kg N/ha**	**35**	**1**	**3**	**3**	**122**	**61**	**98**
External N utilisation	%	40	30	6	32	183	46	59

3.1.7.2 Economics

In terms of economics Table 34 indicates how the farms show a high level of diversity, but the tend is a negative margin of approximately -300 to -500 Euros per hectare. In terms of revenue, crop sales are greatest for SA farms 5, 6 and 7, whilst the SL farms only generate forage or feed for their own use. Farm 1, as an ICL is mixed and generates significant sales for both crop and livestock.

Table 34 Economic performance for NW10

Variable	Unit	FR10_01	FR10_02	FR10_03	FR10_04	FR10_05	FR10_06	FR10_07
Revenue (sold crops)	€ ha^{-1}	212	0	4	0	767	604	1035
Value (own use crops)	€ ha^{-1}	308	126	102	218	0	4	0
Total crop value	€ ha^{-1}	520	126	106	218	767	608	1035
Costs (crops)	€ ha^{-1}	663	53	26	72	1083	1221	1467
Revenue (sold livestock)	€ ha^{-1}	849	103	285	1148	0	290	0
Costs (livestock)	€ ha^{-1}	1102	199	920	1055	0	204	0
Farm partial net margin	€ ha^{-1}	-396	-23	-555	239	-315	-527	-432

3.1.7.3 LCIA: Greenhouse gases and carbon dynamics

The farms were assessed with and without the inclusion of carbon dynamics modelling. Table 35 shows that with the inclusion of the most conservative soil carbon passive pool values, there was very little difference in the results with or without inclusion of the soil carbon changes. All farms showed a slight soil carbon loss, increasing the GHG emissions as CO_2.

When using the alternative functional unit of 1 kg nitrogen, the GHG emissions were considerably lower for the SA farms than the SL farms, with the only ICL farm in this network at an intermediate level. Whilst this functional unit also has drawbacks it provides an indication of the GHGs produced in the generation of 1 kilogram of nitrogen.

Table 35 Environmental performance for NW10 for GHGs (GWP100) with and without soil and biomass carbon dynamics included

Dimension	Unit	FR10_01	FR10_02	FR10_03	FR10_04	FR10_05	FR10_06	FR10_07
No carbon dynamics	kg CO_{2eq} ha^{-1}	8323	1495	8060	5070	1930	3385	3459
	kg CO_{2eq} kg N^{-1}	236	1493	2702	1555	16	56	35
With carbon dynamics	kg CO_{2eq} ha^{-1}	8350	1496	8079	5100	1932	3398	3469
	kg CO_{2eq} kg N^{-1}	237	1495	2708	1564	16	56	35
Change with C dynamic	%	0.32%	0.09%	0.23%	0.60%	0.14%	0.38%	0.29%

3.1.7.4 LCIA: Other environmental indicators

Beyond GHGs, for the other lifecycle impacts assessed per hectare, fossil and nuclear energy use was highest for the SA farms and lowest for the extensive SL, whilst for mineral resources used farm 1 (ICL), used the most resources per hectare of land. For acidification, the SA farms were highest, whilst the extensive farm 2 had the lowest values. For the phosphorus relevant freshwater eutrophication, the livestock farms were generally higher, probably because of concentrate feed use, whilst for the nitrogen relevant marine eutrophication impact, the farms with cropping showed the highest impact values.

When looking at the impacts per kilogram of nitrogen exported the SL farms show very high levels of for all impacts, caused mainly by the low nitrogen output compared to the more intensive cropping systems.

Table 36 Environmental performance for NW010 for energy (FNE), resource (MRU), acidification (FAC, TAC) and eutrophication (FEU, MEU)

Variable	Unit (x ha^{-1})	FR10_01	FR10_02	FR10_03	FR10_04	FR10_05	FR10_06	FR10_07
Fossil and nuclear energy use	MJ deprived	24207	4541	19669	8453	13719	26418	26800
Mineral resources use	kg deprived	133	26	93	40	32	67	43
Freshwater acidification	kg SO_{2eq}	5.7E-05	7.6E-06	4.3E-05	2.0E-05	3.7E-05	6.4E-05	7.5E-05
Terrestrial acidification	kg SO_{2eq}	0.08	0.01	0.06	0.02	0.05	0.10	0.12
Freshwater eutrophication	kg PO_{4eq}	0.34	0.14	0.40	0.19	0.16	0.16	0.16
Marine eutrophication	kg N_{eq}	1.81	0.19	1.76	0.61	1.00	1.65	2.01
Variable	**Unit (x N^{-1})**							
Fossil and nuclear energy use	MJ deprived	688	4535	6592	2592	113	436	274
Mineral resources use	kg deprived	3.79	26.26	31.01	12.28	0.26	1.10	0.44
Freshwater acidification	kg SO_{2eq}	1.6E-06	7.6E-06	1.4E-05	6.0E-06	3.0E-07	1.1E-06	7.7E-07
Terrestrial acidification	kg SO_{2eq}	0.0024	0.0097	0.0209	0.0076	0.0004	0.0016	0.0012
Freshwater eutrophication	kg PO_{4eq}	0.0096	0.1374	0.1332	0.0595	0.0013	0.0027	0.0016
Marine eutrophication	kg N_{eq}	0.0514	0.1938	0.5913	0.1873	0.0082	0.0272	0.0205

The network shows a high diversity of farm systems, and this is reflected within the results. Depending upon the functional unit, the SA farms use more energy and cause more marine eutrophication impacts per hectare, but the SL farms have greater GHGs. When assessed by nitrogen output, the SL farms appear to cause considerably greater impacts. The only ICL farm was often one of the worst performing farms due to both feed and cropping inputs and a intermediate level of nitrogen export

3.1.8 Network 11 (Romania)

3.1.8.1 Network specifics

For the Romanian network (NW11) a typical farm was modelled based on data collected from various farms and relevant literature. It is a grassland-based farm with some fruit trees spread on the area (Table 37). On the livestock side the farm has a dairy herd with a rather high stocking density.

Table 37 NW11 Farm characteristics

Variable	Unit	RO11_01
Farm system type		**ICLF**
Area	ha	3.7
Field crops	%	0
Temporary forage	%	95
Permanent grassland	%	0
Permanent crops	%	5
Livestock	LU	11.60
Livestock density	LU ha^{-1}	3.13

Dairy cattle	%	100
Beef cattle	%	0
Pigs	%	0
Sheep, horses, llamas	%	0
Poultry	%	0

In terms of nitrogen management, the farm is efficient as it imports only some feed products to maintain the dairy herd in addition to the grassland forage as shown in Table 38. Livestock is also the main export for the farm. Overall the NUE is over 100%, which entails the risk of nitrogen mining and decrease in productivity over time.

Table 38 NW11 Farm nitrogen dynamics

Variable	Unit	RO11_01
Nitrogen inputs (fertiliser and manure)	kg N ha^{-1}	139
N% as mineral N	%	1
N% as organic N	%	99
Nitrogen self-sufficiency	**%**	**99**
Imported fertiliser N	kg N ha^{-1}	1
Imported feed	kg N ha^{-1}	50
Total imported N	**kg N ha^{-1}**	**51**
Crops sold	kg N ha^{-1}	2
Livestock sold	kg N ha^{-1}	56
Exported N in products	**kg N ha^{-1}**	**59**
External N utilisation	%	114

3.1.8.2 Economics

The farm has a negative partial net margin, due to the rather high costs for the livestock production (Table 39). On the crop side, however, the farm would already have a positive margin.

Table 39 Economic performance for NW11

Variable	Unit	RO11_01
Revenue (sold crops)	€ ha^{-1}	184
Value (own use crops)	€ ha^{-1}	461
Total crop value	€ ha^{-1}	645
Costs (crops)	€ ha^{-1}	426
Revenue (sold livestock)	€ ha^{-1}	3961
Costs (livestock)	€ ha^{-1}	4512
Farm partial net margin	€ ha^{-1}	-332

3.1.8.3 LCIA: Greenhouse gases and carbon dynamics

For the environmental performance the farm has rather high emissions for a low-input system if compared to other farms in the project (Table 40). This can widely be attributed to the high stocking density with dairy cattle.

Up to 5% of these emissions could be compensated when including organic carbon estimations.

