MEF4CAP

Monitoring and Evaluation Frameworks for the Common Agricultural Policy

[24 May 2022]

Deliverable **D3.3: Potential of current systems and ICT developments for future data needs**

Identification of potential pathways for the monitoring and evaluation framework for future policies

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Objectives and overview

MEF4CAP is a H2020 project with the main purpose of delivering an innovation agenda and roadmap for future monitoring of EU agriculture Policy. The Common Agricultural Policy (CAP) 2023-2027 is targeted towards a wider range of objectives covering broader domains –agriculture sustainability, agri-environmental, food security among others. This fact entails new data sources requirement to measure the effects and the performance of the Policy. Performance is the key concept in the new monitoring and evaluation framework of the CAP (PMEF). At the same time, new technical developments, are enhancing the capability of providing, retrieving and integrating new data that are called to achieve those data needs for CAP monitoring and evaluation. MEF4CAP brings together the expected needs for assessing the performance of future CAP and the newest technologies to address those data requirements.

MEF4CAP's WP 1 has carried out a thorough review of all global policy and societal demands that have influenced the widening of CAP's objectives. It also has explained the implications that data collection has for both administrators and data providers (farmers) and also has explored the potentially beneficial uses these data could deliver to them. The final result of WP1 is a short list of 41 indicators to help the assessment of the CAP 2023-2027 performance. The motivation for choosing these indicators and how they have been selected are thoroughly explained in WP1's deliverables (D1.1 through D1.3).

In other direction, MEF4CAP's WP2 has performed an extended review on the well-established legacy technology services and on the more advanced approaches currently in place for managing the necessary data flows in the agricultural sector. The technologies identified in WP2 are expected to support the data provision for CAP monitoring and evaluation framework.

The main objective of MEF4CAP's WP3, *Current systems and future pathways*, is to identify and define the most promising combination of data sources and technologies to calculate the metrics of the indicators designed for CAP monitoring and evaluation purposes. This combination of technologies and data sources is called pathway. The first step to define these pathways was Deliverable 3.2 which confronted the data needs detected in WP1 with the technologies described in WP2 to identify their potential to provide information for the metric of the indicator. The findings in deliverable 3.2 showed that some additional requirements are needed for the data derived by some technologies to address the metric of the indicator. The most relevant ones are the adoption of Agriculture Information Models to store and exchange information, the use of data exchange standards, the willingness of farmers to share their data and the warranty for these data will be shared following GDPR regulation. Once the potential of each technology is defined and the additional requirements are established, Deliverable 3.3 describes the pathways. For this purpose, a table for each indicator is set. These tables present the description of the indicator, the technologies that potentially derive data for its metric and the description of how these data need to be handled to calculate the metric. In some cases, the achievement of the metric seems to be technically feasible but some questions regarding legal constrains for farmers to share their data and their reluctancy to do so are remarked. Finally, the link between the pathway and the Demo Cases in WP4 is presented. WP4's Demonstration Cases will make practically use of the technologies and data sources described in the pathways.

1. Definition of the pathways

1.a. Economic Sustainability

Table 1: Farm Assets and Liabilities

Indicator Name	Farm Asset Age	
Type of Indicator	Economic	
Definition	The age of key farm assets	
Unit of Measurement	Years	
Methodology/Formula	Recording of the age of key farm assets	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual, but potentially less frequently	
CAP Objective	1. Ensuring Viable Farm Incomes	
Proposed Prioritisation	Medium	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
FMIS (Farm Management Information System): Herd management system	- Records on Animals: age, performance. - Robotic milking parlors and RFID ear tags.	- Adoption of standardised data models and semantics - Adoption of agriculture data sharing protocols
FFA: Farm Financial Accounting	- Records of assets purchases and sells - Robotic accounting: e-Invoicing	- Adoption of standardised data models and semantics - Adoption of agriculture data sharing protocols
FMIS: Farm registry	- Records of machinery in registry: purchase date, type, equipment.	- Adoption of standardised data models and semantics - Adoption of agriculture data sharing protocols

POTENTIAL USE: POTENTIAL

The key assets considered for this indicator are machinery, cattle, land and buildings. Robotic accounting (e-Invoicing) is one of the data sources identified to obtain this information since the date of purchases is included in the invoices. FFA (Farm Financial Accounting systems) is the technology to centralize this financial information. The collection of this kind of data is based on the systematic recording of documents like invoices and delivery notes, or contracts in the administration of a farmer. These systems are already available on many farms for taxing purposes and therefore mature enough.

As for animals, along with age, the performance and productivity of the animals need to be assessed. The information collected by robotic milking parlors jointly with RFID ear tags is one of the most promising data sources to provide information in this regard in the diary sector. Herd management systems are the technology that could centralise all these data.

The analysis of the data stored in FMISs, Herd management systems and in FFA could give farmers and breeders the necessary information to identify the right moment for the assets to be replaced. This analysis could include when animals reach the end of their productive cycle.

In any case, the automatic data collection would release farmers from entering data manually into any of these systems but these systems should adopt standardised data models and semantics which enable data storage and exchange with third parties such as Paying Agencies, administration or insurance companies. Moreover, this automatization will reduce errors (intentional or unintentional). Monitoring and evaluation process would benefit from the automatic extraction of the information gathered by FFA. The adoption of standardised data models will ease the integration of these data in statistical databases (such as FADN, FSS or EAA) and could lead to a reduction of administrative burden.

Additionally, data providers need to keep the control of their data which means that the exchange of information must be compliance with GDPR legislation.

Though, this technology shows great potential "*The integration of existing FMISs with EUs e-Invoicing system is not yet evident on a large scale*" (Kalatzis N. et al, 2021). Besides the previous concern, we identify some questions to be answered prior to the fully exploitation of this technology for CAP monitoring and evaluation purposes:

- Under what circumstances will farmers share this information with third parties?
- Would the type and number of farmers using this system create a bias in the monitoring and evaluation statistical approach?

Demo case 1 in WP4 will show how this technology, robotic accounting and e-Invoicing, is used to collect and integrate data into FADN statistical database.

Table 2: Volatility in Farm Income

Indicator Name	Income Volatility	
Type of Indicator	Economic	
Definition	Variation in farm income	
Unit of Measurement	Percentage change in farm income in a given year relative to the average income of the previous three years.	
Methodology/Formula	N/A	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	1. Ensuring Viable Farm Incomes	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
FFA: Farm Financial Accounting	- Records of purchases and sells - Robotic accounting: e-Invoicing	- Temporal series of purchases and sells - Adoption of standardised data models - Adoption of data sharing protocols
EU data source	Source: - FADN Farm level[1] - FADN Farm level (standard output)[2] - FADN National[3]	

POTENTIAL USE: SOME POTENTIAL

The data source considered in the pathway for this indicator, e-Invoicing, is aiming to automatically read farm invoices. FFA is the technology to centralize this financial information. The collection of this kind of data is based on the systematic recording of documents like invoices and delivery notes, or contracts in the administration of a farmer. These systems are already available on many farms for taxing purposes and therefore mature enough.

The analysis of the evolution of the purchase and sell prices gives valuable information of farm income volatility. The automatic data collection would release farmers from entering data in the system manually which will reduce errors (intentional or unintentional). This system should adopt standardised data models and semantics which enable data storage and exchange with third parties.

[1] https://agridata.ec.europa.eu/extensions/FADNPublicDatabase/FADNPublicDatabase.html#
[2] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ef_m_farmleg&lang=en
[3] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=aact_eaa01&lang=en

The analysis of the data collected by FFA would give farmers information on the performance of their holdings and, when these data are aggregated, on their position in the agri-food sector chain. Monitoring and evaluation process would benefit from the automatic extraction of the information gathered by FFA. The adoption of standardised data models will ease the integration of these data in statistical databases (such as FADN, FSS or EAA) and could lead to a reduction of administrative burden. Additionally, data providers need to keep the control of their data, which means that the exchange of information must follow GDPR legislation. Even this technology shows great potential "*The integration of existing FMISs with EUs e-Invoicing system is not yet evident on a large scale*" (Kalatzis N. et al, 2021). Besides the previous concern, we identify some question to be answered prior to the fully exploitation of this technology for CAP monitoring and evaluation purposes: • Under what circumstances will farmers share this information with third parties? • Would the type and number of farmers using this system bias the monitoring and evaluation statistical approach? **Demo case 1 in WP4 will show how this technology, robotic accounting and e-Invoicing, is used to collect and integrate data into FADN statistical database.**

Table 3: Use of Risk Management tools

Indicator Name	Use of Risk Management Tools	
Type of Indicator	Economic	
Definition	Use of risk management tools	
Unit of Measurement	Number/Types of risk management tools used (to be defined)	
Methodology/Formula	N/A	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	1. Ensuring Viable Farm Incomes	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
FFA: Farm Financial Accounting	- Expenses on risk management measures - Robotic accounting: e-Invoicing	- Adoption of data sharing protocols
POTENTIAL USE: SOME POTENTIAL This indicator is aimed at identifying the use of risk management tools. The management tool that we consider for this indicator are farmers' contracts with insurance companies. The only technology identified to derive data for the computation of this metric is Farm Financial Accounting systems. The automatic recording of the data presented in invoices could give information not only on the expenses in insurance contracts but also on the number and type insurances contracted by the farmer. These systems are already available on many farms for taxing purposes and therefore mature enough. The combined analysis of the total farm incomes with the expenses in risk management tool, both data collected by FFA, could help farmers to assess whether it is worth it to contract them or, on the contrary, the risk is affordable. The automatic data collection would release farmers from entering data in the system manually which will reduce errors (intentional or unintentional). This system should adopt standardised data models and semantics which enable data storage and exchange with third parties. Monitoring and evaluation process would benefit from the automatic extraction of the information gathered by FFA. The adoption of standardised data models will ease the integration of these data in statistical databases (such as FADN, FSS or EAA) and could lead to a reduction of administrative burden. Additionally, data providers need to keep the control of their data, which means that the exchange of information must follow GDPR legislation.		

Even this technology shows great potential "*The integration of existing FMISs with EUs e-Invoicing system is not yet evident on a large scale*" (Kalatzis N. et al, 2021). Besides the previous concern, we identify some question to be answered prior to the fully exploitation of this technology for CAP monitoring and evaluation purposes: • Under what circumstances will farmers share this information with third parties?

