D5.4. Environmental and climate impact assessment module

agricore

Deliverable Number	D5.4
Lead Beneficiary	IAPAS
Authors	IAPAS, IDE
Work package	WP5
Delivery Date	31/08/2022 (M36)
Dissemination Level	Public

www.agricore-project.eu


The Agricore project has received funding from the European Union's Horizon 2020 research and innovation programme under the Grant Agreement No. 816078

Document Information

Project title	Agent-based support tool for the development of agriculture policies
Project acronym	AGRICORE
Project call	H2020-RUR-04-2018-2019
Grant number	816078
Project duration	1.09.2019-31.8.2023 (48 months)
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Version History

Version	Description	Organisation	Date
0.1	Deliverable ToC proposal	IAPAS	27 Jun 2022
0.2	Deliverable ToC approval	IDE	30 Jun 2022
0.3	Inclusion of content (First Draft)	IAPAS	24 Jul 2022
0.4	Revision and comments	IDE	02 Aug 2022
0.5	Implementation of corrections and additional content	IAPAS	21 Aug 2022
0.6	Final exportation and formatting	IDE	30 Aug 2022
1.0	Deliverable completed	IAPAS	31 Aug 2022

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Executive Summary

AGRICORE is a research project funded by the European Commission under the RUR-04-2018 call, part of the H2020 programme, which proposes an innovative way to apply agent-based modelling to improve the capacity of policymakers to evaluate the impact of agricultural-related measurements under and outside the framework of the Common Agricultural Policy (CAP). The AGRICORE suite stands out for being highly modular and customisable. Thanks to its open-source nature AGRICORE can be applied to a multitude of use cases and easily upgraded as future needs arise.

The modules in charge of assessing the impact of the simulated synthetic population in the frame of an agricultural policy are the impact assessment modules (IAMs) and one of them is presented in this deliverable: the environmental and climate IAM. The purpose of this module is to measure the impact of agriculture on the environment and climate and vice-versa and the select KPIs to measure this impact are described in this deliverable. First, the methodology on which the selection of KPIs is based is explained, followed by the 54 KPIs finally selected for the project use cases. These have been characterised and grouped into 6 sections according to the aspect of environment and climate that they measure.

Finally, the software implementation, which has an API and a calculation module, is explained. The former is implemented with the third version of the Protocol Buffers language specification, and it communicates the IAM with the other modules, feeds data for the KPI calculations and returns the values of the KPIs after the computation of the data. The calculation module is developed in Python and is dockerised to avoid possible incompatibilities. The full software implementation has been only developed and tested for two KPIs.

Abbreviations

Abbreviation	Full name
ABM	Agent-based model
DEM	Digital Elevation Model
ECIAM	Environmental and Climate Impact Assessment Module
EEA	European Environment Agency
ESDAC	European Soil Data Centre
ESDB	European Soil Database
FADN	Farm Accountancy Data Network
FAO	Food and Agriculture Organization
FSS	Farm Structure Survey
IAM	Impact assessment module
JRC	Joint Research Centre
KPI	Key Performance Indicator
LUCAS	Land Use and Cover Area frame Survey
OECD	Organization for Economic Cooperation and Development
SAGA	System for Automated Geoscientific Analyses
SAPM	Survey on Agricultural Production Methods
SMART	Specific, Measurable, Attainable, Relevant, and Time-bound

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1 Introduction

The objective of task *5.4. The environmental and climate impact assessment module* is to develop an assessment tool providing operational values of Key Performance Indicators (KPIs), that will allow for validation of the effects and impacts of agricultural policy measures incorporated into the ABM simulation from the environmental and climate perspective. KPIs can be defined as a set of quantifiable measures that can be used to evaluate the assessed impact over time. They are used to estimate the extent to which strategic and operational objectives have been achieved and for comparative assessments.

KPIs will be used by the AGRICORE tool to develop and verify policy actions focused on protecting natural resources including soil, water, and air, as well as endangered habitats in agricultural areas, at the same time maintaining effective agricultural production. They are also aimed at encouraging farmers to adopt farm management practices that are beneficial for natural resource conservation and improvement. The analysis of the environmental KPIs will be also useful for creating biodiversity strategy plans in which the agricultural sector is regarded as a key player in habitat conservation actions.

The selected 54 environmental KPIs within the AGRICORE tool will support the monitoring of the performance of national and regional policies for establishing the basis for thoughtful policy decision-making. The main premise of the selection of environmental KPIs within the AGRICORE tool was the possibility of their evaluation from the level of an individual agent (farm). The input data for their calculation comes not only from available EU databases but also, if available, from national and local resources which makes it possible to incorporate biophysical modelling into the calculation of some required indices (e.g. water and nitrate balance, gas emissions). Some environmental KPIs can be estimated interchangeably: either from biophysical modelling or by using the IPCC approach (e.g. gas emissions).

The majority of the indicators were created based on the IPCC guidelines (IPCC 2000; IPCC 2006, IPCC 2019), however other approaches, enabling TIER3 level evaluation were also incorporated (e.g. for evaluating water erosion, nitrate leaching or crop and livestock biodiversity). Some of the indicators are aimed to give yearly values, whereas others are dedicated to presenting the changes occurring between the beginning and the end of a selected period. A broad range of indicators included in this module, characterizing different aspects of land use, soil management and livestock production, give a chance to develop a more holistic approach to environmental protection and assessment of changes in agroecosystems. Such a holistic approach will serve as a tool for the implementation of the European Green Deal strategy, by assessing the impacts of policies on food security in the face of climate change and biodiversity loss. It will also help to assess for various special scales the environmental and climate footprint of the EU agricultural production system.

The choice of the KPIs included in this module was preceded by a detailed analysis of the literature and EU documents. The basis for creating formulas of selected KPIs was the set of 28 agri-environmental indicators identified in the EU Commission Communication COM (2006) with improvements performed in the DireDate project as well as the indicators provided by the three integrated IA tools (SEAMLESS-IF, SIAT, and MEA-Scope).

2 An overview of the AGRICORE platform with respect to environmental and climate impacts

The environmental and climate impact assessment module is strongly interconnected with other components of AGRICORE including the agent-based simulation module (incorporating synthetic population generator and directly feed by policy environment module), biophysical simulation models, socio-economic impact assessment module, and ecosystem services module (Figure 1). The main purpose of the environmental and climate impact assessment module is to provide a reliable assessment of the environmental impacts of EU agricultural policies. The environmental KPIs, together with socio-economic KPIs and ecosystem services KPIs, will allow for the analysis of the impacts of specific agricultural policies on the environmental and social status of the food production sector, and eventually, provide the contextual framework for the policy re-design.

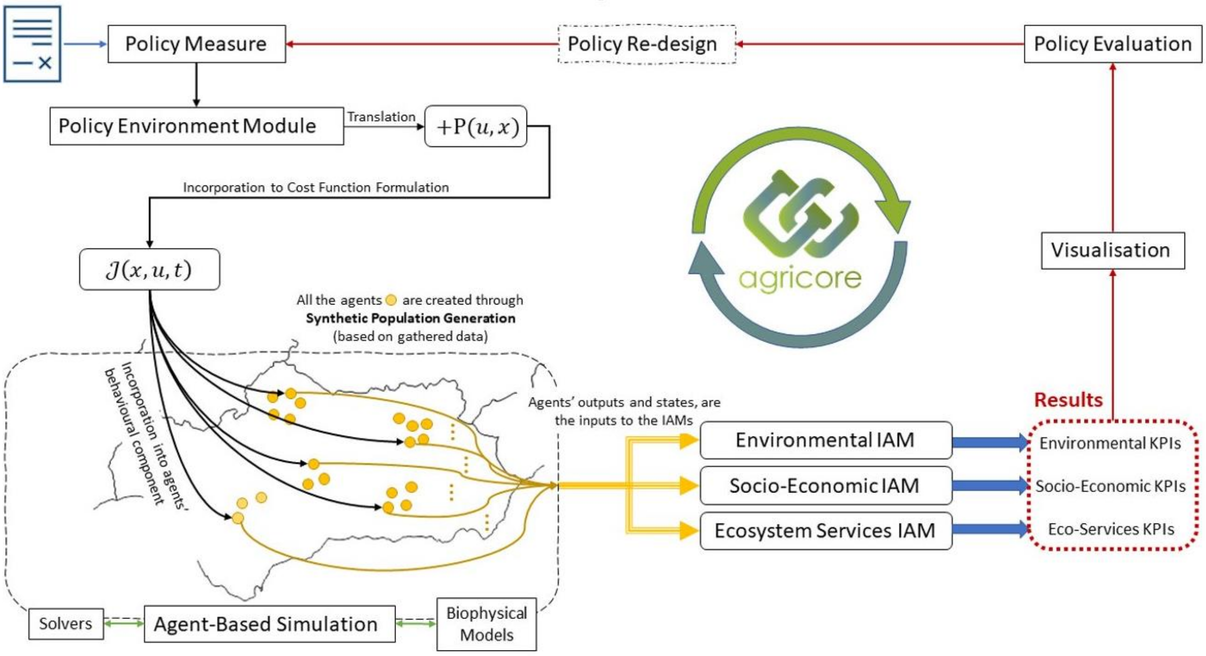

Figure 1: AGRICORE cycle of policy evaluation.

The environmental impact assessment module uses agents' outputs and states derived from agent-based simulations including biophysical models simulations as inputs for the calculation of environmental KPIs. The simulations of the agent-based module performed on the synthetic population of agents take into account agents' behavioural components, actual or predicted climatic conditions, soil status, and management practices, livestock production factors, as well as land use changes. The crop yield, biomass production, and water and nutrient balances are evaluated from biophysical modelling. The results of the agent-based modelling are the inputs to calculate environmental KPIs (Figure 2).

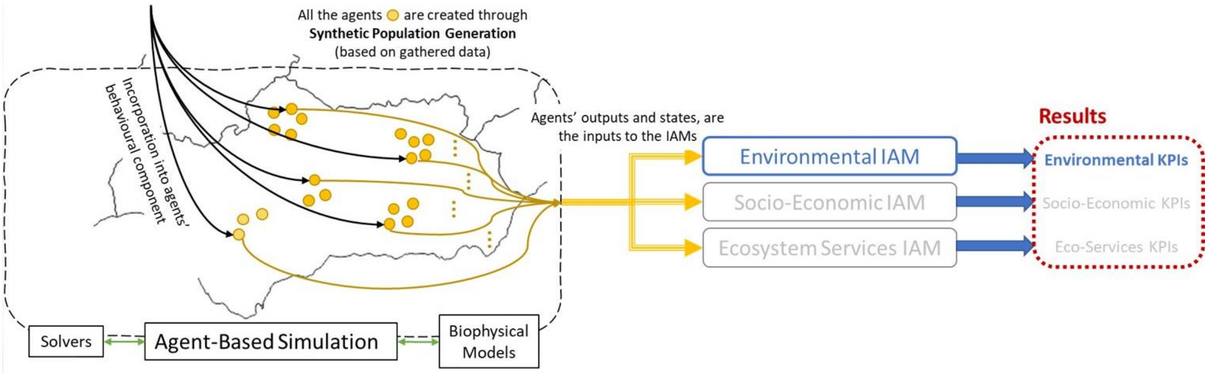

Figure 2: The flowchart of the data processing to estimate Environmental and Climate Impact Assessment Key Performance Indicators.

3 Methodology of environmental and climate impact assessment KPIs

To develop the Environmental and Climate Impact Assessment Module (ECIAM), a set of realistic KPIs had to be identified first. The environmental and climate KPIs cover several broad areas, such as land conversion and habitat loss, wasteful water consumption, soil erosion and degradation, pollution, genetic erosion, and climate change. In a very detailed review of agricultural policy assessment models, tools, and indicators already submitted as D5.1, the wide spectrum of the environmental and climate KPIs identified by various sources was provided (Table 1 with 28 agri-environmental indicators identified in the EU Commission Communication COM (2006) and Table 2 with the environmental impact indicators provided by the three integrated impact assessment tools).

Table 1 The 28 agri-environmental indicators identified in the EU Commission Communication COM (2006) with improvements performed in the DireDate project report2.

The data necessary for EU AEIs calculation is obtained by the surveys (Farm Structure Survey (FSS), Survey on Agricultural Production Methods (SAPM), Farm Accountancy Data Network (FADN), direct measurements, and through modeling (contained in the existing EU databases).

Domain	Subdomain	No.	Indicator	Eurostat database	Most recent data (year)	Responsible	Alternative database
Responses	Public policy	1	Agri-environmental commitments	-	-	DG AGRI	...
		2	Agricultural areas under Natura 2000	-	2016	EEA	...
	Technology and skills	3	Farmers' training levels	X	2016	DG AGRI Eurostat	...
	Market signals and attitudes	4	Area under organic farming	X	2019	Eurostat	...
Driving forces	Input use	5	Mineral fertilizer consumption	X	2018	Eurostat	...
		6	Consumption of pesticides	X	2018	Eurostat	...
		7	Irrigation	X	2016	Eurostat	...
		8	Energy use	X	2018	Eurostat	...
	Land use	9	Land use change	-	-	EEA	D1.2/Land use indicators/FAO D1.2/Land Cover/FAO
		10.1	Cropping patterns	X	2016	Eurostat	D1.2/Land Cover/FAO
		10.2	Livestock patterns	X	2016	Eurostat	D1.2/Livestock Patterns/FAO
	Farm management	11.1	Soil cover	X	2016	Eurostat	...
		11.2	Tillage practices	X	2016	Eurostat	...
		11.3	Manure storage	X	2010	Eurostat	...
	Trends	12	Intensification/ extensification	X	2017	DG AGRI	...
		13	Specialization	X	2016	Eurostat	...
		14	Risk of land abandonment	-	-	JRC	...

Pressures and benefits	Pollution	15	Gross nitrogen balance	X	2018	Eurostat	...
		16	Risk of pollution by phosphorus	X	2018	Eurostat	...
		17	Pesticide risk	X	2018	DG SANTE	D1.2/Pesticides Use/FAO
		18	Ammonia emissions	X	2018	EEA	...
		19	Greenhouse gas emissions	X	2018	EEA	...
	Resource depletion	20	Water abstraction	X	2017	EEA	...
		21	Soil erosion	X	2016	JRC	European Soil Data Centre (ESDAC) database
		22	Genetic diversity	-	-	EEA	D1.2/Biodiversity/Organization for Economic Cooperation and Development (OECD) database
	Benefits	23	High nature value farmland	-	-	DG AGRI	...
		24	Production of renewable energy	-	2016	DG AGRI Eurostat	...
State/Impact	Biodiversity and habitats	25	Population trends of farmland birds	X	2018	EEA	...
	Natural resources	26	Soil quality	-	-	JRC	European Soil Database (ESDB), Land Use and Cover Area frame Survey (LUCAS) topsoil database
		27.1	Water quality - Nitrate pollution	-	-	EEA	...
		27.2	Water quality - Pesticide pollution	-	-	EEA	...
	Landscape	28	Landscape - State and diversity	-	-	JRC	...

