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Environmental indicators in farm-level surveys: A Literature review

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Contents

Executive summary

We have undertaken a systematic literature review of environmental indicators and metrics that are currently used in farm level surveys. This review will inform the production of environmental indicators for farms in the Scottish Farm Business Survey (FBS). Environmental data estimated for the Scottish FBS currently includes greenhouse gas (GHG) emissions and nitrogen (N) use. This data represents impacts on climate change and risk to water quality. Our search therefore focused on indicators and metrics that could be calibrated from this data. We have also highlighted other non-environmental variables in the reviewed surveys that are highly correlated with GHG emissions and nitrogen use.

The objectives of the report are:

- **To identify fit-for-purpose farm level environmental indicators and metrics that are based on data collected for GHG emissions and nitrogen use.**

- **To identify relationships between environmental and other non-environmental (primarily economic) indicators.**

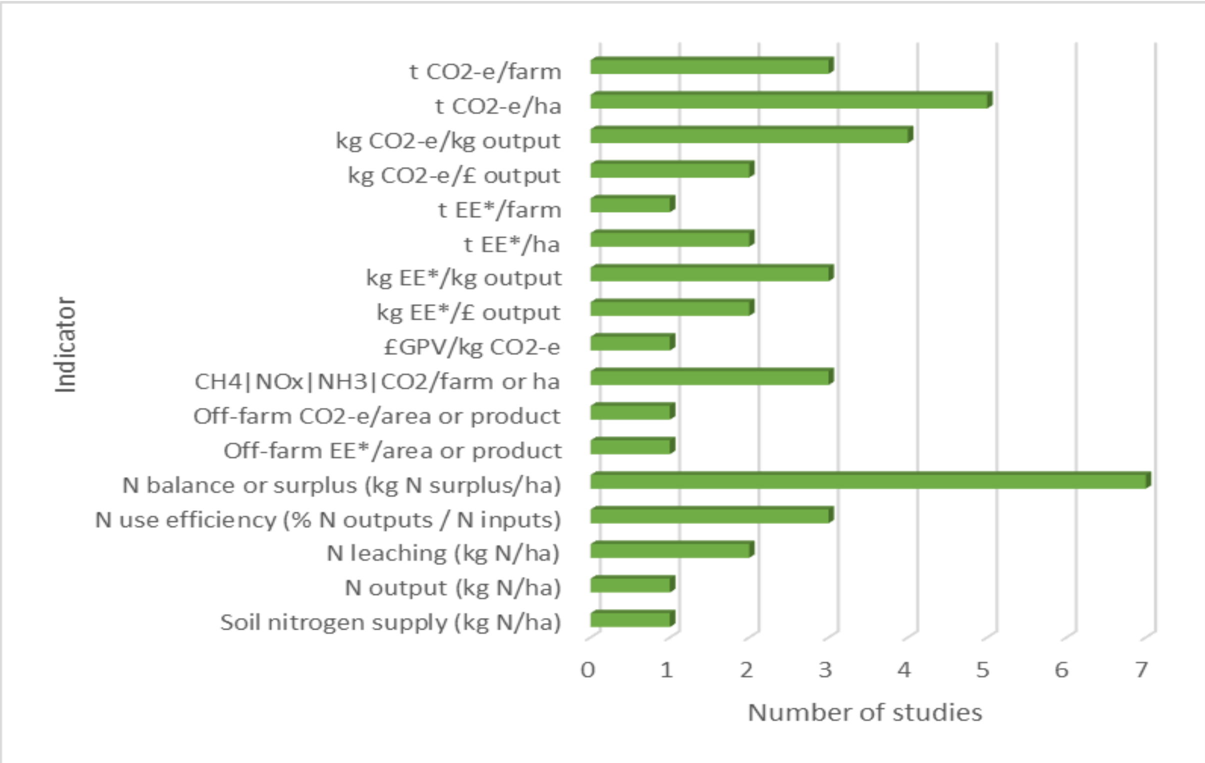
We have identified fourteen papers that met these criteria. Five papers developed indicators for both GHG emissions and nitrogen use, four papers developed indicators for GHG emissions alone, and five papers that developed indicators for nitrogen use.