Table 4: Adoption of Farm Technologies

Indicator Name	Adoption of Farm Technologies	
Type of Indicator	Economic	
Definition	Sector specific technologies (to be defined)	
Unit of Measurement	Binary variable (Yes/No)	
Methodology/Formula	N/A	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	2. Increasing Competiveness (Productivity)	
Proposed Prioritisation	Medium	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
EU data source	Number of farms with energy production/technology[4]	
POTENTIAL USE: NO POTENTIAL		

Table 5: Membership of a Farmer Producer Group

Indicator Name	Membership of a Farmer Producer Group	
Type of Indicator	Economic	
Definition	Membership of farmer producer group and value of production	
Unit of Measurement	Binary variable Yes/No	
Methodology/Formula	N/A	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	3. Strengthening Farmers' Position in Value Chains	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
POTENTIAL USE: NO POTENTIAL		

Table 6: Use of Forward Pricing of Farm Output

Indicator Name	Use of Forward Pricing of Farm Output
Type of Indicator	Economic
Definition	Share of farm output by volume that is forward sold

[4] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ef_mpequip&lang=en

Unit of Measurement	Percentage of output	
Methodology/Formula	Volume of farm output forward sold / total farm output	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	3. Strengthening Farmers' Position in Value Chains	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
FFA: Farm Financial Accounting	- Records of purchases and sells - Robotic accounting: e-Invoicing	- Adoption of standardised data models and semantics - Adoption of agriculture data sharing protocols
POTENTIAL USE: NO POTENTIAL		

Table 7: Proportion of crop forward sold and price

Indicator Name	Proportion of crop forward sold and price	
Type of Indicator	Economic	
Definition	Proportion of crop forward sold and price	
Unit of Measurement	Percentage	
Methodology/Formula	Percentage of output forward sold	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	3. Strengthening Farmers' Position in Value Chains	
Proposed Prioritisation	High – possible to collect through existing mechanisms	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
FFA: Farm Financial Accounting	- Records of purchases and sells - Robotic accounting: e-Invoicing	- Adoption of standardised data models and semantics - Adoption of agriculture data sharing protocols
FMIS: Farm book	Records of crop type	- Adoption of standardised data models and semantics - Adoption of agriculture data sharing protocols
POTENTIAL USE: NO POTENTIAL		

Table 8: Organic Farm Output Sold

Indicator Name	Organic Farm Output Sold
Type of Indicator	Economic
Definition	Share of farm output sold as organic
Unit of Measurement	Percentage of output
Methodology/Formula	Volume of farm output sold as organic/ total farm output
Data Collection Level	Farm level
Data Reporting Level	National, regional, farm level
Frequency	Annual

CAP Objective	3. Strengthening Farmers' Position in Value Chains	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
FFA: Farm Financial Accounting	- Records of purchases and sells - Robotic accounting: e-Invoicing	- Adoption of standardised data models and semantics - Adoption of agriculture data sharing protocols
EU Data sources	- Organic crop production[5] - Organic animal products[6]	
POTENTIAL USE: NO POTENTIAL		

Table 9: Hours Worked On and Off-farm

Indicator Name	Hours Worked On and Off-farm	
Type of Indicator	Economic	
Definition	Total hours worked on the farm or other gainful activities directly related to the holding as well as hours worked off-farm.	
Unit of Measurement	Hours	
Methodology/Formula	N/A	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	8. Jobs growth and rural poverty	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
EU Data sources	Number of farms (farm type/region)[7] Hours worked[8]	
POTENTIAL USE: NO POTENTIAL		

Table 10: Level of Educational Qualification of Farm Employees

Indicator Name	Level of Educational Qualification of Farm Employees
Type of Indicator	Economic
Definition	Highest level of education of farm employees
Unit of Measurement	Use of a European qualification framework measure
Methodology/Formula	Refer to system of European qualification framework
Data Collection Level	Farm level
Data Reporting Level	National, regional, farm level
Frequency	Annual
CAP Objective	8. Jobs growth and rural poverty

[5] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=org_croppro&lang=en
[6] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=org_aprod&lang=en
[7] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ef_oga_main&lang=en
[8] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ef_lf_main&lang=en

Proposed Prioritisation	Medium	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
POTENTIAL USE: NO POTENTIAL		

Table 11: Non-farm income of the Farm holder

Indicator Name	Non-farm income of the Farm holder	
Type of Indicator	Economic	
Definition	Farmer income obtained from activity unrelated to the farm business	
Unit of Measurement	Euro	
Methodology/Formula	Farm	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	8. Jobs growth and rural poverty	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
EU Data sources: Eurostat	Secondairy activities (Regions)[9]	
POTENTIAL USE: NO POTENCIAL		

1.b. Environmental Sustainability

Table 12:Farm Level GHGs

Indicator Name	Farm Level GHGs	
Type of Indicator	Environmental	
Definition	GHGs produced per farm	
Unit of Measurement	Tonnes of CO2 eq. per farm	
Methodology/Formula	Total farm GHGs in tonnes / farm	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	4. Agriculture and Climate Mitigation	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
Machinery	- ISOBUS TC-BAS records: fertilizer and manure volume	- Adoption of standardised data models - Adoption of data sharing protocols
Earth Observation	- Crop type identification	- ML algorithms to identify crop types - Models to estimate GHG emission based on crop
FMIS: Advisory	- Records of nutrient advisory tools (FaST) on	- Adoption of standardised data models

[9] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=agr_r_accts&lang=en

	organic and synthetic fertilizers application	- Adoption of data sharing protocols
Herd management: On-line book-keeping of herd management	- Records of animal information: number, age, performance, weight and feed.	- Adoption of standardised data models - Adoption of data sharing protocols
Herd management: Sensor for CO2 detection	- Records of CO2 measurements	- Adoption of standardised data models - Adoption of data sharing protocols
Digital soil mapping	- Soil properties samples among others texture, nutrients levels (N, P, K) and SOC. - Interpolated maps of soil properties.	- Adoption of standardised data models - Adoption of data sharing protocols - Geo-statistical analysis. - Auxiliary data among others weather, digital elevation models, temporal series of EO images.
Sensors on the field	- Weather: Temperature, rainfall. - Soil: Texture, pH, moisture, SOC	- Adoption of standardised data models. - Adoption of model for data sharing. - Geo-statistical analysis.
EU Data source: Eurostat	National level (agriculture) GHG[10]:	

POTENTIAL USE: POTENTIAL

The GHGs that count for emissions from agriculture are CH_4 and N_2O (90%)[11]. The main CH_4 emission sources are enteric fermentation of ruminants' digestion and manure management. N_2O emissions are related to nitrogen mineral fertilisers, manure spreading, surplus nitrogen lixiviation and crop residues that are incorporated into the soil (nitrification, denitrification). Drained peatlands (organic soils) is another source of CO_2 that accounts for GHG emission from agriculture.

The amount of CH_4 released by ruminant livestock depends on the type of digestive tract, age, weight of the animal, and the quality and quantity of the feed consumed. Feed intake is positively related to animal size, growth rate, and production (e.g., milk production, wool growth, or pregnancy).

The methane emissions from manure management refers to the CH_4 produced during the storage and treatment of manure and from manure deposited on pasture. The main factors affecting these emissions are the amount of manure produced (waste production per animal) and the portion of the manure that decomposes anaerobically. Manure in liquid form decomposes anaerobically and can produce a significant quantity of CH_4 depending on the temperature and the retention time of the storage unit. Solid manure handled as a solid or deposited on pastures and rangelands tends to decompose under more aerobic conditions and therefore less CH_4 is released.

Direct emissions of N_2O in most agricultural soils come from an increased availability of N that enhances nitrification and denitrification rates which leads to the production and release of N_2O. N inputs or N mineralisation has various sources:

- Synthetic N Fertilisers.
- Organic N applied as fertiliser, for instance animal manure, compost, sewage sludge, rendering waste, waste water effluent.
- Urine and dung N deposited on pasture, range and paddock by grazing animals.
- N in crop residues, including from N-fixing crops and from during pasture renewal.
- N mineralisation associated with loss of soil organic matter resulting from change of land use or management of mineral soils.

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[10] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_ac_aigg_q&lang=en

[11] https://www.eea.europa.eu/ims/greenhouse-gas-emissions-from-agriculture#footnote-97HG3VWK

- Drainage/management of organic soils

(IPCC)(Calvo Buendia et al., 2019).

No technology measuring the actual emissions of GHGs at farm level directly has been identified. For instance, data collected by machinery would inform on the volume spread on the land but not on the actual GHGs emissions quantity. These data need to be communicated and integrated into any FMIS automatically in order to make a practical use of them. Other systems, such as herd management systems for instance, require farmers to enter manually the information. Sensors on the field collecting either weather information or soil parameters could provide data to estimate the emissions. In this sense, data derived from EO could act as auxiliary information for modelling GHGs emissions as well.

Regarding this indicator, the considered technologies derive data that enable the estimation of GHG emissions by means of scientific models. The models should estimate:

- CH_4 emissions based on number of animals, age, weight, performance, feed (Lingen et al., 2014),(Kebreab et al., 2008)
- CH_4 emissions based on volume of manure spread and/or mineral fertilizers (Dalby et al., 2021)
- N_2O emissions based on crop type, crop residues, synthetic and organic fertilizer, SOC, soil properties, weather conditions. (Li et al., 1996), (Chen et al., 2008)

The outputs of such models are suitable for monitoring and evaluation purposes since they could estimate GHGs emissions at regional and/or country level when aggregating individual farms data. Nevertheless, there are some important concerns to considered:

- The amount of emissions at farm level highly depends on the above-mentioned factors among others, livestock and manure management, agricultural practices, weather conditions and soil properties. This fact implies that the value yielded by them is subject to uncertainties which need to be quantified.
- The acquisition of input data for these models relies on the willingness of individual farmers to share the information. Apart from obtaining advice from the analysis of the data stored in any kind of FMIS (On-line book-keeping of herd management, for instance), it's not clear how farmers will benefit from sharing their data for the purpose of running these models at regional/national scale and therefore, they may be reluctant to do it.

Another approach to address the metric of this indicator is the integration of the information stored in the FMIS with LifeCycle Assessment (LCA) software/modules incorporating a Greenhouse Gas calculation Protocol. This approach will allow the automated extraction of GHG related performance outcomes based on the activities that are recorded in the FMIS. Alternatively, a manual process may include the extraction of selected datasets from the FMIS, their importing to the LCA software and the calculation of the GHG metrics.

Therefore, sharing on-farm data with the administration or any other stakeholder raises some questions:

- Under what circumstances would farmers share this information with the administration?
- To what extent could this information become compulsory for farmers to obtain CAP subsidies?

Although Demonstration Case 4 in work package 4 is not focusing on this indicator, it will make use of some of the technologies (EO and weather stations among others) and therefore, can be considered as a data acquisition demonstration case.