Table 40 Environmental performance for NW11 for GHGs (GWP100) with and without soil and biomass carbon dynamics included

Dimension	Unit	RO11_01
No carbon dynamics	kg CO_{2eq} ha^{-1}	14695
	kg CO_{2eq} kg N^{-1}	250
With carbon dynamics	kg CO_{2eq} ha^{-1}	13942
	kg CO_{2eq} kg N^{-1}	238
Change with C dynamic	%	-5.4%

Both tree biomass and soil carbon storage increase in the modelled year are contributing to the offset of emissions (Table 41). Most trees are still below 20 years of age and are thus still building up C storage in their biomass. On the other hand, the grazed and rather productive grassland is also assumed to increase the storage in the modelled year.

Table 41 Carbon storage contributions of different variables in the soil carbon and crop biomass dimensions for farm NW11. For both dimensions the change in storage is shown, meaning that a positive value is an increase in carbon in the respective storage, while negative values are a loss to the environment which leads to field emissions.

Dimension	Variable	Unit (x ha^{-1})	RO11_01
Soil carbon change (Tier 2)	Tillage C input	t C	N/A
	Permanent pasture C input	t C	3.59
	Permanent crops C input	t C	2.31
	Farm	kg C	69.81
	Crop	kg C	0.00
	Temporary forage	kg C	70.50
	Permanent forage	kg C	0.00
	Permanent crops	kg C	-0.69
Crop biomass (Tier 1)	Biomass	kg C	135.90

3.1.8.4 LCIA: Other environmental indicators

Looking at other environmental indicators' impacts (Table 42) are widely comparable to DE06_01 and suggest once more that the high stocking density is responsible for the largest changes. A difference to the German farm can be noticed in the impacts per hectare, where the DE06_01 has clearly higher impacts, even though the stocking density is lower. This could be connected to the different impact chickens have compared to dairy cattle (i.e. composition of excreted manure), but even more to the large feed imports (and connected impacts) of the German farm.

Table 42 Environmental performance for NW11 for energy (FNE), resource (MRU), acidification (FAC, TAC) and eutrophication (FEU, MEU)

Variable	Unit (x ha^{-1})	RO11_01
Fossil and nuclear energy use	MJ deprived	56244
Mineral resources use	kg deprived	288
Freshwater acidification	kg SO_{2eq}	1.01E-04
Terrestrial acidification	kg SO_{2eq}	1.22E-01
Freshwater eutrophication	kg PO_{4eq}	0.55
Marine eutrophication	kg N_{eq}	2.63

Variable	Unit (x N^{-1})	RO11_01
Fossil and nuclear energy use	MJ deprived	959
Mineral resources use	kg deprived	4.91
Freshwater acidification	kg SO_{2eq}	1.71E-06
Terrestrial acidification	kg SO_{2eq}	2.08E-03
Freshwater eutrophication	kg PO_{4eq}	9.45E-03
Marine eutrophication	kg N_{eq}	4.48E-02

3.1.9 Network 13 (Poland)

3.1.9.1 Network specifics

The Polish network provided data for one single farm, which is, however, quite large compared to most farms in other networks (1611.6 ha as shown in Table 43). It is also a mixed farm in the sense that it has both forage and field crops on the crop side, and keeps dairy and beef cattle in addition, even though at a rather low stocking density (0.3 LU ha^{-1}). Not visible on the table are hedgerows and tree lines throughout the whole farm. These do not serve a productive purpose, but account for natural buffer areas and organic carbon storage on farm. Thus, they are considered in the following results, but do not show up under “permanent crops” in the farm characteristics since they were assumed to be distributed over fields with other land use types aimed at agricultural production (here field crops and temporary forage). Based on collected farm data we calculated an area of 9.08 ha covered by trees between 13 and 20 years of age and 17ha of hedges, planted on average 10 years before the data collection.

Table 43 NW13 Farm characteristics.

Variable	Unit	PL13_01
Farm system type		**ICL**
Area	ha	1620.722
Field crops	%	41
Temporary forage	%	59
Permanent grassland	%	0
Permanent crops	%	0
Livestock	LU	482.75
Livestock density	LU ha^{-1}	0.30
Dairy cattle	%	89
Beef cattle	%	11
Pigs	%	0
Sheep, horses, llamas	%	0
Poultry	%	0

The farm is fully self-sufficient for fertilisers and nearly so for livestock feed, where only little nitrogen per ha is imported as feed (Table 44). These values need to be seen in relation to the low stocking density and the great surface area of the farm, which in this case relativizes the overall import amount. Another reason for the seemingly lower imports is the nature of imported feed: Lupins and maize are mostly imported to the farm and do not contain very high proportions of nitrogen. If looked at per livestock unit, 23.7 kg of nitrogen are imported as feed. In comparison in the farm DE06_03, which has a similar livestock system only imports 5.6 kg N LU^{-1}. When looked at on a per ha basis the farms are more similar (DE06_03 imports 4 kg N ha^{-1}).

Nevertheless, the farm is still exporting more N in products than it imports and is so overly efficient with a risk of mining the farm's nitrogen reserves.

Table 44 NW13 nitrogen dynamics.

Variable	**Unit**	**PL13_01**
Nitrogen inputs (fertiliser and manure)	kg N ha^{-1}	16
N% as mineral N	%	0
N% as organic N	%	100
Nitrogen self-sufficiency	**%**	**100**
Imported fertiliser N	kg N ha^{-1}	0
Imported feed	kg N ha^{-1}	7
Total imported N	**kg N ha^{-1}**	**7**
Crops sold	kg N ha^{-1}	6
Livestock sold	kg N ha^{-1}	8
Exported N in products	**kg N ha^{-1}**	**14**
External N utilisation	%	198

3.1.9.2 Economics

From a monetary perspective, the farm manages to have a positive net margin of 220€ ha^{-1} despite the very low yields for the grain crops particularly. All tuber crops present on farm as well as the vast production of grassland forage which is valued within the "own use crops" (Table 45) make sure that the crops side margin is positive and even outweighs the slight losses on the livestock side.

Table 45 Economic performance for NW13

Variable	**Unit**	**PL13_01**
Revenue (sold crops)	€ ha^{-1}	107
Value (own use crops)	€ ha^{-1}	600
Total crop value	€ ha^{-1}	707
Costs (crops)	€ ha^{-1}	416
Revenue (sold livestock)	€ ha^{-1}	773
Costs (livestock)	€ ha^{-1}	845
Farm partial net margin	€ ha^{-1}	220

3.1.9.3 LCIA: Greenhouse gases and carbon dynamics

The farm emits 3126 kg GHG ha^{-1} when ignoring all potential carbon storage in soil and biomass (Table 46). Even when including carbon estimations, the difference would be marginal and only 0.4% of emissions could be offset.

The rather low productivity of the farm can be noticed when looking at emissions per kg of N in exported products. These are quite high with around 230 kg GHG kg N^{-1} particularly when compared to similar farm structures in Germany where emissions per kg N are 130 kg CO_{2eq}.

Table 46 Environmental performance for NW13 for GHGs (GWP100) with and without soil and biomass carbon dynamics included

Dimension	Unit	PL13_01
No carbon dynamics	kg CO_{2eq} ha^{-1}	3216
	kg CO_{2eq} kg N^{-1}	231
With carbon dynamics	kg CO_{2eq} ha^{-1}	3204
	kg CO_{2eq} kg N^{-1}	230
Change with C dynamic		-0.40%

The marginal compensation of emissions that can happen on farm according to the carbon storage estimations stems mostly from the biomass accumulation in trees and hedges under 20 years of age (Crop biomass Tier 1 in Table 47). On the other hand, passive soil carbon pools are being depleted as the farm loses 8.5 kg C ha^{-1} every year. Climate change together with tillage processes and low yields (thus low residues) lead to this phenomenon.

Table 47 Carbon storage contributions of different variables in the soil carbon and crop biomass dimensions for farm NW13. For both dimensions the change in storage is shown, meaning that a positive value is an increase in carbon in the respective storage, while negative values are a loss to the environment which leads to field emissions.

