D5.1 State of the Art Review of Agricultural Policy Assessment Models, Tools and Indicators

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Executive Summary

Deliverable 5.1 presents a review of the extant theoretical and empirical literature on the issues associated with the development of the six modules, namely policy impact assessment, socio-economic impacts of agriculture and its integration in rural society, environmental and climatic impacts of agriculture, ecosystem services, agricultural output and input markets and their linkages, and agricultural land markets modules, which will be developed in Task 5.2 to 5.7 of the AGRICORE Project. The domains of analysis of these modules account for the many external factors which affect a farmer's decision-making process and which enrich the results of agricultural policy assessment by means of a farm-level Agent-Based Model like the one to be developed in the AGIRCORE Project.

The review of this ample extant literature has highlighted the increased reliance on both farm-level (or highly disaggregated) data and models which allow for a more granular representation of farmers' behavior in response also to very targeted policy measures, such as those of Pillar II of the Common Agricultural Policy. The review has provided the AGRICORE partners involved in the development of the six modules interacting with the ABM model (WP3) with the information from the previous modeling efforts which will allow for exploring which gaps can be filled by an ambitious, yet realistic, endeavor. To reach the goal of functioning modules and suite, modelers will have to prioritize the avenues for development, while being conscious of the technical capability of the infrastructure the AGRICORE suite will run on.

Abbreviations

Abbreviation	Full name
ABM(s)	Agent-Based Model(s)
AEM	Agri-Environmental Measures
AEI	Agro-Ecological Indicators
AES	Agri-Environmental Schemes
AESA	Agro-Ecological System Attributes
AgCFSR	Agricultural Climate Forecast System Reanalysis
AGMEMOD	Agricultural Member State Modelling
AgMERRA	Agricultural Modern-Era Retrospective analysis for Research and Applications
AHP	Analytic Hierarchy Process
AR5-RCP	IPCC Fifth Assessment Report (AR5) - Representative Concentration Pathways (RCP) scenarios
ARIES	Artificial Intelligence for Ecosystem Services
AWU	Annual Work Unit
BDC	Biodiversity Data Centre
BIOMA	Biophysical Model Applications
BISE	Biodiversity Information System for Europe
BN	Bayesian Networks
BR	Better Regulation
C	Carbon
CA	Counterfactual Analysis
$CaCO_3$	Calcium Carbonates
CAP	Common Agricultural Policy
CAPRI	Common Agricultural Policy Regional Impact
CAPRI-FT	Common Agricultural Policy Regionalised Impact System-Farm Type
CAPSIM	Common Agricultural Policy SIMulation
CBA	Cost-Benefit Analysis
CBR	Case-Based Reasoning
CEA	Cost-Effectiveness Analysis
CEC	Cation Exchange Capacity
CENTURY	Soil Organic Matter Model
CFSR	Climate Forecast System Reanalysis
CGIAR	Consultative Group for International Agricultural Research
CH_4	Methane
CICES	Common International Classification of Ecosystem Services
CIRES	Cooperative Institute For Research In Environmental Sciences
CLC	CORINE Land Cover
CMEF	Common Monitoring and Evaluation Framework
CO_2	Carbon Dioxide
CORINE	Coordination of Information on the Environment
CP	Conditional Probabilities
DDM	Data-Driven Modeling
DEA	Data Envelopment Analysis
DG AGRI	Directorate-General for Agriculture and Rural Development
DG ENV	Directorate-General for Environment
DG SANTE	Directorate-General for Health and Food Safety

DireDate	Direct and Indirect Data Needs Linked to Farms for Agri-Environmental Indicators
DOE	U.S. Department of Energy
DP	Direct Payments
DPSIR	Driving Force-Pressure-State-Impact-Response Model
EC	European Commission
ECA&D	European Climate Assessment & Dataset
ECMWF	European Centre for Medium-Range Weather Forecasts
EEA	European Environment Agency
EFA	Ecological Focus Area
EIA	Environmental Impact Assessment
EIP	European Innovation Partnership
ELECTRE	ELimination Et Choix Traduisant la REalité
ELISA	Environmental Indicators for Sustainable Agriculture
EMA	Environmental Management for Agriculture
EMDS	Ecosystem Management Decision Support
EMODnet	European Marine Observation and Data Network
EMP	Econometric Mathematical Programming
EP	Ecopoints
EPA	United States Environmental Protection Agency
EPIC	Environmental Policy Integrated Climate
ERM	Environmental Risk Mapping
ES	Ecosystem Services
ESDAC	European Soil Data Centre
ESDB	European Soil Database
ESII	Ecosystem Services Identification and Inventory
ESIM	European Simulation Model
ESR	Ecosystem Services Review for Impact Assessment
ESV	Ecosystem Services Valuation
EU	European Union
EUMETNET	European National Meteorological Services
EUMON	EU-wide monitoring methods and systems of surveillance for species and habitats of Community interest
FADN	Farm Accountancy Data Network
FAO	Food and Agriculture Organization
FAPRI	Food and Agricultural Research Institute
FBI	Farmland Birds Index
FBP	Frenchman Bay Partners
FFI	Family Farm Income
FIA	Forest Inventory and Analysis
FNI	Farm Net Income
FNVA	Farm Net Value Added
FSI	Farmer Sustainability Index
FSS	Farm Structure Survey
FSSIM	Farm System Simulator
G8+5	International group that consisted of the leaders of the heads of government from the G8 nations (Canada, France, Germany, Italy, Japan, the United Kingdom, the United States, and Russia), plus the heads of government of the five leading emerging economies (Brazil, China, India, Mexico, and South Africa)

GBIF	Global Biodiversity Information Facility
GCM	General Circulation Model
GDP	Gross Domestic Product
GE	General Equilibrium
GEASS	Global Earth Observation System of Systems
GEO BON	Group on Earth Observations Biodiversity Observation Network
GEOSS	Global Earth Observation System of Systems
GHG	Greenhouse Gas
GIS	Geographic Information System
GMES	Global Monitoring for Environment and Security
GMM	Generalized Method of Moments
GORCAM	Graz-Oak Ridge Carbon Accounting Model
GP	Goal Programming
GREET	Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model
GTAP	Global Trade Analysis Project
GWP	Global Warming Potential
ha	Hectares
HLU	Human Labor Unit
IA	Impact Assessment
IAM	Integrated Assessment and Modelling
ICBM	Introductory Carbon Balance Model
IFS	Indicators of Farm Sustainability
IMAGE	Integrated Model to Assess the Global Environment
IO	Input-Output
IPCC	Intergovernmental Panel on Climate Change
IRENA	Indicator Reporting on the Integration of Environmental Concerns into Agricultural Policy
IT	Information Technology
JMA	Japan Meteorological Agency
JRA-25	Japanese 25-Year Reanalysis
JRC	Joint Research Centre
K	Potassium
KPI	Key Performance Indicator
LAG	Local Action Group
LCA	Life Cycle Analysis
LCAA	LCA for Agriculture
LCAE	LCA for Environmental Farm Management
LCIA	Life Cycle Impact Assessment
LCI	Life Cycle Inventory
LFA	Less Favoured Areas
LP	Linear Programming
LU	Livestock Units
LUCAS	Land Use and Land Cover Survey
LULC	Land Use/Land Cover
MAS	Multi-Agent System
MAUT	Multi-Attribute Utility Theory
MCA	Multi-Criteria Analysis
MEA	Millennium Ecosystem Assessment

MERRA	Modern-Era Retrospective Analysis for Research and Applications
MESALES	Soil Erosion Risk Assessment in Europe Model
MFNVA	Modified Farm Net Value Added
MIDAS	Marine Integrated Decision Analysis System
MIMES	Multi-scale Integrated Models of Ecosystem Services
MIP	Mixed Integer Programming
MLP	Multiple Linear Programming
MMA(s)	Marine Managed Area(s)
MOP	Multi-Objective Parameters
MP	Mathematical Programming
MS(s)	Member State(s)
MUSLE	Modified Universal Soil Loss Equation
N	Nitrogen
NH_3	Ammonia
N_2O	Nitrous Oxide
NARR	North American Regional Reanalysis
NASA	National Aeronautics and Space Administration
NCAR	National Center for Atmospheric Research
NCEP	National Centers for Environmental Prediction
NLP	Non-Linear Programming
NOAA	National Oceanic and Atmospheric Administration
NRN	National Rural Networks
NUTS	Nomenclature of Territorial Units for Statistics
OC	Organic Carbon
OECD	Organization for Economic Co-operation and Development
OS	Operationalizing Sustainability
P	Phosphorous
PCA	Principal Component Analysis
PDO	Protected Designations of Origin
PE	Partial Equilibrium
PES	Payment for Ecosystem Services
PGI	Protected Geographical Indication
PI	Profitability Index
PM	Particulate Matter
PMP	Positive Mathematical Programming
PROMETHEE	Preference Ranking Organization METHod for Enrichment Evaluation
RDP(s)	Rural Development Programme(s)
RNI	Reference Net Income
RothC	Rothamsted Carbon Model
RUSLE	Revised Universal Soil Loss Equation
SAC(s)	Special Area(s) of Conservation
SAPM	Survey on Agricultural Production Methods
SAW	Simple Additive Weighting
SCI(s)	Site(s) of Community Importance
SD	Sustainable Development
SDF	Standard Data Form
SEAMLESS-IF	SEAMLESS - Integrated Framework