Table 13: Farm GHGs per Hectare

Indicator Name	Farm GHGs per Hectare
Type of Indicator	Environmental
Definition	Farm GHG emissions produced on a per ha basis
Unit of Measurement	tonnes CO_2 eq. per ha
Methodology/Formula	Total farm GHGs in tonnes / farm area in hectares
Data Collection Level	Farm level
Data Reporting Level	National, regional, farm level

Frequency	Annual	
CAP Objective	4. Agriculture and Climate Mitigation	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
Machinery	- ISOBUS TC-BAS records: fertilizer and manure volume - Records of machinery positioning system (GNSS) tracks	- Adoption of standardised data models - Adoption of data sharing protocols
FMIS: Advisory	- Records of nutrient advisory tools (FaST) on organic and synthetic fertilizers application	- Adoption of standardised data models - Adoption of data sharing protocols
Earth observation (Crop monitoring): Crop type	- Records of crop type - Vegetation coverage above certain NDVI threadshold - Crop identification: ML algorithms - Spectral reflectance models for soil carbon content estimation.	- ML models for crop type mapping - Models to estimate GHG emission based on crop - Adoption of standardised data models - Adoption of model for data sharing
Digital soil mapping	- Soil properties samples among others texture, nutrients levels (N, P, K) and SOC. - Interpolated maps of soil properties.	- Adoption of standardised data models - Adoption of data sharing protocols - Geo-statistical analysis. - Auxiliary data among others weather, digital elevation models, temporal series of EO images.
Sensors on the field	- Weather: Temperature, rainfall. - Soil: Texture, pH, moisture, SOC	- Adoption of standardised data models. - Adoption of model for data sharing. - Geo-statistical analysis.
Sensors in animals: GPS ear tags	- Records of GNSS positioning tracks	
IACS-LPIS-GSAA	- LPIS parcel - Geo-spatial application geometry	- Adoption of standardised data models - Adoption of model for data sharing - Models to estimate GHG emission based on crop
Herd management: On-line book-keeping of herd management	- Records of animal information: number, age, performance, weight and feed.	- Adoption of standardised data models - Adoption of data sharing protocols
POTENTIAL USE:		

The most important GHGs that count for emissions from agriculture are CH_4 and N_2O (90%)[12]. The main CH_4 emission sources are enteric fermentation of ruminants' digestion and manure management. N_2O emissions are related to nitrogen mineral fertilisers, manure spreading, surplus nitrogen lixiviation and crop residues that are incorporated into the soil (nitrification, denitrification). Drained peatlands (organic soils) is another source of CO_2 that accounts for GHG emission from agriculture.

The amount of CH_4 released by ruminant livestock depends on the type of digestive tract, age, weight of the animal, and the quality and quantity of the feed consumed. Feed intake is positively related to animal size, growth rate, and production (e.g., milk production, wool growth, or pregnancy).

The methane emissions from manure management refers to the CH_4 produced during the storage and treatment of manure and from manure deposited on pasture. The main factors affecting these emissions are the amount of manure produced (waste production per animal) and the portion of the manure that decomposes anaerobically. Manure in liquid form decomposes anaerobically and can produce a significant quantity of CH_4 depending on the temperature and the retention time of the storage unit. Solid manure handled as a solid or deposited on pastures and rangelands tends to decompose under more aerobic conditions and therefore less CH_4 is released.

Direct emissions of N_2O in most agricultural soils come from an increased availability of N enhancing nitrification and denitrification rates which leads to the production and release of N_2O. N inputs or N mineralisation has various sources:

- Synthetic N Fertilisers.
- Organic N applied as fertiliser, for instance animal manure, compost, sewage sludge, rendering waste, waste water effluent.
- Urine and dung N deposited on pasture, range and paddock by grazing animals.
- N in crop residues, including from N-fixing crops and from during pasture renewal.
- N mineralisation associated with loss of soil organic matter resulting from change of land use or management of mineral soils.
- Drainage/management of organic soils

(IPCC)(Calvo Buendia et al., 2019).

No technology measuring the actual emissions of GHGs at farm level directly has been identified. For instance, data collected by machinery could inform on the volume spread on the land but not on the actual GHGs emissions quantity. These data need to be communicated and integrated into any FMIS automatically in order to make a practical use of them. Other systems, such as herd management systems for instance, require farmers to enter the information manually. Sensors on the field collecting either weather information or soil parameters could provide data to estimate the emissions. In this sense, data derived from EO could act as auxiliary information for modelling GHGs emissions as well. The records of the positioning systems tracking attached to both machinery and cattle along with the geographic information coming from IACS/LPIS-GSA enable the location on the territory of those areas with a higher potential for GHGs emission.

Regarding this indicator, the technologies considered derive data that enable the estimation of GHG emissions by means of scientific models. The models would estimate:

- CH_4 emissions based on number of animals, age, weight, performance, feed (Lingen et al., 2014),(Kebreab et al., 2008)
- CH_4 emissions based on volume of manure spread and/or mineral fertilizers (Dalby et al., 2021)
- N_2O emissions based on crop type, crop residues, synthetic and organic fertilizer, SOC, soil properties, weather conditions. (Li et al., 1996), (Chen et al., 2008)

Another approach to address the metric of this indicator is the integration of the information stored in the FMIS with LifeCycle Assessment (LCA) software/modules incorporating a Greenhouse Gas calculation Protocol. This approach will allow the automated extraction of GHG related performance outcomes based on the activities that are recorded in the FMIS. Alternatively, a manual process may include the extraction of selected datasets from the FMIS, their importing to the LCA software and the calculation of the GHG metrics

[12] https://www.eea.europa.eu/ims/greenhouse-gas-emissions-from-agriculture#footnote-97HG3VWK

Herd positioning systems jointly with EO derived data could provide to livestock breeders valuable information on the areas where cattle graze intensely. This type of information could also serve as an evidence of grazing if required for any CAP payment claim. Therefore, sharing on-farm data with the administration or any other stakeholder raises some questions: • Under what circumstances would farmers share this information with the administration? • To what extent could this information become compulsory for farmers to obtain CAP subsidies? Even though **Demonstration Case 4 in work package 4 is not focusing on this indicator, it will make use of some of the technologies and therefore, can be considered as a data acquisition demonstration case.**

Table 14: Carbon Sequestration per Hectare

Indicator Name	Carbon Sequestration per Hectare	
Type of Indicator	Environmental	
Definition	Carbon sequestered in agriculture	
Unit of Measurement	CO_2 eq per hectare	
Methodology/Formula	Depends on form of sequestration to be measured	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	4. Agriculture and Climate Mitigation	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
Earth Observation	- Vegetation coverage above certain NDVI thresholds - Crop identification: ML algorithms - Spectral reflectance models for soil carbon content estimation.	- ML algorithms - Adoption of standardised data models - Adoption of data sharing protocols - Adoption of models to quantify carbon sequestration per crop
Machinery	- ISOBUS TC-BAS records: fertilizer and manure volume - Records of machinery positioning system (GNSS) tracks	- Adoption of standardised data models - Adoption of data sharing protocols
Crop monitoring: Yield estimate	- Records of yields per crop	- Models to estimate residues left on the soil based on Yield estimation - Adoption of standardised data models - Adoption of data sharing protocols
Pasture management: Grass cover	- Records of grass cover	Requirements - Adoption of models to estimate CO_2 sequestration based simply on Grass cover - Adoption of standardised data models and semantics

		- Adoption of data sharing protocols
Digital soil mapping	- Soil properties samples among others texture, nutrients levels (N, P, K) and SOC. - Interpolated maps of soil properties	- Adoption of standardised data models - Adoption of data sharing protocols - Geo-statistical analysis - Auxiliary data among others weather, digital elevation models, temporal series of EO images
IACS LPIS-GSA	- LPIS parcels/ Geospatial application parcel geometry	
FMIS: Farm book	- Records of crop type, tillage practices, yield and residues management	- Adoption of standardised data models Adoption of data sharing protocols.
FMIS: Advisory	- Records of Nutrient advisory tools (FaST) on mineral and organic fertiliser.	- Adoption of standardised data models. - Adoption of data sharing protocols.

POTENTIAL USE: SOME POTENTIAL

The technologies considered for this indicator are aiming at the estimation of storage of carbon in soils and carbon captured by biomass.

The rate of soil organic carbon sequestration depends on soil texture and structure, rainfall, temperature, farming system, and soil management. Strategies to increase the soil carbon pool include soil restoration and woodland regeneration, no-till farming, permanent cover crops, nutrient management, organic fertiliser application, improved grazing, and agroforestry practices (Smith et al., 2020).

Therefore, the technologies considered for this indicator derive data in three directions: for the identification of certain good agricultural practices (tillage, no-tillage, crop rotation), the detection of permanent vegetation in the parcel and the estimate of organic carbon in soils.

Machine Learning algorithms applied to EO images enable the production of crop type maps. The knowledge of the cultivated crop would enable the estimation of above-ground biomass. The use of these algorithms with temporal series of EO data could inform on the crop rotation in the parcel.

The logs of machinery when integrated in a FMIS would inform, if it is the case, on the volume of manure employed. FMIS could also store the fertilization prescriptions delivered by advisory services. These advisory services don't need to be physical personnel but they could be on-line services such as the EC's Farm Sustainability Tool (FaST).

Soil characteristics such as Soil Organic Content (SOC) and textural properties are usually quantified by the analysis of punctual soil samples. Digital Soil Mapping (DSM) technics are employed to estimate soil properties in unvisited locations and to derive continuous maps of the required characteristics. The outputs of DSM technics could serve as inputs to agronomic models[13,14] enabling the modelisation of the evolution of organic carbon in the soil. These models ease the estimation of the expected yield and, therefore, the potential crop residues left on the soil that develop into organic matter.

None of these technologies derive data to measure directly the amount of sequestered CO_2 but they could serve as inputs for models that estimate it.

In this regard, (Smith et al., 2020) made a review of the methods and challenges of measuring SOC change directly in soil and then examined some recent novel developments that have potential for quantifying it.

[13] https://dssat.net/

[14] https://www.fao.org/aquacrop/overview/whatisaquacrop/en/

Some of the projects reviewed in WP2 derive products such as cultivated crop type maps, analytics on vegetation and soil index time-series and the detection of some good environmental agricultural practices (for example grassland mowing events). The use of this information for monitoring and evaluation requires standard models and protocols to store and exchange it as well as methodologies to aggregate data to the needed scale. Both GHG emissions and CO2 sequestration are within the concept of carbon farming. In this regard, MacDonald et al. (2021) consider Monitoring, reporting and verification (MRV) cost and accuracy as one of the key issues that pose challenges to scaling up carbon farming. Nevertheless, sharing on-farm data with the administration or any other agri-food actor raises some questions: • Under what circumstances would farmers share this information with the administration? • To what extent could this information become compulsory for farmers to obtain CAP subsidies? **Demonstration Case 2 (Integrating open-source satellite data with farm level data) and Demonstration Case 4 (New ways for monitoring agri-environmental measures) will make use of some of the data sources and technologies identified for this pathway.**

Table 15: N Balance per Hectare

Indicator Name	N Balance per Hectare	
Type of Indicator	Environmental	
Definition	N inputs less N outputs on a per hectare basis	
Unit of Measurement	Kg of N Surplus per hectare	
Methodology/Formula	N inputs less N outputs per hectare	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	5. Efficient and Sustainable management of natural resources	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
FFA: Farm Financial Accounting	- Records of fertilizers purchases - Robotic accounting: e-Invoicing	- Adoption of standardised data models and semantics - Adoption of agriculture data sharing protocols
FMIS: Fertilization advisory	- Records of Nutrient advisory tools (FaST)	- Adoption of standardised data models and semantics - Adoption of data sharing protocols.
FMIS: Farm book	- Records in digital farm book on nitrogen-based fertilization	- Adoption of standardised data models and semantics - Adoption of data sharing protocols.
Digital soil mapping	- Soil properties samples among others texture, nutrients levels (N, P, K) and SOC. - Interpolated maps of soil properties.	- Adoption of standardised data models and semantics - Adoption of data sharing protocols. - Geo-statistical analysis. - Auxiliary data among others weather, digital elevation models, temporal series of EO images.
IACS LPIS-GSA	- IACS/LPIS-GSA geometry.	