Dimension	Variable	Unit (x ha^{-1})	PL13_01
Soil carbon change (Tier 2)	Tillage C input	t C	1.21
	Permanent pasture C input	t C	0.52
	Permanent crops C input	t C	N/A
	Farm	kg C	-8.49
	Crop	kg C	-12.25
	Temporary forage	kg C	2.36
	Permanent forage	kg C	0.00
	Permanent crops	kg C	0.00
Crop biomass (Tier 1)	Biomass	kg C	13.52

3.1.9.4 LCIA: Other environmental indicators

Table 48 below shows emissions from other selected environmental impact categories for the farm in NW13. As noticed in the GHG section above, emissions per ha are rather low, due to the low productivity and big size of the farm, however when looking at the measures per kg of N in products the emissions are all higher for example when compared once more to DE06_03. This makes NW13 an interesting case also to highlight the different outcomes and performance evaluation a farm can get just based on which indicators are selected.

Table 48 Environmental performance for NW13 for energy (FNE), resource (MRU), acidification (FAC, TAC) and eutrophication (FEU, MEU)

Variable	Unit (x ha^{-1})	PL13_01
Fossil and nuclear energy use	MJ deprived	12565
Mineral resources use	kg deprived	59
Freshwater acidification	kg SO_{2eq}	1.75E-05
Terrestrial acidification	kg SO_{2eq}	1.97E-02
Freshwater eutrophication	kg PO_{4eq}	1.79E-01
Marine eutrophication	kg N_{eq}	0.47

Variable	Unit (x N^{-1})	PL13_01
Fossil and nuclear energy use	MJ deprived	901
Mineral resources use	kg deprived	4.24
Freshwater acidification	kg SO_{2eq}	1.25E-06
Terrestrial acidification	kg SO_{2eq}	1.41E-03
Freshwater eutrophication	kg PO_{4eq}	1.29E-02
Marine eutrophication	kg N_{eq}	3.40E-02

3.2 Whole farm analysis across all networks

Following the clustering procedure, four clusters were identified, as shown in Figure 5. Examining the descriptives for these groups they were identified as two larger clusters of integrated farms with (ICLF) or without agroforestry elements (ICL), respectively; as well as specialist arable (SA) and specialist livestock (SL) farm types.

Clusters

Input (Predictor) Importance

1.0 0.8 0.6 0.4 0.2 0.0

Cluster	3	1	2	4
Label	Integrated crops, livestock & ...	Integrated crop & livestock (ICL)	Specialist arable (SA)	Specialist livestock (SL)
Description	Integration of agroforestry with crops, livestock or both (ICLF)	Integration of crops and livestock (ICL)	Specialist arable with very little or no livestock interaction (SA)	Specialist livestock with very little or no arable cropping (SL)
Size	38.8% (19)	36.7% (18)	14.3% (7)	10.2% (5)
Inputs	AF_1_0 1.00 (100.0%)	AF_1_0 0.00 (100.0%)	AF_1_0 0.00 (100.0%)	AF_1_0 0.00 (100.0%)
	field_crop_perc 0.25	field_crop_perc 0.73	field_crop_perc 0.94	field_crop_perc 0.02
	perm_grass_perc 0.36	perm_grass_perc 0.10	perm_grass_perc 0.01	perm_grass_perc 0.97
	LU_1_0 1.00 (78.9%)	LU_1_0 1.00 (100.0%)	LU_1_0 0.00 (100.0%)	LU_1_0 1.00 (100.0%)

**Input variables: "AF" - agroforestry present (binary), "field_crop_perc" – proportion of UAA as field cropping (continuous), "perm_grass_perc" - proportion of UAA as permanent pasture (continuous), "LU" – livestock on farm (binary)*

Figure 5 Cluster formation and input variable* importance for the four system types

3.2.1 Whole farm analysis by MiFAS farm system type

After assigning the farms to each cluster type, a dataset of key characteristics and indicators was compiled, with several variables also assessed for differences between the groups using the Kruskal Wallis non-parametric method.

Table 49 indicates that the ICL and ICLF clusters were larger than the specialist systems, but this is expected given the focus of the project. However, the specialist systems also act as a type of control for comparison against the more integrated systems.

The farm areas were much greater for the ICL, SA and SL systems, with the ICLF significantly smaller at a median of only 11ha. The land use is also very representative of the clusters, with the ICL and SA types both having a high proportion of field cropping. However, the ICL also includes a reasonable proportion of temporary forages and a little grassland. The SL is dominated by permanent grassland, whilst the median values of the ICLF show around 9% of land as permanent crops and 24% as permanent grassland (medians for cropland and temporary forage were zero).

Livestock numbers were zero for the SA farms, followed by a low number for ICLF and similar numbers for ICL and SL. However, the pattern for livestock stocking density showed highest values for the ICLF, though only significantly different to the SA group.

Table 49 MiFAS type farm characteristics (median values and KW non-parametric ANOVA)

Variable	Unit	ICL		SA		SL		ICLF		Sig
Cluster size (farms)	n	18		7		5		19		
Area	**ha**	**265**	b	**136**	b	**193**	b	**11**	a	***
Field crops	%	74%		100%		0%		0%		
Temporary forage	%	11%		0%		0%		0%		
Permanent grassland	%	3%		0%		100%		24%		
Permanent crops	%	0%		0%		0%		9%		
Livestock	**LU**	**151**	c	**0.00**	a	**102.56**	c	**11.60**	b	***
Livestock density	**LU/ha**	**0.55**	b	**0.00**	a	**0.23**	b	**1.07**	b	***
Dairy cattle	%	0%		0%		0%		0%		
Beef cattle	%	8%		0%		100%		0%		
Pigs	%	0%		0%		0%		29%		
Sheep, horses, llamas	%	0%		100%		0%		0%		
Poultry	%	0%		0%		0%		0%		

*Significance levels: ***-p<0.001, **-p<0.01, *-p<0.05, ns-not significant. Identical small letters denote residence within a homogenous group. Different letters indicate significant difference at a maximum p-value of <0.05.*

The main nitrogen indicators (Table 50) all showed significant differences between the groups, except for the utilisation of externally sourced nitrogen. Fertiliser applied N was greatest on SA systems, though only significantly higher than the lower input SL farms. Nitrogen self-sufficiency and the proportion of N applied as organic manures showed a pattern of the SA farms being the least self-sufficient and the lowest users of organic manures, whilst the ICLF and SL farms were the greatest and the ICL farms in the middle. In terms of nitrogen exported off-farm as products SL was lowest while ICL and SA were the highest, indicating the greater N exported per hectare of cropland.

Table 50 MiFAS type farm nitrogen dynamics (median values and KW non-parametric ANOVA)

Variable	Unit	ICL		SA		SL		ICLF		Sig
Nitrogen fertiliser applied	**kg N/ha**	**134**	b	**152**	b	**24**	a	**104**	b	**
N% as mineral N	%	58%		85%		0%		0%		
N% as organic N	%	42%	b	15%	a	100%	c	100%	c	***
Nitrogen self-sufficiency	**%**	**17%**	b	**0%**	a	**100%**	c	**99%**	c	***
Imported fertiliser N	**kg N/ha**	**119**	b	**152**	b	**0**	a	**1**	a	***
Imported feed	**kg N/ha**	**4**	b	**0**	a	**3**	b	**50**	b	*
Total imported N	kg N/ha	126		152		10		100		
Crops sold	kg N/ha	91		128		0		15		

Livestock sold	kg N/ha	7		0		1		14		
Exported N in products	**kg N/ha**	**96**	c	**128**	c	**3**	a	**42**	b	***
External N utilisation	**%**	**73%**	ns	**88%**	ns	**31%**	ns	**50%**	ns	ns

*Significance levels: ***-p<0.001, **-p<0.01, *-p<0.05, ns-not significant. Identical small letters denote residence within a homogenous group. Different letters indicate significant difference at a maximum p-value of <0.05.*

3.2.1.1 Economics

Economically, the revenue from crops and livestock reflected the specialisations, though the ICL type had similar output to the SA for cropping and both the ICL and ICLF had similar livestock revenues to the specialist livestock type (Table 51). However, in terms of net margins, there was no significant differences between the farm system types, despite a trend of increasing losses for the SA and ICL farms.