For indicators used to express GHG emissions, there was a clear distinction between biological and non-biological sources of emissions, individual and aggregated greenhouse gases (methane, nitrogen oxides, and carbon dioxide emissions vs total emissions), and on- and off- farm emissions. Overall, these indicators were presented by unit area (e.g. tonnes of CO_2-e per hectare or farm) or by output product (e.g. kg CO_2-e per kg of agricultural output). In some studies, the unit of agriculture outputs was presented in monetary terms instead of physical quantities (e.g. kg CO_2-e / € output). This was done to eliminate differences between commodities and therefore facilitate the comparison across different farm types. Non-biological sources of emissions were captured by non-renewable energy use indicators (e.g. GHG emissions from energy use per farm, hectare, and kg or € of output). To develop these indicators, the energy value from fossil fuel use (in MJ) was initially estimated, which was then used to estimate GHG emissions (in CO_2-e). Moreover, on-farm and off-farm emissions indicators were commonly used in those studies that employed life cycle assessment methodology. Finally, one study used a ratio of farm's gross

production value to carbon emissions (i.e. carbon productivity indicator; €GVP/kg CO_2-e) as a metric for GHG emissions.

Nitrogen use was also presented by several indicators. The most common indicators used were nitrogen balance per unit area (defined as imports of N less exports and is measured as kg N surplus/ha), nitrogen use efficiency (presented as a percentage and calculated as a farm gate ratio of N outputs to N inputs), nitrogen surplus per unit area (kg N surplus/ha), nitrate leaching per unit area (kg N/ha), and Nitrate concentration per farm output (e.g. mg NO_3/litre). One study used soil nitrogen supply which is considered a measure of the N supply in an unfertilized situation. Nitrogen surplus and nitrate leaching are often considered as a proxy for the risk of N loss to the environment, while N output is considered as an indicator of farm productivity. Finally, nitrogen use efficiency is regarded as an indicator of resource efficiency. Among all indicators, CO_2-e per hectare or kg of output as well as N balance/surplus and N use efficiency are the most used indicators in literature to represent GHG emissions and nitrogen use data.

Figure. List of indicators considered in our review and the number of studies that used these indicators.



*** EE = Emissions related to energy use**

Some of the studies have also investigated the relationship between environmental indicators and non-environmental (primarily economic) indicators. For instance, one study has captured this relationship by developing a ratio indicator between carbon productivity (CP) (i.e. farm's gross production value per unit of emissions) and farm net value added. While carbon productivity levels were generally associated with better economic performance, the relationship between CP and Farm net value added was non-linear and varied among different farm types. Another study presented the relationship by plotting the estimated emissions and nitrogen balance against the top, middle, and bottom performing farms.

Overall, the way in which the indicators are presented were highly dependent on the objective of the study. This includes evaluating policy intervention (e.g. adoption of certain farming practices or imposing a tax on pollutants) and evaluating the environmental performance of sampled farms. To evaluate policy intervention, indicators and metrics were often presented as a percentage change from a baseline. Another way to present the impacts of a policy intervention was to compare the metrics and indicators of two groups of farms: an experimental group (that for instance adopted new farming practices) and a control one (that serves as a baseline). For those studies which aim to evaluate the environmental performance of sampled farms, the values of the indicators were often presented across different categories such as farm type, farm size, and economic performance.

Finally, a recent report funded by Scotland's centre of expertise 'ClimateXChange' has used FBS to explore the economic and environmental performance of Scottish farms. The authors used gross emissions and production intensities (CO_2-e per kg of output) instead of total emissions and total output to compare farms of different sizes. They also used N use efficiency as the main metric to present the nitrogen use data in their analysis. While N use efficiency was a useful proxy for farm level N use estimates, it did not account for some important input information such as legumes. The authors also recommended including net emissions indicator in future studies to account for carbon sequestration by farm soils and woodland.

1 Introduction

The Scottish Farm Business Survey (FBS) is a well-established annual survey that collects financial and production data of approximately 400 Scottish farms. Besides the economic data, the survey also collects some biophysical information which helps in understanding the factors that underpin the financial position of the farms. The FBS is based on a harmonised data collection methodology which ensures that the information provided to the Scottish government is reliable and comparable across farms. While FBS has been primarily used to inform the government on the status of the Scottish agricultural economy, it has also been used to inform policy development and advise farm businesses.