EU Data sources: Eurostat	Nitrogen balance[15] Consumption of inorganic fertilizer[16]	

POTENTIAL USE: SOME POTENTIAL

The technologies identified for this indicator are based on the use of a FMIS and therefore, the interaction with the farmer. A FMIS that implements crop nutrition advisory module or are able to incorporate fertilization plan from advisory tool such as EC's FaST could provide valuable information to quantify N surplus. FFA could give information on the type and amount of fertiliser purchases but it couldn't inform on the actual application of N. The use of LPIS information enables the location of the application on the field. Farmers therefore, could benefit from using this kind of module by optimising the amount of N applied and therefore achieve a potential reduction in fertiliser expenses.

Nevertheless, some requirements are needed:

- The adoption of trustable models for crop nutrition advisory, in this case Nitrogen.
- The adoption of models to store and share with third parties this information if required.
- The establishment of legal framework compliance with GDPR.

This information would be valuable for monitoring and evaluation purposes if shared with administrators and/or researchers. In this regard, some additional requirements are found:

- The need to put in place a cross-validation system that will prevent intentional or unintentional entry of wrong data in the analysis.
- The adoption of models to aggregate data to the adequate scale.
- Increasing interoperability and harmonisation between data bases.

Some questions raise from this combination of technologies:

- Under what circumstances would farmers share this information with the administration?
- To what extent could this information become compulsory for farmers to obtain CAP subsidies?

Demonstration Case 1 (Polish case) is aiming to obtain more accurate data on NPK (Nitrogen, Phosphorus, Potassium) surplus, to inform farmers on potential inaccurate application of fertilisers and to allow them adjust fertilizers usage at farm level. Furthermore, the relevant stakeholders will have additional information that will help them structure and propose more precise policy and advisory programs for farmers aiming at NPK use optimization and leaching reduction.

Demonstration Case 2 (Greek case) is aimed at extracting aggregates on fertilisers and pesticides use of a farm and regional level based on data collections from FMISs at the area.

Table 16: P Balance per Hectare

Indicator Name	P Balance per Hectare
Type of Indicator	Environmental
Definition	P inputs less P outputs on a per hectare basis
Unit of Measurement	Kg of P Surplus per hectare
Methodology/Formula	P inputs less P outputs per hectare
Data Collection Level	Farm level
Data Reporting Level	National, regional, farm level
Frequency	Annual
CAP Objective	5. Efficient and Sustainable management of natural resources
Proposed Prioritisation	High

[15] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=aei_pr_gnb&lang=en
[16] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=aei_fm_usefert&lang=en

TECHNOLOGY	SOURCE	REQUIREMENTS
FFA: Farm Financial Accounting	- Records of fertilizers purchases - Robotic accounting: e-Invoicing	- Adoption of standardised data models and semantics - Adoption of agriculture data sharing protocols
FMIS: Fertilization advisory	- Records of Nutrient advisory tools (FaST)	- Adoption of standardised data models - Adoption of data sharing protocols.
FMIS: Farm book	- Records in digital farm book on nitrogen-based fertilization	- Adoption of standardised data models- Adoption of data sharing protocols.
Digital soil mapping	- Soil properties samples among others texture, nutrients levels (N, P, K) and SOC. - Interpolated maps of soil properties.	- Adoption of standardised data models. - Adoption of data sharing protocols. - Geo-statistical analysis. - Auxiliary data among others weather, digital elevation models, temporal series of EO images.
IACS LPIS-GSA	- IACS/LPIS-GSA geometry.	

POTENTIAL USE: SOME POTENTIAL

The technologies identified for this indicator are based on the use of a FMIS and therefore, the interaction with the farmer. A FMIS that implements crop nutrition advisory module or are able to incorporate fertilization plan from advisory tool such as EC's FaST could provide valuable information to quantify P surplus. FFA could give information on the type and amount of fertiliser purchases but it couldn't inform on the actual application of P yet it could be considered as cross-check validation data. The use of LPIS information enables to locate the application on the field. Farmers therefore, could benefit from using this kind of module by optimising the amount of P applied and therefore achieve a potential reduction in fertiliser expenses.

Nevertheless, some requirements are needed:

- The adoption of trustable models for crop nutrition advisory, in this case Phosphorus.
- The adoption of models to store and share with third parties this information if required.
- The establishment of legal framework compliance with GDPR.

This information would be valuable for monitoring and evaluation purposes if shared with administrators and/or researchers. In this regard, some additional requirements are found:

- The need to put in place a cross-validation system that will prevent intentional or unintentional entry of wrong data in the analysis.
- The adoption of models to aggregate data to the adequate scale.
- Increasing interoperability and harmonisation between data bases.

Some questions raise from this combination of technologies:

- Under what circumstances would farmers share this information with the administration?
- To what extent could this information become compulsory for farmers to obtain CAP subsidies?

Demonstration Cases 1 (Polish case) is aiming to obtain more accurate data on NPK (Nitrogen, Phosphorus, Potassium) surplus, to inform farmers on potential inaccurate application of fertilizers and to allow them to adjust fertilizer usage at farm level. Furthermore, the relevant stakeholders will have additional information that will help them structure and propose more precise policy and advisory programs for farmers aiming at NPK use optimization and leaching reduction.

Demonstration Case 2 (Greek case) is aimed at extracting aggregates on fertilisers and pesticides use of a farm and regional level based on data collections from FMISs at the area.

Table 17: N Use Efficiency per Farm

Indicator Name	N Use Efficiency per Farm	
Type of Indicator	Environmental	
Definition	Proportion of N retained in the farm system (N outputs/N inputs)	
Unit of Measurement	Percentage	
Methodology/Formula	Percentage of N outputs/N inputs	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	5. Efficient and Sustainable management of natural resources	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
Machinery	- Records of harvested yield	- Models to relate: N output ~ Yield + estimates of residues left on the soil - Adoption of standardised data models. - Adoption of data sharing protocols.
FMIS: Farm book	- Records of yield per crop.	- Nitrogen output based on crop yield. - Adoption of standardised data models. - Adoption of data sharing protocols.
FMIS: Fertilization advisory	- Records of Nutrient advisory tools (FaST).	- Adoption of standardised data models. - Adoption of data sharing protocols.
FFA: Farm Financial Accounting	- Records of fertilizers purchases - Robotic accounting: e-Invoicing	- Adoption of standardised data models and semantics - Adoption of agriculture data sharing protocols
IACS-LPIS/GSA	- LPIS or GSA geometry parcel	
Earth Observation	- Temporal series of vegetation indexes (VIs). - Maps of crop type.	- ML algorithms to obtain crop type maps.
Crop modelling	- Estimates of crop yield based on agronomic models' outputs	- Weather and soil data - Historical crop yield data - EO data
EU data sources: Eurostat	National[17]	

[17] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=aei_pr_gnb&lang=en

POTENTIAL USE: SOME POTENTIAL The technologies identified for this indicator are similar to those detected for N balance indicator. They are mainly based on the use of a FMIS. In this case, additional information on the yield harvested is required to estimate the share of nitrogen retained in the farm. This information, besides using the records in FMIS farm book, could be collected by harvesting machinery and automatically integrated in the FMIS. FFA could give information on the quantity and type of fertiliser purchases but it couldn't inform on the actual application of N. Yet the information stored in FFA could be utilised as cross-check validation data. The use of LPIS information enables the location of the nitrogen application on the field. At lager scales than farm level, N output could be estimated by means of crop modelling (agronomic models). These models usually need information such as meteorological and soil data and can be complemented with EO data. As for detailed information at farm level, we identify the following requirements: - The adoption of models to store and share this information with third parties if required. - The establishment of legal framework compliance with GDPR. Larger scales would require: - The adoption of trustable and adequate agronomic models for crop yield estimations. Since the technologies involved in this indicator are quite similar to the ones described in N balance pathway, farmers could benefit from them in the same way that was stated there. The information collected at farm level would be also valuable for monitoring and evaluation purposes if it is shared with administrators and/or researchers. In this regard, some additional requirements are found: - The need to put in place a cross-validation system that will prevent intentional or unintentional entry of wrong data in the monitoring and evaluation procedure. - The adoption of models to aggregate data to the adequate scale. - Increasing interoperability and harmonisation between data bases. Some questions raise from this combination of technologies: • Under what circumstances would farmers share this information with the administration? • To what extent could this information become compulsory for farmers to obtain CAP subsidies? **Demonstration Case 1 (Polish case) is aiming to obtain more accurate data on NPK (Nitrogen, Phosphorus, Potassium) surplus, to inform farmers on potential inaccurate application of fertilizers and to allow them adjust fertilizers' usage at farm level. Furthermore, the relevant stakeholders will have additional information that will help them structure and propose more precise policy and advisory programs for farmers aiming at NPK use optimization and leaching reduction.** **Demonstration Case 2 (Greek case) is aimed at extracting aggregates on fertilisers and pesticides use of a farm and regional level based on data collections from FMISs at the area.**

Table 18: P Use Efficiency per Farm

Indicator Name	P Use Efficiency per Farm
Type of Indicator	Environmental
Definition	Proportion of P retained in the farm system (P outputs/P inputs)
Unit of Measurement	Percentage
Methodology/Formula	Percentage of P outputs/P inputs
Data Collection Level	Farm level
Data Reporting Level	National, regional, farm level
Frequency	Annual
CAP Objective	5. Efficient and Sustainable management of natural resources

Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
Machinery	- Records of harvested yield	- Models to relate: P output ~ Yield + estimates of residues left on the soil - Adoption of standardised data models. - Adoption of data sharing protocols.
FMIS: Farm book	- Records of yield per crop.	- Phosphorous output based on crop yield. - Adoption of standardised data models. - Adoption of data sharing protocols.
FMIS: Fertilization advisory	- Records of Nutrient advisory tools.	- Adoption of standardised data models. - Adoption of data sharing protocols.
FFA: Farm Financial Accounting	- Records of fertilizers purchases - Robotic accounting: e-Invoicing	- Adoption of standardised data models and semantics - Adoption of agriculture data sharing protocols
IACS-LPIS/GSA	- LPIS or GSA geometry parcel	
Earth Observation	- Temporal series of vegetation indexes (VIs). - Maps of crop type.	- ML algorithms to obtain crop type maps.
Crop modelling	- Estimates of crop yield based on agronomic models' outputs	- Weather and soil data - Historical crop yield data - EO data
EU data sources: Eurostat	National[18]	

POTENTIAL USE:

The technologies identified for this indicator are similar to those detected for P balance indicator. They are mainly based on the use of a FMIS. In this case, additional information on the harvested yield is required to estimate the share of phosphorous extracted from the farm. This information, besides using the records in FMIS farm book, could be collected by harvesting machinery and be automatically integrated in the FMIS. FFA could give information on the quantity and type of fertiliser purchases but it couldn't inform on the actual amount of phosphorous applied. Yet, the information stored in accountancy module could be utilised as cross-check validation data. On the other hand, the use of LPIS information enables the location of the phosphorous application on the field.