Table 51 MiFAS type farm economic figures (median values and KW non-parametric ANOVA)

Variable	Unit	ICL		SA		SL		ICLF		Sig
Value (sold crops)	**€/ha**	**807**	c	**1093**	c	**4**	a	**272**	b	***
Value (own use crops)	€/ha	173		0		102		259		
Costs (crops)	€/ha	883		1240		72		1339		
Revenue (sold livestock)	**€/ha**	**790**	b	**0**	a	**126**	b	**344**	b	***
Costs (livestock)	€/ha	1173		0		408		2754		
Net margin	€/ha	-268	ns	-120	ns	-23	ns	-54	ns	ns

*Significance levels: ***-p<0.001, **-p<0.01, *-p<0.05, ns-not significant. Identical small letters denote residence within a homogenous group. Different letters indicate significant difference at a maximum p-value of <0.05.*

3.2.1.2 LCIA: Greenhouse gases and other environmental indicators

When comparing the farm type groups, all environmental indicators for both the functional units significantly differed (Table 52).

For GHGs per hectare, the lowest CO_2 equivalent emissions originated from the SA and SL farms, though the SL farms were also grouped with the greater emitting ICL and ICLF groups (which were very similar), indicating a large variance in the SL emissions per hectare. However, when considered per kg of nitrogen exported, the results show a very different pattern with all groups significantly different and SL the highest emitter as a result of the very low nitrogen output per hectare and despite the lowest emissions per hectare.

Fossil and nuclear energy use per hectare was significantly greater for all types except SL, reflecting the high energy use for field cropping. However, when considered per kg of N exported the SA farms were lowest, the ICL at an intermediate level and the ICLF and SL requiring the greatest energy impacts per unit of output.

For the mineral resource use, the specialist cropping and livestock farm types had lower use per hectare than the two integrated systems, with the ICLF having the greatest impacts. When considered per kg of N exported, both energy and resource use indicators showed the lowest impacts for SA farms, with ICL at an intermediate level and the SL and ICLF farms the greatest.

For the acidification impacts per hectare, both indicators showed the same pattern with SL farms having a much lower impact than the other types, probably reflected by the much lower levels of N inputs per hectare. However, per kg of N exported SL and ICLF showed the greatest impacts and SA the lowest.

For freshwater eutrophication per hectare the SL and SA systems had significantly lower impacts than the ICL and ICLF, though for freshwater eutrophication the SL farms had the highest impacts and SA the lowest, with the integrated systems at an intermediate level. For marine eutrophication impacts per hectare, the result was similar, with the SL showing much lower impacts, but the highest impacts when considered per kg of N exported.

Table 52 MiFAS type farm environmental performance (median values and KW non-parametric ANOVA). for GHGs (GWP100), energy (FNE), resource (MRU), acidification (FAC, TAC) and eutrophication (FEU, MEU)

Variable	**Unit**	**ICL**		**SA**		**SL**		**ICLF**		**Sig**
							a			
GHG (GWP100)	kg CO2 eq ha^{-1}	8289	b	3528	a	4469	b	8583	b	*
Fossil and nuclear energy use	MJ dep. ha^{-1}	32897	b	29236	b	6602	a	36426	b	**
Mineral resources use	kg dep. ha^{-1}	140	b	53	a	40	a	189	b	**
Freshwater acidification	kg SO2eq ha^{-1}	6.26E-05	b	5.82E-05	b	9.26E-06	a	1.95E-04	b	**
Terrestrial acidification	kg SO2eq ha^{-1}	0.108	b	0.079	b	0.012	a	0.144	b	*
Freshwater eutrophication	kg PO4eq ha^{-1}	0.360	b	0.193	a	0.161	a	0.447	b	*
					a					
Marine eutrophication	kg Neq ha^{-1}	1.91	b	1.51	b	0.21	a	2.72	b	*
GHG (GWP100)	kg CO2 eq kgN^{-1}	78	b	28	a	1493	d	234	c	***
Fossil and nuclear energy use	MJ dep. kgN^{-1}	382	b	238	a	2592	c	773	c	***
Mineral resources use	kg dep. kgN^{-1}	1.33	b	0.44	a	12.28	c	4.77	c	***
Freshwater acidification	kg SO2eq kgN^{-1}	8.28E-07	b	4.56E-07	a	6.01E-06	c	2.20E-06	c	***
Terrestrial acidification	kg SO2eq kgN^{-1}	1.26E-03	b	6.21E-04	a	7.59E-03	c	2.19E-03	c	***
Freshwater eutrophication	kg PO4eq kgN^{-1}	0.003	b	0.001	a	0.059	d	0.010	c	***
Marine eutrophication	kg Neq kgN^{-1}	0.025	b	0.011	a	0.187	c	0.046	c	**

*Significance levels: ***-p<0.001, **-p<0.01, *-p<0.05, ns-not significant. Identical small letters denote residence within a homogenous group. Different letters indicate significant difference at a maximum p-value of <0.05.*

3.3 Enterprise analysis across all networks

Following the analysis at farm scale, an analysis of the management characteristics, environmental impacts and net margin were undertaken. A selection of common crops and livestock enterprises that could be assessed across the different system types were chosen.

3.3.1 Wheat

Wheat was grown in most networks, with some farms also growing multiple plots of wheat within their rotations, therefore a sample of 36 wheat crops could be compiled. The results (Table 53), indicated very different management between the farm types, with higher levels of mineral nitrogen used on ICL and SA farms but yields also much greater than on ICLF farms. For the environmental impacts, most were not significant per hectare due to heterogeneity within the data, however for GHGs and energy use, the ICLF and SL were lower. The economic results were not significant, except for input costs, but it should be noted that revenue for the lower yielding ICLF group was influenced by organic price premiums for some of the farms. Values per kilogram of wheat were assessed for environmental impact, but all indicators were found to be non-significant (see appendix 6.2).

Table 53 Wheat crop analysis by MiFAS type farm management characteristics, environmental impacts and net margin per hectare and kilogram fresh matter yield (85% dry matter). (median values and KW non-parametric ANOVA).

Variable	**Unit**	**ICL**		**SA**		**SL**		**ICLF**		**Sig***
Sample size	n	21		9		1		5		
FM yield (15%mc)	kg ha^{-1}	8248	b	8504	b	9300	b	4069	a	*
Organic_N%	%N_plot	29%	a	12%	a	36%	ab	100%	b	**
Organic_N%_rot	%N_rotation	30%	b	7%	a	40%	bc	100%	c	**
NUE	%	101%	ns	74%	ns	188%	ns	86%	ns	ns
C input_(plot)	t C ha^{-1}	5.01	ns	4.88	ns	5.44	ns	3.70	ns	ns
C input_crops	t C ha^{-1}	3.77	ns	3.77	ns	4.44	ns	2.95	ns	ns
Mineral N (plot)	kg N ha^{-1}	138	b	205	b	60	ab	0	a	**
Organic N (plot)	kg N ha^{-1}	42	ns	29	ns	34	ns	59	ns	ns
N self-suff (plot)	%	1%	ab	0%	a	1%	ab	65%	b	*
GHG (GWP100)	kg CO2 eq ha^{-1}	3867	b	4214	b	3297	ab	2706	a	*
FNE	MJ dep. ha^{-1}	30481	b	34778	b	24999	ab	17349	a	*
MRU	kg dep. ha^{-1}	61	ns	62	ns	51	ns	46	ns	ns
FAC	kg SO2eq ha^{-1}	6.4E-05	ns	8.3E-05	ns	4.3E-05	ns	4.2E-05	ns	ns
TAC	kg SO2eq ha^{-1}	1.2E-01	ns	1.2E-01	ns	7.7E-02	ns	9.0E-02	ns	ns
FEU	kg PO4eq ha^{-1}	0.25	b	0.25	b	0.27	b	0.17	a	*
MEU	kg Neq ha^{-1}	1.79	ns	2.15	ns	1.24	ns	1.31	ns	ns
Revenue_per_ha	€ ha-1	1332	ns	1375	ns	1438	ns	1366	ns	ns
Labour_costs	€ ha-1	194	ns	164	ns	127	ns	142	ns	ns
Machinery_costs	€ ha-1	587	ns	552	ns	332	ns	484	ns	ns
Diesel_costs	€ ha-1	69	ns	45	ns	61	ns	71	ns	ns
Input_costs	€ ha-1	512	b	545	b	503	b	170	a	*
Total_costs	€ ha-1	1333	ns	1326	ns	1023	ns	849	ns	ns
Net_margin	€ ha-1	32	ns	32	ns	415	ns	517	ns	ns

Statistical assessment using Kruskal-Wallis with significance levels: *-p<0.001, **-p<0.01, *-p<0.05, ns-not significant. Identical small letters denote residence within a homogenous group. Different letters indicate significant difference at a maximum p-value of <0.05.*

Contribution analysis of the economic and environmental factors is shown in Figure 6 and highlights that although the economic margins were not statistically different, some of the environmental indicators were different, including GHGs, energy and freshwater eutrophication, for which ICLF was lower.