SEC	Sustainability of Energy Crops
SIAT	Sustainability Impact Assessment Tool
SMART	Simple Multi-Attribute Rating Technique
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SPA(s)	Special Protection Area(s)
SPADE	Soil Profile Analytical Database for Europe
SPS	Single Payment Scheme
SRES	Special Report on Emission Scenarios
STICS	Simulateur mulTIdisciplinaire pour les Cultures Standard
SWAT	Soil & Water Assessment Tool
TEEB	Economics of Ecosystems and Biodiversity’
TESSA	Toolkit for Ecosystem Services Site Based Assessment
TM/ETM	Thematic Mapper/Enhanced Thematic Mapper
TOPSIS	Technique for Order of Preference by Similarity to Ideal Solution
TSG	Traditional Specialty Guaranteed
UAA	Utilized Agricultural Area
UK	United Kingdom
UNEP-WCMC	UN Environment Programme World Conservation Monitoring Centre
USA	United States of America
USGS	United States Geological Survey
USLE	Universal Soil Loss Equation
WFM	World Food Model
YFP	Young Farmer Problem

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1 Introduction

Deliverable 5.1 presents a review of the extant theoretical and empirical literature on the issues associated with the development of the six modules, namely policy impact assessment, socio-economic impacts of agriculture and its integration in rural society, environmental and climatic impacts of agriculture, ecosystem services, agricultural output and input markets and their linkages, and agricultural land markets modules, which will be developed in Task 5.2 to 5.7 of the AGRICORE Project. These Tasks will extend the core Agent-Based Model (ABM), prepared in WP3, to account for the many external factors which affect a farmer's decision-making process and give rise, together with the synthetic population model, set-up in WP2, and the necessary user-interfaces (WP4) to the AGIRCORE suite (WP6).

The latter will be then demonstrated in the three use cases foreseen in the project mainly to assess the effects of selected Common Agricultural Policy (CAP) measures. Moreover, policy assessment will be undertaken taking into account the relationships of the individual agent (i. e., the farmer) with the environment in terms of the constraints the latter places on the former due to - for instance - the erratic and also possibly extreme rainfall brought about by climate change. However, because agriculture is recognized as the source of a sizeable share of greenhouse gas emissions and other types of pollution, it cannot be overlooked that also the agriculture has to reduce its impact on the environment, both because of farmers' individual interest in limiting their footprint and because of a response to policy reforms and incentives. While (industrial) agriculture has been recently considered to have significant negative effects on several ecosystems, the reforms aimed at - for instance - increasing the utilize agricultural area cultivated and the output produced following the organic method can help to make agriculture part of the solution towards climate change mitigating, ecosystem maintenance and restoration. Because ABMs rely on modeling the relationships among (different) agents which originate also in the "markets", it is necessary to understand what are the most relevant issues in the agricultural input and output markets, and how they have been modeled in the recent literature. In particular, since the agricultural land market conditions and evolution are so relevant for investigating both static (i. e., farm income generation and distribution within as well as outside the agricultural sector) and dynamic issues (i. e., land-use change), it is the subject of dedicated analysis.

What follows provides in-depth reviews of the literature related to the issues which could be modeled upon developing the modules fulfilling the requirements of Tasks 5.2 to 5.7 of the AGRICORE Project. The partners involved in Task 5.1, which will also be completing Tasks 5.2 to 5.7, have tried to structure their reviews in a homogeneous manner, focusing each section of the Deliverable on the data and methods already employed to perform the type of analysis foreseen in each task. However, because the areas of analysis may be significantly different, exceptions to a general structure are allowed.

2 Policy Impact Assessment

2.1 Policy impact assessment: the origin and scope

Policy impact assessment (IA) has spread rapidly around the world in the last two decades [1] providing further innovation and understanding in the way in which assessment is conceived, practiced, and researched. The origin of policy IA can be traced back to the United States of America (USA), which is often reported as one of the early adopters of policy IA, and is still sometimes considered at the forefront of international practice [2]. In the early 1990s, only a few countries belonging to the Organisation for Economic Co-operation and Development (OECD) were using policy IA. Following an OECD recommendation on regulatory reform [3], there was a rapid rise in the adoption of policy IA in the OECD and European countries in the second half of the 1990s. In Europe and other OECD countries, policy IA is commonly reported to be driven by three specific global trends. Firstly, the need for a more strategic approach to evaluation arose from the apparent inability of existing assessment schemes to deal with "big issues" at the project level [4]. However, the second trend, which is connected with delivering "better regulation" in the political agenda, has arguably been the main driving force behind the diffusion of policy IA in the OECD countries [5],[6],[7]. "Better regulation" refers to the notion of attempting to rationalize and simplify both existing and new legislation [6]. Finally, policy IA also arose out of calls for the integration of environmental objectives or, more broadly, sustainability objectives into policy-making [8]. Policy IA has the potential to contribute to solving complex cross-cutting issues, such as sustainable development (SD), because it requires policy-makers to consider them at the initial stages of the decision-making process [9],[10].

Policy IA seeks to inform decision-makers by predicting and evaluating the potential impacts of policy options [3]. Specifically, policy IA is a regulation process that prepares evidence for decision-makers on the advantages and disadvantages of possible policy options by assessing their potential impacts, and it can be considered a prerequisite in policy development to address the challenges related to SD in a globalized world. The scope of policy IA includes ex-ante and ex-post IA. The former, which is conducted before the policy measure(s) being discussed is (are) agreed and implemented, informs decision-makers about its (their) possible effects. The latter, which is conducted once the measure(s) is (are) applied, provides decision-makers with evidence of the actual outcomes of the policy(ies) implemented[11]. Evaluating public policies before their approval (ex-ante policy IA) is a significant step in policy design. Usually, it consists of the assessment of the likely impacts of the new policy measures proposed with the final aim of maximizing the benefits to society and avoiding undesirable outcomes. Policy IA aims to, among others, support SD by assessing the likely intended and unintended economic, social, and environmental impacts of policy options and to encourage evidence-based policy-making systematically. The results of policy IA enable policy-makers to make better-informed decisions [12]. IA is now compulsory for any reform of the most important EU policies, including the Common Agricultural Policy (CAP), one of the oldest policies common to the EU.

Nowadays, advances in the policy and science domains are, to some extent, occurring in parallel [13]. At the policy level, agricultural and environmental challenges (e.g., climate change, environmental degradation, biodiversity loss, rural population decline) have resulted in strategic responses centered around the concepts and practices of climate-smart agriculture, bio-based and circular economy, resource efficiency, and socially acceptable farming [12]. At the scientific level, research has made numerous efforts to respond to these challenges by developing models and tools capable of analyzing the economic, environmental, and social dimensions of SD [14],[15]. There is a wide variety of models and tools used for IA studies, employing both qualitative and quantitative methods and concerning the whole national (European) economy(ies) and/or selected sector(s) thereof. The peculiar characteristics of the agricultural industry and its complex interactions with the economy, society, and the environment call for specific modeling approaches [16].

Over the last few decades, there has been an increasing concern about the relationships between agriculture and the environment. Since the 1990s, the CAP has introduced agri-environmental measures to prevent the occurrence of the negative, and promote that of the positive, environmental externalities of agricultural activities. Compared with more aggregated approaches, farm-level modeling presents clear advantages for depicting the complex interactions between agriculture and the environment. Furthermore, the joint ex-ante assessment of the economic and environmental effects of agricultural policies offers clear benefits because it helps to better target policies towards their intended outcomes. Not only are farmers' responses assessed, but the environmental consequences of farmers' reactions are also accounted for. Compared with more aggregated models, farm-level models are better suited to simulate the interaction of policy incentives, farmer responses, and environmental outcomes.