The Scottish government aims to achieve a sustainable economy and become carbon neutral by 2045. One of the main tools to achieve this goal is to monitor the impact of farm level agricultural production on the environment. In the last few years, there have been research efforts to expand the scope of FBS to include environmental information (Barnes et al 2020). In particular, the Agricultural Resources Calculator (Agrecalc) has been used to estimate the GHG emissions and nitrogen use of the FBS sampled farms. This study was important to quantify some of the potential unwanted environmental by-products that are associated with farm level production. However, due to the complex and dynamic relationship between farm production and environmental pollutants, it is quite challenging to identify appropriate indicators that capture this relationship and to determine the best way to present them to policy makers. Developing appropriate farm-level indicators will ultimately help in informing policy development and improve reporting on the state of the environment.

The objective of this report is therefore to assist in developing fit-for-purpose indicators that are based on farm level data collected for GHG emissions and nitrogen use as well as the relationship between environmental and other non-environmental (primarily economic) indicators. To achieve this object, we have reviewed the literature on previous research attempts that developed farm-level environmental indicators. As the Scottish FBS was previously one of the sources of the FADN database, our review has also focused on research work that developed environmental indicators for FADN surveys in other European countries.

2 Methods

A targeted systematic literature review was carried out using Google Scholar, ISI Web of Science and Scopus. Grey literature has also been searched using public and private websites. This includes reports published by Scotland's centres of expertise and the Scottish government. In addition, experts in the fields of the farm level survey were contacted and asked to provide research that they felt was relevant to the review. Several keywords were used for the literature selection and screening process (Table 1). The results of our search have then been classified into three groups of relevant studies:

- Studies that developed indicators for GHG emissions and a nitrogen budget;
- Studies that developed indicators for GHG emissions;
- Studies that developed indicators for a nitrogen use;

Table 1: Search strategies used

Environmental variable	Search terms
Greenhouse gases (GHG)	"Environmental indicators" OR "carbon indicator" OR "GHG indicator" OR "GHG emissions indicator" OR "sustainability indicator" OR "FADN" AND "farm level surveys"
Nutrient budgets	"Environmental indicators" OR "nutrient/nitrogen indicator" OR "nutrient/nitrogen balance" OR "nutrient/nitrogen leaching" OR "sustainability indicator" OR "FADN" AND "farm level surveys"

3 Results

3.1 Overview of studies

Our literature review identified fourteen papers that met our research criteria (Table 2 and 3). We found five papers that developed indicators for both GHG emissions and nitrogen use, four papers that developed indicators for only GHG emissions, and five papers that developed indicators for only nitrogen use. A description of each study is shown below in the next sections.

Table 2: Indicators for GHG emissions

Reference	Indicators	Relation to other (non-environmental) variables
Ryan et al. (2016)	t CO_2eq/farm CO_2eq/kg output (agriculture) CO_2eq/kg output (energy)	Emissions per kg of product sold relative to gross margins per hectare. To present this relationship, the average carbon emissions were tabulated against the top, middle, and bottom economically performed farms.
Coderoni & Vanino (2022)	Farm-level carbon productivity (ration of farm gross production value to farm's carbon emissions)	The OECD macro-level CP indicator was reconstructed at the farm-level and its effect on farm's economic performance was quantified.
Henry et al (2017)	Methane emissions (kg CO_2-eq/ha) Nitrous oxide emissions (kg CO_2-eq/ha) Carbon dioxide emissions (kg CO_2/ha) Total GHG emissions (kg CO_2-eq/ha)	A follow-up study by Soliman & Djanibekov (2020) has used the New Zealand Monitor Farm Data to estimate the ecological-economic performance or 'eco-efficiency'. This analysis identifies the best performance farms and the factors that prevent the inefficient farms from operating at the frontier. They used GHG emissions and nutrient (nitrate and phosphorous) leaching per hectare as indicators to analyse environmental performance of farms.
Samson et al (2012)	kg CO_2-e/1,000 euros of production ton CO_2-e/ha Non-renewable energy use in MJ/1,000 euros of production Non-renewable energy use in MJ/ha	The authors found that Livestock production was highly correlated with GHG emissions while cereals and cash crops showed high non-renewable energy use, due to intensive use of mineral fertilizers.
Dolman et al (2014)	On-farm emissions (kg CO_2eq/kg FPCM) Off-farm emissions (kg CO_2eq/kg FPCM) Total emissions (kg CO_2eq/kg FPCM)	Farms that applied practices to improve internal nutrient cycling had a lower non-renewable energy use per kg fat-and-protein-corrected milk (FPCM), higher soil organic carbon content and received higher annual payments for agri-environmental measures, while other indicators did not change.