Figure 6 Contribution analysis for wheat economic and environmental impact indicators per hectare

Statistical assessment using Kruskal-Wallis. Identical small letters denote residence within a homogenous group. Different letters indicate significant difference at a maximum p-value of <0.05.

3.3.2 Beef (data will be re-run with additional beef types, e.g. weaned calves sold as well as finished animals)

Beef animals were reared on 21 farms within the networks and included animals from both dairy and suckler cows. Table 54 highlights the main system characteristics as well as the estimated environmental impacts from the beef production. Stocking density was greater on the ICLF and per forage area, also higher on the ICL farms. Ration descriptions were not significantly different, with all systems receiving a high median level of forage, and most of the feed nitrogen arising from the home farm.

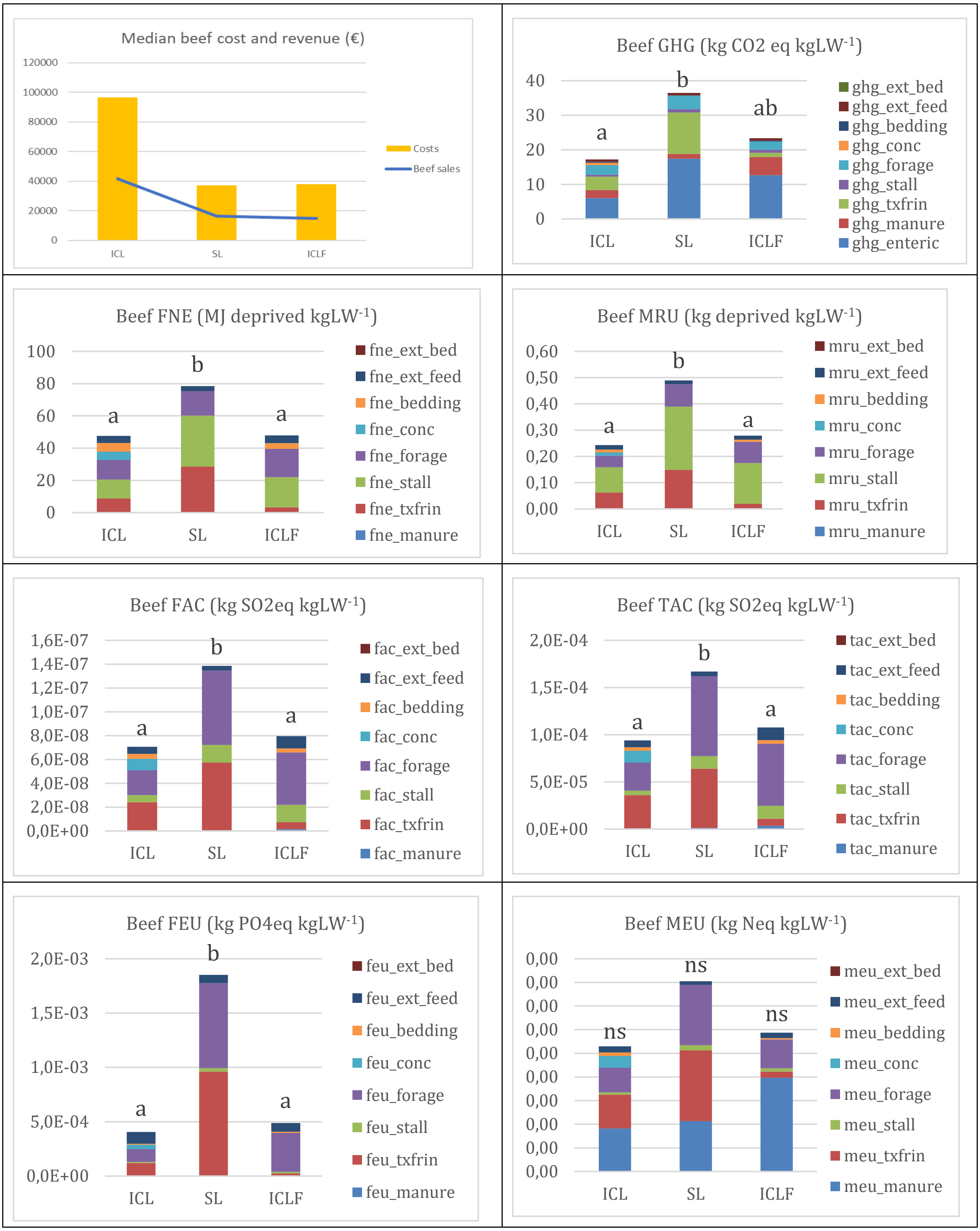
However, when environmental impacts are considered, all except the marine eutrophication (linked to nitrogen inputs) were significantly different between farm types. The SL farm types usually showed the highest impacts, with contribution analysis subsequently shown in Figure 7.

Table 54 Finished beef enterprise analysis by MiFAS type farm management characteristics, environmental impacts and net margin per kilogram liveweight. (median values and KW non-parametric ANOVA).

Variable	Unit	ICL		SL		ICLF		Sig
Sample size	n	11		5		5		
Production	kg LW/farm	21800	ns	8550.0	ns	4400.00	ns	ns
Livestock	LU	155	ns	29	ns	103	ns	ns
Stocking density	LU ha^{-1}	0.52	a	0.97	a	0.23	b	*
Stocking density - forage	LU forage ha^{-1}	2.22	b	1.56	a	0.23	b	*
Ration - forage	%	97%	ns	100%	ns	99%	ns	ns
Ration - concentrates	%	3%	ns	0%	ns	1%	ns	ns
Feed nitrogen (farm sourced)	%	80%	ns	97%	ns	90%	ns	ns
GHG (GWP100)	kg CO2 eq $kgLW^{-1}$	17.75	ns	23.35	ns	32.49	ns	ns
Fossil and nuclear energy use	MJ deprived $kgLW^{-1}$	49.26	ns	47.83	ns	65.59	ns	ns
Mineral resources use	kg deprived $kgLW^{-1}$	2.5E-01	ns	2.8E-01	ns	3.8E-01	ns	ns
Freshwater acidification	kg SO2eq $kgLW^{-1}$	7.1E-08	ns	8.0E-08	ns	1.1E-07	ns	ns
Terrestrial acidification	kg SO2eq $kgLW^{-1}$	9.4E-05	a	1.1E-04	b	1.5E-04	a	*
Freshwater eutrophication	kg PO4eq $kgLW^{-1}$	4.1E-04	ns	4.9E-04	ns	1.2E-03	ns	ns
Marine eutrophication	kg Neq $kgLW^{-1}$	2.6E-03	ns	2.9E-03	ns	4.0E-03	ns	ns
Costs	€ $farm^{-1}$	96511	ns	37083	ns	38054	ns	ns
Beef sales	€ $farm^{-1}$	41463	ns	16262	ns	14969	ns	ns
Nitrogen exported (beef)	Kg N $farm^{-1}$	411	ns	161	ns	116	ns	ns

Contribution analysis is shown in Figure 7 and highlights the greater impacts of the SL system for most impact categories. For GHGs this is mostly as a result of greater enteric emissions, and embedded emissions from transferred in stock, e.g. weaned suckler cow calves. For energy and resource use housing and transfer ins are the greatest contributors whilst for acidification and freshwater eutrophication forage production becomes an important factor. For the nitrogen sensitive marine eutrophication impacts, manure emission become the greatest impact, especially for the ICLF systems.

Figure 7 Beef costs and revenue. Contribution analysis for beef economic and environmental impact indicators per kilogram LW.



Statistical assessment using Kruskal-Wallis. Identical small letters denote residence within a homogenous group. Different letters indicate significant difference at a maximum p-value of <0.05.