Table 2 Environmental impact indicators provided by the three integrated IA tools (SEAMLESS-IF, SIAT, and MEA-Scope).

Environmental	SEAMLESS-IF	SIAT	MEA-Scope
Land-use	Percentage of area operated with conservation tillage	Area of recently abandoned arable land	Change in UAA
	Percentage of low fertilized grassland	Area of irrigated arable land	Extensive area
	Percentage of non-sprayed area	Area of recently abandoned pasture land	Land abandonment
	Percentage of area with catch crop	Area of arable land not irrigated	Cropping pattern
	Percentage of crops area	Forest area	LU per ha
	Crop diversity index	Area of (semi-) natural vegetation	
		Area of pasture	
		Area of permanent crops	
		Area of built-up land	
Fertilizers	NH3 volatilization	NH3 emission from agriculture	NH3 loss total, field
	Nitrate leaching	Nitrogen oxide emissions	N-leaching potential
	Nitrate surplus	N surplus	N-balance

	Mineral N fertilizer use	P surplus	Soil N-change
	Indirect energy use by mineral fertilizer	Pesticide use	Energy input
	Mineral P, K use		Pesticides in ground and surface water
	Pesticide consumption		
	Pesticide leaching		
	Pesticide runoff		
	Pesticide volatilization		
Water	Water use by irrigation	Water retention capacity of soil	Groundwater recharge
	Runoff	Soil erosion risk by water	Nutrients in surface water (N, P)
	Soil erosion	Soil sealing	Water erosion
	Soil fertility change	Wind erosion risk	Soil compaction
	Soil organic matter change	Soil organic carbon content	
		Carbon sequestration in biomass, soil and dead organic matter	
GHG	Total CH_4 emissions	CH_4 emission	GHGs
	Total N_2O emissions	Nitrous oxide emission	
	Global warming potential	CO_2 emission	
		Renewable energy production – biomass (fossil energy demand area, animal)	
		Global warming potential	
Biodiversity	Crop diversity	Terrestrial habitat at risk from eutrophication	Field hares
		Population trends of farmland birds	
		Deadwood	
		High nature value farmland	
		Spatial cohesion	

The spectrum of the identified environmental and climate KPIs of potential interest for AGRICORE was very wide. To select the most relevant KPIs, two criteria were taken into account. First of all, the SMART (Specific, Measurable, Attainable, Relevant, and Time-bound) criterium was considered, which implied that the selected KPIs had to be:

- relevant and performance-oriented,
- easy to understand,
- measurable (described by the formula),
- attainable (using the data possible to obtain from ABM simulations),
- achievable in a reasonable time frame (i.e. short-term (yearly, related to an agricultural production cycle) or long-term (ABM simulation horizon)).

Secondly, the selected KPIs had to correspond to the most essential features related to the environmental and climatic impact of agriculture analyzed as an effect of the implementation of the Measures being the subject of the three use cases (M11 in the Andalusian Use Case, M10 in the Polish Use Case, and M06 in the Greek Use Case).

Based on the SMART criteria and Measures evaluation reports, the wide spectrum of the environmental and climate KPIs has been narrowed down to those, which are of the highest interest for AGRICORE use cases and can be quantified using the outputs from the ABM simulation (Table 3). Since the structure of AGRICORE is modular, the ECIAM can be easily expanded in the future to cover a much wider range of environmental and climatic KPIs.

Table 3 Environmental impact indicators identified using the SMART criteria and M11, M10 and M06 evaluation reports for the specific use cases.

Environmental KPI type	Andalusian use case	Polish use case	Greek use case
Land conversion and habitat loss	· Soil cover (the area under wheat, maize, etc.) · Share of the area with specific soil cover · The area with conventional tillage · Share of the area with conventional tillage · The area under organic farming · Share of the area under organic farming · Change in the area under organic farming · The area converted to organic · The area of arable land · Share of the area of arable land · The area of recently abandoned arable land · The area of irrigated arable land · Share of the irrigated arable land area · Change in the irrigated arable land area · The area of arable land not being irrigated · Share of the arable land not being irrigated · Change in the arable land not being irrigated · The area of pasture land · Share of the area of pasture land · The area of recently abandoned pasture land · Agricultural areas under Natura 2000 · Cropping patterns · Tillage practices	· Soil cover (the area under wheat, maize, etc.) · Share of the area with specific soil cover · Change in the area with specific soil cover · The area with conventional tillage · Share of the area with conventional tillage · Change in the area with conventional tillage · The area of arable land · Share of the area of arable land · Change in the area of arable land · The area of recently abandoned arable land · The area of pasture land · Share of the area of pasture land · Change in the area of pasture land · The area of recently abandoned pasture land · Agricultural areas under Natura 2000 · Share of the agricultural areas under Natura 2000 · Change in the agricultural areas under Natura 2000 · Forest area · Share of the forest area · Change in the forest area · Cropping patterns · Tillage practices	· Soil cover (the area under wheat, maize, etc.) · Share of the area with specific soil cover · The area under organic farming · Share of the area under organic farming · The area converted to organic · The area of arable land · Share of the area of arable land · The area of recently abandoned arable land · The area of irrigated arable land · Share of the irrigated arable land area · Change in the irrigated arable land area · The area of arable land not being irrigated · Share of the arable land not being irrigated · Change in the arable land not being irrigated · The area of pasture land · Share of the area of pasture land · The area of recently abandoned pasture land · Forest area
Wasteful water consumption	· Water used for irrigation · Water retention capacity of soil	· Water retention capacity of soil	· Water used for irrigation
Soil erosion and degradation	· Soil erosion · Soil fertility change	· Soil erosion · Soil fertility change	· Soil erosion · Soil fertility change

	· Soil organic matter change · N surplus · P surplus	· Soil organic matter change · N surplus · P surplus	· Soil organic matter change · N surplus · P surplus · Soil pH · Topsoil organic carbon content
Pollution	· Nitrate leaching · Mineral N fertilizer use · Mineral P use · Mineral K use · Pesticide use · Ammonia emissions	· Nitrate leaching · Mineral N fertilizer use · Mineral P use · Mineral K use · Pesticide use · Ammonia emissions	· Pesticide use · Mineral N fertilizer use · Mineral P use · Mineral K use
Climate change	· CH4 emissions · N2O emissions · CO2 emissions	· CH4 emissions · N2O emissions · CO2 emissions	· CH4 emissions · N2O emissions · CO2 emissions
Biodiversity	· Crop diversity · Livestock patterns · Livestock Units per ha · Livestock diversity	· Crop diversity · Livestock patterns · Livestock Units per ha · Livestock diversity	· Crop diversity · Livestock Units per ha · Livestock diversity

The set of environmental and climate KPIs identified in task 5.4 to be used in the AGRICORE project is therefore composed of 54 Key Performance Indicators. To introduce a reliable methodology for calculating these KPIs, several features had to be defined for each one of them:

- category,
- indicator name,
- meaning (what does the KPI mean and measure? how to operationalize it to be able to measure properly?),
- unit (e.g. kg/ha, %, hours per...?, or maybe a scale [1-10]),
- baseline value,
- target value,
- timespan.

3.1 Land conversion and habitat loss KPI forms

Table 4 Characterisation of the LU1 KPI: Soil cover.

ID	LU1
KPI	Soil cover
DIMENSION	Land conversion and habitat loss
DEFINITION	The area covered by the specific type of land use/land cover/crop (i.e. the maize area, forest area, etc.)
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$S_c^{t_x} = \sum_{m=1}^{k} S_{m,c}^{t_x}$$ where *m* is numbering the agents (from 1 to k), *c* denotes a specific type of land use/land cover/crop (wheat, maize, grassland, etc.), t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value) and $S_{m,c}^{t_x}$ stands for the area with a specific type of the land use/land cover/crop *c* for the agent *m* in a year t_x
UNIT OF MEASURE	ha
FREQUENCY OF RECORDING	At the end of each production year

Table 5 Characterisation of the LU2 KPI: Share of the area with specific soil cover.

ID	LU2
KPI	Share of the area with specific soil cover
DIMENSION	Land conversion and habitat loss
DEFINITION	The ratio of the area covered by the specific type of crop to the total area
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$PS_c^{t_x} = \frac{S_c^{t_x}}{S_{tot}^{t_x}} * 100$$ where $$S_{tot}^{t_x} = \sum_{c=1}^{l} \sum_{m=1}^{k} S_{m,c}^{t_x}$$ where *m* is the number of the agent, *c* denotes a specific type of land use/land cover/crop (wheat, maize, grassland, etc.), t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value), $S_{m,c}^{t_x}$ stands for the area with a specific type of the land use/land cover/crop *c* for the agent *m* in a year t_x, and $S_{tot}^{t_x}$ stands for the total area in a year t_x
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of each production year

Table 6 Characterisation of the LU3 KPI: Change in the area with specific soil cover.

ID	LU3
KPI	Change in the area with specific soil cover
DIMENSION	Land conversion and habitat loss
DEFINITION	The change in the area covered by the specific type of land use/land cover/crop (i.e. the maize area, forest area, etc.) during the assessed period

METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$CS_c = PS_c^{t_k} - PS_c^{t_0}$
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

Table 7 Characterisation of the LU4 KPI: Area with conventional tillage.

ID	LU4
KPI	The area with conventional tillage
DIMENSION	Land conversion and habitat loss
DEFINITION	The crop area on which the conventional tillage practices are performed
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$S_{ct}^{t_x} = \sum_{m=1}^{k} S_{m,ct}^{t_x}$$ where *m* is the number of the agent, c=*ct* denotes conventional tillage, t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value), and $S_{m,ct}^{t_x}$ stands for the area with conventional tillage *ct* for the agent *m* in a year t_x
UNIT OF MEASURE	ha
FREQUENCY OF RECORDING	At the end of each production year

Table 8 Characterisation of the LU5 KPI: Share of the area with conventional tillage.

ID	LU5
KPI	Share of the area with conventional tillage
DIMENSION	Land conversion and habitat loss
DEFINITION	The ratio of the crop area on which the conventional tillage practices are performed to the total crop area
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$PS_{ct}^{t_x} = \frac{S_{ct}^{t_x}}{S_{tot}^{t_x}} * 100$$ where *m* is the number of the agent, c=*ct* denotes conventional tillage, t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value), and $S_{ct}^{t_x}$ stands for the area with conventional tillage *ct* in a year t_x
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of each production year

Table 9 Characterisation of the LU6 KPI: Change in the area with conventional tillage.

ID	LU6
KPI	Change in the area with conventional tillage
DIMENSION	Land conversion and habitat loss
DEFINITION	The change in the area with conventional tillage during the assessed period

METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$CS_{ct} = PS_{ct}^{t_k} - PS_{ct}^{t_0}$
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

Table 10 Characterisation of the LU7 KPI: Area of arable land.

ID	LU7
KPI	The area of arable land
DIMENSION	Land conversion and habitat loss
DEFINITION	The arable land area
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$S_{al}^{t_x} = \sum_{m=1}^{k} S_{m,al}^{t_x}$$ where *m* is the number of the agent, c=*al* denotes arable land, t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value), and $S_{m,al}^{t_x}$ stands for the arable land area *al* for the agent *m* in a year t_x
UNIT OF MEASURE	ha
FREQUENCY OF RECORDING	At the end of each production year

Table 11 Characterisation of the LU8 KPI: Share of the area of arable land.

ID	LU8
KPI	Share of the area of arable land
DIMENSION	Land conversion and habitat loss
DEFINITION	The ratio of the arable land area to the total area
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$PS_{al}^{t_x} = \frac{S_{al}^{t_x}}{S_{tot}^{t_x}} * 100$$ where *m* is the number of the agent, c=*al* denotes arable land, t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value), and $S_{al}^{t_x}$ stands for the arable land area *al* in a year t_x
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of each production year

Table 12 Characterisation of the LU9 KPI: Change in the area of arable land.

ID	LU9
KPI	Change in the area of arable land
DIMENSION	Land conversion and habitat loss
DEFINITION	The change in the arable land area during the assessed period
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$CS_{al} = PS_{al}^{t_k} - PS_{al}^{t_0}$$
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

Table 13 Characterisation of the LU10 KPI: Area of recently abandoned arable land.

ID	LU10
KPI	The area of recently abandoned arable land
DIMENSION	Land conversion and habitat loss
DEFINITION	The area recently cessed of farming and given away for natural successions, such as grasses, shrubs, and trees
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$S_{abar}^{t_x} = \sum_{m=1}^{k} S_{m,abar}^{t_x}$$ where *m* is the number of the agent, c=*abar* denotes abandoned arable land, t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value), and $S_{m,abar}^{t_x}$ stands for the area of abandoned arable land for the agent *m* in a year t_x
UNIT OF MEASURE	ha
FREQUENCY OF RECORDING	At the end of each production year

Table 14 Characterisation of the LU11 KPI: Area under organic farming.

ID	LU11
KPI	The area under organic farming
DIMENSION	Land conversion and habitat loss
DEFINITION	The area in which organic farming practices are performed
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$S_{org}^{t_x} = \sum_{m=1}^{k} S_{m,org}^{t_x}$$ where *m* is the number of the agent, c=*org* denotes the organic farming practices, t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value), and $S_{m,org}^{t_x}$ stands for the area under organic farming *org* for the agent *m* in a year t_x
UNIT OF MEASURE	ha
FREQUENCY OF RECORDING	At the end of each production year

Table 15 Characterisation of the LU12 KPI: Share of the area under organic farming.

ID	LU12
KPI	Share of the area under organic farming
DIMENSION	Land conversion and habitat loss
DEFINITION	The ratio of the area in which the organic farming practices are performed to the total area
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$PS_{org}^{t_x} = \frac{S_{org}^{t_x}}{S_{tot}^{t_x}} * 100$$ where *m* is the number of the agent, c=*org* denotes the organic farming practices, t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value), and $S_{org}^{t_x}$ stands for the area under organic farming *org* in a year t_x
UNIT OF MEASURE	%

FREQUENCY OF RECORDING	At the end of each production year

Table 16 Characterisation of the LU13 KPI: Change in the area under organic farming.

ID	LU13
KPI	Change in the area under organic farming
DIMENSION	Land conversion and habitat loss
DEFINITION	The change in the area in which the organic farming practices are performed during the assessed period
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$CS_{org} = PS_{org}^{t_k} - PS_{org}^{t_0}$$
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

Table 17 Characterisation of the LU14 KPI: Area of irrigated arable land.