	On/off-farm non-renewable energy use (MJ/kg FPCM)	
Dabkiene et al (2021)	GHG emissions (t CO2-eq /farm)	A relationship matrix (correlogram) between environmental indicators and non-environmental indicators was estimated (Figure 1). The results showed that mixed crops-livestock farms that have medium economic performance are the best environmentally performed farms.
Daigneault et al (2018)	GHG emissions (ton CO_2-eq/ha)	In this study, GHG emissions were estimated for all farm types at a per hectare basis. For livestock farms, this was done by multiplying the estimated number of stocking unit per hectare times the average carbon emissions per a stocking unit. Nutrient (Nitrogen and phosphorus) leaching per hectare was also estimated in this model.
Buckley & Donnellan (2021)	GHG emissions per area (t CO_2-eq/farm or hectare) GHG emissions per kg or € of output Emissions from on-farm energy use per farm/ha/ unit of output Ammonia emissions (NH_3) per farm/hectare/unit of output	While emissions intensity (CO_2-e/kg output) from dairy farms has improved, the total emissions (CO_2-e/ha) has increased. This is because larger volumes of milk have been produced which offset the achieved improvements in emission intensity. GHG emissions from other farm types have also increased due to higher livestock stocking rates and increased liming activity.
Bazzani et al (2021)	CO_2 emissions (Abatement cost of kg of CO_2)	The study estimates the abatement cost of CO_2 emissions from arable crops. The estimated abatement cost was shown to be higher than the European Emission Trading System (ETS) prices. This indicates that investment in new technologies is needed to reduce the cost of reducing CO_2 emissions in Italian arable land.

Table 3: Indicators for nitrogen use

Reference	Indicators	Relation to other (non-environmental) variables
Ryan et al. (2016)	Nitrogen surplus per unit area (kg N surplus/ha)	The authors assessed the relationship between kg N surplus per ha and the gross margins per hectare. Aggregated results of this relationship were represented for the top, middle, and bottom economically performed farms.
Henry et al (2017)	Nitrate leaching (kg N/ha)	A follow-up study by Soliman & Djanibekov (2020) has used the New Zealand Monitor Farm Data to estimate the ecological-economic

		performance or 'eco-efficiency'. This analysis identifies the best performance farms and the factors that prevent the inefficient farms from operating at the frontier.
Quemada et al (2020)	Nitrogen use efficiency (farm gate ratio of N outputs to N inputs, in %) Nitrogen surplus (kg N surplus per ha) Nitrogen output (kg N per ha)	Farming systems and farm management practices have high effect on the N use efficiency and N surplus indicators. The authors also set up targets for each farm type by using certain quantiles of the sampled farms. For instance, the median and the third quantile values were set as ambitious and modest targets for N use efficiency, respectively; while the first quantile and median values were set as ambitious and modest targets for N surplus, respectively.
Pesti & Keszthelyi (2009)	Nitrogen balance (kg N surplus/ha)	The authors found that farm level environmental pollution in Hungary is lower than those in western Europe due to lower fertilizer use and livestock density which is a result of lower income levels.
Dolman et al (2014)	Soil nitrogen supply (kg/ha) Nitrate concentration (mg NO_3 /litre)	Farms that applied practices to improve internal nutrient cycling had a lower non-renewable energy use per kg fat-and-protein-corrected milk, higher soil organic carbon content and received higher annual payments for agri-environmental measures, while other indicators did not change.
Daigneault et al (2018)	Nitrate leaching (kg N/ha)	The authors estimated carbon emissions and nutrient leaching at a per hectare basis to be able to quantify the trade-offs between environmental and economic impacts that result from policy interventions. Nutrient leaching per unit area was used because the economic impacts (changes in net revenues) for all farm types were also estimated at a per hectare basis.
Ehrmann (2010)	nitrogen balance (kg N/ha)	While the fertilizer taxes have decreased N surplus of dairy farms, it has also reduced their profits. The intervention also changed the intensification level of arable farms. The results were presented as percentage change from baseline and were categorised by farm and scenario type.
Buckley & Donnellan (2021)	Nitrogen use efficiency (% N outputs / N inputs) Nitrogen balance (kg N surplus/ha)	Nitrogen pollution has decreased in Dairy and Tillage farms due to better farming practices.
Betts et al (2023)	Nitrogen balance (kg N surplus/ha)	Nitrogen (kg N/ha) is adversely related to farm performance. Moreover, farmers who use independent advice on fertilizer application have better performance than those who took