A common approach to assess the environmental impacts of agricultural policies is to monitor environmental indicators. Several sets of environmental indicators have been developed internationally. The set of environmental indicators proposed by the OECD has been developed and refined continuously since the 1990s, and the modeling of these serves as a basis for informed green growth policies. The European Commission (EC) also produces a set of agri-environmental indicators to monitor the integration of environmental concerns into agricultural policy. The inclusion of environmental aspects into farm-level modeling is straightforward when we assume a direct link between farm inputs/outputs and some environmental indicators. Based on technical coefficients, the nutrient, energy, or carbon balances can be calculated for each activity. Many studies have analyzed the impacts of agri-environmental policy measures by translating model outputs into changes in environmental indicators [17], [18]. However, due to the complexity of the interactions between farming practices and the environment, even highly disaggregated models may fail to capture some environmental effects. For instance, establishing the relationship between nitrate percolation and groundwater quality, or analyzing the impacts of land-use changes on biodiversity and the landscape are challenging tasks. Also, data availability and accuracy are often significant limitations for depicting the relationship between agricultural activities and the environment. A more sophisticated way to account for the interactions between agriculture and the environment is the bioeconomic approach, which combines biophysical and economic models [19],[20]. Belhouchette et al. (2011) [21] linked the Farm System Simulator (FSSIM) model [22] to crop growth models to assess environmental externalities. Jayet and Petsakos (2013) [23] coupled the economic models AROPAj with the crop growth model Simulateur mulTIdisciplinaire pour les Cultures Standard (STICS) (which enables the derivation of nitrogen-yield response functions) to assess the effects of nitrogen taxes in France under different agricultural policy scenarios. Schonhart et al. (2011) [24] coupled the bioeconomic farm optimization model FAMOS, the crop rotation model Crop-Rota and the biophysical process model Environmental Policy Integrated Climate (EPIC) to assess the cost-effectiveness of agri-environmental measures in a set of farms, belonging to diverse types, in Austria. Because of biophysical models operate at a high spatial resolution and are data-intensive, increasing the regional coverage of bioeconomic models without loss in accuracy is very challenging [16].

Notwithstanding, the assessment of agri-environmental impacts has experienced significant advances with the development of bioeconomic models, the design of interlinked multi-disciplinary modeling tools, and the variety of environmental effects considered.

Because decoupled direct payments (DP) encourage more extensive agriculture, they may improve the soil and water conditions. However, the effects on biodiversity are less clear. An agent-based approach was applied to analyze the impacts of decoupling on land-use and biodiversity in a set of EU regions [25]. They found that DP may result in further homogenization of land-use and loss of biodiversity. Furthermore, to assess biodiversity Bamiere et al. (2011) [26] used a spatially explicit Mathematical Programming (MP) farm-based model which accounts for three spatial levels (field, farm, and landscape) to show that valuable insights into agri-environmental program design could be gained through a detailed representation of the farming management system.

Models, therefore, that integrate the multiple dimensions constitute crucial tools for assessing current EU policies. In recent years, there has been a significant development in the bioeconomic approaches, not only to address the multiplicity of objectives in new agricultural policies but also to assess the impacts of climate change in agriculture. Actually, the integration of biophysical and economic models is the most widely used approach to evaluate the complex interrelations between climate change, agricultural production, and the sustainability of natural resources [27].

While farm-models can capture interactions between agriculture and the environment at a disaggregated level, these models focus on supply responses and do not take into account market interactions. Specifically, input and output prices are exogenous in this type of model, such that price effects are not accounted for at least endogenously. On the contrary, partial equilibrium agro-economic models, which have been standard tools for policy IA to date, are well suited to represent not only the production, but also the demand for and trade, of agricultural and food products, but they fail to capture the effects of farm-specific policy measures. In the current context of increased globalization, the lack of market feedback is one of the main limitations of farm-level modeling. This limitation can be overcome by linking farm models to partial equilibrium tools. Applications of multi-scale approaches in IA include the AGRISIMU modelling framework [28], which integrates a farm level optimization model, a regional sector model, and biophysical models, to assess alternative policy options in Finland. The FARMIS model has also been linked to the market model European Simulation Model (ESIM) to measure the impacts of liberalizing European agriculture on farm income distribution in Western Germany [29]. In most cases, the link to markets is done through a soft-linked approach in which the outcomes from the market model are used as inputs in the farm-model. The Common Agricultural Policy Regionalised Impact System-Farm Type (CAPRI-FT) model is a unique case because, in this approach, farm-level models and a global market model are fully integrated and solved iteratively [30]. The distinctive feature of CAPRI-FT is that it enables the assessment of farm-level impacts while covering the whole EU and taking into account market feedback.

2.2 Methodologies used for policy IA

Over the last 30 years, there has been an increasing propensity at different levels of government around the world to embrace and implement principles of Better Regulation (BR). BR, as conceived in the context of the EU, refers to the basis for timely and sound policy decision-making, taking into account the views of citizens and stakeholders who are most affected daily, to make changes, simplify or even repeal laws in response to this feedback. The BR Agenda, which was introduced in 2015, represents the main regulatory framework for the current EU policy [31]. The BR Agenda is recognized as a step forward towards a sound use of evidence for all policymaking activities [32],[33], [34] and constitutes a "cultural change" within the EC [35]. The BR Agenda attempts to consider both qualitative and quantitative approaches to policy IA and evaluation, and tries also to contemplate various regulatory quality-enhancing aspects (e.g., legal validity), as well as different types of impacts (such as competitiveness). The BR Toolbox is welcomed as one comprehensive set of templates to provide extensive practical guidance, In general, the Toolbox provides guidance, tips, and collects best practices in IA. Researchers tasked with performing the IA of a(n) (EU) policy measure employing the EC BR Toolbox are not expected to employ each tool therein, but to use the best tool for the job and apply common sense when making this choice. However, some aspects of the Toolbox must be implemented because they are linked to the requirements of the BR Guidelines, the EC's working methods or political commitments. The introduction part of each chapter of the BR Toolbox describes these mandatory elements. This section provides a general description of the diverse methodological and modeling approaches used in IA because of being part of the EC BR Toolbox.

2.2.1 Cost-Benefit Analysis

Cost-Benefit Analysis (CBA) can be a powerful tool for policy design and decision-making. CBA is grounded in welfare economics, and its application to the evaluation of whether new transport, water, and energy infrastructural projects should be undertaken is firmly established. More recently, CBA has also been successfully applied to the evaluation of environmental, educational, and cultural investment decisions[36].

CBA is mostly used during the appraisal stage of a new policy intervention, and it mainly focuses on selecting the option that exhibits the highest net benefit. Accordingly, the most common methodology employed in CBA is the calculation of "net benefits", which differs from the "benefit/cost ratio" that is typically used in cost-effectiveness analysis. However, the most crucial difference between performing a CBA calculating "net benefits" and the "benefit/cost ratio" is the amount of data required by each methodology. The latter requires less data for its calculation. The main advantage of CBA is the possibility of using an objective unit of measurement (monetized values) to compare alternative options and to choose the one that maximizes the benefits (e.g., the societal welfare). One of the main disadvantages of CBA is that it overlooks any distributional effects (e.g., how cost and benefits are ultimately distributed in the economy). More precisely, CBA does not take into account whether those individuals that benefit from a policy have higher or lower incomes, or higher or lower levels of welfare-relevant attributes (e.g., health) than those who are disadvantaged by the implementation of the policy. Furthermore, CBA lacks objectivity when choosing specific parameters (e.g., the intertemporal discount rate), which can favor specific policy options over others. (Tool 57. Analytical methods to compare options or assess performance).

In ex-post IAs, CBA can help determine the overall impact of an intervention and whether it has been worth undertaking it. It also provides evidence on the validity and appropriateness of the assumptions and projections used in the ex-ante IA for the examined intervention, such that it can be used to demonstrate the added value of a wide range of intervention types. A significant advantage of using CBA in ex-post evaluations lies in ensuring that the costs and benefits of an intervention are considered systematically and explicitly. However, it is more difficult to apply in cases where the evaluations concern non-monetary impacts such as environmental, social, and health effects. The main reason is that assigning a monetary value to non-monetary costs and benefits can sometimes be difficult and may rely on several assumptions, which can differ according to the views of the researcher undertaking the CBA. Therefore, intangible values or outcomes may be under/overestimated or even overlooked. Accordingly, multi-criteria analysis tends to be used more frequently (Tool 57. Analytical methods to compare options or assess performance).