At lager scales than farm level, phosphorous output could be estimated by means of crop modelling (agronomic models). This models usually need information such as meteorological and soil data and can be complemented with EO data. Nevertheless, phosphorous inputs are necessary and therefore aggregation of data at farm level are still needed.

As for detailed information at farm level, we identify the following requirements:

- The adoption of models to store and share this information with third parties if required.
- The establishment of legal framework compliance with GDPR.

[18] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=aei_pr_gnb&lang=en

Larger scales would require: - The adoption of trustable and adequate agronomic models for crop yield estimations. Since the technologies involved in this indicator are quite similar to the ones described in P balance indicator, farmers could benefit from them in the same way that was stated there. The information collected at farm level would be also valuable for monitoring and evaluation purposes if it's shared with administrators and/or researches. In this regard, some additional requirements are found: - The need to put in place a cross-validation system that will prevent intentional or unintentional wrong data entry in the monitoring and evaluation procedure. - The adoption of models to aggregate data to the adequate scale. - Increasing interoperability and harmonisation between data bases. Some questions raise from this combination of technologies: • Under what circumstances would farmers share this information with the administration? • To what extent could this information become compulsory for farmers to obtain CAP subsidies? **Demonstration Case 1 (Polish case) is aiming to obtain more accurate data on NPK (Nitrogen, Phosphorus, Potassium) surplus, to inform farmers on potential inaccurate application of fertilizers and to allow them to adjust fertilizers' usage at farm level. Furthermore, the relevant stakeholders will have additional information that will help them structure and propose more precise policy and advisory programs for farmers aiming at NPK use optimization and leaching reduction.** **Demonstration Case 2 (Greek case) is aimed at extracting aggregates on fertilisers and pesticides use of a farm and regional level based on data collections from FMISs at the area.**

Table 19: Crop Rotation

Indicator Name	Crop Rotation	
Type of Indicator	Environmental	
Definition	Crop type by land parcel by year	
Unit of Measurement	Area change from one year to the next	
Methodology/Formula	N/A	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	5. Efficient and Sustainable management of natural resources	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
Earth Observation	- Temporal series of satellite images. - Crop type and land cover maps	- Adoption of accurate and trustable ML algorithm - Ancillary data required by ML algorithm. - Adoption of standardised data models.
IACS/LPIS-GSA	- Records of crop declared in previous campaigns	
FMIS: Farm book	- Records of crop in digital farm book - Historical records of crops - Geotagged photograph	- Adoption of standardised data models and semantics - Adoption of agriculture data sharing protocols

		- Methods to ensure the inalterability of the positioning tag. - AI/ML algorithms for crop identification.

POTENTIAL USE: SOME POTENTIAL

The metric of this indicator requires the knowledge of the crop grown in each parcel of the farm in certain periods of time.

Earth Observation is one of the technologies identified for the definition of this pathway. In this case, remote sensing images could be considered as inputs for machine learning algorithms to compute crop type maps which enable the identification of the crop planted in a parcel. This technology doesn't require the interaction of farmers but, on the contrary, the production of this kind of maps needs to be carried out by entities with enough knowledge and resources, that is, research centres, private companies, PAs. Geotagged photograph is another technology considered in this pathway since it could give information on those small parcels for which the spatial resolution images (the minimum ground area represented by each pixel) of the satellite images are not enough to identify the crop planted. Geotagged photographs can be combined with AI/ML processing algorithms for an automated inference/analysis on what is depicted in the image, that is, the crop. Nevertheless, the use of this technology for the purpose of this indicator requires the storage of historical records of previous campaigns.

FMISs is the other technology identified in this pathway. More precisely, the historical records of crops in the farm book module is the data source. In this case, farmer's interaction is required. The use of this technology for the purpose of this indicator requires both the adoption of standardised data models (semantics and ontologies) to store the information and the adoption of agriculture data sharing protocols.

The combination of crop type maps with the information stored in IACS/LPIS offers valuable information not only for CAP control tasks but also for monitoring and evaluation purposes. Administrations would benefit from these technologies by reducing the burden in performing controls on the field. This kind of use is already in place and adopted by some Paying Agencies under the new paradigm of Check by Monitoring (CbM).

As for farmers, apart from the fact that they would know whether they meet the requirements to obtain CAP subsidies, the advantage of using these technologies is limited. In this regard, some questions raise:

- Under what circumstances would farmers share this information with the administration?
- To what extent could this information become compulsory for farmers to obtain CAP subsidies?

Table 20:Soil Cover

Indicator Name	Soil Cover	
Type of Indicator	Environmental	
Definition	Usage of soil cover between harvesting and planting	
Unit of Measurement	Number of hectares where soil cover crop is planted	
Methodology/Formula	To be considered	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	5. Efficient and Sustainable management of natural resources	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
Earth Observation	- Green cover: NDVI or LAI above certain threshold	- Adoption of standardised data models.

	- Brown/Senescent cover: Brown LAI above certain threshold (Amin et al., 2020)	
FMIS: Farmbook	- Geotagged photographs	- Methods to ensure the inalterability of the positioning tag. - AI/ML algorithms for crop identification.
IACS/LPIS-GSA	- Parcel geometry	
EU data source: Eurostat	Soil cover[19]	

POTENTIAL USE: POTENTIAL

The technologies considered in this pathway, derive information on the presence or absence of vegetal coverage in the parcel between harvesting and planting, that is the land cover (soil cover). The data sources proposed in this pathway are vegetation indices that are obtained after processing remote sensing optical images. These indices not only inform on the presence of vegetation in the parcel but also on whether plants are photosynthetically active or not. One of the disadvantages of this technology is that cloud coverage could impede the acquisition of image and therefore it might not be useful in some countries with long periods of cloud coverage. This disadvantage can be solved by using active sensors such as the Synthetic Aperture Radar (SAR) which is not affected by cloud coverage. Another aspect to be considered regarding EO technology is the resolution of the images (the minimum ground area represented by each pixel) that may not provide meaningful information for small parcels. Geotagged photograph has been included in this pathway to overcome this limitation. The geotagged photograph can be combined with AI/ML processing algorithms for an automated inference/analysis on what is depicted in the image and then identify the land cover in the parcel.

Vegetation indices give farmers an overview of their parcels and allow them to identify those areas with less vegetative development. This information is valuable especially for large or remote parcels.

Vegetation indices at parcel level along with the geographical information stored in IACS/LPIS prove to be a valuable combination for monitoring and evaluation purposes.

EO data have a great potential for this pathway and are mature enough since they have already been employed within CAP context in order to carry out the so-called Checks by Monitoring.

Nevertheless, we find the following question in this pathway:

- To what extent is the Integrated Administration and Control System (IACS) adapted to integrate this type of information?

Demonstration Case 4 will show how the combination of herd position collected from GPS devices, Satellite data and farmers' LPIS information derives benefits in favor of extensive cattle breeders along with monitoring and evaluation processes.

Table 21: Tillage Management Practices Against Erosion

Indicator Name	Tillage Management Practices Against Erosion
Type of Indicator	Environmental
Definition	Incidence of practices used to prevent erosion
Unit of Measurement	Type of management practice - Binary variable Yes/No
Methodology/Formula	N/A
Data Collection Level	National, regional, farm level
Data Reporting Level	Farm level
Frequency	Annual
CAP Objective	5. Efficient Soil Management

[19] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ef_mp_soil&lang=en

Proposed Prioritisation	Medium	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
Earth Observation	- Tillage detection: combination of optical and radar signals. - Crop identification	- Algorithms to detect tillage events. - Adoption of standardised data models. - Adoption of model for data sharing.
Digital Soil Mapping (DSM): Interpolated maps based on soil samples.	Sensors on the field: - Soil (clay, loam and silt content) - Weather stations	- Use of geo-statistics methodologies. - Adoption of standardised data models. - Adoption of model for data sharing.
Machinery	- Machinery positioning system (GNSS) tracks	- Ancillary data: Digital Elevation Model (DEM) and information derived from them - Adoption of standardised data models. - Adoption of model for data sharing
FMIS: Farm book	- Records of the work performed.	- Adoption of standardised data models. - Adoption of model for data sharing.
IACS/LPIS-GSA	- LPIS/GSA Parcel geometry	
EU data source: Eurostat	Tillage[20] Soil erosion[21]	

POTENTIAL USE: POTENTIAL

The metric of this indicator intents to identify whether farmers have carried out agricultural practice avoiding soil degradation or not. The practices to identify in this pathway are tillage (not tillage) and the presence of vegetation cover on the parcel. Although the metric of this indicator is a binary variable, the definition aims to measure the incidence of practices used to prevent erosion and therefore, a widen view of soil erosion needs to be taken.

The method used to estimate soil loss in Europe for the reference year 2010 has been the Revised Universal Soil Loss Equation (RUSLE2015) (Panagos et al., 2015). G2 erosion model takes advantage of RUSLE model to derive maps of soil loss and sediment yield rates on month-time intervals (Karydas & Panagos, 2018) and is expected to be an evolution of the previous one. The data requirements for these models are related to soil properties, vegetation coverage, meteorological data and agricultural practices. This pathway, therefore is aimed at the identification of this items.

Farm book modules of FMISs could store the information on the type of tillage performed on a parcel. The registration of these labours could be done either directly by the farmer or automatically transfered from the machinery logs. In the latter case, if the GNSS position tracking is enable, the labour carried out could be geographically assigned to the IACS/LPIS parcel. The logs of GNSS position combined with external information such as Digital Terrain Models (DTM) could be used to determine whether the tillage has been performed following contour lines or not.