		advice from fertilizer suppliers (advice linked to fertilizer sales).
Buckley et al (2015)	Nitrogen use efficiency (% N outputs / N inputs) Nitrogen balance (kg N surplus/ha)	While nitrogen balances of dairy farms were 2–4 times higher than livestock rearing and specialist tillage systems, nitrogen use efficiency was lower across milk producing systems compared to livestock rearing and tillage systems.

3.2 Studies that developed indicators for GHG emissions and nitrogen use

Ryan et al. (2016) developed a range of sustainability indicators for the Teagasc National Farm Survey (NFS) data in Ireland. This includes indicators for economic, environmental, social and innovation aspects of the Irish farms. The NFS data has been traditionally used to report to the EU Farm Accountancy Data Network (FADN) and consists of 1000 farms. Related to the scope of our study, the authors suggested three indicators for air quality and one for the risk of water quality. These are (1) GHG emissions per farm [t CO_2-e / farm], (2) GHG emissions per kilogram of agricultural output [CO_2-e / kg output], (3) emissions from fuel and electricity [CO_2-e / kg output], and (4) nitrogen balance [kg N surplus/ha]. The emissions estimates in this study were calculated using the Intergovernmental Panel on Climate Change (IPCC) methodology by utilising a combination of Tier 1 and Tier 2 approaches. The three selected GHG indicators show that the authors have differentiated between biological and non-biological sources for GHG emissions. The authors also find that there is a positive relationship between GHG emissions and economic performance in which the top economic performing livestock farms produce the lowest emissions. A similar trend was also captured for nitrogen balance. To present the results, the average emissions and nitrogen balance were tabulated against the top, middle, and bottom economically performed farms.

Henry et al (2017) integrated two farm level datasets to create the New Zealand Monitor Farm Data (NZMFD). The first dataset represents financial information of surveyed farms which was collected by the New Zealand Ministry of Agriculture and Forestry (MAF). The second dataset contains geophysical and environmental information for the same surveyed farms that was modelled by a decision support tool called “OVERSEER”. NZMFD consists of information for 259 livestock farms which are presented over four years. Among the environmental information modelled for the surveyed farms is GHG emissions and nitrogen use. These two variables were represented by a range of indicators on a hectare basis including methane, nitrous oxide, carbon dioxide, and total emissions, as well as nitrate leaching. GHG emissions in OVERSEER are estimated based on international life cycle assessment (LCA) standards. The applied accounting methodology considers all direct, indirect, and embodied GHG emissions up to the farm gate. A follow-up study by Soliman & Djanibekov (2020) has used the NZMFD to estimate the ecological-economic performance or 'eco-efficiency'. This analysis identifies the best performance farms and the factors that prevent the inefficient farms from operating at the frontier. In this study, GHG emissions and nutrient (nitrate and phosphorous) leaching per hectare were the indicators used to analyse environmental performance of farms.

Dolman et al (2014) evaluated the effects of farming practices that aim to improve internal nutrient cycling (INC) in Dutch dairy farms. Improved INC is predicted to improve the on- and off- farm environmental impacts of dairy farms. To estimate these effects, a group of farms that apply INC practices was compared to another benchmark group. The data for this study was sourced from the Dutch FADN data set. In addition, a set of economic, environmental, and social indicators were derived from LCA to quantify the effects of INC practices on farm performance. These includes global warming potential indicators (on-farm/off-farm emissions [kg CO_2-e / kg fat-and-protein-corrected milk], on-farm/off-farm non-renewable energy use [MJ/kg fat-and-protein-corrected milk]), on-farm soil and water quality indicators (soil phosphorus content (P-Al, mg/100 g soil), soil nitrogen supply (kg/ha) and nitrate concentration (mg NO3/litre)). The soil nitrogen supply is considered as a measure of the N supply in an unfertilized situation, while soil phosphorus content gives a rough indication of the level of P saturation and therefore the amount of P that could be lost to the environment. The authors found that farms that applied INC practices had a lower non-renewable energy use per kg fat-and-protein-corrected milk, higher soil organic carbon content and received higher annual payments for agri-environmental measures, while other indicators did not change.