2.2.2 Multi-Criteria Analysis

Multi-Criteria Analysis (MCA) is employed to assess and rank alternative options in IA, or to establish the extent to which a variety of objectives have been met in an ex-post evaluation or fitness check. Ex-post evaluation gathers evidence to assess the outcome of a specific intervention taking account of earlier predictions made in the context of an IA and whether there were unexpected effects that were not anticipated by the IA or the legislation agreed by the policy-maker. An ex-post evaluation also concludes whether the EU intervention continues to be justified or should be modified to improve its effectiveness or should be repealed. A fitness check is a comprehensive evaluation of a policy area that usually addresses how several related legislative acts have contributed (or not) to the attainment of policy objectives. Fitness checks are particularly well-suited to identify overlaps, inconsistencies, synergies, and the cumulative impacts of the regulation (BR guidelines). MCA is particularly useful in case of complex interventions with diverse impacts being quantified and measured in different units and/or when qualitative effects are considered (in particular factors which cannot be expressed in monetary terms). Also, MCA is particularly useful when IA has to be reconciled with specific policy objectives and, as such, it is used as an instrument for ensuring the simultaneous assessment of the effectiveness (which policy option maximizes the positive impacts and achieves the desired outcomes across multiple impact categories and best contributes to broader goals such as the Sustainable Development Goals), efficiency (which policy option generates the most positive impacts for a given level of resources), and coherence (which policy option is most likely to avoid negative impacts, limit trade-offs and achieve net benefits across the various impact categories that are relevant to policy objectives) of policies. This method allows capturing distributional impacts (e.g., in terms of stakeholder types, (EU) regions/countries or time) and trade-offs among dimensions (e.g., economic, social, or environmental impacts; among some groups of criteria) (Tool 57. Analytical methods to compare options or assess performance). The major shortcoming of MCA arises when many policy options need comparing and the enumeration of all possible rankings becomes computationally intractable. In such cases, more sophisticated techniques are required to identify the optimal ranking or, if that is not possible, provide its best approximation. An additional practical shortcoming of MCA is that it may, at times, lead to inconclusive policy rankings, as nothing precludes the existence of multiple optimal options. Finally, MCA underperforms when it is required to make inter-temporal comparisons because it does not foresee any analytical technique, like discounting, to compare impacts (benefits and costs) occurring in different years.

MCA is mainly organized into the following phases [37]:

- Phase 1. Definition of the projects or actions to be evaluated.
- Phase 2. Definition of the evaluation criteria.
- Phase 3. Analysis of the impacts of the actions.
- Phase 4. Evaluation of the effects of the actions in terms of each of the selected criteria.
- Phase 5. Aggregation of evaluations.

MCA has been primarily used in industrial, corporate, and medical settings. Examples include engineering design, quality assurance, production, strategic and medical planning, transportation, and proposal analysis. While it is a well-established methodology employed by private agents in their decision-making process, more recently, MCA has been adopted to aid decision of public institutions to tackle environmental and natural resources problems in areas such as forestry, water resources, urban and transportation planning, energy policy and planning, pollution, ecosystem restoration, and in the siting of nuclear or thermal power plants, and industrial services [38].

2.2.2.1 Multi-criteria methods

In real life, it is not easy to find a decision-making problem with only one goal. Multi-criteria techniques are appropriate when there are several goals and there is a trade-off between them[39]. Velaskez et al. (2013) [40] reviewed the literature to identify the most popular MCA approaches used in decision analysis. According to their findings, the most popular MCA methods include: 1) the Multi-Attribute Utility Theory (MAUT), 2) the Analytic Hierarchy Process (AHP), 3) the Fuzzy Set Theory, 4) the Case-Based Reasoning (CBR), 5) the Data Envelopment Analysis (DEA), 6) the Simple Multi-Attribute Rating Technique (SMART), 7) the Goal Programming (GP), 8) the ELimination Et Choix Traduisant la REalité (ELECTRE), 9) the Preference Ranking Organization METHod for Enrichment Evaluation outranking procedures (PROMETHEE), 10) the Simple Additive Weighting (SAW), and 11) the Technique for Order of Preference by Similarity to

Ideal Solution (TOPSIS). Next, a brief description of the advantages and disadvantages of each method will be presented.

- **MAUT:** the overall evaluation of an alternative is defined as a weighted sum of its values with respect to its relevant value dimensions (called attributes). This technique requires the decision-maker to evaluate the alternatives on each attribute separately. Next, the decision-maker assigns relative weights to the various attributes that express the trade-off among them. Values and weights are then combined and aggregated through a formal model that generates an overall evaluation of each alternative. Finally, sensitivity analyses are carried out to evaluate the stability of the results, and recommendations are proposed [41]. Although MAUT is considered a rather complicated method, it is mainly used to help decision-makers to gain further knowledge and understanding of the problem. MAUT has been used to evaluate economic, financial, actuarial, water and energy, as well as agricultural problems [40].
- **AHP:** it is a theory of measurement through pairwise comparisons and relies on the judgment of experts to derive priority scales. It is one of the most popular methods of MCA and has many advantages, as well as disadvantages. One of its advantages is the ease of use. Pairwise comparisons can allow decision-makers to weigh coefficients and compare alternatives easily. It is scalable, and it can analyze large decision-making problems thanks to its hierarchical structure. Although it requires enough data to perform pairwise comparisons properly, it is not as data-intensive as MAUT. The method has suffered from problems of interdependence between criteria and alternatives. Due to the approach of pairwise comparisons, it can also be subject to inconsistencies in the evaluation and ranking criteria. Furthermore, it does not allow decision-makers to grade one instrument in isolation, but only in comparison with the rest. One of its biggest criticisms is that the general form of AHP is susceptible to rank reversal. Because comparisons are based on rankings, adding an alternative at the end of the process could cause the final rankings to reverse. AHP has been used in performance-type, resource management, corporate policy and strategy, public policy, political strategy, and planning problems [40].
- **Fuzzy Set Theory:** Fuzzy set theory is an extension of classical set theory that allows solving many problems connected to the imprecise and uncertain nature of data. The main advantages of fuzzy logic relate to its capability of utilizing, manipulating, and interpreting data and information that are vague and lack certainty. However, fuzzy MCA models tend to be challenging to develop. In many cases, they require numerous simulations before being used in the real world. Fuzzy set theory has been employed in applications such as engineering, economic, environmental, social, medical, and management [40].
- **CRB:** it is an MCA method that retrieves cases similar to the problem in hand from an existing database and, based on these, proposes a solution. This provides the first of its advantages since it requires little effort to acquire the necessary data. Also, it constitutes an MCA method that can be improved over time, especially as more cases are added to the database. Its major drawback is its sensitivity to inconsistent data, as previously examined cases could be invalid. Sometimes similar cases may not always be the most accurate source of information for solving the problem in hand. CBR is used in industries where a substantial number of previous cases already exists [40].
- **DEA:** it uses a linear programming (LP) technique to measure the relative efficiency of a set of alternatives. The most efficient alternative receives a rating of 1.0, while all the other alternatives are rated a fraction of 1.0. The main advantage of this method is its ability to handle multiple inputs and outputs, as well as the fact that efficiency can be analyzed and quantified. Furthermore, it can uncover relationships that may remain hidden using other methods. An important disadvantage of this technique is that does not deal with imprecise data and assumes that all input and output data are exactly known. In real world situations,

however, this assumption may not always be true. The results can be sensitive depending on the inputs and outputs. DEA is commonly used in economic, medical, agricultural, retail, and business problems [40].