The soil properties that these models require are related to soil structure, that is, clay, loam, silt and organic carbon content. Soil sensors collect data on these variables at the precise locations

[20] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ef_mp_prac&lang=en

[21] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=aei_pr_soiler&lang=en

where the sensors are placed. Raw data from sensors can be used as input for Digital Soil Mapping (DSM) technics which derive continuous maps of such variables. Depending on the amount of data and its location, DSM technics are able to produce maps at different scales, from parcel to European level. Meteorological stations registering data on precipitation, temperature and evapotranspiration, among others, are a key data source for these models. Likewise punctual soil data, these meteorological data collected at precise locations can be interpolated by means of very well-known geostatistical methods producing continuous maps of the required variable at different scales. Data derived from EO technology, such as vegetation indices, crop type maps, or land cover maps, inform on the type of cover presented. When time series of these type of maps are used, they give information on the permanence of certain types of coverage during a given period of time. The joint use of machinery positioning logs, the IACS/LPIS parcel geometry and FMISs is the combination that shows more potential for farmers to benefit from since it could serve as evidence of tillage. Nevertheless, some considerations need to be done in this regard. The first one is that GNSS devices attached to machinery only shows that the machine has been in the parcel but say nothing about the labour performed. The second regards to the legal framework for the CAP subsidy control system to use this information and the last consideration is on the reluctancy of farmers to share these data. The technologies considered in this pathway collect data at parcel/farm level that achieve directly the binary metric of this indicator. Apart from the use of these technologies for CAP monitoring and evaluation, the data that these technologies derived, when aggregated and adequately processed, could be used as inputs for any of the above-described models. The output of these models gives valuable information on soil erosion which is an important environmental indicator.

Table 22: Usage of Precision Farming Techniques

Indicator Name	Usage of Precision Farming Techniques	
Type of Indicator	Environmental	
Definition	Incidence of precision technology use on farm	
Unit of Measurement	Type of Precision Technique - Binary variable Yes/No	
Methodology/Formula	N/A	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	5. Efficient Soil Management	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
Machinery	- Machinery positioning system (GNSS) tracks - ISOBUS TC-BAS records	- Adoption of standardised data models - Adoption of model for data sharing
POTENTIAL USE: NO POTENTIAL		

Table 23: Farmland Bird Index

Indicator Name	Farmland Bird Index
Type of Indicator	Environmental
Definition	Abundance and variety of farmland birds observed
Unit of Measurement	Number of farmland birds observed

Methodology/Formula	Number of farmland birds observed in a given area/period	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	6. Biodiversity and enhanced eco system services	
Proposed Prioritisation	Medium	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
External data sources	Bird counting systems and portals[22]	
EU data sources	Farmland bird index (national)[23]	
POTENTIAL USE: NO POTENTIAL		

Table 24: Grassland Butterflies Index

Indicator Name	Grassland Butterflies Index	
Type of Indicator	Environmental	
Definition	Abundance and variety of grassland butterflies observed	
Unit of Measurement	Number of grassland butterflies observed	
Methodology/Formula	Number of grassland butterflies observed in a given period/area	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	6. Biodiversity and enhanced eco system services	
Proposed Prioritisation	Medium	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
External data sources	Butterfly count apps [24] [25]	
EU data source: European Environmental Agency	Grassland butterflies — population index[26] [27]	
POTENTIAL USE: NO POTENTIAL		

Table 25: Record of Farm Landscape Features

Indicator Name	Record of Farm Landscape Features
Type of Indicator	Environmental
Definition	Number of farmland features observed
Unit of Measurement	Number of farmland features relative to the previous period
Methodology/Formula	Change in the number of landscape features over time

[22] https://eurobirdportal.org/
[23] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_bio2&lang=en
[24] https://www.natural-apptitude.co.uk/project/big-butterfly-count/
[25] https://play.google.com/store/apps/details?id=uk.ac.ceh.ebms&hl=en_GB&gl=US
[26] https://www.eea.europa.eu/ims/abundance-and-distribution-of-selected
[27] https://butterfly-monitoring.net/

Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	6. Biodiversity and enhanced eco system services	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
Earth Observation	- Land cover features identification/change in time series	- Definition of the minimum size of the features - Adoption of the ML algorithms
FMIS: Farm book	- Geotagged photographs	- Adoption of model for data sharing - Data sharing compliance with GDPR
IACS/LPIS	- Parcel geometry	
EU data source: EC-JRC	Eurostat[28] [29]	

POTENTIAL USE: POTENTIAL

This indicator is aimed at quantifying the change in the number of farm landscape features. In this case, the area coverage expressed as % of farmland seems to be more appropriate for this metric.

We consider that the landscape features to search in this indicator would include buffer strips, rotational or non-rotational fallow land, hedges, terrace walls, and ponds. The technologies identified for this pathway have a strong geographical component. Earth Observation is the most relevant technology identified. Machine learning algorithms applied to remote sensing optical images can be used to identify different types of landscape features. The limitation of this technology is the spatial resolution of the images (the minimum ground area represented by each pixel) that could hamper the identification of some small features. The use of remote sensors with finer resolutions could solve this limitation. Nevertheless, the cost of these images needs to be previously assessed since it could be unaffordable for large regions. Another disadvantage of using remote sensing optical images is that cloud coverage could impede the acquisition of image and therefore it might not be useful in some countries. The use of active sensors such as the Synthetic Aperture Radar (SAR) which is not affected by cloud coverage could settle this problem. The use of remote sensing data enables both the identification of landscape features and the quantification of covered area by these features over the total farmland.

Geotagged photo is another data source considered in this pathway. Unlike remote sensing images which are systematically collected, the taking of geotagged photographs needs to be performed on the field by farmers. In this regard, systems to ensure that the photograph is kept unaltered and its geo-reference is reliable need to be established. These systems will enable the possibility of using this information as evidence of landscape feature existence on the farmland. Methods to share this kind of information with the administration (PA) securely need also to be considered. Geotagged photographs can be combined with AI/ML processing algorithms for an automated inference/analysis on what is depicted in the image and then identify the land cover in the parcel.

As it is remarked in some other pathways, the execution of ML/AI algorithms needs to be carried out by entities with enough knowledge and resources, that is, research centres, private companies, PAs and the like.

Both technologies, earth observation and geotagged photograph, have showed their applicability within the context of CAP payments control as supporting evidence to scheme applications in the so-called Checks by Monitoring and they can be considered to be mature enough.

[28] https://ec.europa.eu/eurostat/web/lucas

[29] https://ec.europa.eu/statistical-atlas/viewer/?config=LUCAS-2018.json

Once these data are collected by the administration and the required ML/AI algorithms are run, the outputs can be used not only for CAP monitoring and evaluation purposes but also for the evaluation of many other environmental policies.

Table 26: Presence of High Nature Value Farming

Indicator Name	Presence of High Nature Value Farming	
Type of Indicator	Environmental	
Definition	Proportion of farm deemed to be of high nature value	
Unit of Measurement	Area of land classified as being of high nature value	
Methodology/Formula	No. of HNV hectares/ Total farm hectares	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	6. Biodiversity and enhanced eco system services	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
Earth Observation	- Land cover features identification/change in time series	- Definition of the minimum size of the features - Adoption of the ML algorithms
FMIS: Farm book	- Geotagged photos	- Methods to ensure the inalterability of the positioning tag. - AI/ML algorithms for crop identification.
IACSS/LPIS	- Parcel geometry and declared crop	
EU data source: European Environmental Agency (EEA)	HNV farmland in Europe[30]	

POTENTIAL USE: SOME POTENTIAL This indicator is aimed at quantifying the proportion of farm deemed to be of High Nature Value (HNV) within the farmland. High nature value (HNV) encompasses many different concepts. As for this pathway, HNV areas in Europe are defined as those where agricultural activities support and are associated with exceptionally high biodiversity, where natural constraints prevent intensive production and where low-intensity livestock farming is usually involved[31]. This indicator is tightly linked to other indicators such as crop rotation, land cover (soil cover) and presence of farm landscape features. The technologies identified for HNV indicator are the same than those described in the above-mentioned indicators. Therefore, this pathway could benefit from their outputs. In this pathway, we focus on the way of quantifying biodiversity. We propose utilizing the approach followed by FarmLand project[32] which make use of the aggregation method 'CONTRA' that integrates landscape variables such as crop diversity, mean field size and the proportion of semi-natural areas. User Case UC1c in H2020-NIVA[33] project is adapting this methodology to

[30] https://www.eea.europa.eu/data-and-maps/data/high-nature-value-farmland

[31] http://hnvlink.eu/

[32] https://www.farmland-biodiversity.org/index.php?sujet=1&lang=en

[33] https://www.niva4cap.eu/uploads/USE%20CASE%20PROGRESS/NIVA_UC_progress_for_webpage_UC1b_01Apr2021.pdf

obtain biodiversity indices in a grid of 1 Km^2. In this UC the main input for the model is the information of IACS/LPIS. As for this pathway, we propose exploring the use of the information derived by EO, more precisely crop type maps, as an alternative input to the model.

Table 27: Ammonia Emissions per Farm

Indicator Name	Ammonia Emissions per Farm	
Type of Indicator	Environmental	
Definition	The average amount of ammonia produced per farm	
Unit of Measurement	Kg ammonia per farm	
Methodology/Formula	Amount of ammonia emitted in agricultural activity on a farm.	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	4. Agriculture and Climate Mitigation	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
Gas Sensor: Ammonia	- Records of NH_3 measurements.	- Adoption of standardised data models - Adoption of data sharing protocols
Herd management: On-line book-keeping of herd management	- Number of animals. - Productive stage. - Feeding.	
Machinery	- Variable Rate application (VRT): Records of the volume of Fertilizer applied. - GNSS positioning system logs.	
FFA: Farm Financial Accounting	- Robotic accounting (e-Invoicing).	
FMIS: Farm book	- Fertiliser and manure application method and soil incorporation.	- Adoption of standardised data models - Adoption of data sharing protocols
FMIS: Advisory	- Records of Nutrient advisory tools (FaST) on manure and synthetic fertilizers application.	- Adoption of standardised data models - Adoption of data sharing protocols

POTENTIAL USE: POTENTIAL

This indicator is aimed at measuring the amount of ammonia emitted in agricultural activity on a farm.

Ammonia (NH_3) is a gaseous form of nitrogen and it is considered an air pollutant. Ammonia comes mainly from management of animal manures (housing, slurry storage and land spreading) but also from grazing animals, and finally from spreading of synthetic fertiliser. Ammonia can indirectly contribute to greenhouse gas emissions[34].

One of the data sources identified to compute this indicator is the information collected by ammonia sensors on the field that record directly the volume of ammonia emitted.