ID	LU14
KPI	The area of irrigated arable land
DIMENSION	Land conversion and habitat loss
DEFINITION	The area in which the irrigation is used
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$S_{irr}^{t_x} = \sum_{m=1}^{k} S_{m,irr}^{t_x}$$ where *m* is the number of the agent, c=*irr* denotes irrigation, t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value), and $S_{m,irr}^{t_x}$ stands for the area under irrigation *irr* for the agent *m* in a year t_x
UNIT OF MEASURE	ha
FREQUENCY OF RECORDING	At the end of each production year

Table 18 Characterisation of the LU15 KPI: Share of the irrigated arable land area.

ID	LU15
KPI	Share of the irrigated arable land area
DIMENSION	Land conversion and habitat loss
DEFINITION	The ratio of the area in which the irrigation is used to the total area
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$PS_{irr}^{t_x} = \frac{S_{irr}^{t_x}}{S_{tot}^{t_x}} * 100$$ where *m* is the number of the agent, c=*irr* denotes irrigation, t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value), and $S_{irr}^{t_x}$ stands for the area under irrigation *irr* in a year t_x
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of each production year

Table 19 Characterisation of the LU16 KPI: Change in the irrigated arable land area.

ID	LU16
KPI	Change in the irrigated arable land area
DIMENSION	Land conversion and habitat loss
DEFINITION	The change in the area in which the irrigation is used during the assessed period
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$CS_{irr} = PS_{irr}^{t_k} - PS_{irr}^{t_0}$$
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

Table 20 Characterisation of the LU17 KPI: Area of arable land not being irrigated.

ID	LU17
KPI	The area of arable land not being irrigated
DIMENSION	Land conversion and habitat loss
DEFINITION	The area in which the irrigation is not being used
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$S_{notirr}^{t_x} = S_{tot}^{t_x} - S_{irr}^{t_x}$$ where *m* is the number of the agent, c=not *irr* denotes that irrigation was not used, t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value), and $S_{m,irr}^{t_x}$ stands for the area under irrigation *irr* for the agent *m* in a year t_x
UNIT OF MEASURE	ha
FREQUENCY OF RECORDING	At the end of each production year

Table 21 Characterisation of the LU18 KPI: Share of the arable land not being irrigated.

ID	LU18
KPI	Share of the arable land not being irrigated
DIMENSION	Land conversion and habitat loss
DEFINITION	The ratio of the area in which the irrigation is not used to the total area
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$PS_{notirr}^{t_x} = 100\% - PS_{irr}^{t_x}$$
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of each production year

Table 22 Characterisation of the LU19 KPI: Change in the arable land not being irrigated.

ID	LU19
KPI	Change in the arable land not being irrigated
DIMENSION	Land conversion and habitat loss
DEFINITION	The change in the area in which the irrigation is not used during the assessed period
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$CS_{notirr} = PS_{notirr}^{t_k} - PS_{notirr}^{t_0}$$
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

Table 23 Characterisation of the LU20 KPI: Area of pasture land.

ID	LU20
KPI	The area of pasture land
DIMENSION	Land conversion and habitat loss
DEFINITION	The pasture land area
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$S_{pl}^{t_x} = \sum_{m=1}^{k} S_{m,pl}^{t_x}$$ where *m* is the number of the agent, *pl* denotes pasture land, t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value), and $S_{m,pl}^{t_x}$ stands for the pasture land area *pl* for the agent *m* in a year t_x
UNIT OF MEASURE	ha
FREQUENCY OF RECORDING	At the end of each production year

Table 24 Characterisation of the LU21 KPI: Share of the area of pasture land.

ID	LU21
KPI	Share of the area of pasture land
DIMENSION	Land conversion and habitat loss
DEFINITION	The ratio of the pasture lands area to the total area
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$PS_{pl}^{t_x} = \frac{S_{pl}^{t_x}}{S_{tot}^{t_x}} * 100$$ where *m* is the number of the agent, *pl* denotes pasture land, t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value), and $S_{pl}^{t_x}$ stands for the pasture land area *pl* in a year t_x
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of each production year

Table 25 Characterisation of theLU22 KPI: Change in the area of pasture land.

ID	LU22
KPI	Change in the area of pasture land
DIMENSION	Land conversion and habitat loss
DEFINITION	The change in the area with conventional tillage during the assessed period
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$CS_{pl} = PS_{pl}^{t_k} - PS_{pl}^{t_0}$$
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

Table 26 Characterisation of the LU23 KPI: Area of recently abandoned pasture land.

ID	LU23
KPI	The area of recently abandoned pasture land
DIMENSION	Land conversion and habitat loss
DEFINITION	The area recently cessed of pasturing and given away for natural successions, such as grasses, shrubs, and trees
METHOD	obtained directly from the Land Market module
FORMULA	$$S_{abp}^{t_x} = \sum_{m=1}^{k} S_{m,abp}^{t_x}$$ where *m* is the number of the agent, c=*abp* denotes abandoned pasture, t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value), and $S_{m,abp}{}^{t_x}$ stands for the area of abandoned pasture for the agent *m* in a year t_x
UNIT OF MEASURE	ha
FREQUENCY OF RECORDING	At the end of each production year

Table 27 Characterisation of the LU24 KPI: Agricultural area under Natura 2000.

ID	LU24
KPI	Agricultural areas under Natura 2000
DIMENSION	Land conversion and habitat loss
DEFINITION	The area in which the Natura 2000 nature protection areas exists
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$S_{Nat2000}^{t_x} = \sum_{m=1}^{k} S_{m,Nat2000}^{t_x}$$ where *m* is the number of the agent, *Nat2000* denotes Natura 2000, t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value), and $S_{m,Nat2000}{}^{t_x}$ stands for the area under Natura 2000 *Nat2000* for the agent *m* in a year t_x
UNIT OF MEASURE	ha
FREQUENCY OF RECORDING	At the end of each production year

Table 28 Characterisation of the LU25 KPI: Share of the agricultural areas under Natura 2000.

ID	LU25
KPI	Share of the agricultural areas under Natura 2000
DIMENSION	Land conversion and habitat loss
DEFINITION	The ratio of the areas in which the Natura 2000 nature protection areas exist to the total area
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$PS_{Nat2000}^{t_x} = \frac{S_{Nat2000}^{t_x}}{S_{tot}^{t_x}} * 100$$ where *m* is the number of the agent, *Nat2000* denotes Natura 2000, t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value), and $S_{Nat2000}{}^{t_x}$ stands for the area under Natura 2000 *Nat2000* in a year t_x
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of each production year

Table 29 Characterisation of the LU26 KPI: Change in the agricultural areas under Natura 2000.

ID	LU26
KPI	Change in the agricultural areas under Natura 2000
DIMENSION	Land conversion and habitat loss
DEFINITION	The change in the areas in which the Natura 2000 nature protection areas exist
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$CS_{Nat2000} = PS_{Nat2000}^{t_k} - PS_{Nat2000}^{t_0}$$
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

Table 30 Characterisation of the LU27 KPI: Forest area.

ID	LU27
KPI	Forest area
DIMENSION	Land conversion and habitat loss
DEFINITION	The areas with forest land cover
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$S_{fa}^{t_x} = \sum_{m=1}^{k} S_{m,fa}^{t_x}$$ where *m* is the number of the agent, *fa* denotes forest area, t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value), and $S_{m,fa}{}^{t_x}$ stands for the areas with the forest land cover for the agent *m* in a year t_x
UNIT OF MEASURE	ha
FREQUENCY OF RECORDING	At the end of each production year

Table 31 Characterisation of the LU28 KPI: Share of the forest area.

ID	LU28
KPI	Share of the forest area
DIMENSION	Land conversion and habitat loss
DEFINITION	The ratio of the areas with forest land cover to the total area
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$PS_{fa}^{t_x} = \frac{S_{fa}^{t_x}}{S_{tot}^{t_x}} * 100$$ where *m* is the number of the agent, *fa* denotes forest area, t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes initial, starting value), and $S_{fa}^{t_x}$ stands for the areas with the forest land cover in a year t_x
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of each production year

Table 32 Characterisation of the LU29 KPI: Change in forest area.

ID	LU29
KPI	Change in forest area
DIMENSION	Land conversion and habitat loss
DEFINITION	The change in the areas with forest land cover during the assessed period
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$CS_{fa} = PS_{fa}^{t_k} - PS_{fa}^{t_0}$$
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

Table 33 Characterisation of the LU30 KPI: Share of specific cropping patterns.

ID	LU30
KPI	Share of specific cropping patterns
DIMENSION	Land conversion and habitat loss
DEFINITION	The ratio of the area belonging to a specific cropping pattern to the total area
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$PS_{cpat_n}^{t_x} = \frac{S_{cpat_n}^{t_x}}{S_{tot}^{t_x}} * 100$$ where *n=1,...,4* is the number characterizing a specific cropping pattern: $cpat_1$ - monocropping (one crop in the field per year), $cpat_2$ - multiple cropping (more than one crop in the same field per year), $cpat_3$ - intercropping (two or more crops growing simultaneously in the same field per year), $cpat_4$ - sequential cropping (two crops are planted consecutively in one growing season (the portion of the year in which conditions permit crop growth),

	t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes the initial, starting value), and $S_{tot}{}^{t_x}$ stands for the total cultivated area in a year t_x. $S_{cpat_n}^{t_x} = \sum_{m=1}^{k} S_{m,cpat_n}^{t_x}$
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of each production year

Table 34 Characterisation of the LU31 KPI: Tillage practices.

ID	LU31
KPI	Tillage practices
DIMENSION	Land conversion and habitat loss
DEFINITION	The shares of the arable land being under conservation tillage, conventional tillage, and zero tillage
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$PS_{tl_r}^{t_x} = \frac{S_{tl_r}^{t_x}}{Sar_{tot}^{t_x}} * 100$ where: $PS_{tl(r)}^{tx}$ - shares of the arable land belonging to 3 tillage practices (r) in the year tx *Sar_{tot}^{tx} - the total surface of arable land in the year tx (ha)* *$S_{tl(r)}^{tx}$ - the surface of the arable land under specific tillage practice (r)* $S_{tl_r}^{t_x} = \sum_{m=1}^{k} S_{m,tl_r}^{t_x}$ where: *r=1,...,3* is the number characterizing a specific tillage practice: tl_1 - conservation tillage, tl_2 - conventional tillage, tl_3 - zero tillage.
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

3.2 Wasteful water consumption KPI forms

Table 35 Characterisation of the WW1 KPI: Water used for irrigation.

ID	WW1
KPI	Water used for irrigation
DIMENSION	Wasteful water consumption
DEFINITION	Amount of water used for the irrigation of crops
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$WAT_{irr} = \sum_{t_x=1}^{t_x=k} \sum_{m=1}^{k} WAT_{m,irr}^{t_x}$$
UNIT OF MEASURE	m^3
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

Table 36 Characterisation of the WW2 KPI: Water retention capacity of soil.

ID	WW2
KPI	Water retention capacity of soil
DIMENSION	Wasteful water consumption
DEFINITION	The difference in the relative amount of soil water available to the plants
METHOD	Based on the methodology proposed by Wosten (1999) [1] for the European soils
FORMULA	The difference in the relative amount of soil water available to the plants during the assessed period W_T can be defined as: $$W_T = \frac{\sum_{m=1}^{k} (W_T^{t_x,m} - W_T^{t_0,m})}{k}$$ where k is the total number of agents. Soil water availability $W_T^{t_x,m}$ for the agent m in the year t_x can be calculated using the hydraulic properties of the soils as [1]: $$W_T^{t_x,m} = (W_T^{t_x,m}(FC) - W_T^{t_x,m}(WP))$$ where:

	$W_T^{t_x,m}$ is the relative amount of the soil water available to the plants (in m^3 m^{-3}) for the agent m in the year t_x, $W_T^{t_x,m}$ (FC) is the soil water content at Field Capacity FC (in m^3 m^{-3}) for the agent m in the year t_x, $W_T^{t_x,m}$ (WP) is the soil water content at Wilting Point WP (in m^3 m^{-3}) for the agent m in the year t_x, The above equation can be rewritten using the Mualem-van Genuchten [2] [3]equation as: $$W_T^{t_x,m} = (\theta_S^{t_x,m} - 0.01)\left(\frac{1}{(1+50\alpha^{t_x,m})^{1-\frac{1}{n^{t_x,m}}}} - \frac{1}{(1+15000\alpha^{t_x,m})^{1-\frac{1}{n^{t_x,m}}}}\right)$$ with: $\alpha^{t_x,m} = e^{\alpha_*^{t_x,m}}$ $n^{t_x,m} = e^{n_*^{t_x,m}} + 1$ $$\begin{aligned}\theta_S^{t_x,m} = \; & 0.7919 + 0.001691 * Clay^{t_x,m} - 0.29619 * BD^{t_x,m} - 0.000001491 * (Silt^{t_x,m})^2 \\ & +0.0000821 * (C_{org}^{t_x,m})^2 + 0.02427 * (Clay^{t_x,m})^{-1} + 0.01113 * (Silt^{t_x,m})^{-1} \\ & +0.01472 * ln(Silt^{t_x,m}) - 0.0000733 * C_{org}^{t_x,m} * Clay^{t_x,m} - 0.000619 * BD^{t_x,m} * Clay^{t_x,m} \\ & -0.001183 * BD^{t_x,m} * C_{org}^{t_x,m} - 0.0001664 * Silt^{t_x,m}\end{aligned}$$ $$\begin{aligned}\alpha_*^{t_x,m} = \; & -14.96 + 0.03135 * Clay^{t_x,m} + 0.0351 * Silt^{t_x,m} + 0.646 * C_{org}^{t_x,m} + 15.29 * BD^{t_x,m} \\ & -0.192 - 4.671 * (BD^{t_x,m})^2 - 0.000781 * (Clay^{t_x,m})^2 - 0.00687 * (C_{org}^{t_x,m})^2 \\ & +0.0449 * (C_{org}^{t_x,m})^{-1} + 0.0663 * ln(Silt^{t_x,m}) + 0.1482 * ln(C_{org}^{t_x,m}) - 0.04546 * BD^{t_x,m} * Silt^{t_x,m} \\ & -0.4852 * BD^{t_x,m} * C_{org}^{t_x,m} + 0.00673 * Clay^{t_x,m}\end{aligned}$$ $$\begin{aligned}n_*^{t_x,m} = \; & -25.23 - 0.02195 * Clay^{t_x,m} + 0.0074 * Silt^{t_x,m} - 0.194 * C_{org}^{t_x,m} + 45.5 * BD^{t_x,m} \\ & -7.24 * (BD^{t_x,m})^2 + 0.0003658 * (Clay^{t_x,m})^2 + 0.002885 * (C_{org}^{t_x,m})^2 - 12.81 * (BD^{t_x,m})^{-1} \\ & -0.1524 * (Silt^{t_x,m})^{-1} - 0.01958 * (C_{org}^{t_x,m})^{-1} - 0.02876 * ln(Silt^{t_x,m}) - 0.0709 * ln(C_{org}^{t_x,m}) \\ & -44.6 * ln(BD^{t_x,m}) - 0.02264 * BD^{t_x,m} * Clay^{t_x,m} + 0.0896 * BD^{t_x,m} * C_{org}^{t_x,m} + 0.00718 * Clay^{t_x,m}\end{aligned}$$ where Clay is the clay content, Silt is the silt content, BD is the bulk density, and C_{org} is the soil organic matter content in the soil.
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

3.3 Soil erosion and degradation KPI forms

Table 37 Characterisation of the SE1 KPI: Soil erosion.