- **SMART:** it was initially described in 1977 by Edwards [42] as the process of rating alternatives and weighing criteria, such that it can be considered a simplified form of MAUT. This method conveniently converts importance weights into actual numbers. The major advantages of SMART are that it is simple to use, and it allows for using any type of weights (e.g., relative, absolute). However, other methods are more popular to study more complex problems. Typical applications include the analysis of environmental, transportation and logistics, military and construction problems [40].
- **GP:** it is a programming method that can choose from an infinite number of alternatives. One of its advantages is that it can handle large-scale problems. Its ability to produce countless alternatives puts it at a significant advantage over the methods providing a limited number of alternatives. A significant disadvantage is its inability to weight coefficients. Many applications require it to be coupled with other methods, such as AHP, to weigh the coefficients properly. Therefore, one of its weaknesses is eliminated, while the possibility of choosing from infinite alternatives is maintained. GP has been applied to production planning, scheduling, healthcare, portfolio selection, distribution system design, energy planning, water reservoir management, timber harvest scheduling, and wildlife management problems [40].
- **ELECTRE:** this method ranks alternatives based on concordance and discordance indices that are calculated with data extracted from a decision table. This method has four main steps. In the first step, each criterion must be weighed employing a normalization theory that ensures that the sum of all weights must be equal to 1. Furthermore, a threshold function - expressing the presence of concordance - must be established. In the second step, the concordance and discordance indices for a pair of alternatives must be calculated. In the next step, the outranking degree must be calculated for each pair of alternatives based on a concordance and discordance index. Finally, a partial ranking will be made, considering all pairs of alternatives. The most significant disadvantage of this method is that it requires establishing an additional threshold, and the ranking of alternatives depends on the value of the threshold, for which there exists no "correct" value. The main advantage is that ELECTRE can handle both quantitative and qualitative data to outrank alternatives [43]. ELECTRE has been used to evaluate energy, economics, environmental, water management, and transportation problems [40].
- **PROMETHEE:** it is an outranking method that does not eliminate any alternative in pairwise comparisons, but it orders them according to the criteria and preferences of the decision-maker. This method can deal with a finite number of actions to gain a partial (PROMETHEE I) or a complete preorder (PROMETHEE II). The PROMETHEE method has 5 main steps. In the first step, a preference function is defined to express the preference of the decision-maker for a given action, in a pairwise comparison. The second step concerns the pairwise comparison of the suggested alternatives using the preference function. As a third step, the outcomes of these comparisons are presented, in an evaluation matrix, as the estimated value of every criterion for every alternative. The ranking is obtained in the two final steps: the fourth one requires applying the PROMETHEE I method to achieve a partial ranking, while the fifth step employs the PROMETHEE II method to complete the ranking of the alternatives. The main advantage of this method is that normalizing the scores is not required, while the main disadvantage is that weights must be defined separately, considering that the weighting techniques are not part of this method

[43]. PROMETHEE has been used in environmental and water management, hydrology, business and financial management, chemistry, logistics and transportation, manufacturing and assembly, energy management, and agriculture [40].

- **SAW:** it uses a value function that is established based on a simple addition of scores that represent achieving the goal under each criterion, multiplied by the relevant weights. It can compensate among criteria, and the calculation is simple and can be performed without relying on sophisticated computer programs. However, the estimates obtained from the SAW method do not always reflect the real situation. The results obtained may not be logical, with the values of one particular criterion being widely different from those of other criteria. SAW has been applied to water, business, and financial management [40].
- **TOPSIS:** it is an approach to identify an alternative that is closest to the ideal solution and farthest from the most negative one. The former is the one that maximizes the benefit and minimizes the cost criteria. The latter maximizes the cost and minimizes the benefit criteria. Some of the advantages of the TOPSIS method include its simplicity, good computational efficiency, and the ability to measure the relative performance for each alternative in a simple mathematical form. However, the main disadvantages of the TOPSIS method include the correlation between criteria as well as the difficulty in weighing attributes and in making consistent judgments, especially in the presence of a rising number of attributes. TOPSIS has been used in supply chain management and logistics, design, engineering and manufacturing systems as well as business, marketing, environmental, human resources, and water resources management [40].

2.2.3 Cost-Effectiveness Analysis

Cost-Effectiveness Analysis (CEA) is a tool assisting the decision-making process that compares alternatives to achieve a goal based on their resource utilization (cost) and outcomes (effectiveness). CEA can be used to find the least cost to achieve a goal or to estimate the expected costs of obtaining a particular outcome. It can also be used to compare the impacts and costs of various alternative means of achieving the same objective. The result of a CEA is expressed as the ratio (cost-effectiveness ratio) of cost to outcome [44].

In IA, the method that is used in CEA is the “benefit/cost ratio”, which means dividing the benefits by costs. The significant advantage of CEA is that it is easy to calculate since it requires fewer data, which may also be easily accessible. CEA is more challenging to be applied to interventions with more than one main objective. If the intervention aims to achieve several objectives (e.g., job creation, environmental protection), or have indirect impacts, the results of CEA may be misleading or irrelevant (Tool 57. Analytical methods to compare options or assess performance). CEA is often used in the field of health services as well as in agriculture, transport, education, and the service sector [44].

2.2.4 Counterfactual Analysis

Counterfactual Analysis (CA) is a statistical method quantifying whether a given intervention produces the desired effects on some pre-established dimension of interest. More precisely, CA consists of comparing the outcomes of interest experienced by the beneficiaries of a policy intervention (i.e., the “treatment group”) with those experienced by a group similar in all respects to the treatment group (i.e., the “control group”) except that it has not been subject to the policy intervention. The control group informs us of what would have happened to the members of the treatment group if they had not been exposed to the policy under scrutiny. Its advantage consists of the observed differences in the outcomes between the treatment and the control group providing estimates of the effect of the policy intervention. However, CA requires extensive datasets of variables that can be affected by policy interventions, collected before and after the policy intervention. The evaluator employing this method should avoid a causal interpretation of the differences that are due to factors other than the intervention itself (Tool 57. Analytical methods to compare options or assess performance).

According to the EC methodological documents, counterfactual impact evaluation methods usually encompass double difference (or difference-in-difference) analysis, randomized selection of subjects, propensity score matching, and instrumental variable analysis. Furthermore, a combination of methods can be applied [45]. Finally, the Common Monitoring and Evaluation Framework (CMEF) has recommended employing CA to assess the impacts of the EU Rural Development Programme(s) (RDP(s)) measures (i.e., the CAP Pillar II measures) [46]. In fact, contrary to the CAP Pillar I measures which benefit all active farmers, access to the CAP Pillar II measures is subject to an application and an awarding process. Indeed, this determines the existence of a group of farmers who have access to the CAP Pillar II subsidies (i.e., the "treatment group") and of a group of farmers who do not have access to the same subsidies, and among which the "control group" can be found.

2.2.5 Life Cycle Analysis

Life Cycle Analysis (LCA) is considered a systematic tool evaluating the environmental impacts of the entire life cycle of a product, process, or activity. This approach leads to understanding the overall environmental performance and the relative contributions of the different stages [47]. LCA is divided into 4 phases: i) Goal and scope definition phase which is related with the aims of the LCA and the description of the central assumptions and system choices; ii) Life Cycle Inventory (LCI) which is associated with the collection of the data on the emissions and resources connected to the chosen products/services for each life cycle stage; iii) Life Cycle Impact Assessment (LCIA) which is related to the translation of the data collected in the LCI into indicators that reflect the impacts on ecosystems and human health as well as considerations associated with resource availability, covering different impact categories; iv) Interpretation, in which the outcome of the LCA calculation is interpreted following the aim established in the goal and scope definition phase of the study (Tool 64. Life Cycle Analysis). One of the main strengths is the comprehensiveness of the approach since it analyses the environmental aspects of all inputs and outputs associated with the materials and processes in a product life cycle. One of the main weaknesses of LCA is the large amount of detailed data, as well as the extensive time and significant expertise necessary to apply it [47].

2.2.6 Econometric models

Econometric models are generally suitable for medium/long term forecasting and analysis. Various types of data are used in the estimation of the econometric models, including a) time-series data that give information about the numerical values of variables from period to period, b) cross-section data that give information on the variables concerning individual agents (e.g., individuals, firms) at a given point of time, c) panel data that give information of a repeated survey of a single sample in different periods of time and d) dummy variable data in cases the variables are qualitative in nature and data is recorded in the form of the indicator function. Such models are not generally suitable for short-term analysis (but in some cases cover different time frames). The econometric estimation methodology is well suited to do ex-post IA [48] and agriculture is one of the domains in which this approach has been extensively used. Specifically, it has been used to establish the effects of subsidies on the (re)distribution of income, the introduction/reshaping/removal of production quota, trade policies, and of the production and market effects of introducing and/or reforming decoupled DP [48].

The advantage of this approach is that the effects are calculated based on the observed behavior of agents. Additionally, the estimated econometric model can be statistically tested and validated in all phases of the modeling work: specification of the model, estimation, hypothesis testing and simulation [49]. However, an essential requirement for obtaining reliable results is the availability of data in sufficient detail and quality. In practice, however, this is not often the case as either data are not available to study the impact of the policy of interest or the quality of the data is not appropriate to causally identify the policy impacts. An additional significant shortcoming of the econometric approach is that it is not always able to capture the structure of the analyzed sector sufficiently well. Commonly applied econometrically estimated models adopt a simplified representation of the analyzed markets (e.g., due to data constraints) or have a reduced form structure, which makes it challenging to identify potential non-linearities, sector interlinkages, and various channels of policy transmission to agricultural markets. These disadvantages of econometric models make them less useful for policy impact analysis and, in particular, for the evaluation of new policies [48].