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[34] https://www.teagasc.ie/publications/2020/ammonia-emissions-in-agriculture-sources-importance-and-mitigation.php

The information related to animal feeding along with livestock numbers could be used to estimate the amount of animal manure that farms could produce and therefore the volume of ammonia potentially released. The type and composition of animal feed is highly related to the N excreted. This information can be obtained from invoices. Robotic accounting (e-Invoicing) enable the automatic recording of this information. Herd management information systems store the information related to livestock not only on the number of animals but also on their productive stage and feeding. Combining the latter two data sources, both the volume of manure produced in the farm and the potential ammonia release can be estimated. The Spreading of nitrogen-based fertilizers is another potential source of ammonia emission. The information contained in invoices informs about the type and quantity of fertilizers purchases which enable the estimate of the potential ammonia emissions. In this regard, FFA systems by means of robotic accounting (e-Invoicing) technology are able to collect this information automatically and systematically. The volume of fertilizers applied can be directly obtained from machinery logs. Variable Rate Application (VRA) technology helps farmers to apply the adequate fertilize doses on the precise area/zone of the parcel. The doses to apply are read from predefined prescriptions delivered by advisory services. These advisory services don't need to be physical personnel but they could be on-line services such as the EC's Farm Sustainability Tool (FaST). FMIS could store the fertilization prescriptions and therefore it could be used to estimate the potential emissions of ammonia. Farmers could benefit from the combined analysis of the data derived by the technologies presented in this pathway by adjusting the quantity of nitrogen-based fertilizers to apply. There are some aspects that need to be addressed for this pathway to be operative within CAP monitoring and evaluation framework. From a technical perspective, data flows from farm machinery, FMIS and FFA to administration needs to follow common semantics and ontologies that ease data sharing and interoperability between stakeholders (farmers, PA, agri-food industry, certification bodies, researchers). Statistical data bases could also benefit from both data standardization and interoperability between systems. The technologies presented in this pathway are mature enough individually, but the synergy derived from their combined use is still to be reached. In other direction, there are legal concerns that must be attended as well. In this regard, data providers need to keep the control of their data, which means that the exchange of information must follow GDPR legislation. Besides the previous concerns, this pathway identifies some question to be answered prior the fully exploitation of this technology for CAP monitoring and evaluation purposes: • Under what circumstances will farmers share this information with third parties (cooperatives, PA, agri-food sector, certification bodies)? • Will it be mandatory for farmers to communicate this information to the administration to obtain CAP subsidies? **Demostration Case 1 (Dutch case) will provide and test means to reduce the burden (and costs) associated with the provision of data and to enhance monitoring and evaluation of farm by enriching, combining and crossing data from existing sources (such as FADN) with alternative sources of information on economic data, environmental data, sustainability data, fertiliser use, antibiotics use, etc. As for ammonia emissions, DC1 will deploy multiple devices per farm to measure not only NH_3 emissions, but also PM10, PM2.5, CO, CO_2, NO, NO_2, O_3 and SO_2.** **Demonstration Case 2 (Greek case) is aimed at extracting aggregates on fertilisers and pesticides use of a farm and regional level based on data collections from FMISs at the area.**

Table 28: Ammonia Emissions per Hectare

Indicator Name	Ammonia Emissions per Hectare
Type of Indicator	Environmental
Definition	The amount of ammonia emissions produced on farm expressed on a per ha basis
Unit of Measurement	Kgs of ammonia per ha

Methodology/Formula	Total farm ammonia in tonnes/farm area in ha	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	4. Agriculture and Climate Mitigation	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
FMIS: Farm book	- Fertiliser and manure application method and soil incorporation	- Adoption of standardised data models - Adoption of data sharing protocols
FFA: Farm Financial Accounting	- Robotic accounting (e-Invoicing)	
Herd management: On-line book-keeping of herd management	- Number of animals - Productive stage - Feeding	
Machinery	- Variable Rate application (VRT): Records of the volume of Fertilizer applied - GNSS positioning system logs	
Gas Sensor: Ammonia	- Records of NH3 measurements	- Adoption of standardised data models - Adoption of data sharing protocols
FMIS: Fertilization advisory	- Records of Nutrient advisory tools (FaST) about Urea application	- Adoption of standardised data models - Adoption of data sharing protocols
IACS LPIS-GSA	- Eligibility area	

POTENTIAL USE: POTENCIAL

This indicator is aimed at measuring the amount of ammonia emitted in agricultural activity on a farm.

Ammonia (NH_3) is a gaseous form of nitrogen and it is considered an air pollutant. Ammonia comes mainly from management of animal manures (housing, slurry storage and land spreading) but also from grazing animals, and finally from spreading of synthetic fertiliser. Ammonia can indirectly contribute to greenhouse gas emissions[35].

One of the data sources identified to compute this indicator is the information collected by ammonia sensors on the field that record directly the volume of ammonia emitted.

The information related to animal feeding along with livestock numbers could be used to estimate the amount of animal manure that a farm could produce and therefore the volume of ammonia potentially released. The type and composition of animal feed is highly related to the N excreted. This information can be obtained from purchases invoices. Robotic accounting (e-Invoicing) technology enable the automatic recording of this information. Herd management information systems store the information related to livestock not only on the number of animal but also on their productive stage and feeding. Combining both data sources, both the volume of manure produced in the farm and the potential ammonia release can be estimated.

The Spreading of nitrogen-based fertilizers is another potential source of ammonia emission. The information contained in invoices informs about the type and quantity of fertilizers purchases which enable the estimate of the potential ammonia emissions. In this regard, FFA systems by

[35] https://www.teagasc.ie/publications/2020/ammonia-emissions-in-agriculture-sources-importance-and-mitigation.php

means of robotic accounting (e-Invoicing) technology are able to collect this information automatically and systematically. The volume of fertilizers applied can be directly obtained from machinery logs. One of the key elements of Variable Rate Application (VRA) technology is that it makes use of the GNSS positioning systems to locate the fertilizer application precisely. Moreover, the recording of these geographical position enables the possibility of assigning the type and the amount fertilizer to the IACS/LPIS parcel. VRA technology helps farmers to apply the correct fertilize doses on the precise area/zone of the parcel. The doses to apply are read from predefined prescriptions delivered by advisory services. These advisory services don't need to be physical personnel but they could be on-line services such as the EC's Farm Sustainability Tool (FaST). FMIS could store the fertilization prescriptions and therefore it could be used to estimate the potential emissions of ammonia. Farmers could benefit from the combined analysis of the data derived by the technologies presented in this pathway by adjusting the quantity of nitrogen-based fertilizers to apply. There are some aspects that need to be addressed for this pathway to be operative within CAP monitoring and evaluation framework. From a technical perspective, data flows from farm machinery, FMIS and FFA to administration needs to follow common semantics and ontologies that ease data sharing and interoperability between stakeholders (farmers, PA, agri-food industry, certification bodies, researchers). Statistical data bases could benefit from both data standardization and interoperability between systems. The technologies presented in this pathway are mature enough individually, but the synergy derived from their combined use is still to be reached. In other direction, there are legal concerns that must be attended as well. In this regard, data providers need to keep the control of their data, which means that the exchange of information must follow GDPR legislation. Besides the previous concerns, this pathway identifies some question to be answered prior the fully exploitation of this technology for CAP monitoring and evaluation purposes: • Under what circumstances will farmers share this information with third parties (cooperatives, PA, agri-food sector, certification bodies)? • Will it be mandatory for farmers to communicate this information to the administration to obtain CAP subsidies? **Demostration Case 1 (Dutch case) will provide and test means to reduce the burden (and costs) associated with the provision of data and to enhance monitoring and evaluation of farm by enriching, combining and crossing data from existing sources (such as FADN) with alternative sources of information on economic data, environmental data, sustainability data, fertiliser use, antibiotics use, etc. As for ammonia emissions, this DC will deploy multiple devices per farm to measure not only NH_3 emissions, but also PM10, PM2.5, CO, CO_2, NO, NO_2, O_3 and SO_2.** **Demonstration Case 2 (Greek case) is aimed at extracting aggregates on fertilisers and pesticides use of a farm and regional level based on data collections from FMISs at the area.**

Table 29: Adoption of (Natural) Biocontrols on Farm

Indicator Name	Adoption of (Natural) Biocontrols on Farm
Type of Indicator	Environmental
Definition	Type of biocontrol in use
Unit of Measurement	Number of biocontrol measures used per farm (to be defined)
Methodology/Formula	N/A
Data Collection Level	Farm level
Data Reporting Level	National, regional, farm level
Frequency	Annual
CAP Objective	6. Biodiversity and enhanced eco system services

Proposed Prioritisation	High
POTENTIAL USE: NO POTENTIAL	

Table 30: Renewable Energy Produced on Farm

Indicator Name	Renewable Energy Produced on Farm	
Type of Indicator	Environmental	
Definition	Amount of renewable energy generated on farms	
Unit of Measurement	KWh per farm	
Methodology/Formula	Energy produced per farm	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	4. Agriculture and Climate Mitigation	
Proposed Prioritisation	Medium	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
FFA: Farm Financial Accounting	- Records of renewable energy sold off-farm - Robotic accounting: e-Invoicing	- Adoption of standardised data models

POTENTIAL USE: SOME POTENTIAL

This indicator is aiming at quantifying the amount of renewable energy generated on farms.

The data source considered in this pathway is the information on energy sold off-farm. FFA systems could obtain these data from documents like invoices and delivery notes, or contracts that are systematically and automatically recorded.

This technology is already in place in many countries for taxing purposes and it can be considered mature enough. Nevertheless, its use for CAP monitoring and evaluation purposes is still unclear and requires this data to be communicated and somehow integrated in both statistical and administrative data bases. In this sense, the adoption of standardised data models and semantics for this type of information is necessary.

In this pathway an additional question is arises:

- Under what circumstances will farmers share this information with third parties (cooperatives, PA, agri-food sector, certification bodies)?

Table 31: Pollinators

Indicator Name	Pollinators
Type of Indicator	Environmental
Definition	Abundance of pollinators (bees) observed
Unit of Measurement	Number of pollinators (bees) observed
Methodology/Formula	Number of pollinators (bees) observed in a given period/area
Data Collection Level	Farm level
Data Reporting Level	National, regional, farm level
Frequency	Annual
CAP Objective	6. Biodiversity and enhanced eco system services
Proposed Prioritisation	Medium

TECHNOLOGY	SOURCE	REQUIREMENTS
External data sources	the bee hub[36]	
POTENTIAL USE: NO POTENTIAL		

[36] https://www.bee-life.eu/post/eu-bee-partnership-unveils-new-online-platform-for-data-on-pollinator-health

1.c. Social Sustainability

No technology found for Income level of young farmers, Extent of farm specialisation by age of farmer, Access to Finance and Credit, Broadband availability and Broadband Speed, Off-farm Income

Table 32: Pesticide Use on Farms

Indicator Name	Pesticide Use on Farms	
Type of Indicator	Social	
Definition	To Be Defined	
Unit of Measurement	To Be Defined	
Methodology/Formula	To Be Defined	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	5. Efficient Soil Management	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
Machinery	- Variable Rate application (VRT): Records of the volume of pesticide applied - GNSS positioning records - ISOBUS	- Adoption of standardised data models - Adoption of data sharing protocols
Earth Observation	- Vegetation Indices from Remote Sensing images - Images from Unmanned Aerial Vehicle (UAV)	
FFA: Farm Financial Accounting	- Records of pesticides purchases - Robotic accounting: e-Invoicing	- Adoption of standardised data models - Adoption of data sharing protocols
FMIS: Farm book	- Records in digital farm book: crop, activity, date, product.	- Adoption of standardised data models - Adoption of data sharing protocols
IACSS/LPIS	- Geometry of the parcel	
EU data sources: Eurostat	Pesticide use[37] Harmonised pesticide indicator[38]	

POTENTIAL USE: POTENTIAL

This indicator aims to identify the use of pesticide on the farm and to quantify the volume utilized. The technologies considered for this pathway span from the information collected by the FFA to the data obtained by sensor on board of Unmanned Aerial Vehicle (UAV).