4 Discussion and conclusions

The environmental and economic assessment of many real farms across a range of networks in different countries presented several challenges, however, the results generated indicate that this process could be achieved, through the development of the assessment model and a significant amount of time for data handling and use of validation procedures.

4.1 Network analysis

The networks assessed provided a wide variety of farm systems across a wide geographical area. The data provided about the farm systems included full farm systems through to specific areas of farms that focussed on a particular topic, e.g. agroforestry. The farms also ranged from very diverse, complex systems with crops, livestock and agroforestry through to large highly specialised units, which were included within the MIXED project due to their participation in landscape scale collaborations. These specialised systems also proved extremely valuable as comparators to the more MiFAS type systems.

Whilst farms within some of the networks were consistent and had a common theme, such as the French (NW09), that included multiple pig farms utilising woodland and pasture, others were highly diverse such as French (NW10), with systems ranging from extensive livestock through to intensive, specialised cropping. Livestock types were also diverse, with all sectors except broiler chickens.

Initially, the farms were assessed within their networks, providing a comparison within a similar geographical and socio-economic context. In Denmark (NW02), the network was organised around reducing nutrient excesses. This centred around exchanges of manures with biogas plants and other farms, as well as returns of digestates. The farms produced a wide range of arable crops, as well as speciality seed crops. When livestock were kept, they were generally large herds of intensively, high output cattle or pig systems with high external inputs, causing environmental impacts per hectare. Economically, the dairy sector seemed to generate the best returns.

In Scotland NW04 was focussed on the trialling of winter grazing of cereals by sheep, as well as other material exchanges such as straw and manures, but the network also included mixed farms with beef cattle. In general, the network achieved some of the most balanced nitrogen utilisation rates, in part due to high crop yields, but some farms also imported high levels of feed, leading to emissions. This network also included the largest farm assessed with extensive grazing meaning impacts were very low per hectare area.

The German network NW5 centred around peatland restoration on former intensively farmed land. The farms were fairly unique amongst the dataset, and whilst emissions from peat have clearly declined as a result of the measures, production from this land, such as extensive beef, has very high emissions. This is due to the transfer of embedded emissions from the forage to the cattle, as well as a slow rearing period with high levels of enteric emissions. The second German network NW06 comprised three farms developing agroforestry. The systems were all different with a free-range egg system DE06_01 very reliant on external feeds, resulting in high nitrogen related emissions.

In Switzerland NW07 comprised farms with high-stemmed fruit trees as an agroforestry system, combined with grazing livestock and or crops. Many of the trees were older, so using the Tier 1 methodology, biomass carbon was assumed to be at equilibrium, though new trees can mitigate some of the system GHGs. The Swiss farms also demonstrated the improved circularity from using livestock manures as the primary fertiliser source. However, when livestock are maintained with high levels of imported feed, emissions rise, such as on farm CH07_04. Offsetting emissions through carbon: In the Swiss case it was also observed that a low nitrogen use efficiency seemed related to lower economic performance, such as farms 02, 04 and 06.

In France two separate networks provided data. They comprised the NW09, with a focus on outdoor pig production in an agroforestry/woodland setting. However, high feed imports and stocking densities in some farms resulted, as well as slower growth rates due to breed choice, caused high emissions, though no fertiliser was required. Although comprising a significant level of woodland, the trees were generally older (around 70 years), therefore biomass carbon was assumed to be in equilibrium as per Tier 1 guidelines, so there was little calculated GHG mitigation from the trees. However, when new trees were planted, this provided some offsetting. The pig systems also appeared to underperform financially, though this is likely due to the use of standard pig price data, when the unique characteristics of the system would provide a significant premium. Overall, the farms with lower stocking density and better feed self-sufficiency had lower emissions.

The second French system (NW10) was quite different and located in the SW of France with a mix of mixed, arable and specialist livestock farms. The network was collaborating with partners in the region to improve exchanges of materials and nutrients between farms, however the farms were assessed individually in the context of Task 5.1. The specialist livestock farms were generally very extensive, whilst the cropping farms were quite intensive. Emissions depended largely on the intensity, and cropping farms could have higher environmental impacts than livestock or mixed farms (FR10_06 and 07):

To the east of Europe, the Romanian network comprised farms collaborating with agri-tourism in the region of diverse small farms. However, this presented problems in collecting high quality data and unfortunately, due to the high data demands of LCA, a single typical farm for the region was constructed based on the data collected. Typically, these farms have few but a high intensity of livestock, with feeds purchased and diverse fruit trees on pasture or in orchards. The common exchange of goods between farms for agri-tourism was beyond the scope of this task, therefore few conclusions can be made.

In Poland, the network farm was a single very large biodynamic mixed farm, comprising dairy and arable production. The data showed that while the farm has fewer external inputs, that its low crop yields are a severe handicap to economic performance, as well as causing some higher-than-expected product impacts (due to the low yield to spread the emissions).

4.2 Farm system comparison

With such a diverse range of farms in the dataset it was difficult to make clear conclusion about the performance of different farm system types. Therefore, all the farm data was combined into a single dataset. After some trials, a two-step clustering procedure with four variables was found to classify the farms into four system types, integrated cropping and livestock, specialist arable, specialist livestock and integrated cropping/livestock and agroforestry, that allowed for a good system comparison. Ideally, we would also have liked to compare organic and conventional systems, but the dataset was too small to undertake any sensible comparison.

Use of the non-parametric Kruskal Wallis one-way ANOVA test, (when assumptions of normality and variance are not important as it uses ranking to determine differences between groups), allowed the comparison of a high number of variables for differences between the farm system groups.

We found that the ICL and ICLF farm clusters were larger than the specialist systems, but we also had sufficient numbers of specialist farms to act as a type of control for comparison against the more integrated systems. We found that the farm areas were much greater for the ICL, SA and SL systems, whilst the ICL and SA types both had a high proportion of field cropping. However, we could also observe the that the more integrated system had a reasonable proportion of temporary forages, wish a little grassland. The SL was dominated by permanent grassland, with similar livestock numbers for both ICL and SL, though livestock stocking density was greatest for ICLF, probably because of the French pig systems.

The main nitrogen indicators all showed significant differences between the groups, whilst fertiliser application of nitrogen was greatest on SA systems. Nitrogen self-sufficiency and the proportion of N applied as organic manures was always lowest on SA farms, intermediate for ICL and greatest on the ICLF and SL farms, as may be expected with greater livestock levels. However, nitrogen export as products was lowest for SL, with ICL and SA the highest as a result of the greater N exported per hectare of cropland.

Whilst we found differences in revenue and costs between the farm systems, overall, there was no significant differences between the farm system types. However, when comparing environmental impacts, all environmental indicators showed significant differences between groups.

For GHG emissions we found that per hectare, the SA farms were the lowest emitting, with SL at an intermediate level and the two integrated systems showing the greatest impacts. Using the alternative per kg of nitrogen exported functional unit, the results showed the greatest emissions for the SL group, likely due to the low productivity extensive systems causing a high concentration of emissions within a small volume of products, whilst the integrated systems were at an intermediate, though far lower level.

For fossil and nuclear energy use The SL farms were lowest per hectare, but again, when assessed by kilogram of N exported, became the highest energy user. The cropping systems showed the greatest energy use per hectare, but SA farms were the lowest per kg nitrogen exported. In terms of mineral resource use, the SA and SL farm types had lower use per hectare, whilst per kg of N exported, SA farms had the lowest impacts, ICL was intermediate with the SL and ICLF farms the largest resource users.

Considering acidification impacts, both indicators showed SL farms to have low impacts reflecting the far lower levels of N inputs per hectare, whilst for impacts per kg N exported, SA systems showed lowest impacts due to high N outputs compared to the livestock centric ICLF and SL systems. Eutrophication results per hectare reflected the low phosphorus inputs of the SA and SL systems, whilst for marine eutrophication, the SL system was lowest per hectare but greatest per kg N exported. The integrated systems were intermediate for both functional units.

4.3 Enterprise level system comparison

Following the analysis at farm scale, we undertook analysis of the most common crop and livestock enterprises within the sample, which were wheat and beef respectively. In total we found 36 wheat crops, and results of comparing the underlying farming system indicated very different management between the farm types. The highest levels of mineral nitrogen were used on ICL and SA farms who also achieved the greatest yields. This probably results in the GHGs and energy use, being lower for the ICLF and SL, however due to heterogeneity within the data, most of the environmental impacts were not significant.