2.2.7 General Equilibrium models

General Equilibrium (GE) models are often created to evaluate very specific policy interventions (i.e., one or two to begin with) and maybe afterwards they are extended to cover more areas of intervention. The disaggregation of the results that these models can produce depends upon the disaggregation of the modelling effort, which foresees equations for different types of households, firms, farms, products traded and countries trading. They could provide detailed information on the policy impact of a particular variable of interest (Tool 62. The use of Analytical models and methods). GE models, in contrast to Partial Equilibrium (PE) models, can quantify policy-induced changes on the whole of the economy and their feedback on - for instance - agriculture. At the same time, they may be less flexible in capturing the specific characteristics of (agricultural) markets and policies [48].

In the context of the CAP, GE models may be more effective, than PE ones, particularly in modeling policies of the EU RDPs since these measures therein go beyond agriculture and impact other sectors in the economy (e.g., the tourism industry due to the multifunctional agri-touristic activities of farmers, the construction industry through farmers' demand for new and refurbished buildings and facilities). GE models can better capture these effects because of their inter-sector coverage. However, the inherent complexity and the regional differentiation of RDP measures can also be an obstacle to incorporating them properly into a GE modeling framework [50]. A few examples of applied GE models include the Global Trade Analysis Project (GTAP), GLOBE, and RUNS.

2.2.8 Partial Equilibrium models

Partial Equilibrium (PE) models are used in the detailed analysis of a specific economic sector or a combination of related ones over the short/medium/long term. The main advantage of PE models is that they can represent agricultural markets and the policy instruments in great detail. This allows the structure of the analyzed markets and the intervention logic of policies to be modeled more accurately. The drawback concerns the fact that these models are unable to capture the interactions with other sectors and the effects in other markets but remain in equilibrium within the sector(s) in question. Factors related to issues outside of the sector(s) under investigation must be supplied exogenously, and interactions/feedback to the rest of the economy are ignored (Tool 62. The use of Analytical models and methods). PE models are widely used in sector-specific policy analysis and have found numerous applications in the context of economic policy analysis in agriculture [51]. A few examples of applied multi-regional PE models include AGLINK, Agricultural Member State Modelling (AGMEMOD), AROPAj, Common Agricultural Policy Regional Impact (CAPRI), ESIM, Food and Agricultural Research Institute (FAPRI), FSSIM, and World Food Model (WFM) [52].

2.2.9 Micro-simulation models

Microsimulation modeling is a simulation-based tool with a micro unit of analysis that can be used for ex-ante analysis. It focuses on micro units of analysis such as individuals, households, firms, and farms while it utilizes computer programs to simulate the public policy, economic or social changes on the micro population of interest [53]. The rapid development of microsimulation modeling has been facilitated by the advent of computers in the 1980s and the availability of micro-data.

For most of the history of this research area [53], the focus has been on the household as the unit of analysis and related policies such as tax, social policy, and pensions. There is now a growing literature focusing on firms [54] or farms [55]. Whether formally called micro-simulation modeling or not, ex-ante micro- and simulation-based analysis is now used extensively around the world for policy analysis and design [56].

The field is multidisciplinary and, depending upon the policy area, the discipline has different names. Particularly, for those researchers working in public finance and social policy it is called micro-simulation. For others in labor economics, it constitutes a branch of applied micro-econometrics, while for researchers of agricultural policy it is called farm-level modeling. Farm-level simulation modeling has historically developed as a parallel field to micro-simulation modeling, while other parallel areas include agent-based modeling [53]. In the following subsections a general description of farm-level models and agent-based models (ABMs) will be presented.

2.2.9.1 Farm-level modeling

Over the last decades, reliance on farm-level models for agricultural policy analysis has increased significantly [57]. This growing interest can be attributed to the increasing demand for tools and methods for micro-level policy analysis to achieve a better understanding of farm-level decision-making. There are several approaches to farm-level modeling which include farm supply, bioeconomic, and agricultural household models. While farm supply models mainly focus on economic objectives, bioeconomic ones integrate economic and environmental objectives, and agricultural household models incorporate the social dimension.

Farm-level models vary in terms of whether modeled farms are based on individual (real) farms [58], [59], [60], [48] or on a farm-type which corresponds to a predefined typology. The main distinction between the two modeling approaches is that the former models single farm units (usually from survey data) while the latter models aggregated farm units (i. e., a "representative" farm for each "farm type") such as in CAPRI-FT [30]. Representative farm units, created on the basis of their production specialization, farm size, production technology or other characteristics, are employed in models such as FSSIM [22] or AROPAj [61]. The key advantages of the individual farm modeling approach are that it allows the modeler to better take into account the variation in farm characteristics (e.g., specialization, technology), and it can cover farm activities and processes in greater detail. The significant computational requirements, particularly if the geographical coverage of the model is large (e.g., the whole EU) and the model is complex, constitute the main disadvantages of this approach. The farm-type modeling allows better interlinkage of farm types with market models, generating market feedback at the farm-type level. However, the aggregated/representative farm-type models average out a significant share of farm heterogeneity, which can curtail or bias the policy IA.

Traditionally, four approaches are often used for building a farm-level model: MP [including LP, non-linear programming (NLP), mixed integer programming (MIP), positive mathematical programming (PMP)], the econometric approach, the econometric mathematical programming (EMP), and the simulation approach. The type of farm modeling approach of choice often depends on data availability, model specification, and research scope [62].

Regarding the modeling of the CAP measures, Ciaian et al. (2013) [62] concluded that there is a significant difference in the requirements of models evaluating the Pillar I and Pillar II measures. Pillar I measures of the CAP are well represented in farm-level models while all the Pillar II measures are not taken into account, except for the subsidies benefitting Less Favoured Areas (LFA) and for the Agri-Environmental Measures (AEM) which are implemented in selected farm-level models (e.g., CAPRI-FT, FARMIS, FAMOS).

2.2.9.2 Agent-based modeling

Agent-based modeling (ABM) is a powerful tool that is being used to inform policy or decisions in many fields of practical importance, including ecosystem and natural-resource management, control of communicable disease outbreaks, marketing and private sector logistics, economic policy and education [63]. In recent years, Agent-Based Models (ABMs) have gained increasing popularity for modeling agricultural systems and the impacts of related policies. Agent-based modeling is a process-based ”bottom-up” approach that attempts to describe the behaviors and interactions among autonomous agents, through which agricultural systems are evolving. In turn, this simulates emergent phenomena without having to make a priori assumptions regarding the properties of the whole system [64], [65]. Therefore, agent-based modeling is a suitable tool for improving the understanding of farmers’ behavior in response to changing environmental, economic, or institutional conditions, particularly on the local level [66], [67].

ABMs have several differences with the traditional farm-level models. The modeling of farm and consumer heterogeneity, their spatial location, and the interactions between farms and/or consumers (e.g., social networks, land markets, imitation behaviors) are distinctive features of ABMs. Moreover, while in the case of traditional farm models the market outcome arises from equating the aggregate supply and demand functions, in the ABM case the market is stimulated through individual transactions [68].

Agent-based modeling faces difficulties in being widely adopted because these models are extremely time-consuming to be parameterized and calibrated and thus are not (yet) applicable to large-scale analyses [62].

In general, European agricultural ABMs focus on production decisions and the resulting income, the farm structural changes, and the environmental impacts or landscape changes [69]. The key elements of ABMs which cover regional, national and European spatial extents and are used in the context of European agriculture are presented in the following table.

Model	Emerging phenomena	Spatial and time dimension	Agent	Policies
ABMSIM	Spatially explicit land-use, farm structures	1,300 km² – 30 years	Individual farms, aggregate land-use agent	Decoupled DP, environmental standards
AGRIPOLIS	Structural change (farm structures, land-use, production) and land prices	200 – 1,700 km² - 15 years	Individual farms	The CAP
CRAFTY	Land-use change at the European scale	1,600 km² – 30 years	Land manager, institutional agents	Institutions implement types of polices (subsidies, protection)
GLUM	Transition from rainfed to irrigated agriculture	16,000 km² – retrospective (1960-2010)	Farm types (part-time, family farm, business-oriented)	Relevant CAP policies

MPMAS (Germany)	Regional agricultural supply, land-use, farm structures, participation in agri-environmental schemes (AES)	1,300 km² – 10 years	Farming households (full-time farms)	The CAP, AES, the Renewable Energy Act
RULEX	Land markets, spatially explicit land-use change, rural depopulation, farm size growth, intensification	300 km² – retrospective (2001-2009)	Landowners: individual farmers (subdivided into categories), individual estate owners, and nature conservation organizations	Policies for implementing national ecological network
SERA	Land-use patterns	606 km² – 25 years	Dairy farm households (traders) and auctioneer	AES
SWISSLAND	Land-use, farm structures and production, nitrogen (N) flows	55,000 farms – 15 years	FADN farms	Full representation of Swiss agricultural policies

Table 1 Key elements of agricultural agent-based models in European case studies

Source: Huber et al. (2018) [69].