Daigneault et al (2018) developed an economic land use model to assess agri-environmental policies in New Zealand. To parameterise the economic model, they used a farm level survey "Farm Monitoring data" in conjunction with other environmental and geophysical datasets. In this model, GHG emissions were estimated for all farm types at a per hectare basis. For livestock farms, this was done by multiplying the estimated number of stocking units per hectare times the average carbon emissions per a stocking unit. Nutrient (Nitrogen and phosphorus) leaching per hectare was also estimated in this model. The authors estimated carbon emissions and nutrient leaching at a per hectare basis to be able to quantify the trade-offs between environmental and economic impacts that result from policy interventions. This is because the economic impacts (changes in net revenues) for all farm types were also estimated at a per hectare basis.

Buckley & Donnellan (2021) have used the Teagasc national farm survey to measure the sustainability performance of Irish farms. Economic, environmental, social, and innovation indicators were estimated from approximately 840 farms across Ireland. Greenhouse gas (GHG) emissions and nitrogen use were represented by a range of indicators such as nitrogen surplus and nitrogen use efficiency as well as absolute emissions (t CO_2-e / ha) and emissions intensity (kg CO_2-e / kg output). Environmental performance was tracked for four farm types. These are dairy, cattle, sheep, and tillage. While emissions intensity from dairy farms has decreased, the total absolute emissions have increased. This is because larger volumes of milk have been produced which offset the achieved improvements in emissions intensity. GHG emissions from other farm types have also increased due to higher livestock stocking rates and increased liming activity. Nitrogen pollution however has decreased in dairy and tillage farms due to better farming practices.

3.3 Studies that developed indicators for GHG emissions

The OECD has developed a carbon productivity (CP) indicator at the national level which gauges the level of economic growth that could be achieved by emitting additional units of GHG (OECD 2017). This is done by measuring the agriculture gross production value per unit of carbon equivalents emitted by agriculture. Coderoni & Vanino (2022) however reconstructed the CP indicator at the farm level and identified its effect on farm's economic performance (Farm Net Value Added). This work would therefore determine the effect of the green growth of the agriculture sector (and in particular the more efficient path of GHG emissions) on farm's economic viability. The authors used a sample of the Italian FADN dataset that consists of ~2000 farms to determine this relationship. They also used the IPCC methodology to estimate the GHG emissions values. They found that the relationship between CP and Farm Net Value Added is non-linear and varies among different farm types. They also found that higher CP levels are associated with better economic performance.

Samson et al (2012) developed environmental indicators to measure the impacts of different agriculture systems on climate change. The analysis employed an LCA approach to derive the environmental indicators from FADN sample data of French farms. These include GHG emissions (kg of CO_2-e per 1,000 euros of production and tonnes of CO_2-e per hectare of land area) and non-renewable energy use (non-renewable energy use in MJ per 1,000 euros of production and non-renewable energy use in MJ per ha). The results showed that livestock, in particular cattle, production was a key source of GHG emissions. Cereals and cash crops production also required high non-renewable energy use, which was mainly needed to apply fertilizers.

Dabkiene et al (2021) constructed an Agri-environmental Footprint Index to assess the environmental performance of Lithuanian farms. This index, which was estimated from Lithuanian FADN data, consists of a range of indicators that reflect several themes such as agricultural practices, energy, diversity, organisation of spaces, natural resources, farmer's agricultural skills. One of the used indicators was GHG emissions which were measured as tonnes of CO_2-e per farm. Relationship between indicators was also measured to avoid double counting the same environmental impact element on farms (Figure 1). The results showed that mixed crops-livestock farms that have medium economic performance are the best environmentally performed farms.