From FFA systems, apart from the sales on pesticides, the type and quantity can be obtained since this information is detailed in the invoices. Nevertheless, this information proves that the pesticide has been bought but say nothing about the actual application of the product.

[37] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=aei_pestuse&lang=en

[38] https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=aei_hri&lang=en

Variable Rate Application (VRA) technology helps farmers to apply the correct pesticide doses on the precise zone within the parcel. The doses to apply are based on predefined prescriptions that can be done in form of prescription maps. These maps can be generated, among others, through field monitoring technologies (cameras embedded on an unmanned aerial vehicle, for instance). Remote sensing images, more precisely vegetation indices, could also help in the definition of the treatment areas. Prescription maps therefore, information on the quantity of pesticide to apply and the areas where it should be applied. Prescription maps along with the GNSS positioning systems attached to tractors make both reach the precise location and apply the exact volume of product possible. The volume and the location are stored in the logs of the machinery. The information in these logs can be further exploited when it is communicated to a FMIS and it is combined with the data stored in such systems, for instance, the information of the farm book. In view of the technologies described in this pathway, the benefit for farmers seems to be clear since the technologies would help them to adequate the volume of pesticides and therefore the expenses. On the contrary, the cost of this equipment could make the adoption of these technologies unaffordable for some farmers, especially the smallest ones. There is no doubt on the value of these data for monitoring and evaluation purposes. For instance, Data logs generated by agricultural machinery could be used as evidences during the CAP payments control. The aggregation of these data could also give and overview on the pesticide use at different scales from agriculture holding level to national or European level. However, there are some aspects that need to be addressed for this pathway to be operative. From a technical perspective, data flows from farm machinery, FMIS and FFA to administration needs to follow common semantics and ontologies that ease data sharing and interoperability between stakeholders (farmers, PA, agri-food industry, certification bodies) and subsequently and reduce in the administrative burden is expected. Statistical data bases could benefit from both data standardization and interoperability between systems. While these technical issues can be addressed, legal concerns must be attended as well. In this regard, data providers need to keep the control of their data, which means that the exchange of information must follow GDPR legislation. Besides the previous concerns, this pathway identifies some question to be answered prior the fully exploitation of this technology for CAP monitoring and evaluation purposes: • Under what circumstances will farmers share this information with third parties (cooperatives, PA, agri-food sector, certification bodies)? • Will it be mandatory for farmers to communicate this information to the administration to obtain CAP subsidies? • Would the type and number of farmers using this system create a bias in the monitoring and evaluation statistical approach? **Demonstration Case 2 (Greek case) is aimed at extracting aggregates on fertilisers and pesticides use of a farm and regional level based on data collections from FMISs at the area**.

Table 33: Sales of Veterinary Antimicrobial Agents for Farm Use

Indicator Name	Sales of Veterinary Antimicrobial Agents for Farm Use	
Type of Indicator	Social	
Definition	Amount and value of antimicrobials purchased	
Unit of Measurement	Number of animal doses and euro value	
Methodology/Formula	To be further considered	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	9. Health, Food and Anti-microbial Resistance	
Proposed Prioritisation	High	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**

FFA: Farm Financial Accounting	- Records of antimicrobials purchases - Robotic accounting: e-Invoicing	- Adoption of standardised data models - Adoption of data sharing protocols
Herd management: On-line book-keeping of herd management	- Records of antimicrobials use	- Adoption of standardised data models - Adoption of data sharing protocols

POTENTIAL USE: POTENTIAL

This indicator is aimed at the quantifying of veterinary antimicrobial use within the farm. The most suitable technology identified for this pathway is FFA and more precisely, the data obtained from robotic accounting (e-Invoicing) systems since the type and quantity of antimicrobial purchases are included in the invoices. The collection of these data is based on the systematic recording of documents like invoices and delivery notes, or contracts. These systems are already available on many farms due to the fact that it is compulsory for taxing purposes.

The analysis of the data by the FFA could give breeders information not only on the expenses in antimicrobial but also on an increase in its use which could mean a potential health problem in the herd.

This automatically-collected data would release farmers from entering data manually which is prone to intentional or unintentional errors. These systems should adopt standardised data models and semantics that enable data storage and exchange with third parties such as paying agencies, administration, agri-food industry or certification bodies. Monitoring and Evaluation process would also benefit from the automatic extraction of the information gathered by FFA. The adoption of standardised data models will ease the integration of the information in statistical databases (such as FADN, FSS or EAA) and could lead to a reduction of administrative burden.

Additionally, a couple of remarks need to be done. The first is on the need for the sharing of these data to be compliance with GDPR legislation since data providers need to keep the control of their data. The second is that although, this technology shows great potential "The integration of existing FMISs with EUs e-Invoicing system is not yet evident on a large scale" (Kalatzis N. et al, 2021). Besides the previous concern, we identify some questions to be answered prior to the fully exploitation of this technology for CAP monitoring and evaluation purposes:

- Under what circumstances will farmers share this information with third parties?
- Is the legal framework developed enough to protect data providers and data users when sharing and use these data?

Table 34:Physical Distance from Services

Indicator Name	Physical Distance from Services	
Type of Indicator	Social	
Definition	Travel distance (km) to services (to be defined)	
Unit of Measurement	Km	
Methodology/Formula	N/A	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	8. Jobs Growth and Rural Poverty	
Proposed Prioritisation	Medium	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**

- Geographic Information System (GIS) analysis	**-** Regional boundaries and local boundaries	
	- Urban/rural classification	
	- Digital Elevation Model	
	- Inhabitants and Population disaggregation	
	- Road network	
IACS/LPIS	- Geometry of the parcel declared	
POTENTIAL USE: POTENTIAL We consider this indicator to be related with the concept of remoteness. We adopt the definition of remote region stated in (Dijkstra & Poelman, 2008). In this sense, a region is classified as remote if at least half of its population lives at more than 45 minutes by road from any city of at least 50000 inhabitants. In this case, we assume that the services are located in this type of cites and to where the distance needs to be measured. The metric of this indicator can be computed by means of a Geographic Information System (GIS) analysis. These systems are designed to combine different types of cartographic and alphanumeric information to derive distance maps showing the distance to get to certain service located in the above-described cities. The indicator doesn't specify where the distance needs to be measured from but if the starting point is the LPIS parcel, its geographical location can be combined with previous distance map to evaluate whether the parcel can be considered to be in a remote region. The storage of this information in the IACS could be employed to compute the share of beneficiaries and/or hectares obtaining subsidies located within a certain distance to the service.		

Table 35:Region Remoteness

Indicator Name	Region Remoteness	
Type of Indicator	Social	
Definition	Travel time to services (to be defined)	
Unit of Measurement	Travel distance (time) to services (to be defined)	
Methodology/Formula	Minutes	
Data Collection Level	Farm level	
Data Reporting Level	National, regional, farm level	
Frequency	Annual	
CAP Objective	8. Jobs Growth and Rural Poverty	
Proposed Prioritisation	Medium	
TECHNOLOGY	**SOURCE**	**REQUIREMENTS**
- Geographic Information System (GIS) analysis	**-** Regional boundaries and local boundaries	
	- Urban/rural classification	
	- Digital Elevation Model	
	- Inhabitants and Population disaggregation	
	- Road network	
IACS/LPIS	- LPIS geometry	
POTENTIAL USE: POTENTIAL		

For the description of the pathway for this indicator we use the definitions presented in (Dijkstra & Poelman, 2008). This paper defines a region as “remote” if at least half of its population lives at more than 45 minutes by road from any city of at least 50000 inhabitants.

The metric of this indicator can be achieved by means of a Geographic Information System analysis (GIS). These systems are able to combine different types of cartographic and alphanumeric information such as the above-mention data sources to derive maps of the time required to get to certain service.

Once this map is created every geographical location (parcel, agri-food industries, rural area) can be assigned with a travel time to services. This type of maps could be combined with LPIS parcel geometry to assess whether it can be considered to be in a remote region.

This information, when stored in the IACS data base could be employed to compute the share of beneficiaries and/or hectares obtaining subsidies located within a certain distance to the service.

Conclusions and recommendations

This deliverable has described the most suitable combination of technologies providing data to compute the metrics of the identifed indicators for monitoring and evaluation of the common agricultural policy in the next period.

The description of the pathways is presented by means of a set of tables, one for each indicator. Each table brings together all the characteristics that define the indicator (among others, name, objective and metric) and the most suitable technologies providing data for the computation of the metric. Althought the requirements and concerns for the technologies to address the metric indicators have been discussed in the pathway description, we bring here the commonest ones for all indicators.

Interoperability between systems and data bases is one of the concerns that were found when defining the patways. This interoperability requieres both the adoption of common ontologies and semantics adapted to agriculture data and the adoption of common data sharing protocols.

Reluctancy of farmers to share their data. Many of the pathways relay on the data provided by farmers regardless these data are collected automatically or not. One of the main farmers' concerns is the uncertainty on what their data will be used for and whether they will be used to penalize them or not. One way of overcoming this reluctancy could be to make added value products out of this information and return them back to the farmers. How farmers could benefit from the use of the technologies identified for each indicator has been described in the definition of the pathways but not in all indicators has been possible. A clear legal framework according to the General Data Protection Regulation that ensures data providers to keep the control of their data might reduce farmers' concerns when sharing their information.

Technology adoption is another issue that the definition of the pathways has identified. This issue is described at two diferent levels, farmer level and administration/country level. As for the farm level, some of the pathways relay on the data collected by farm machinery which is more common to find in larger farms than in the smaller ones. This fact might cause a bias when using these data for monitoring and evaluation purposes. At administration level, this issue is presented when using Earth Observation tecnology. Depending on the sensor, the spatial resolution of remote sensing images could make obtaining information from small parcels quite dificult. The acquisition of images with a finer resolution to settle this limitation needs to be carefully assessed in order not to increase the monetary burden.

A final remark is that some of the pathways discribed make use of the combination of several data sources. Some of these data sources are prone to intentional or unintentional errors and therefore the risk of fraud exists. To prevent this problem there needs to be a cross check data validation system. Although this issue has been pointed out briefly in some pathway it hasn't been cosidered when defining it and could be subject of futher resarch.

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