2.2.10 Input-Output models

Input-Output (IO) analysis belongs to the family of IA methods aiming to map the direct and indirect consequences of an initial impulse into an economic system across all economic sectors. It is essentially a method that depicts the system-wide effects of an exogenous change in a relevant economic system [70], [71]. IO models are based on the idea that any output requires a corresponding set of inputs. These inputs may comprise raw materials and services from other industries, labor from households, or certain public goods provided by the government. The output consists of products and services from a variety of industries. An IO model is an equilibrium model that assumes that production equals consumption. This model is also static, meaning that an IO model is a snapshot of the economy at a particular time.

The models are based on economic IO tables which indicate the values of purchases of one economic sector from another (the others) in a given year. A conventional IO table is based on the double-entry bookkeeping rules: column totals equal row totals. IO tables are usually available at the national level although they can be both aggregated at a lower and/or disaggregated at a higher spatial resolution (Tool 62. The use of Analytical models and methods).

The major advantage of the IO models is their internal consistency. All effects of any given change in final demand can be recorded. Important, and sometimes, restrictive assumptions made in the IO model are that all firms in a given industry employ the same production technology and produce identical products, there are no economies of scale in production and/or factor substitution and that they do not foresee the existence of supply constraints. Furthermore, because the tables are usually produced for a certain period/a reference year, the model can become irrelevant as a forecasting tool when production technologies change. Another problem concerns the fact that IO models are essentially based on a linear production technology: doubling the level of agricultural production will double the inputs levels. This reveals something of the inflexibility of the model, as in real-world situations this assumption may not always be true. Thus, the model is entirely demand-driven, implying that bottlenecks in the supply of inputs are largely ignored. Finally, in IO models data are expressed in monetary terms because, otherwise, it is impossible to compare different physical measurement units. However, any monetary value may vary simply due to price changes. Yet, IO analysis is considered to be a very clear and important method that is often embedded as a module in more extensive models (i.e., (computable) GE models) [70].

With the help of regional IO tables, inter-dependencies and linkages between industries, households, and the government in and between regions can be examined. An example concerns the impact of a certain industry, such as forestry, on other industries. Because the forestry industry uses inputs from other industries as well as labor from the households in the area and it delivers products to several industries, an IO analysis is a proper analytical instrument. McGregor and McNicoll (1992) [72] performed this exercise in the United Kingdom and, in a simulation experiment, they assumed a reduction in output of the forestry industry to zero. Of course, the largest impact was recorded in the forestry industry but the households and the banking, finance, and insurance sectors, as well as the energy and water industries experienced major negative effects [70]. Also, economists have used IO models to examine the economic interrelationship between the agricultural sector and other sectors of the economy, such as the manufacturing and energy sectors.

2.2.11 Integrated modeling approaches

An integrated assessment has been defined as "an interdisciplinary and participatory process combining, interpreting, and communicating knowledge from diverse scientific disciplines to allow a better understanding of complex phenomena" [73]. Model building is only one option to perform an integrated assessment [74]. Integrated Assessment and Modelling (IAM) has been proposed by researchers as a means for enhancing the management of complex systems and to improve integrated assessment [74], [75], [76]. It is based on systems analysis as a way to consider, in a balanced integration, the biophysical, economic, social, and institutional aspects of the system under study. The assumption underlying IAM is that a formal model of the system, solved by software packages and code, contributes to a better informed ex-ante integrated assessment of new policies and technologies. It certainly does not replace a participatory process in which many other factors and knowledge sources play a crucial role but allows for the safe and relatively cheap experimentation with and quantification of the effectiveness and efficiency of different policy alternatives [77]. Despite its strengths, an integrated model requires many resources to be constructed. The difficulties lie in the likely different theoretical approaches of dedicated and separate models that may be based on different assumptions, as well as on the practicalities of linking different sets of computer code. (Tool 62. The use of Analytical models and methods).

One of the domains in which integrated modeling approaches have been used is agriculture. Uthes et al. (2010) proposed a comparison of three policy IA tools employed to analyze the CAP instruments and their effects [78]. Specifically, they compared the characteristics and performance of the Sustainability Impact Assessment Tool (SIAT), which was developed to enable the evaluation of the compliance of the EU policy proposals with the European Guidelines for Sustainable Development [79]; the SEAMLESS - Integrated Framework (SEAMLESS-IF), which focuses primarily on the agricultural sector and attempts to bridge the gap between the micro (field-farm-small region) and the macro (market, sector) scales [77], and the MEA-Scope tool which was motivated by the fact that most integrated assessment tools lack the ability to simultaneously consider farm structural change, joint production, and spatial heterogeneity [80]. Uthes et al. (2010) [78] identified that market instruments and DP are comparatively well represented, while the ability to model rural development measures is mostly beyond the scope of these tools. Also, the choice of the tool for a particular application depends strongly on the policy research question being analyzed, since each tool has found a different solution to deal with the common challenges of IAM. The SIAT provides the "big picture" results thanks to its ability to represent broad changes in policy instruments with EU-wide cross-sector impacts. The most comprehensive analysis of agricultural policy instruments can be obtained with SEAMLESS-IF, while the MEA-Scope tool complements the other two approaches with detailed regional profiles.

The characteristics of the SIAT, SEAMLESS-IF, and MEA-Scope tools are presented in the table below.

Model	Key issues addressed	Spatial and time dimension	Land-use sectors	Stand-alone model components of the integrated tools
SIAT	Synthesizing multi-sector simulations, quick-scan analysis[1], IA tool	European – 15 years	Agriculture, forestry, tourism, transport, energy, nature conservation	NEMESIS (macro-econometric), CAPRI (agriculture, partial equilibrium), EFISCEN (forestry), DYNA-CLUE (land-use change)
SEAMLESS-IF	Focus on the agricultural sector, a bridge between the macro and the microscale, flexibility of the tool because of the component-based structure	European – 10-15 years	Agriculture	CAPRI (agriculture, partial equilibrium), FSSIM (PMP), APES (mechanistic), and others
MEA-Scope tool	Farm structural change, a bridge between individual farms/fields types and the regional scale, spatial heterogeneity	Selected EU regions – 10-15 years	Agriculture	Agri Polis (ABM), MODAM (LP + rule-based environmental impacts), FASSET (LP + mechanistic environmental impacts)

Table 2 Characteristics of the SIAT, SEAMLESS, and MEA-Scope tools

Source: Uthes et al. (2010) [78].

The following table summarizes the advantages and disadvantages, data requirements, and applications of the methodologies and modeling approaches used for policy IA.

[1] Quick-scan analysis allows for a cross-case exploration of multiple case studies, on the basis of a pre-determined set of variables. The method may be employed at the beginning of a research project in order to determine a set of relevant case studies for the specific field, and obtain a valuable overview of existing research on a topic. A mapping of variables and indicators into a single matrix facilitates the identification and analysis of similarities and variances between them. Consequently, a more in-depth analysis of some of the case studies may be pursued, in order to acquire a deeper understanding of the interconnections that are suspected or have already been identified between the cases[81]

Methodologies	Advantages	Disadvantages	Data requirements	Application
CBA	Uses an objective unit of measurement to compare alternative options and choose the one that maximizes the benefits	Overlooks distributional impacts, lacks objectivity in parameters selection	Time-series data, cross-sectional data, panel data, dummy variable data	Determines the overall impact of an intervention, policy design, decision-making, assesses the performance of a project
MCA	Captures the distributional impacts and trade-offs between dimensions	The major shortcoming of MCA arises when many policy options need to be compared and the enumeration of all possible rankings becomes computationally intractable; MCA may lead to inconclusive policy rankings since nothing precludes the existence of multiple optimal options, MCA underperforms when inter-temporal comparisons need making because of it has no analytical technique to compare impacts occurring in different years	Time-series data, cross-sectional data, panel data, dummy variable data	Decision-making in industrial, corporate, and medical settings, decision-making in environmental and natural resources problems
MAUT	Helps decision-makers gain further knowledge and understanding of the problem	It is a complex method	Time-series data, cross-sectional data, panel data, dummy variable data	Economic, financial, water management, energy management, and agricultural problems
AHP	It is an easy and scalable method, it allows decision-makers to weigh coefficients and compare alternatives with relative ease, it is scalable and can accommodate large decision-making problems due to its hierarchical structure	It suffers from the interdependence between criteria and alternatives, due to the pairwise comparisons it can also be subject to inconsistencies in judgment and ranking criteria, it does not permit decision-makers to grade one instrument in isolation, but only in comparison with the others, without identifying weaknesses and strengths	Time-series data, cross-sectional data, panel data, dummy variable data	Performance-type problems, resource management, corporate policy and strategy, public policy, political strategy, and planning
Fuzzy Set Theory	It allows using, manipulating, and interpreting data and information that are vague and lack certainty	Fuzzy MCA models tend to be difficult to develop, in many cases they require numerous simulations before being used in the real world	Time-series data, cross-sectional data, panel data, dummy variable data	Engineering, economic, environmental, social, medical, and management