ID	SE1
KPI	Soil erosion
DIMENSION	Soil erosion and degradation
DEFINITION	The potential soil erosion rate
METHOD	estimated with the use of the RUSTLE model[4]
FORMULA	Mean values of soil loss rates can be calculated by using the Revised Universal Soil Loss Equation (RUSLE) model [4]: $$E = \sum_{t_x=1}^{t_x=k} (R^{t_x} * C^{t_x} * K^{t_x} * LS^{t_x} * P^{t_x})$$ where R is the rainfall erosivity factor (MJ mm ha^{-1} h^{-1} yr^{-1}), C is the cover management factor (-), K is the soil erodibility factor (t ha h ha^{-1} MJ^{-1} mm^{-1}), LS is the topographic characteristics of the area (-), and P is the support practice factor [-]. The values of the R-factor are already calculated based on high-resolution temporal rainfall data (5, 10, 15, 30, and 60 min) collected from 1541 well-distributed precipitation stations across Europe [5], and can be downloaded from the Rainfall Erosivity Database (REDES) [5]. If access to the database cannot be obtained, then R-factor can be calculated as [6][7]: $$R^{t_x} = \sum_{t=1}^{y_h} 0.138 * i_{e,t}^2$$ $$i_{e,t} = \begin{cases} 0 \text{ if } SWE_t > 0 \\ \mathrm{i}_t \text{ if } SWE_t = 0 \end{cases}$$ $$SWE_t = SWE_{t-1} + \begin{cases} +min\{max\{0; \frac{T_{sup} - T_t}{T_{sup} - T_{inf}}\}; 1\} * \mathrm{i}_t \text{ if } i_t > 0 \\ -min\{max\{0; C_m * (T_t - T_m)\}; SWE_{t-1}\} \text{if} i_t = 0 \end{cases}$$ where $i_{e,t}$ (mm h^{-1}) is the effective hourly intensity of precipitation, y_h is the yearly number of hours, i_t (mm h^{-1}) is the precipitation intensity (rain + snow), SWE_t (mm) is the snow water equivalent, T_t (°C) is the air temperature, T_{inf} (°C) is the threshold temperature below which all the precipitation is snow (T_{inf} = -3 °C), T_{sup} (°C) is the threshold temperature above which the precipitation is rain (T_{sup} = 0 °C), T_m (°C) is the threshold temperature above which snow melting begins (T_m = 0 °C), and C_m (mm h^{-1} $°C^{-1}$) is the snow melting rate (C_m = 0.18).

The general values of C are tabularized (Table 4). More detailed values of the C-factor modeled for nonarable lands using a combination of land-use class and vegetation density, while for arable lands C-factor is based on crop composition and land management practices (reduced/no-tillage, cover crops, and plant residues) are provided in the paper by Pangos (2015) [8].

The K-factor can be estimated using the equation proposed by Wischmeier and Smith (1978) [9] and Renard et al. (1997) [10] as:
In a simpler version, the already estimated values of the K-factor can be downloaded from a 500 m resolution K-factor map of Europe from the European Soil Data Centre (ESDAC) [11], in which K values were estimated for the 20000 field sampling points included in the Land Use/Cover Area frame (LUCAS) survey and then interpolated with a Cubist regression model using spatial covariates such as remotely sensed data and terrain features [11].

$$K^{t_x} = (2.1 * 10^{-4} * M^{1.14} * (12 - OM) + 3.25 * (s - 2) + 2.5 * (p - 3)) * (\frac{0.1317}{100})$$

where M is calculated using the formula M = (% fine sand + silt)*(100 - % clay), OM is the percentage of organic matter, b is permeability (p = 1: very rapid, ..., p=6: very slow), and s is the soil structure class (the soil structure class (s= 1: very fine granular, s = 2: fine granular, s = 3, medium or coarse granular, s = 4: blocky, platy or massive).

The values of the LS-factor can be downloaded from the System for Automated Geoscientific Analyses (SAGA) [12]. They were calculated using the data from Digital Elevation Model (DEM) and applying the equations proposed by Desmet and Govers (1996) [13]:

$$S^{t_x} = 10.8 * sin\ (\Theta) + 0.03, \text{when the slope gradient} < 0.09$$
$$S^{t_x} = 16.8 * sin\ (\Theta) - 0.50, \text{when the slope gradient} > 0.09$$

$$L^{t_x} = (\frac{\lambda^{t_x}}{22.13})^m$$

where Θ is the gradient of slope in degrees, λ is the slope length (in meters) and m is equivalent to 0.5 for slopes steeper than 5%, 0.4 for slopes between 3%–4%, 0.3 for slopes between 1%–3% and 0.2 for slopes less than 1%.
The general values of P are tabularized (Table 4). The more detailed, gridded values of the P-factor taking into account a) contour farming implemented in EU agro-environmental policies, and the protection against soil loss provided by (b) stone walls and (c) grass margins [14], can be downloaded free from the European Soil Data Centre [15].

Table 38 Values of C and P factors.

Land Use	C	P
Wooded, reforested, and forested area	0.002	1
Grassland	0.07	1
Agricultural area	0.45	1
Orchard and vineyard	0.37	0.45
Urban area	0.003	1
Bare areas	0.36	1

UNIT OF MEASURE	t ha^{-1}
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

Table 39 Characterisation of the SE2 KPI: Topsoil organic carbon content.

ID	SE2
KPI	Topsoil organic carbon content
DIMENSION	Soil erosion and degradation
DEFINITION	The percentage content of the organic carbon in the topsoil
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$SOC^{t_x} = \frac{\sum_{m=1}^{k} SOC_m^{t_x}}{k}$$ where $SOC_m^{t_x}$ is the soil organic carbon content in the topsoil (in %) for the agent m in the year t_x,
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of each production year

Table 40 Characterisation of the SE3 KPI: Soil organic matter change.

ID	SE3
KPI	Soil organic matter change
DIMENSION	Soil erosion and degradation
DEFINITION	The change in the percentage content of the organic carbon in the topsoil during the assessed period
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$SOC_{change} = SOC^{t_k} - SOC^{t_0}$$
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

Table 41 Characterisation of the SE4 KPI: Soil fertility change.

ID	SE4
KPI	Soil fertility change
DIMENSION	Soil erosion and degradation
DEFINITION	The change in the content of nitrogen in the soil during the assessed period
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$N_{change} = \frac{\sum_{m=1}^{k}(N^{t_x} - N^{t_0})}{k}$$
UNIT OF MEASURE	kg N
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

Table 42 Characterisation of the SE5 KPI: Soil pH.

ID	SE5
KPI	Soil pH
DIMENSION	Soil erosion and degradation
DEFINITION	Average pH of the soils
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$pH^{t_x} = \frac{\sum_{m=1}^{k} pH_m^{t_x}}{k}$$
UNIT OF MEASURE	pH scale
FREQUENCY OF RECORDING	At the end of each production year

Table 43 Characterisation of the SE6 KPI: N surplus.

ID	SE6
KPI	N surplus
DIMENSION	Soil erosion and degradation
DEFINITION	The average amount of excessive nitrogen content left in the soil after one year of the simulation

METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$N_{excess}^{t_x} = \frac{\sum_{m=1}^{k}(N^{t_x,m} - N^{t_{x-1},m})}{k}$
UNIT OF MEASURE	kg N
FREQUENCY OF RECORDING	At the end of each production year

Table 44 Characterisation of the SE7 KPI: P surplus.

ID	SE7
KPI	P surplus
DIMENSION	Soil erosion and degradation
DEFINITION	The average amount of excessive phosphorous content left in the soil after one year of the simulation
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$P_{excess}^{t_x} = \frac{\sum_{m=1}^{k}(P^{t_x,m} - P^{t_{x-1},m})}{k}$
UNIT OF MEASURE	kg P
FREQUENCY OF RECORDING	At the end of each production year

3.4 Pollution KPI forms

Table 45 Characterisation of the POL1 KPI: Nitrate leaching.

ID	POL1
KPI	Nitrate leaching
DIMENSION	Pollution
DEFINITION	The nitrate leaching risk from arable land
METHOD	Obtained either from the ABM biophysical model simulations or calculated based on the concept of a soil nitrogen balance (i.e. the difference between the sum of all the sources of nitrogen applied to the soil such as fertilizer, soil nitrogen supply and atmospheric deposition, and the sum of all nitrogen removed from the soil, mainly in crop offtake). From this balance, any surplus nitrogen is considered at risk of leaching. The nitrogen that leaches from the soil is calculated as a function of soil properties and excess rainfall.
FORMULA	The nitrate leaching from arable land is calculated in the DNDC model and it is foreseen to obtain this data directly from the ABM simulation as: $$N_{leach}^{t_x} = \sum_{m=1}^{k} N_{leach}^{t_x,m} * AREA^{t_x,m}$$ where $N_{leach}^{t_x,m}$ is the nitrogen leached the agent m in the year t_x (in kg N $year^{-1}$ ha^{-1}), $AREA^{t_x,m}$ is the area of the land that agent m has in the year t_x (in ha), However, if the data from ABM biophysical model (DNDC) simulations is not available the concept of a soil nitrogen balance can be used. Amount of nitrogen lost from the arable soil as a result of leaching $L_{n,area}$: $$L_{n,area} = P * N_{res,area}$$ where P-proportion of residual N leached (fraction) calculated as [16]: $$P = 0.01 * (121.03 * \varepsilon - 34.51 * \varepsilon^2)\ where\ \varepsilon \leq 1.35$$ $$P = 1\ where\ \varepsilon > 1.35$$ ε - soil drainage efficiency calculated as: $\varepsilon = h/\varphi$ where h is cumulative soil drainage (mm), φ is the soil field capacity (mm) $N_{res,area}$ is an adjusted residual N after harvest (kg N ha^{-1}) calculated as:

$$N_{res,adj} = N_{res} * \sum_{m=1}^{k} \frac{M_1 * M_2 *\ldots* M_k}{100}$$

where Mk - one or more mitigation efficiencies (%) for pre- and post-harvest. The following mitigation measures are incorporated to reduce the residual N, for which the mitigation effectiveness in pre- and postharvest applications are given in Table 46 (after Newell-Price et al., (2011) [17]).

Table 46 Mitigation effectiveness (%) in pre- and post-harvest periods for various mitigation measures [18]

Mitigation measure	Note	Mitigation effectiveness (%) (pre-harvest)	Mitigation effectiveness (%) (post-harvest)
1: Plant autumn cover crops		100	50
2: Early harvest and establishment		100	70
3: Spring not autumn cultivation		65	100
4: Reduced cultivation		80	100
5: Maintain SOM levels		120	100
6: Allow drainage to deteriorate		80	100
7: Improve drainage		130	100
8: Maintain ditches		120	100
9: Plant N-efficient crops		90	100
10: Calibrate fertiliser spreader	f	95	100
11: Use fertiliser recommendations	f	95	100
12: Integrate fertiliser and manure	f, m	90	100
13: Avoid high-risk areas (fertiliser)	f	98	100
14: Avoid high-risk times (fertiliser)	f	95	100
15: Use fertiliser placement	f	98	100
16: Use nitrification inhibitors	f	65	100
17: Replace urea with ammonium nitrate	f	95	100
18: Calibrate manure spreader	m	95	100
19: Avoid high-risk times (slurry)	m	80	100
20: Avoid high-risk times (FYM)	m	95	100
21: Undersowing of maize		851	100[1]

N_{res} - residual N after harvest (kg N ha^{-1}) is based on the nitrogen balance equation:

$$N_{res} = I_f + I_m + I_{atm} + I_{bio} + I_s - L_{crop}$$

where:
I_f - annual addition of manufacturing fertilizer, including autumn and spring applications (kg N ha^{-1}),
I_m - annual addition of organic manure including separate applications (kg N ha^{-1}) which can be calculated from the following equation and Table 47:

$$I_m = \sum A * N_t$$

A - annual applicable rate for each type of manure (t ha^{-1}),
N_t - readily available nitrogen content for each type of manure (kg N t^{-1}) which can be taken from Table 47,

I_{atm} - annual addition from atmospheric deposition (kg N ha^{-1}); the value of 12 kg N ha^{-1} can be assumed as a default,
I_{bio} - biological nitrogen fixation by legume crops (kg N ha^{-1}) which after Baddeley and others can be assumed to be equal to 224.6 kg N ha^{-1} for beans and 140.7 kg N ha^{-1} for peas (if no more specific data are available).
I_s - soil nitrogen supply based on previous cropping (kg N ha^{-1}) is the amount of nitrogen (kg N/ha) in the soil (apart from that applied for the crop in manufactured fertilisers and manures) that is available for uptake by the crop throughout its entire life, taking account of nitrogen losses. It can be assessed by direct measurements of soil samples or from the field assessment taking into account the soil type, crop type and excess winter rainfall.
L_{crop} - offtake of nitrogen by previous crop (kg N t^{-1} of fresh weight) can be calculated from the formula and some default values of this coefficient are presented in Table 48 (based on Eurostat (2011) [19], and the nitrate leaching tool - technical reference of Chief Scientist's Group report (2021) [18])

$$L_{crop} = \sum c_p * Y$$

where c_p - nitrogen coefficient for the content in edible crop kg N ha^{-1},

Table 47 Readily available nitrogen contents (Nt) for various types of organic manure taken from the Fertilizer Manual RB209 [20]

Manure type	Readily available N (kg N t^{-1}) in fresh weight of manure
Fresh cattle FYM	1.2
Old cattle FYM	0.6
Fresh pig FYM	1.8
Old pig FYM	1.0
Fresh sheep FYM	1.4
Old sheep FYM	0.7
Fresh duck FYM	1.6
Old duck FYM	1.0
Poultry litter	9.5
Broiler/turkey litter	10.5

Cattle slurry (2% DM)	0.9
Cattle slurry (6% DM)	1.2
Cattle slurry (10% DM)	1.3
Cattle slurry liquid only (1.5% DM)	0.8
Cattle slurry liquid only (3% DM)	1.0
Cattle slurry liquid only (4% DM)	1.5
Cattle slurry solid only (20% DM)	1.0
Pig slurry (2% DM)	2.2
Pig slurry (4% DM)	2.5
Pig slurry (6% DM)	2.8
Pig slurry liquid only (3% DM)	2.2
Pig slurry solid only (20% DM)	1.3
Biosolids (digested liquid)	0.8
Biosolids (digested cake)	1.6
Biosolids (thermally dried)	2.0
Biosolids (lime stabilised)	0.9
Biosolids (composed)	0.6

Table 48 Crop yields and nitrogen coefficients used to calculate arable crop offtake [21][19]

Land use	Nitrogen coefficient (kg N t^{-1} FW)
Arable: Asparagus	2
Arable: Brussels sprouts and Cabbage	5
Arable: Cauliflower	5
Arable: Forage maize	3
Arable: Onions	4
Arable: Potatoes	3
Arable: Fodder beet	2
Arable: Rye or triticale	16
Arable: Ryegrass (seed)	26
Arable: Spring barley	15
Arable: Spring oats	16
Arable: Spring oilseed rape or linseed	38

		Arable: Spring-sown grass	26
		Arable: Spring wheat	21
		Arable: Sugar beet	2
		Arable: Winter barley	15
		Arable: Winter oats	16
		Arable: Winter oilseed rape	30
		Arable: Winter wheat	21
		Veg: Beans	42
		Veg: Peas	35
UNIT OF MEASURE	$kg\ N\ ha^{-1}$		
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon		

Table 49 Characterisation of the POL2 KPI: Pesticide use.