Beef animals were reared on 21 farms within the networks and included animals from both dairy and suckler cows. We found that stocking density was greatest on the ICLF and ICL farms, whilst rations were not significantly different, with all systems receiving a high median level of forage. However, the environmental impacts were significantly different between farm types, with the SL farm types showing the highest impacts. Contribution analysis highlighted the greater impacts of the SL system for most impact categories, with greater GHGs likely because of greater enteric emissions and transferred in livestock such as weaned suckler cow reared calves with their embedded emissions.

4.4 Methodological results

A significant part of the effort in this task comprised the task of assessing such a wide range of farm systems that included conventional field crops and forages, all farmed livestock species as well as orchard, biomass and highly integrated systems.

Task 5.1 began with assisting in the design of the data collection through WP2, and this largely provided the data required. However, further plausibility checks would enable more consistent data to be compiled at source and reduce the need for further checking of values with the original enumerator in multiple instances. One of the main drawbacks of using real farm data is that farm management can change, and livestock numbers may not be consistent year to year, or rotations may be adapted in a specific year, and this can represent an issue when trying to achieve a representative reflection of a farm system.

The diverse systems to be assessed as well as a wide geographical coverage and inclusion of agroforestry within a detailed farm system assessment represented considerable development challenges. However, the use of methods such as Hemery 2015 for allocation of trees and their impacts within an agroforestry setting, or adaptation of the Tier 2 soil assessment methods allowed for a comprehensive assessment of a wide range of systems. Use of the standard KTBL economic database meant that economic performance across the farms could be considered on a similar basis, with the agronomic performance driving the results, rather than specific socio-economic factors of a farm or region.

Within the tool, the implementation of plausibility checks for feed intakes, fertiliser requirements and other parameters based on entered yield or growth rate values was invaluable in validating the farm survey data. Despite best efforts to design an interactive data collection sheet and provide training, errors in the data were still present, and the tool helped identify them for querying, and this allowing the results to be of a much higher quality. This was especially important due to the distance between the modellers and the farms.

The results show very limited changes in the SOC, and this is mainly due to the reporting of only the passive soil pool. Changes in the more active soil pools are short term and therefore inappropriate to report within GHG (GWP100). Soil carbon changes were also more limited due to the single time frame of the detailed data collection, therefore the management was assumed to have been similar for the previous period, unless there was specific information, such as trees being planted within the last 20 years. However, this issue will be tackled in the next task (T5.4), which will model potential transition pathways for specialised farms to more MiFAS type systems, and time will become a component. One factor that became apparent within the modelling, was that in the absence of fundamental system changes, the temperature effect on soil C degradation is already apparent. As temperature increases, we see greater SOC loss under the same management (Garcia-Franco et al., 2024), and as the model uses a 20-year period for assessing SOC, the increasing temperature within the climate datasets increases the SOC lost, and this is why the SOC is generally being lost in the carbon dynamic tables.

The biomass modelling was entirely new for the project and whilst further development would be needed, the Tier 1 method, together with adaptations for tree size and planting density adopted already provides some insight into the potential of agroforestry. We saw that there was a great difference in tree biomass potential carbon storage based on their age structure of the trees. This is partly as a direct result of the modleling assumptions, i.e. no additional storage in AF systems after 20 years, but this is also likely the situation. Most AF systems are built around early maturing trees, like fruit or nut trees, often which have a relatively short lifespan compared to a native broadleaf forest. Furthermore, whilst the initial planting of AF trees adds new above and belowground biomass carbon storage, this is potentially at the cost of soil carbon initially (Renna et al., 2024), and it may take up to 30 years before an increase in SOC is observed (Paul et al., 2002) Furthermore, AF may not support soil carbon increases due to absence of regular litter due to biomass clearance (Rahman, et al., 2017) by machine or livestock, compared to a natural forest environment. However, the ecosystem services of AF go beyond carbon storage and still represents a viable climate change mitigation option.

The LCA within the FarmLCA tool was conducted successfully, with the successful allocation of co-existing productions such as trees and pasture, as well as cover crops and cash crops. This goes beyond the typical approach of LCA that simplifies reality and prevents accurate allocation. We found that detailed crop and livestock management information enabled LCIA results to better reflect the realities of production, and through alternative functional units, we were also able to highlight, for example the trade-offs between extensive production causing lower impacts per area, but the low productivity causes higher impacts per unit of product, e.g. kg nitrogen, protein or product. The use of per kilogram nitrogen allowed for a common functional unit for crops and livestock output, that better related to the agronomic production than using economic unit, e.g. Euros.

4.5 Conclusions

Overall, we were able to assess a very diverse range of farm systems in varying geographical locations to at least partly, answer the question of whether MiFAS systems provide environmental and potentially economic benefits. The answer is sometimes and depending on the indicator and functional unit applied. The ICL and ICLF systems, as well as the SL were more self-sufficient in nitrogen supply, but SA farms had better external nitrogen utilisation. In terms of GHG, the SA farms emitted the least at both per hectare and per kg nitrogen exported from the farm, with SL emitting the most and the ICL and ICLF farms at an intermediate level. For the other environmental indicators, the SL farms were usually the lowest per hectare as a result of their extensive characteristics, whilst for the per kg nitrogen FU, SA farms were lowest and SL the highest.

However, these results are influenced by the farms within each type, and there were clear trade-offs between per area and per product impacts. The results also showed that the impacts are very related to the specific situation on the farm and that strategies such as agroforestry alone will not solve issues, but a whole farm approach to reducing impacts through reduction and efficient use of fertilisers and feeds, combined with additional strategies will have the greatest impact. Some of the ICLF systems were situated with existing woodlands and due to its age, new carbon sequestration was unlikely, whilst the system was also supported by considerable external feed inputs, therefore the system does not appear to be a solution from an LCA impact perspective. However, the more extensive versions of this systems provided direct benefits as well as other factors such as welfare which may be much improved compared to intensive indoor production. The results from this analysis should be viewed with caution as the systems assessed were only within a range of networks available within the MIXED project, and even within the MIFAS system clusters, results were heavily influenced by certain networks and generalisations should not be made.

Therefore, whilst LCA remains a good option for assessing environmental impacts, there is still much work to be undertaken to allow farm LCA assessments to fully understand the complexities of the systems. Furthermore, other ecosystem services and societal aspects are still absent from this study and most LCAs, including biodiversity and animal welfare as two major topics. Increasing crop and forage diversity, agroforestry and a more diverse landscape are all likely positives for ecosystem services, but their assessment remains challenging at a wider scale. Whilst the Farm LCA tool proved adequate as a tool for assessing farm system characteristics, as well as both environmental and economic impacts, the more diverse nature of ICL and ICLF farms likely results in positive aspects not quantified within this work. In general, the LCA and economic results show that their impacts are often similar or lower per hectare, and yet not as high as extensive livestock production per kilogram of product.

Overall, and from a policy perspective, the results point to variation in impacts result from the specifics of a production system. Farms and policies must find a balance between productivity whilst minimising external inputs, with the potential to add agroforestry for additional benefits.