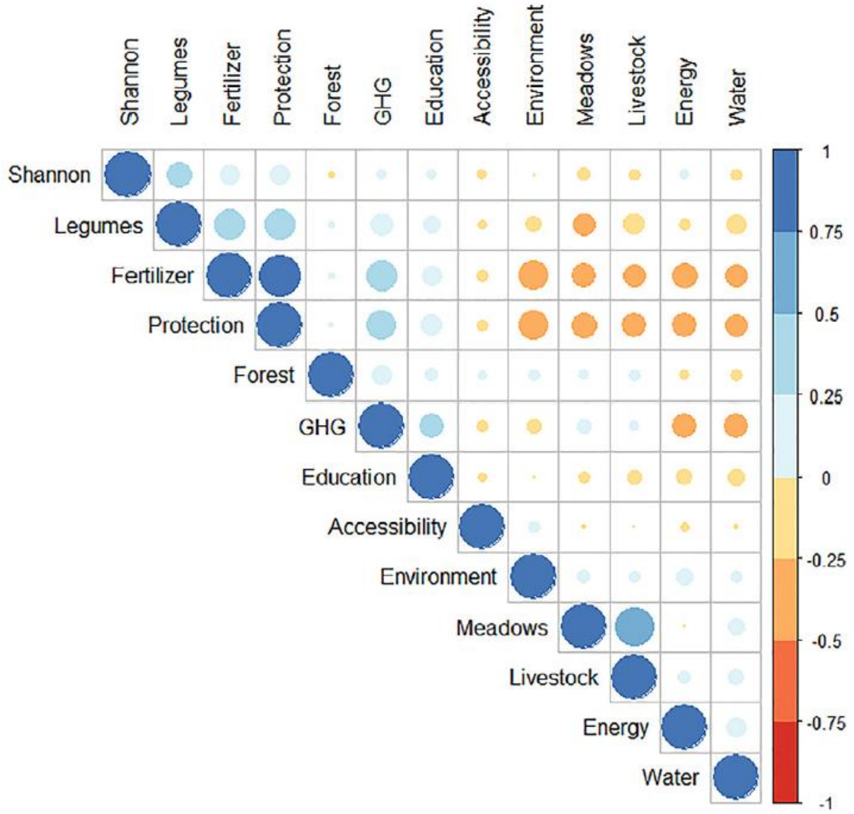


Fig. 1. Correlogram of agri-environmental indicators.

Bazzani et al (2021) estimated the abatement cost of CO_2 emissions from arable crops. The authors employed a linear multi-objective programming model which was parameterised from the Italian FADN data set. The study focuses only on CO_2 emissions which is mainly emitted from the use of machinery. Only seven regions in Italy were able to afford reduction of CO_2 emissions higher than 5 kg/ha at an abatement cost lower than 1 EUR/kg. Moreover, the estimated abatement cost was shown to be higher than the European Emission Trading System (ETS) prices. This indicates that investment in new technologies is needed to reduce the cost of reducing CO_2 emissions in Italian arable land.

3.4 Studies that developed indicators for nitrogen use

Quemada et al (2020) evaluated the environmental performance of 1240 farms in several European countries. They also evaluated the suitability of three different nitrogen indicators as a measure for farm performance. These indicators are N use efficiency, which was defined as farm gate ratio of N outputs to N inputs (%), N surplus (kg N per ha) and N output (kg N per ha). Nitrogen indicators were estimated following an approach developed by the the EU Nitrogen expert panel (EUNEP, 2016). They found that farming systems and farm management practices have a high effect on N use efficiency and N surplus indicators. Arable farms had the lowest N input and surplus and the highest N output and use efficiency, while in contrast livestock farms had the highest N input and surplus and the lowest N output and use efficiency. The authors also set up targets for each farm type by using certain quantiles of the sampled farms. For instance, the median and the third quartile values were set as ambitious and modest targets for N use efficiency, respectively; while the first quartile and median values were set as ambitious and modest targets for N surplus, respectively. Although geophysical factors (e.g. soil and climate) were not considered in the analysis, it is expected that these factors will also have an effect on the indicators values.