ID	POL2
KPI	Pesticide use
DIMENSION	Pollution
DEFINITION	The amount of pesticides used to protect the crops
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$PEST = \sum_{t_x=1}^{t_x=k}\sum_{m=1}^{k} PEST_m^{t_x}$
UNIT OF MEASURE	kg
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

Table 50 Characterisation of the POL3 KPI: Ammonia emissions.

ID	POL3
KPI	Ammonia emissions
DIMENSION	Pollution
DEFINITION	NH_3 emissions from managed soils

METHOD	Obtained directly from the ABM biophysical model simulations
FORMULA	The ammonia emissions from arable land are calculated in the DNDC model and it is foreseen to obtain this data directly from the ABM simulation as: $$ENH3_{DNDC}^{t_x} = \sum_{m=1}^{k} ENH3_{DNDC}^{t_x,m} * AREA^{t_x,m}$$ where $ENH3_{DNDC}^{t_x,m}$ are the ammonia emissions for the agent m in the year t_x (in kg NH_3 $year^{-1}$ ha^{-1}), $AREA^{t_x,m}$ is the area of the land that agent m has in the year t_x (in ha),
UNIT OF MEASURE	kg NH_3 $year^{-1}$
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

Table 51 Characterisation of the POL4 KPI: Mineral N fertilizer use.

ID	POL4
KPI	Mineral N fertilizer use
DIMENSION	Pollution
DEFINITION	The amount of mineral N fertilizer used to fertilize the crops
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$N_{fert} = \sum_{t_x=1}^{t_x=k} \sum_{m=1}^{k} N_{m,fert}^{t_x}$$
UNIT OF MEASURE	kg N
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

Table 52 Characterisation of the POL5 KPI: Mineral P use.

ID	POL5
KPI	Mineral P use
DIMENSION	Pollution
DEFINITION	The amount of mineral P fertilizer used to fertilize the crops
METHOD	Obtained directly from the outputs of the ABM simulation

FORMULA	$P_{fert} = \sum_{t_x=1}^{t_x=k}\sum_{m=1}^{k} P_{m,fert}^{t_x}$
UNIT OF MEASURE	kg P
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

Table 53 Characterisation of the POL6 KPI: Mineral K use.

ID	POL6
KPI	Mineral K use
DIMENSION	Pollution
DEFINITION	The amount of mineral K fertilizer used to fertilize the crops
METHOD	obtained directly from the outputs of the ABM simulation
FORMULA	$K_{fert} = \sum_{t_x=1}^{t_x=k}\sum_{m=1}^{k} K_{m,fert}^{t_x}$
UNIT OF MEASURE	kg N
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

3.5 Climate change KPI forms

Table 54 Characterisation of the CC1 KPI: CO2 emissions.

<table>
<tr><td>ID</td><td>CC1</td></tr>
<tr><td>KPI</td><td>CO_2 emissions</td></tr>
<tr><td>DIMENSION</td><td>Climate change</td></tr>
<tr><td>DEFINITION</td><td>Direct CO_2 emissions from managed soils</td></tr>
<tr><td>METHOD</td><td>Obtained either from the ABM biophysical model simulations or with the use of the set of equations recommended by the IPCC (2019)[22]</td></tr>
<tr><td>FORMULA</td><td>The direct CO_2 emissions from managed soils are calculated in the DNDC model and it is foreseen to obtain this data directly from the ABM simulation as:

$$ECO2_{DNDC}^{t_x} = \sum_{m=1}^{k} ENH3_{DNDC}^{t_x,m} * AREA^{t_x,m}$$

where

$ECO2_{DNDC}^{t_x,m}$ are the ammonia emissions for the agent m in the year t_x (in kg CO_2 year^{-1} ha^{-1}),
$AREA^{t_x,m}$ is the area of the land that agent m has in the year t_x (in ha),

However, if the data from DNDC will not be available, (i.e. due to the lack of input data needed for the model initialization) a set of equations recommended by IPCC can be used [22]:

$$ECO2^{t_x} = \sum_{m=1}^{k} (\Delta C_{Mineral,LU}^{t_x,m} + AG_{DM(T)}^{t_x,m} * 0.4) AREA^{t_x,m} * (44/12)$$

where:

$AG_{DM(T)}^{tx,m}$ is the above-ground residues dry matter (in kg d.m.) for the agent m in the year t_x. $AG_{DM(T)}^{tx,m} = AA_{(T)}^{tx,m} * Crop_{(T)}^{tx,m} + BB_{(T)}^{tx,m}$, where $AA_{(T)}^{tx,m}$ is the slope of the linear fit for crop type T, $BB_{(T)}^{tx,m}$ is the intercept, and $Crop_{(T)}^{tx,m}$ is the harvested yield. $AG_{DM(T)}^{tx,m}$ can be calculated using the data from Table 55.

Table 55 Default factors for the estimation of N added to soils from crop residues

<table>
<tr><th>Crop type T</th><th>Dry matter fraction of harvested product (DRY/WET)</th><th>$AA_{(T)}^{tx,m}$</th><th>$BB_{(T)}^{tx,m}$</th></tr>
<tr><td>Grains (general)</td><td>0.88</td><td>1.09</td><td>0.88</td></tr>
<tr><td>Maize</td><td>0.87</td><td>1.03</td><td>0.61</td></tr>
<tr><td>Wheat</td><td>0.89</td><td>1.51</td><td>0.52</td></tr>
<tr><td>Winter wheat</td><td>0.89</td><td>1.61</td><td>0.4</td></tr>
<tr><td>Spring wheat</td><td>0.89</td><td>1.29</td><td>0.75</td></tr>
<tr><td>Rice</td><td>0.89</td><td>0.95</td><td>2.46</td></tr>
<tr><td>Barley</td><td>0.89</td><td>0.98</td><td>0.59</td></tr>
</table>
</td></tr>
</table>

Oats	0.89	0.91	0.89
Millet	0.90	1.43	0.14
Sorghum	0.89	0.88	1.33
Rye	0.88	1.09	0.88
Beans (general)	0.91	1.13	0.85
Soybean	0.91	0.93	1.35
Dry bean	0.90	0.36	0.68
Tubers	0.22	0.1	1.06
Root crops (general)	0.94	1.07	1.54
Potato	0.22	0.1	1.06
Peanut	0.94	1.07	1.54
N-fixing forages	0.9	0.3	0
Non-N-fixing forages	0.9	0.3	0
Perennial grasses	0.9	0.3	0
Grass-clover mixtures	0.9	0.3	0
Alfalfa	0.9	0.29	0
Non-legume hay	0.9	0.18	0

$AREA^{t_x,m}$ is the area of the land that agent m has in the year t_x (in ha),
$\Delta C_{Mineral,\ LU}^{tx,\ m}$ is the average annual loss of soil carbon for each land-use type (LU) (in tonnes C), for the agent m in the year t_x (if more detailed information is not available, then $\Delta C_{Mineral,\ LU}^{tx,\ m}$ should be assumed as a single value for all land-uses and management systems, whereas in more detailed calculations (Tier 2) the value of $\Delta C_{Mineral,\ LU}^{tx,\ m}$ should be disaggregated by individual land-use and/or management systems).

$$\Delta C_{Mineral,LU}^{t_x,m} = \frac{(SOC^{t_x,m} - SOC^{t_x-1,m})}{D}$$

where:

$SOC^{tx,\ m}$ is the mineral soil organic C stock ($SOC_{Mineral}$) in the last year of an inventory time period t_x (in tonnes C) for the agent m,
$SOC^{tx-1,\ m}$ is the mineral soil organic C stock ($SOC_{Mineral}$) in the first year of an inventory time period t_x (in tonnes C) for the agent m,
D is the time dependence of mineral soil organic C stock change factors which is the default time period for transition between equilibrium SOC values (in years). (commonly 20 years, but depends on assumptions made in computing the factors $F_{LU(c,s,i)}^{tx,\ m}$, $F_{MG(c,s,i)}^{tx,\ m}$ and $F_{I(c,s,i)}^{tx,\ m}$. If T exceeds D, use the value for T to obtain an annual rate of change over the inventory time period (0-T years)).

$$SOC^{t_x,m} = \sum_{c,s,i} (SOC_{REF(c,s,i)}^{t_x,m} * F_{LU(c,s,i)}^{t_x,m} * F_{MG(c,s,i)}^{t_x,m} * F_{I(c,s,i)}^{t_x,m} * Area_{(c,s,i)}^{t_x,m})$$

where:

	$F_{LU(c,s,i)}^{tx,m}$ is the stock change factor for mineral soil organic C land-use systems or sub-systems for a particular land-use (dimensionless), for the agent m in the year t_x, $F_{MG(c,s,i)}^{tx,m}$ is the stock change factor for mineral soil organic C for management regime (dimensionless), for the agent m in the year t_x, $F_{I(c,s,i)}^{tx,m}$ is the stock change factor for mineral soil organic C for the input of organic amendments (dimensionless), for the agent m in the year t_x, $Area_{(c,s,i)}^{tx,m}$ is the land area of the stratum being estimated (in ha) for the agent m in the year t_x,. The values of $F_{LU(c,s,i)}^{tx,m}$, $F_{MG(c,s,i)}^{tx,m}$, and $F_{I(c,s,i)}^{tx,m}$ are provided in the Table 56, whereas $Area_{(c,s,i)}^{tx,m}$ will be taken directly from the ABM simulations (land market module).

Table 56 The default values of the stock change factors suggested by the IPCC (2019) [22]

Temperature regime	Moisture regime	$F_{LU(c,s,i)}^{tx,m}$	$F_{MG(c,s,i)}^{tx,m}$	$F_{I(c,s,i)}^{tx,m}$
long-term cultivated	paddy rice	perennial/tree crop	set aside	full tillage
Cool temperate	Dry	0.77	1.35	0.72
Moist	0.7	1.35	0.72	0.82
Warm temperate	Dry	0.76	1.35	0.72
Moist	0.69	1.35	0.72	0.82

If there are changes in land use categories, then the changes in $\Delta C_{Mineral,LU}^{tx,m}$ can be estimated using data from Table 57.

Table 57 Estimated changes in soil organic carbon content dependence on changes in land use [23]

Land use conversion	$\Delta C_{Mineral,LU}^{tx,m}$
Crops→grassland	+1.25%
Crops→forest	+3.75%
Grassland→forest	+2.5%
Grassland→crops	−5%
Forest→crops	−8.75%
Forest→grassland	3.75%

UNIT OF MEASURE	kg CO_2 year^{-1}
FREQUENCY OF RECORDING	At the end of each production year

Table 58 Characterisation of the CC2 KPI: CH4 emissions.

ID	CC2
KPI	CH_4 emissions
DIMENSION	Climate change
DEFINITION	Direct CH_4 emissions from managed soils and livestock
METHOD	Direct CH_4 emissions from managed soils are obtained from the outputs of the ABM biophysical model (DNDC) simulations, whereas direct CH_4 emissions from livestock are obtained with the use of the equation recommended by the IPCC (2006) [24]
FORMULA	Direct CH_4 emissions from managed soils are obtained from the outputs of the ABM biophysical model (DNDC) simulations as:

$$ECH4_{DNDC}^{t_x} = \sum_{m=1}^{k} ECH4_{DNDC}^{t_x,m} * AREA^{t_x,m}$$

where

$ECH4_{DNDC}^{t_x,m}$ are the methane emissions for the agent m in the year t_x (in kg CH4 year^{-1} ha^{-1}),
$AREA^{t_x,m}$ is the area of the land that agent m has in the year t_x (in ha),

In case the data from ABM biophysical model (DNDC) simulations is not available (the model could not be/was not initialized), the direct CH_4 emissions from managed soils are assumed to be 0.
The livestock CH_4 emissions were calculated based on the equation:

$$EF_{m,s,n}^{t_x} = \frac{(GE_{m,s,n}^{t_x} * \frac{Y_{m,s,n}^{t_x}}{100} * 365)}{55.65}$$

where

$EF_{m,s,n}^{tx}$ – CH_4 emissions from animal N of livestock species/category s for the agent m in the year t_x (in kg CH_4 animal^{-1} year^{-1}),
$GE_{m,s,n}^{tx}$ – animal N of livestock species/category s energy demand for the agent m in the year t_x (in MJ animal^{-1} year^{-1}),
$Y_{m,s,n}^{tx}$ – conversion factor to methane for animal N of livestock species/category s for the agent m in the year t_x (share of GE in the feed converted to methane) (in %).

The average values of the CH_4 emissions were calculated for several livestock species (Table 59) assuming the values of daily energy requirements for selected categories of animals/cattle $GE^{tx,m}$ and the share of GE in the feed converted to methane $Y_n^{tx,m}$ in line with IPCC (2006) [24] recommendations and assumptions.

Table 59 Calculated CH4 emissions for several livestock species.