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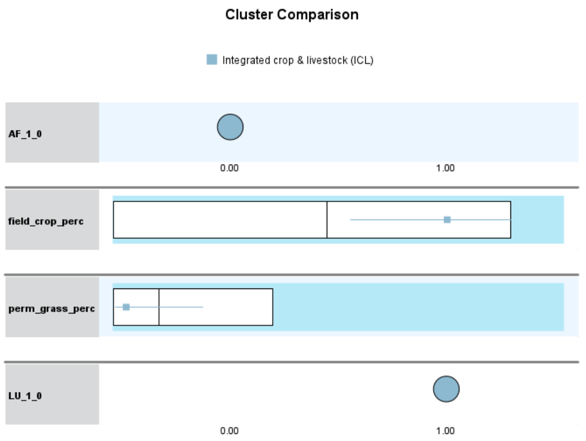
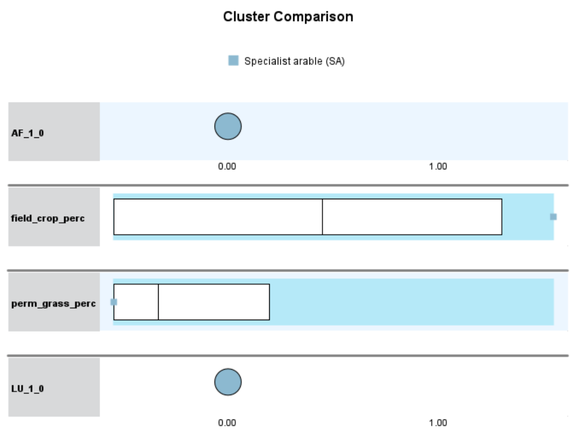
6 Annex

6.1 Clustering variable importance within clustered groups

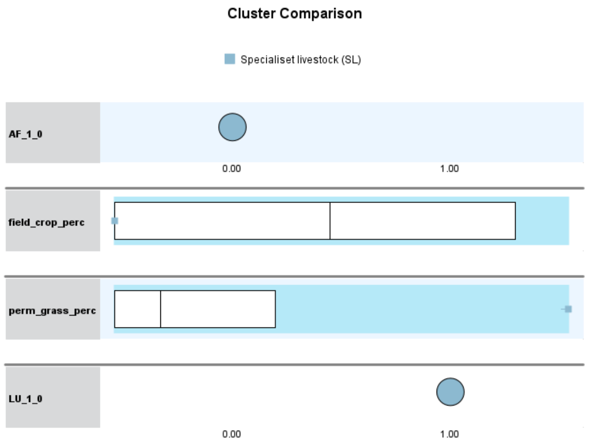
ICL



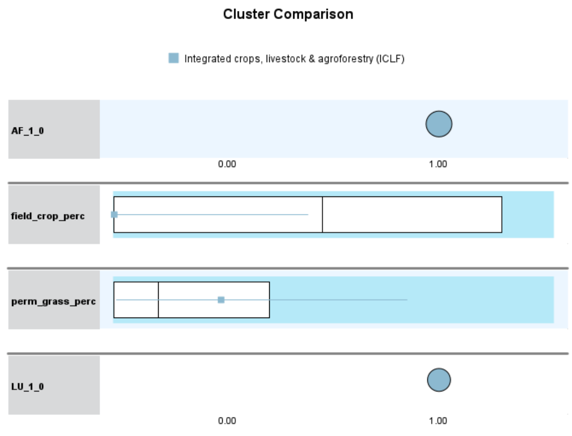
SA



SL



ICLF



6.2 Wheat environmental impact values per kilogram of product

Variable	Unit	ICL		SA		SL		ICLF		Sig*
GHG_kgFM	kg CO2 eq	0.54	ns	0.56	ns	0.35	ns	0.59	ns	ns
FEN_kgFM	MJ deprived	4.13	ns	4.36	ns	2.69	ns	4.81	ns	ns
MRU_kgFM	kg deprived	0.0080	ns	0.0075	ns	0.0055	ns	0.0090	ns	ns
FAC_kgFM	kg SO2eq	8.7E-09	ns	8.8E-09	ns	4.7E-09	ns	7.3E-09	ns	ns
TAC_kgFM	kg SO2eq	1.5E-05	ns	1.2E-05	ns	8.3E-06	ns	1.6E-05	ns	ns
FEU_kgFM	kg PO4eq	3.5E-05	ns	2.9E-05	ns	2.9E-05	ns	3.7E-05	ns	ns
MEU_kgFM	kg Neq	0.0003	ns	0.0002	ns	0.0001	ns	0.0002	ns	ns
tillage_ghg	kg CO2 eq	180	ns	146	ns	212	ns	218	ns	ns
sowing_ghg	kg CO2 eq	168	b	178	b	181	b	121	a	*
fertilization_ghg	kg CO2 eq	1271	ns	1402	ns	1484	ns	606	ns	ns
plant_protection_ghg	kg CO2 eq	34	b	43	b	54	b	0	a	*
harvest_ghg	kg CO2 eq	590	ns	605	ns	163	ns	417	ns	ns
field_emission_ghg	kg CO2 eq	1636	b	2341	b	1203	ab	1145	a	*
tillage_fne	MJ deprived	2441	ns	1989	ns	2874	ns	2979	ns	ns
sowing_fne	MJ deprived	1435	b	1524	b	1529	b	991	a	*
fertilization_fne	MJ deprived	17959	b	18323	b	17410	ab	7286	a	*
plant_protection_fne	MJ deprived	541	b	671	b	873	b	0	a	*
harvest_fne	MJ deprived	9411	ns	9584	ns	2313	ns	7382	ns	ns
tillage_mru	kg deprived	7.41	b	6.77	a	11.35	b	10.74	b	*
sowing_mru	kg deprived	4.54	b	4.68	b	4.70	b	4.07	a	*
fertilization_mru	kg deprived	29.73	b	27.28	ab	27.43	ab	12.20	a	ns
plant_protection_mru	kg deprived	0.97	ab	1.38	b	1.50	b	0.00	a	ns
harvest_mru	kg deprived	18.04	ns	17.28	ns	6.29	ns	16.38	ns	ns
tillage_fac	kg SO2eq	2.5E-06	ns	2.1E-06	ns	3.0E-06	ns	3.1E-06	ns	ns
sowing_fac	kg SO2eq	2.7E-06	ns	2.6E-06	ns	2.9E-06	ns	2.6E-06	ns	ns
fertilization_fac	kg SO2eq	1.3E-05	ns	1.4E-05	ns	1.7E-05	ns	8.2E-06	ns	ns
plant_protection_fac	kg SO2eq	6.7E-07	b	8.4E-07	b	1.1E-06	b	0.0E+00	a	*
harvest_fac	kg SO2eq	8.3E-06	ns	8.5E-06	ns	2.9E-06	ns	6.1E-06	ns	ns
field_emission_fac	kg SO2eq	3.8E-05	ns	5.4E-05	ns	1.7E-05	ns	1.6E-05	ns	ns
tillage_tac	kg SO2eq	0.002	ns	0.002	ns	0.003	ns	0.003	ns	ns
sowing_tac	kg SO2eq	0.003	ns	0.003	ns	0.004	ns	0.004	ns	ns
fertilization_tac	kg SO2eq	0.034	ns	0.016	ns	0.039	ns	0.013	ns	ns
plant_protection_tac	kg SO2eq	0.001	b	0.001	b	0.001	b	0.000	a	*
harvest_tac	kg SO2eq	0.007	ns	0.007	ns	0.003	ns	0.005	ns	ns
field_emission_tac	kg SO2eq	0.067	ns	0.088	ns	0.029	ns	0.024	ns	ns
tillage_feu	kg PO4eq	0.005	ns	0.004	ns	0.006	ns	0.006	ns	ns
sowing_feu	kg PO4eq	0.074	b	0.072	b	0.081	b	0.023	a	*
fertilization_feu	kg PO4eq	0.015	ns	0.016	ns	0.031	ns	0.004	ns	ns
plant_protection_feu	kg PO4eq	0.006	b	0.007	b	0.011	b	0.000	a	*
harvest_feu	kg PO4eq	0.010	ns	0.010	ns	0.005	ns	0.010	ns	ns
field_emission_feu	kg PO4eq	0.133	ns	0.114	ns	0.140	ns	0.127	ns	ns
tillage_meu	kg Neq	0.033	ns	0.028	ns	0.040	ns	0.043	ns	ns
sowing_meu	kg Neq	0.055	ns	0.053	ns	0.059	ns	0.053	ns	ns
fertilization_meu	kg Neq	0.657	ns	0.519	ns	0.607	ns	0.501	ns	ns
plant_protection_meu	kg Neq	0.021	b	0.025	b	0.036	b	0.000	a	*
harvest_meu	kg Neq	0.086	ns	0.086	ns	0.040	ns	0.076	ns	ns

field_emission_meu	kg Neq	1.051	ns	1.423	ns	0.460	ns	0.405	ns	ns

Statistical assessment using Kruskal-Wallis with significance levels: *-p<0.001, **-p<0.01, *-p<0.05, ns-not significant. Identical small letters denote residence within a homogenous group. Different letters indicate significant difference at a maximum p-value of <0.05.*