To better understand the environmental state of Hungarian farms and the effects of farm agricultural production on the environment, Pesti & Keszthelyi (2009) developed an index system that integrates several environmental indicators. This index system was estimated from the Hungarian FADN data and consisted of the following indicators: nutrient (nitrogen, phosphorus, and potassium) balance, biodiversity, proportion of cereals and pulses, energy consumption, winter soil surface coverage. The index system was also compared to the economic performance of the farms. The authors found that environmental pollution in Hungary is lower than those in western Europe due to lower fertilizer use and low livestock density which is a result of lower income levels.

Ehrmann (2010) assessed the impact of policy interventions on economic and environmental performance of German farms. The policy interventions examined in the analysis were the impacts of imposing fertilizer taxes and limits and changes in direct payments. The analysis used simulation modelling which was parameterised from the German FADN data. Ecological indicators such as nitrogen balance (kg N/ha) and pesticide use (€/ha) were also used to quantify the effects of the intervention. While the fertilizer taxes have decreased the N surplus of dairy farms, it has also reduced their profits. Moreover, the intervention reduced the intensive production systems of arable farms. The results were presented as percentage change from baseline and were categorised by farm and scenario type.

Gray Betts et al (2023) used mixed effects generalized modelling to assess the relationship between farm financial performance, farm application advice, and nitrogen balance. General cropping and cereal farms of the English FBS dataset was used in the regression analysis. The authors found that nitrogen (kg N/ha) is adversely related to farm performance. High levels of nitrogen surplus (>60 kg per hectare) have also led to significant impact on farm performance. Moreover, it was shown that farmers who use independent advice on fertilizer application have better performance than those who took advice from fertilizer suppliers (advice linked to fertilizer sales).

A study by Buckley et al (2015) used the Irish FADN data set to compare nitrogen use across different types of farms. Nitrogen use was represented by nitrogen use efficiency (%) and nitrogen balance (kg N/ha) indicators. While nitrogen balances of dairy farms were 2–4 times higher than livestock rearing and specialist tillage systems, nitrogen use efficiency was lower across milk producing systems compared to livestock rearing and tillage systems.

4 Conclusion

Environmental indicators and metrics are used by several public and private entities to achieve a wide range of objectives (Gallopin 1997). These include reporting on the state of the environment, advising policy development and farm businesses, and prioritising budgetary decisions. To identify fit-for-purpose indicators that could represent environmental data in the Scottish FBS, it is important to assess and understand indicators and metrics that have been used in previous studies. This report therefore reviews the wider literature on environmental indicators and metrics that could represent GHG emissions and nitrogen use data collected for the Scottish FBS.

Our results showed that a range of indicators have been used in literature for GHG emissions and nitrogen use. Overall, GHG emissions indicators were presented by unit area and/or by product. There was also a distinction between emissions from biological and non-biological sources, different types of gases (methane, nitrous oxide, carbon dioxide), and on-farm and off-farm emissions. Similarly, indicators for nitrogen use have also been presented by unit area and/or by product and mainly driven from or mapped to the components of nitrogen balance. This includes nitrogen use efficiency, nitrogen surplus, nitrate leaching, and nitrate concentration. Our results showed that tonnes CO_2-e per hectare and kg CO_2-e per kg of output as well as nitrogen balance/surplus and nitrogen use efficiency are the most used indicators in literature to represent GHG emissions and nitrogen use data.

Our findings are in line with insights from previous literature reviews. For example, Goodlass et al. (2003) reviewed 55 farm-level studies that employed Input Output Accounting systems to evaluate environmental performance. They found that the most common indicator used for nitrogen use is nitrogen balance followed by nitrate leaching. In addition, a recent report funded by Scotland's centre of expertise 'ClimateXChange' has used FBS to explore the economic and environmental performance of Scottish farms (Barnes et al 2022). In this report, the authors used gross emission and production intensities (CO_2-e per kg of output) instead of total emissions and total output to compare farms of different sizes. They also used N use efficiency as the main metric to present the nitrogen use data in their analysis. While nitrogen use efficiency was a useful indicator for farm level nitrogen use estimates, it did not account for some important input information such as legumes. Barnes et al (2022) also recommended including net emissions indicator in future studies in order to account for carbon sequestration by farm soils and woodland. Our literature review helps in selecting fit-for-purpose indicators for the recent environmental information integrated to the Scottish farm business survey. The selected indicators are expected to be SMART indicators (i.e. Specific, Measurable, Accurate, Relevant, and Trackable) and easily understandable by the public and decision makers.

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