Animal	CH_4 emissions [kg CH_4 animal^{-1} year^{-1}]		
	CH_4 from enteric fermentation		CH_4 from faeces
	Western Europe	Eastern Europe	
Dairy cattle	126	93	11.87

Other cattle	52	58	2.15
Swine	1.5	1.5	3.07
Poultry	-	-	0.03
Sheep	9	9	-
Goat	9	9	-
Horse	18	18	1.56
Mule/ass	10	10	-
Camel	46	46	-
Ostrich	5	5	5.67
Buffalo	78	68	-
Deer	20	20	0.22
Llamas and alpacas	8	8	-

Therefore, the total direct CH4 emissions from managed soils and livestock can be calculated as:

$$ECH4 = \sum_{m=1}^{k}(SCH4^{t_x,m} + (\sum_{s=1}^{s=5}\sum_{n=1}^{N}(EFCH4^{t_x}_{m,s,n} + FCH4^{t_x}_{m,s,n})))$$

where:

$ECH4^{tx}$ are the CH_4 emissions from managed soils and livestock in the year t_x (in kg CH_4 year^{-1}),
$SCH4^{tx,\,m}$ are the CH_4 emissions from the soil for the agent m in the year t_x (in kg CH_4 animal^{-1} year^{-1}) (assumed to be 0 if the data on direct CH_4 emissions from managed soils from ABM biophysical model (DNDC) simulations is not available)
$EFCH4_{m,s,n}^{tx}$ are the CH_4 emissions from enteric fermentation of animal N of livestock species/category s for the agent m in the year t_x (in kg CH_4 animal^{-1} year^{-1}),
$FCH4_{m,s,n}^{tx}$ are the CH_4 emissions from faeces of animal N of livestock species/category s for the agent m in the year t_x (in kg CH_4 animal^{-1} year^{-1}),

UNIT OF MEASURE	kg CH_4 year^{-1}
FREQUENCY OF RECORDING	at the end of each production year

Table 60 Characterisation of the CC3 KPI: N2O emissions.

ID	CC3
KPI	N_2O emissions
DIMENSION	Climate change
DEFINITION	Direct N_2O emissions from managed soils
METHOD	Obtained either from the ABM biophysical model simulations or with the use of the set of equations recommended by the IPCC (2006)[24] and IPCC (2019) [22]
FORMULA	The direct N_2O emissions from managed soils are calculated in the DNDC model and it is foreseen to obtain this data directly from the ABM simulation as: $$EN2O_{DNDC}^{t_x} = \sum_{m=1}^{k} EN2O_{DNDC}^{t_x,m} * AREA^{t_x,m}$$ where $EN2O_{DNDC}^{t_x,m}$ are the nitrous oxide emissions for the agent m in the year t_x (in kg N_2O year^{-1} ha^{-1}), $AREA^{t_x,m}$ is the area of the land that agent m has in the year t_x (in ha), However, if the data from DNDC will not be available, (i.e. due to the lack of input data needed for the model initialization) a set of equations recommended by IPCC [22] can be used: $$N_2O_{Direct}{}^{t_x} = \sum_{m=1}^{k} (N_2O_{N_{inputs}}^{t_x,m} + N_2O_{PRP}^{t_x,m}) * (\frac{44}{28}),$$ where $$N_2O_{N_{inputs}}^{t_x,m} = (F_{SN}^{t_x,m} + F_{ON}^{t_x,m} + F_{CR}^{t_x,m} + F_{SOM}^{t_x,m}) * EF_1^{t_x,m}),$$ and $$N_2O_{PRP}^{t_x,m} = [(F_{PRP,CPP}^{t_x,m} * EF_{3PRP,CPP}^{t_x,m}) + (F_{PRP,SO}^{t_x,m} * EF_{3PRP,SO}^{t_x,m})].$$ In the above set of equations: *m* is numbering the agents (from 1 to k), t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes the initial, starting value) $N_2O_{Direct}^{tx,m}$ are annual direct N_2O emissions produced from managed soils (in kg N_2O year^{-1}) for the agent m in the year t_x, $N_2O_{inputs}^{tx,m}$ are annual direct N_2O emissions from N inputs to managed soils (in kg N_2O–N year^{-1}) for the agent m in the year t_x, $N_2O_{PRP}^{tx,m}$ are annual direct N_2O emissions from urine and dung inputs to grazed soils (in kg N_2O–N year^{-1}) for the agent m in the year t_x, $F_{SN}^{tx,m}$ is an annual amount of synthetic fertilizer N applied to soils (in kg N year^{-1}) for the agent m in the year t_x, $F_{ON}^{tx,m}$ is an annual amount of animal manure, compost, sewage sludge, and other organic N additions applied to soils (in kg N year^{-1}) for the agent m in the year t_x, (Note: If including sewage sludge, cross-check with Waste Sector to ensure there is no double counting of N_2O emissions from the N in sewage sludge) $F_{CR}^{tx,m}$ is an annual amount of N in crop residues (above-ground and below-ground), including N-fixing crops, and from forage/pasture renewal, returned to soils (in kg N year^{-1}) for the agent m in the year t_x,

$F_{SOM}^{tx,m}$ is an annual amount of N in mineral soils that is mineralized, in association with loss of soil C from soil organic matter as a result of changes to land use or management (in kg N year^{-1}) for the agent m in the year t_x,
$F_{PRP}^{tx,m}$ is an annual amount of urine and dung N deposited by grazing animals on pasture, range, and paddock (in kg N year^{-1}) for the agent m in the year t_x, (Note: the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively)
$EF_1^{tx,m}$ is the emission factor for N_2O emissions from N inputs (in N_2O–N (kg N_{input})$^{-1}$) for the agent m in the year t_x, (default value from IPCC (2019)[22] recommendations is 0.01)
$EF_{3PRP}^{tx,m}$ is the emission factor for N_2O emissions from urine and dung N deposited on pasture, range and paddock by grazing animals (in N_2O–N (kg N_{input})$^{-1}$) for the agent m in the year t_x, (Note: the subscripts CPP and SO refer to Cattle, Poultry and Pigs, and Sheep and Other animals, respectively) (default values from IPCC (2019) [22] recommendations are 0.004 for $EF_{3PRP,CPP}^{tx,m}$ and 0.003 for $EF_{3PRP,SO}^{tx,m}$).

To calculate the N_2O emissions the variables $F_{SN}^{tx,m}$, $F_{ON}^{tx,m}$, $F_{CR}^{tx,m}$, $F_{SOM}^{tx,m}$, and $F_{PRP}^{tx,m}$ needs to be defined. The quantity of synthetic fertilizer N applied to soils $F_{SN}^{tx,m}$ is output from the internal ABM modules and will be taken directly from the ABM simulation.
The rest of the coefficients are defined as:

$$F_{ON}^{t_x,m} = F_{AM}^{t_x,m} + F_{SEW}^{t_x,m} + F_{COMP}^{t_x,m} + F_{OOA}^{t_x,m}$$

where

$F_{ON}^{tx,m}$ is the total annual amount of organic N fertilizer applied to soils other than by grazing animals (in kg N year^{-1}) by the agent m in the year t_x,
$F_{AM}^{tx,m}$ is an annual amount of animal manure N applied to soils (in kg N year^{-1}) by the agent m in the year t_x,
$F_{SEW}^{tx,m}$ is an annual amount of total sewage N (coordinate with Waste Sector to ensure that sewage N is not double-counted) that is applied to soils (in kg N year^{-1}) by the agent m in the year t_x,
$F_{COMP}^{tx,m}$ is an annual amount of total compost N applied to soils (ensure that manure N in compost is not double-counted) (in kg N year^{-1}) by the agent m in the year t_x,
$F_{OOA}^{tx,m}$ is an annual amount of other organic amendments used as fertilizer (e.g., rendering waste, guano, brewery waste, etc.) (in kg N year^{-1}) by the agent m in the year t_x,
$F_{ON}^{tx,m}$, $F_{AM}^{tx,m}$, $F_{SEW}^{tx,m}$, $F_{COMP}^{tx,m}$, and $F_{OOA}^{tx,m}$ are the outputs from the ABM internal modules and will be taken directly from the ABM simulation.

The annual amount of N in crop residues $F_{CR}^{tx,m}$ is calculated using the IPCC (2006) [24] methodology as:

$$F_{CR}^{t_x,m} = \sum_T Crop_T^{t_x,m} * Frac_{Renew(T)}^{t_x,m} * [(Area_T^{t_x,m} - Areaburnt_T^{t_x,m} * C_f^{t_x,m}) * R_{AG(T)}^{t_x,m} * N_{AG(T)}^{t_x,m} * (1 - Frac_{Remove(T)}^{t_x,m}) + Area_T^{t_x,m} * R_{BG(T)}^{t_x,m} N_{BG(T)}^{t_x,m}]$$

where

$F_{CR}^{tx,m}$ is an annual amount of N in crop residues (above and below ground), including N-fixing crops, and from forage/pasture renewal, returned to soils annually (in kg N yr^{-1}) for the agent m in the year t_x,
T = crop or forage type
$Crop_{(T)}^{tx,m}$ is the harvested annual dry matter yield for crop T (in kg d.m. ha^{-1}) for the agent m in the year t_x,
$Area_{(T)}^{tx,m}$ is the total annual area harvested of crop T (in ha year^{-1}) for the agent m in the year t_x,
$Areaburnt_{(T)}^{tx,m}$ is the annual area of crop T burnt (in ha year^{-1}) for the agent m in the year t_x,

$C_f^{tx, m}$ is the combustion factor (dimensionless) for the agent m in the year t_x,
$FracRenew_{(T)}^{tx, m}$ is the fraction of the total area under crop T that is renewed annually (dimensionless) for the agent m in the year t_x, (for countries where pastures are renewed on average every X years, FracRenew = 1/X, while for annual crops FracRenew = 1)
$R_{AG(T)}^{tx, m} = AG_{DM(T)}^{tx, m} / Crop_{(T)}^{tx, m}$ is the ratio of above-ground residues dry matter ($AG_{DM(T)}^{tx, m}$) to harvested yield for crop T ($Crop_{(T)}^{tx, m}$) (in kg d.m. (kg d.m.)$^{-1}$) for the agent m in the year t_x, (if alternative data is not available, the mass above-ground residues dry matter ($AG_{DM(T)}^{tx, m}$) can be calculated from harvested yield for crop T ($Crop_{(T)}^{tx, m}$) using linear interpolation $AG_{DM(T)}^{tx, m} = AA_{(T)}^{tx, m} * Crop_{(T)}^{tx, m} + BB_{(T)}^{tx, m}$, where $AA_{(T)}^{tx, m}$ is the slope of the linear fit for crop type T, and $BB_{(T)}^{tx, m}$ is the intercept, using the data from Table 61)
$N_{AG(T)}^{tx, m}$ is the N content of above-ground residues for crop T (in kg N (kg d.m.)$^{-1}$), for the agent m in the year t_x,
$FracRemove_{(T)}^{tx, m}$ is the fraction of above-ground residues of crop T removed annually for purposes such as feed, bedding, and construction (in kg N (kg crop-N)$^{-1}$), for the agent m in the year t_x. A Survey of experts in the country is required to obtain data. If data for FracRemove is not available, assume no removal ($FracRemove_{(T)}^{tx, m} = 0$).
$R_{BG(T)}^{tx, m}$ is the ratio of below-ground residues to harvested yield for crop T (in kg d.m. (kg d.m.)$^{-1}$) for the agent m in the year t_x (if alternative data is not available, $R_{BG(T)}^{tx, m}$ may be calculated by multiplying $R_{BG-BIO}^{tx, m}$ by the ratio of total above-ground biomass to crop yield $(AG_{DM(T)}^{tx, m}+Crop_{(T)}^{tx, m})/Crop_{(T)}^{tx, m}$ using the information from Table 61).
$N_{BG(T)}^{tx, m}$ is the N content of below-ground residues for crop T (in kg N (kg d.m.)$^{-1}$), for the agent m in the year t_x.
The data on T, $Crop_{(T)}^{tx, m}$, $Area_{(T)}^{tx, m}$, $Areaburnt_{(T)}^{tx, m}$, $C_f^{tx, m}$, $FracRenew_{(T)}^{tx, m}$, $AG_{DM(T)}^{tx, m}$, and $FracRemove_{(T)}^{tx, m}$ will be taken directly from the ABM simulation.

Table 61 Default factors for the estimation of N added to soils from crop residues

Crop type T	Dry matter fraction of harvested product (DRY/WET)	$AA_{(T)}^{tx, m}$	$BB_{(T)}^{tx, m}$	$N_{AG(T)}^{tx, m}$	$R_{BG-BIO}^{tx, m}$	$N_{BG(T)}^{tx, m}$
Grains (general)	0.88	1.09	0.88	0.006	0.22	0.009
Maize	0.87	1.03	0.61	0.006	0.22	0.007
Wheat	0.89	1.51	0.52	0.006	0.24	0.009
Winter wheat	0.89	1.61	0.4	0.006	0.23	0.009
Spring wheat	0.89	1.29	0.75	0.006	0.28	0.009
Rice	0.89	0.95	2.46	0.007	0.16	-
Barley	0.89	0.98	0.59	0.007	0.22	0.014
Oats	0.89	0.91	0.89	0.007	0.25	0.008
Millet	0.90	1.43	0.14	0.007	-	-
Sorghum	0.89	0.88	1.33	0.007	-	0.006
Rye	0.88	1.09	0.88	0.005	-	0.011
Beans (general)	0.91	1.13	0.85	0.008	0.19	0.008
Soybean	0.91	0.93	1.35	0.008	0.19	0.008
Dry bean	0.90	0.36	0.68	0.01	-	0.01
Tubers	0.22	0.1	1.06	0.019	0.2	0.014
Root crops (general)	0.94	1.07	1.54	0.016	0.2	0.014
Potato	0.22	0.1	1.06	0.019	0.2	0.014
Peanut	0.94	1.07	1.54	0.016	-	-

N-fixing forages	0.9	0.3	0	0.027	0.4	0.022
Non-N-fixing forages	0.9	0.3	0	0.015	0.54	0.012
Perennial grasses	0.9	0.3	0	0.015	0.8	0.012
Grass-clover mixtures	0.9	0.3	0	0.025	0.8	0.016
Alfalfa	0.9	0.29	0	0.027	0.4	0.019
Non-legume hay	0.9	0.18	0	0.015	0.54	0.012

$$F_{SOM}^{t_x,m} = \sum_{LU} \Delta C_{Mineral,LU}^{t_x,m} * \frac{1}{R^{t_x,m}} * 1000$$

where:

$F_{SOM}^{tx,m}$ is the net annual amount of N mineralized in mineral soils as a result of loss of soil carbon through a change in land use or management (in kg N), for the agent m in the year t_x,
LU is the land-use and/or management system type,
$\Delta C_{Mineral,LU}^{tx,m}$ is the average annual loss of soil carbon for each land-use type (LU) (in tonnes C), for the agent m in the year t_x (if more detailed information is not available, then $\Delta C_{Mineral,LU}^{tx,m}$ should be assumed as a single value for all land-uses and management systems, whereas in more detailed calculations (Tier 2) the value of $\Delta C_{Mineral,LU}^{tx,m}$ should be disaggregated by individual land-use and/or management systems).
$R^{tx,m}$ is C:N ratio of the soil organic matter for the agent m in the year t_x, (if more specific data is not available, then a default value of 15 (uncertainty range from 10 to 30) for the C:N ratio R may be used for situations involving land-use change from Forest Land or Grassland to Cropland, whereas a default value of 10 (range from 8 to 15) may be used for situations involving management changes on Cropland Remaining Cropland).
The information on LU type and $R^{tx,m}$ will be taken directly from the outputs of the ABM simulations (if the data $R^{tx,m}$ will not be available, then the default values recommended by the IPCC (2019) [22] are assumed), whereas the average annual loss of soil carbon for agricultural land-use type (LU) $\Delta C_{Mineral,LU}^{tx,m}$ is calculated as:

$$\Delta C_{Mineral,LU}^{t_x,m} = \frac{(SOC^{t_x,m} - SOC^{t_x-1,m})}{D}$$

where:

$SOC^{tx,m}$ is the mineral soil organic C stock ($SOC_{Mineral}$) in the last year of an inventory time period t_x (in tonnes C) for the agent m,
$SOC^{tx-1,m}$ is the mineral soil organic C stock ($SOC_{Mineral}$) in the first year of an inventory time period t_x (in tonnes C) for the agent m,
D is the time dependence of mineral soil organic C stock change factors which is the default time period for transition between equilibrium SOC values (in years). (commonly 20 years, but depends on assumptions made in computing the factors $F_{LU(c,s,i)}^{tx,m}$, $F_{MG(c,s,i)}^{tx,m}$ and $F_{I(c,s,i)}^{tx,m}$. If T exceeds D, use the value for T to obtain an annual rate of change over the inventory time period (0-T years)).

$$SOC^{t_x,m} = \sum_{c,s,i} (SOC_{REF(c,s,i)}^{t_x,m} * F_{LU(c,s,i)}^{t_x,m} * F_{MG(c,s,i)}^{t_x,m} * F_{I(c,s,i)}^{t_x,m} * Area_{(c,s,i)}^{t_x,m})$$

$F_{LU(c,s,i)}^{tx,m}$ is the stock change factor for mineral soil organic C land-use systems or sub-systems for a particular land-use (dimensionless), for the agent m in the year t_x,
$F_{MG(c,s,i)}^{tx,m}$ is the stock change factor for mineral soil organic C for management regime (dimensionless), for the agent m in the year t_x,
$F_{I(c,s,i)}^{tx,m}$ is the stock change factor for mineral soil organic C for the input of organic amendments (dimensionless), for the agent m in the year t_x,
$Area_{(c,s,i)}^{tx,m}$ is the land area of the stratum being estimated (in ha) for the agent m in the year t_x,.
The values of $F_{LU(c,s,i)}^{tx,m}$, $F_{MG(c,s,i)}^{tx,m}$, and $F_{I(c,s,i)}^{tx,m}$ are provided in the Table 62, whereas $Area_{(c,s,i)}^{tx,m}$ will be taken directly from the ABM simulations (land market module).

Table 62 The default values of the stock change factors suggested by the IPCC (2019) [22]

Temperature regime	Moisture regime	$F_{LU(c,s,i)}^{tx,m}$				$F_{MG(c,s,i)}^{tx,m}$			$F_{I(c,s,i)}^{tx,m}$			
		long-term cultivated	paddy rice	perennial/tree crop	set aside	full tillage	reduced tillage	no-tillage	low	medium	high without manure	high with manure
Cool temperate	Dry	0.77	1.35	0.72	0.93	1	0.98	1.03	0.95	1	1.04	1.37
	Moist	0.7	1.35	0.72	0.82	1	1.04	1.09	0.92	1	1.11	1.44
Warm temperate	Dry	0.76	1.35	0.72	0.93	1	0.99	1.04	0.95	1	1.04	1.37
	Moist	0.69	1.35	0.72	0.82	1	1.05	1.1	0.92	1	1.11	1.44

If there are changes in land use categories, then the changes in $\Delta C_{Mineral,\,LU}^{tx,m}$ can be estimated using data from Table 63.

Table 63 Estimated changes in soil organic carbon content dependence on changes in land use [23]

Land use conversion	$\Delta C_{Mineral,\,LU}^{tx,m}$
Crops→grassland	+1.25%
Crops→forest	+3.75%
Grassland→forest	+2.5%
Grassland→crops	–5%
Forest→crops	–8.75%
Forest→grassland	3.75%

$$F_{PRP}^{t_x,m} = \sum_s N_s^{t_x,m} * Nex_s^{t_x,m} + MS_{s,PRP}^{t_x,m}$$

where

$F_{PRP}^{tx,m}$ is an annual amount of urine and dung N deposited on pasture, range, paddock, and by grazing animals (in kg N $year^{-1}$) for the agent m in the year t_x,
$N_{(s)}^{tx,m}$ is the number of heads of livestock species/category s at the farm of the agent m in the year t_x,
$Nex_{(s)}^{tx,m}$ is an annual average N excretion per head of species/category s in the farm (in kg N $animal^{-1}$ $year^{-1}$) for the agent m in the year t_x, ($Nex_{(s)}^{tx,m} = N_{rate(s)}^{tx,m}$ * $TAM_{(s)}^{tx,m}$ * (365/1000), where $N_{rate(s)}^{tx,m}$ is a default N excretion rate for livestock category s, and TAM_s is a typical animal mass for livestock category s)

$MS_{(s,PRP)}^{tx,\,m}$ is the fraction of total annual N excretion for each livestock species/category s that is deposited on pasture, range, and paddock for the agent m in the year t_x.

The value of the $N_{(s)}^{tx,\,m}$ will be taken directly from the outputs of the ABM simulations, whereas the values of $Nex_{(s)}^{tx,\,m}$, and $MS_{(s,PRP)}^{tx,\,m}$ are provided in Table 64 and
Table 65, respectively.
Table 64. Default values for nitrogen excretion rate (in kg N (1000 kg animal mass)$^{-1}$ day^{-1}), typical animal mass for livestock category s and annual average N excretion per head of species/category s in the farm (in kg N animal^{-1} yr^{-1})

Table 64 Default values for nitrogen excretion rate (in kg N (1000 kg animal mass)-1 day-1), typical animal mass for livestock category s and annual average N excretion per head of species/category s in the farm (in kg N animal-1 yr-1)

Livestock category s	Region					
	Western Europe			Eastern Europe		
	$N_{rate(s)}^{tx,\,m}$ (kg N (1000 kg animal mass)$^{-1}$ day^{-1})	$TAM_{(s)}^{tx,\,m}$ (kg (animal)$^{-1}$)	$Nex_{(s)}^{tx,\,m}$ (kg N (animal)$^{-1}$ year^{-1})	$N_{rate(s)}^{tx,\,m}$ (kg N (1000 kg animal mass)$^{-1}$ day^{-1})	$TAM_{(s)}^{tx,\,m}$ (kg (animal)$^{-1}$)	$Nex_{(s)}^{tx,\,m}$ (kg N (animal)$^{-1}$ year^{-1})
Dairy cattle	0.50	600	109.50	0.42	550	84.315
Other cattle	0.42	405	62.09	0.47	389	66.73295
Swine (in general)	0.65	76	18.03	0.63	77	17.70615
Swine (finishing)	0.76	61	16.92	0.77	59	16.58195
Swine (breeding)	0.38	190	26.35	0.36	204	26.8056
Poultry (in general)	0.99	1.4	0.51	0.96	1.3	0.45552
Poultry (hens >/= 1 year)	0.87	1.9	0.60	0.81	1.9	0.561735
Poultry (pullets)	0.58	1.5	0.32	0.58	1.3	0.27521
Poultry (other chickens)	0.83	1.8	0.55	0.82	1.8	0.53874
Poultry (broilers)	1.14	1.2	0.50	1.12	1.1	0.44968
Poultry (turkeys)	0.74	6.8	1.84	0.74	6.8	1.83668
Poultry (ducks)	0.83	2.7	0.82	0.83	2.7	0.817965
Sheep	0.36	40	5.26	0.36	40	5.256
Goat	0.46	40	6.72	0.44	36	5.7816
Horse	0.26	377	35.78	0.3	377	41.2815
Mule/ass	0.26	130	12.34	0.3	130	14.235
Camel	0.38	217	30.10	0.38	217	30.0979
Ostrich	0.34	120	14.89	0.34	120	14.892

Buffalo	0.45	509	83.60	0.35	467	59.65925
Deer	0.67	120	29.35	0.67	120	29.346
Reindeer	0.23	120	10.07	0.23	120	10.074
Mink and polecat	-	-	4.59	-	-	4.59
Rabbit	-	1.6	8.1	-	1.6	8.1
Fox and raccoon	-	-	12.09	-	-	12.09

Table 65 Default values of the fraction of total annual N excretion for each livestock species/category s that is deposited on pasture, range, and paddock.

Livestock category s	$MS_{(s,PRP)}^{tx,m}$ ((kg N deposited (animal)$^{-1}$ day^{-1})(kg N (animal)$^{-1}$ day^{-1})$^{-1}$)	
	Western Europe	Eastern Europe
Dairy cattle	0.76	0.79
Other cattle	0.93	0.93
Swines	0.7	0.7
Poultry	0.7	0.7
Sheeps	0.9	0.9
Goats	0.9	0.9
Horses	0.93	0.93
Camels	0.93	0.93
Buffalos	0.93	0.93

UNIT OF MEASURE	kg N_2O year^{-1}
FREQUENCY OF RECORDING	At the end of each production year

3.6 Biodiversity KPI forms

Table 66 Characterisation of the BIO1 KPI: Crop diversity.

ID	BIO1
KPI	The Shannon index of crop diversity
DIMENSION	Biodiversity
DEFINITION	The crop diversity calculated as a mean value of the Shannon index [25] for all the agents.
METHOD	The original Shannon index [25] was used to measure diversity in the ecology context [26][27], and crop diversity [28][29]. In an earlier study of farm-level assessment of this index for a large number of farms in Germany [30], the following interpretation of the HS is derived: HS values>2.2 are considered as optimal, >1.25 and less than 2.2 as tolerable, while values below 1.25 as not sustainable.
FORMULA	$$HS^{t_x} = \frac{\sum_{m=1}^{k}(-\sum_{i=1}^{t} p_i^{t_x,m} * ln(p_i^{t_x,m}))}{k}$$ where t is the number of crop species for a given agent, and p_i is the proportion of hectares of one particular species area S_n for a given agent divided by the total hectares of crop production (S_{tot}) of this agent, k is the number of agents
UNIT OF MEASURE	-
FREQUENCY OF RECORDING	At the end of each production year

Table 67 Characterisation of the BIO2 KPI: Crop diversity.

ID	BIO2
KPI	Number of crops diversity index (Crops > 5%AL)
DIMENSION	Biodiversity
DEFINITION	The number of crops that have a share in total arable area>5% (Crops > 5%AL).
METHOD	This cultivar diversity index was suggested and described by Oppermann et al. (2005)[31]
FORMULA	$$CD^{t_x} = \frac{\sum_{m=1}^{k} N_{>5\%}^{t_x,m}}{k}$$ where $N_{>5\%}$ is the number of crops with a share in a total arable area larger than 5%.
UNIT OF MEASURE	-
FREQUENCY OF RECORDING	At the end of each production year

Table 68 Characterisation of the BIO3 KPI: Livestock patterns.

ID	BIO3
KPI	Livestock patterns
DIMENSION	Biodiversity
DEFINITION	The shares of livestock species in the total number of livestock
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$SHL_{lp(s)}^{t_x} = \frac{L_{lp(s)}^{t_x}}{L_{tot}^{t_x}} * 100$$

	where $$L_{lp(s)}^{t_x} = \sum_{m=1}^{k} lp(s)^{t_x,m}$$ *s =1,...,S* is the number characterizing a specific livestock pattern. t_x denotes the year of the simulation (from t_0 to t_k, where t_0 denotes the initial, starting value), *m* is the number of the agent, $L_{tot}^{t_x}$ is the total number of livestock in a year t_x. $L_{lp(s)}^{t_x}$ the number of specific livestock types in a year t_x
UNIT OF MEASURE	%
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

Table 69 Characterisation of the BIO4 KPI: Livestock Units per ha.

ID	BIO4
KPI	Livestock Units per ha
DIMENSION	Biodiversity
DEFINITION	The number of livestock units per one hectare
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$LU_{ha}^{t_x} = \frac{\sum_{m=1}^{k} LU_m^{t_x}}{S_{tot}^{t_x}}$$ where *m* is the number of the agent, t_x denotes the year of the simulation (from t_0 to t_k), and $LU_{m,}^{t_x}$ stands for the livestock units for the agent *m*
UNIT OF MEASURE	LU/ha
FREQUENCY OF RECORDING	At the end of each production year

Table 70 Characterisation of the BIO5 KPI: Livestock diversity.

ID	BIO5
KPI	Livestock diversity
DIMENSION	Biodiversity
DEFINITION	The average number of livestock species
METHOD	Obtained directly from the outputs of the ABM simulation
FORMULA	$$LD^{t_x} = \frac{\sum_{m=1}^{k} LD^{t_x,m}}{k}$$ where $LD^{tx,\,m}$ is the number of livestock species for the agent m in the year t_x.
UNIT OF MEASURE	-
FREQUENCY OF RECORDING	At the end of the ABM simulation horizon

4 Structure of environmental and climate impact assessment module

4.1 Interface definition

The environmental and climate impact assessment module was implemented as a server awaiting requests providing data indispensable for the determination of the KPIs and returning the calculated value as a response. The communication between the developed module and other modules of the Agricore suite is realized using the gRPC protocol. As a result, Protocol Buffers are used for the interface definition. The third version of the Protocol Buffers language specification was used for interface definition.

Below the Protocol Buffers code defining the interfaces is presented.

Code Block 1 Interfaces Definition using Protocols Buffer Language

```
syntax = "proto3";

service KpiService {
  rpc kpiSoilErosion (kpiSoilErosionRequest) returns (kpiSoilErosionReply) {};
  rpc kpiNEmission (kpiNEmissionRequest) returns (kpiNEmissionReply) {};
}

enum TKpiType {
  FAKE_KPI_TYPE = 0;
  KPI_SOIL_EROSION = 1;
  KPI_N_EMISSION = 2;
}

enum TReturnCode {
  FAKE_RETURN_CODE = 0;
  OK = 1;
  ERR_REQUEST = 2;
  ERR_RUNTIME = 3;
}

enum TTillage {
  CONVENTIONAL = 0;
  CONSERVATION_RIDGE = 1;
  NO_TILLAGE = 3;
}

enum TSoilStructure {
  GOOD = 0;
  NORMAL = 1;
  POOR = 2;
  HUMIC_OR_PEATY = 4;
}

message kpiSoilErosionRequest {
  message TSoilInfo {
    float OrganicMatter = 1;
    float ClayFraction = 2;
    float SiltFraction = 3;
    float SandFraction = 4;
    TSoilStructure  SoilStructure = 5;
  }
  message TRainData {
    int32 YearTime = 1;
    float RainMM = 2;
  }
  TKpiType KpiType = 1;
  float LSFactorMap = 2;
  float PFactorMap = 3;
  TCropName CropName = 4;
  TTillage Tillage = 5;
  bool AreResiduesLeft = 6;
  bool IsCoverCropUsed = 7;
  oneof KFactorData {
    float KFactorMap = 8;
    TSoilInfo SoilInfo = 9;
  }
  repeated TRainData RainData = 10;
}

message kpiSoilErosionReply {
  TKpiType KpiType = 1;
  TReturnCode ReturnCode = 2;
  string RunInfo = 3;
  float KpiValue = 4;
}
```

```
enum TCropName {
  FALLOW = 0;
  CORN = 1;
  WINTER_WHEAT = 2;
  SOYBEAN = 3;
  LEGUME_HAY = 4;
  NON_LEGUME_HAY = 5;
  SPRING_WHEAT = 6;
  SUGARCANE = 7;
  BARLEY = 8;
  OATS = 9;
  ALFALFA = 10;
  ANNUAL_GRASS = 11;
  PERENNIAL_GRASS = 12;
  SORGHUM = 13;
  COTTON = 14;
  RYE = 15;
  VEGETABLES = 16;
  PAPAYA = 17;
  POTATO = 18;
  BEET = 19;
  PADDY_RICE = 20;
  BANANA = 21;
  CELERY = 22;
  PEANUT = 23;
  UPLAND_RICE = 24;
  RAPESEEDS = 25;
  TOBACCO = 26;
  MILLET = 27;
  SUNFLOWER = 28;
  BEANS = 29;
  DEEPWATER_RICE = 30;
  ONION = 31;
  PALM = 32;
  STRAWBERRY = 33;
  LETTUCE = 34;
  ARTICHOKE = 35;
  FLOWERS = 36;
  SPROUT = 37;
  BERRIES = 38;
  TRUCK_CROPS = 39;
  FRUIT_TREES = 40;
  CITRUS = 41;
  GRAPE = 42;
  SILAGE_CORN = 43;
  HOPS = 44;
  TOMATO = 45;
  RAINFED_RICE = 46;
  COVER_CROP = 47;
  SAFFLOWER = 48;
  FLAX = 49;
  SEDGE = 50;
  CASSAVA = 51;
  CATTAIL = 52;
  CA_BROCCOLI = 53;
  EVERGREENS = 54;
  CABBAGE = 55;
  GREEN_ONION = 56;
  MUSTARD = 57;
  TULE = 58;
  MOSS = 59;
  RADISH = 60;
  SHRUB = 61;
  BOREAL_SEDGE = 62;
  ALMOND = 63;
```

```
  NUT_TREE = 64;
  MELON = 65;
  PASTURE_HAY = 66;
  SMALL_GRAIN_HAY = 67;
  CARROTS = 68;
  PEPPERS = 69;
  ASPARAGUS = 70;
  CAULIFLOWER = 71;
  ARTICHOKES = 72;
  SWEET_POTATO = 73;
  BEANS_GREEN = 74;
  COT = 75;
  OLIVES = 76;
  PLUMS = 77;
  CHERRIES = 78;
  PEACH = 79;
  PEARS = 80;
  APPLES = 81;
  DATES = 82;
  AVOCADOS = 83;
  APRICOTS = 84;
  FIGS = 85;
  PRUNES = 86;
  LEMONS = 87;
  FPEAS = 88;
  LEY = 89;
  LENTIL = 90;
}

enum TLivestockName {
  DAIRY_CATTLE = 0;
  OTHER_CATTLE = 1;
  MARKET_SWINE = 2;
  BREEDING_SWINE =3;
  POULTRY = 4;
  SHEEP = 5;
  GOATS = 6;
  HORSES = 7;
  CAMELS = 8;
  BUFFALO = 9;
}

enum TCountryName {
  ANDORRA = 0;
  ALBANIA = 1;
  ARMENIA = 2;
  AUSTRALIA = 3;
  AUSTRIA = 4;
  AZERBAIJAN = 5;
  BELARUS = 6;
  BELGIUM = 7;
  BOSNIA_AND_HERZEGOVINA = 8;
  BULGARIA = 9;
  CANADA = 10;
  CROATIA = 11;
  CZECH_REPUBLIC = 12;
  DENMARK = 13;
  ESTONIA = 14;
  FINLAND = 15;
  FRANCE = 16;
  GEORGIA = 17;
  GERMANY = 18;
  GREECE = 19;
  HUNGARY = 20;
  ICELAND = 21;
```

```
    IRELAND = 22;
    ISRAEL = 23;
    ITALY = 24;
    LATVIA = 25;
    LIECHTENSTEIN = 26;
    LITHUANIA = 27;
    LUXEMBOURG = 28;
    MALTA = 29;
    MOLDOVA = 30;
    MONACO = 31;
    MONTENEGRO = 32;
    NETHERLANDS = 33;
    NEWZEALAND = 34;
    NORTH_MACEDONIA = 35;
    NORWAY = 36;
    POLAND = 37;
    PORTUGAL = 38;
    ROMANIA = 39;
    RUSSIA = 40;
    SANMARINO = 41;
    SERBIA = 42;
    SPAIN = 43;
    SWEDEN = 44;
    SWITZERLAND = 45;
    TURKEY = 46;
    UNITED_KINGDOM = 47;
  }
  message kpiNEmissionRequest {
    message TCropInfo {
      TCropName CropName = 1;
      float CropCYield = 2; //Harvested annual dry matter yield for crop, given
as a C yield (default retun from DNDC) [kg C ha-1]
      float CropArea = 3; //Area of a given crop [ha]
      int32 IsAnnual = 4; //0 - parennial crop not rotated, 1 - annual crop, N>1
parennial crop rotated every N years
      float AreaBurntFraction = 5; //The fraction of the CropArea burnt annually
      float AreaRemovedFraction = 6;
    }
    message TLivestockInfo {
      TLivestockName LivestockName = 1;
      int32 LivestockNumber = 2;
    }

    TKpiType KpiType = 1;
    float AnnualNFertAmount = 2; //annual amount of synthetic fertiliser N
applied to soils, [kg N yr-1] (p. 11.7)
    float AnnualNSewageAmount = 3; //annual amount of total sewage N that is
applied to soils, [kg N yr-1] (p. 11.12)
    float AnnualNCompostAmount = 4; // annual amount of total compost N applied
to soils [kg N yr-1] (p. 11.12)
    float AnnualNOtherAmount = 5; //annual amount of other organic amendments
used as fertiliser [kg N yr-1] (p. 11.13)
    repeated TCropInfo CropInfo = 6;
    repeated TLivestockInfo LivestockInfo = 7;
    TCountryName CountryName = 8;
    float FractionOfManagedManureUsedForFeed = 9;
    float FractionOfManagedManureUsedForFuel = 10;
    float FractionOfManagedManureUsedForConstruction = 11;
  }
  message kpiNEmissionReply {
    TKpiType KpiType = 1;
    TReturnCode ReturnCode = 2;
    string RunInfo = 3;
    float KpiValue = 4;
  }
```

4.2 Environmental and climate impact assessment software development

The code was implemented using Python programming language. Some new Python language features were used in the code so at least version 3.10 of the Python interpreter is needed to run the code of the module.

The server-side executable was implemented which provides two endpoints estimating the soil erosion (kpiSoilErosion) and N2O emissions (kpiNEmission). Despite the standard, general-purpose Python modules the code utilizes tho third-party specialized modules: soil texture - for determination of the soil texture class based on the soil's particle size distribution (https://github.com/sagitta1618/soiltexture), factor - for calculation of the R factor in the RUSLE model for erosion estimation (https://pypi.org/project/rfactor).

4.2.1 Docker microservice implementation

The server was implemented as a docker microservice. The Docker container creation configuration file defining essential software runtime dependencies for the biophysical model and the server itself is provided below. The current implementation of the container is based on the Windows 10 OS, although due to the minimal and standard software dependencies this could be also implemented based on the Linux-based container.

Code Block 2: Docker image configuration

```
#
# NOTE: THIS DOCKERFILE IS GENERATED VIA "apply-templates.sh"
#
# PLEASE DO NOT EDIT IT DIRECTLY.
#
# https://hub.docker.com/_/python

FROM mcr.microsoft.com/windows:20H2

SHELL ["powershell", "-Command", "$ErrorActionPreference = 'Stop';
$ProgressPreference = 'SilentlyContinue';"]

# https://github.com/docker-library/python/pull/557
ENV PYTHONIOENCODING UTF-8

ENV PYTHON_VERSION 3.10.5

RUN $url = ('https://www.python.org/ftp/python/{0}/python-{1}-amd64.exe' -f
($env:PYTHON_VERSION -replace '[a-z]+[0-9]*$', ''), $env:PYTHON_VERSION); \
    Write-Host ('Downloading {0} ...' -f $url); \
    [Net.ServicePointManager]::SecurityProtocol =
[Net.SecurityProtocolType]::Tls12; \
    Invoke-WebRequest -Uri $url -OutFile 'python.exe'; \
    \
    Write-Host 'Installing ...'; \
# https://docs.python.org/3/using/windows.html#installing-without-ui
    $exitCode = (Start-Process python.exe -Wait -NoNewWindow -PassThru \
        -ArgumentList @( \
            '/quiet', \
            'InstallAllUsers=1', \
            'TargetDir=C:\Python', \
            'PrependPath=1', \
            'Shortcuts=0', \
            'Include_doc=0', \
            'Include_pip=0', \
            'Include_test=0' \
        ) \
    ).ExitCode; \
    if ($exitCode -ne 0) { \
        Write-Host ('Running python installer failed with exit code: {0}' -f
$exitCode); \
        Get-ChildItem $env:TEMP | Sort-Object -Descending -Property
LastWriteTime | Select-Object -First 1 | Get-Content; \
        exit $exitCode; \
    } \
    \
# the installer updated PATH, so we should refresh our local value
    $env:PATH = [Environment]::GetEnvironmentVariable('PATH',
[EnvironmentVariableTarget]::Machine); \
    \
    Write-Host 'Verifying install ...'; \
    Write-Host '  python --version'; python --version; \
    \
    Write-Host 'Removing ...'; \
    Remove-Item python.exe -Force; \
    Remove-Item $env:TEMP/Python*.log -Force; \
    \
    Write-Host 'Complete.'

# if this is called "PIP_VERSION", pip explodes with "ValueError: invalid truth
value '<VERSION>'"
ENV PYTHON_PIP_VERSION 22.0.4
# https://github.com/docker-library/python/issues/365
ENV PYTHON_SETUPTOOLS_VERSION 58.1.0
# https://github.com/pypa/get-pip
```

```
ENV PYTHON_GET_PIP_URL https://github.com/pypa/get-
pip/raw/6ce3639da143c5d79b44f94b04080abf2531fd6e/public/get-pip.py
ENV PYTHON_GET_PIP_SHA256
ba3ab8267d91fd41c58dbce08f76db99f747f716d85ce1865813842bb035524d

RUN Write-Host ('Downloading get-pip.py ({0}) ...' -f $env:PYTHON_GET_PIP_URL);
\
    [Net.ServicePointManager]::SecurityProtocol =
[Net.SecurityProtocolType]::Tls12; \
    Invoke-WebRequest -Uri $env:PYTHON_GET_PIP_URL -OutFile 'get-pip.py'; \
    Write-Host ('Verifying sha256 ({0}) ...' -f $env:PYTHON_GET_PIP_SHA256); \
    if ((Get-FileHash 'get-pip.py' -Algorithm sha256).Hash -ne
$env:PYTHON_GET_PIP_SHA256) { \
        Write-Host 'FAILED!'; \
        exit 1; \
    }; \
    \
    $env:PYTHONDONTWRITEBYTECODE = '1'; \
    \
    Write-Host ('Installing pip=={0} ...' -f $env:PYTHON_PIP_VERSION); \
    python get-pip.py \
        --disable-pip-version-check \
        --no-cache-dir \
        --no-compile \
        ('pip=={0}' -f $env:PYTHON_PIP_VERSION) \
        ('setuptools=={0}' -f $env:PYTHON_SETUPTOOLS_VERSION) \
    ; \
    Remove-Item get-pip.py -Force; \
    \
    Write-Host 'Verifying pip install ...'; \
    pip --version; \
    \
    Write-Host 'Complete.'

RUN pip install grpcio
RUN pip install protobuf
RUN pip install pandas
RUN pip install openpyxl
RUN pip install soiltexture
RUN pip install rfactor

EXPOSE 50051

COPY ./lib c:/server/lib
COPY ./lib_kpi_srv c:/server/lib_kpi_srv
COPY *.py c:/server/
CMD ["python.exe","c:/server/kpi_server.py"]
```

4.3 Functionality tests

The exploratory functional tests were performed for different scenarios in a non-automated manner using the client python-based (kpi_client.py) implementation forming the gRPC request to the different endpoints based on the request data stored in the form of the JSON files.

5 Conclusions

This deliverable presents the theoretical definition and implementation of the environmental and climate impact assessment module. The former basically consists of the selection and definition of KPIs to be calculated with this module. To this end, 54 KPIs have been selected based on their relevance for the project use cases and their compliance with the SMART criteria (specific, measurable, attainable, relevant, and time-bound). The calculation of these KPIs is based on the set of 28 agri-environmental indicators identified in the EU Commission Communication COM (2006) and those provided by three integrated IA tools (SEAMLESS-IF, SIAT, and MEA-Scope). The selected KPIs have been characterised and grouped into 6 clusters: land conversion and habitat loss, wasteful water consumption, soil erosion and degradation, pollution, climate change and biodiversity. Each KPI characterisation has an identification, name, dimension, definition, method, formula, unit of measure and frequency of recording.

The software implementation of the module has been developed and tested for the calculation of two KPIs (soil erosion and N20 emissions). The software development in charge of the KPIs calculation is implemented using Python, and, for the two tested KPIs, two third-party specialised modules have been used: *soil texture* and *rfactor.* This application has been dockerised for Windows 10 OS. Furthermore, this implementation needs data provided by external databases and other modules of the AGRICORE tool. To this end, an API has been implemented with the third version of the Protocol Buffers language specification. This is in charge of the communication between the IAM and other modules, providing the data required for the KPI calculations and returning the calculated values. The next step would be to extend the developed application to the rest of the KPIs.

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For preparing this report, the following deliverables have been taken into consideration:

Deliverable Number	Deliverable Title	Lead beneficiary	Type	Dissemination Level	Due date
D5.1	State of the art review of agricultural policy assessment models, tools and indicators	UNIPR	Report	Public	M12
D4.3	Validated design for the AGRICORE interface	AAT	Report	Public	M27
D1.9	Agricultural Research Data Index Tool (ARDIT)	UNIPR	Other	Public	M31
D6.2	External Interface Module	IDE	Report	Public	M31
D5.2	AGRICORE Land Market Module	AKD	Report	Public	M34
D5.3	AGRICORE Market Module	AKD	Report	Public	M34
D6.3	Biophysical model connection modules	IAPAS	Report	Public	M34