CBR	It has parsimonious data requirements, it can improve over time	Sensitive to inconsistent data, requires many cases	Specific data from previous situations (time-series data, cross-sectional data, panel data, dummy variable data)	Used in applications for which a substantial number of previous cases already exists
DEA	It can handle multiple inputs and outputs, it can analyze and quantify the level of efficiency, it can uncover relationships that may remain hidden employing other methods	This technique does not deal with imprecise data and assumes that all input and output data are exactly known. In real-world situations, however, this assumption may not always be true. The results can be sensitive depending on the inputs and outputs	Time-series data, cross-sectional data, panel data, dummy variable data	Economic, medical, agricultural, retail, and business problems
SMART	It is simple to use, it accommodates any type of weight assignment technique	It is not the best option for very complex problems	Time-series data, cross-sectional data, panel data, dummy variable data	Environmental, transportation and logistics, military and construction problems
GP	It can handle large-scale problems; it can produce infinite alternatives	It cannot weigh coefficients, typically it needs to be used in combination with other MCA methods to weigh coefficients	Time-series data, cross-sectional data, panel data, dummy variable data	Production planning, scheduling, healthcare, portfolio selection, distribution systems, energy planning, water reservoir, and wildlife management
ELECTRE	It can handle both qualitative and quantitative data to outrank alternatives	It requires an additional threshold to be introduced and the ranking of the alternatives depends on the size of this threshold for which there exists no “correct" value	Time-series data, cross-sectional data, panel data, dummy variable data	Energy, economics, environmental, water management, and transportation problems
PROMETHEE	Normalizing the scores is not required	Weight must be defined separately as the weighing techniques are not part of this method	Time-series data, cross-sectional data, panel data, dummy variable data	Environmental, hydrology and water management, business and financial management, chemistry, logistics and transportation, manufacturing, energy management, and agriculture
SAW	It compensates among criteria, it is computationally simple and does not require complex computer programs	Estimates do not always reflect the real situation, results may not be logical	Time-series data, cross-sectional data, panel data, dummy variable data	Water, business, and financial management

TOPSIS	It is simple, it has good computational efficiency and is capable of measuring the relative performance of each alternative in a simple mathematical form	It suffers from the correlation between criteria, it is difficult to weigh attributes and keep a consistent judgment, especially if the number of attributes is increasing	Time-series data, cross-sectional data, panel data, dummy variable data	Supply chain management and logistics, design, engineering and manufacturing systems, business, human resources, and marketing management, environmental and water resources management
CEA	This method requires fewer data, which should also be more accessible	It is more difficult to apply to interventions with more than one main objectives	Time-series data, cross-sectional data, panel data, dummy variable data	Health services, agriculture, transport, education, and service sector
CA	It provides the estimation of the effects of a policy intervention	It requires extensive datasets, it may suffer from the interpretation bias of the evaluator	Time-series data, cross-sectional data, panel data, dummy variable data	RDP(s)
LCA	The main strength is the comprehensiveness of the approach since it analyses the environmental impacts of all materials and processes in a product life cycle	The main weaknesses of LCA are the large amount of detailed data, time, and expert knowledge necessary to apply it	Time-series data, cross-sectional data, panel data, dummy variable data	Environmental impacts
Econometric models	The effects are calculated based on the observed behavior of (market) agents, the econometric model can be statistically tested and validated	It is not suitable for short term analysis, data may have insufficient detail and quality to grant reliable results, it is not always able to capture the structure of the analyzed sector sufficiently well	Time-series data, cross-section data, panel data, dummy variable data	Distributional effects of subsidies on income, analysis of the introduction/reform/removal of production quota, trade policies, production, and market effects of decoupled DP
GE models	They are able to produce disaggregated results, they can account for policy-induced changes on the whole of the economy and their feedback on agriculture	They are less flexible when capturing the specificities of agricultural markets, such as the detailed rules for implementing agricultural policies	Data sources include IO tables and national accounts, other data related to taxes, income, and expenditure	RDP
PE models	They are able to represent agricultural markets and policy instruments in great detail	They are unable to capture the interactions with other sectors	Trade flows, trade policy (tariff), couple of behavioral parameters	Sector-specific policy analysis in agriculture

Farm-type modeling	It can provide better interlinkages of farm types with market models and thus it can generate market feedback at the farm-type level	It averages out a significant share of farm heterogeneity which can curtail the accuracy or bias policy IA	FADN dataset, regional statistics (detailed and disaggregated data)	Impacts of the policy measures from the Pillar I and Pillar II of the CAP
Individual farm modeling	It allows the modeler to better account for the variation in farm characteristics, farm activities, and processes in detail	It has significant computational requirements also arising from the high model complexity	FADN dataset, regional statistics (detailed and disaggregated data)	Adaptation of individual farmers to policy and market changes
ABM	It accounts for farms and consumer heterogeneity, spatial location, and the interactions between farms and/or consumers	These models are extremely time-consuming in terms of parameterization and calibration	Big data, empirical data, survey data, and panel data	Production decisions and resulting outcomes, development of farm structures, environmental impacts, or landscape changes
IO models	They present internal consistency, all the effects of any change in final demand can be recorded	All firms in a given industry employ the same production technology and produce identical products, because the IO tables are produced for a given period/year, the model can become irrelevant as a forecasting tool when production techniques change, the model assumes that there are no economies in production or factor substitution; the models do not foresee the existence of supply constraints, developing new IO tables is very labor-intensive, the data are expressed in monetary terms	Expenditures and revenues of each branch of the economy (inputs and outputs for each component of the system)	Investigation of inter-dependencies and linkages between industries, households, and the government in and between regions, investigation of economic interrelationship between the agricultural sector and other sectors of the economy, such as the manufacturing and energy sectors
Integrated modeling approach – SIAT	It enables multi-regional analysis, the evaluation of land-use change between sectors, sustainability IA including the calculation of macro-economic indicators	It provides a coarse representation of policy instruments, it does not model farm-level decision-making	Use of official data (e.g., Eurostat OECD)	Synthesizing multi-sector simulations, quick-scan analysis, IA
Integrated modeling approach - SEAMLESS-IF	It has a refined representation of agricultural supply in the PE model, accounts for the environmental effects, the farm model receives prices from a PE model, the technical coefficients	It does not calculate economy-wide effects, it has a coarse representation of farm-level decision-making	Use of official data (FADN data) + additional data collection	Focus on the agricultural sector, it bridges the macro- and the micro-scale, it is flexible because of its component-based structure

	and environmental effects derived from a mechanistic model			
Integrated modeling approach – MEA-Scope tool	It accounts for the dynamic farm development over time, it bridges the gap between agent-based and mechanistic models, it quantifies the associated environmental effects	It does not calculate economy-wide effects, it does not have price-quantity effects, it suffers from the long simulation time, it does not have a user interface, it works for selected case studies only	Use of official data (FADN data) + additional data collection on crop and livestock production	Farm structural change, it bridges between individual farms/fields types and the regional scale, it allows for spatial heterogeneity

Table 3 Summary of the methodologies and modeling approaches used for policy IA

Source: authors' elaboration

2.3 Changes in the objectives of the CAP and the development of IA models

Early CAP measures mostly included price and market support (relying on intervention prices as well as production and export subsidies) and benefitted from the existence of quota and high tariffs on agri-food imports from abroad. Accordingly, PE models that depict the functioning of agri-food markets were commonly used in policy impact studies. Besides these, GE models were applied to analyze economy-wide impacts and spillover effects between sectors. The early reforms in the 1990s addressed long-standing problems which were connected to overproduction and escalating budgetary costs. Quantitative tools to analyze the impacts of the CAP policy reform(s) were extensively used in those years to properly inform the reform toward a CAP capable of achieving its objectives while costing less to taxpayers in the EU. Furthermore, the rapid progress in information and communication technologies, alongside easier access to datasets covering several geographical areas of Europe and of the world as well as topics, boosted the development of increasingly sophisticated models [16].

A profound change of the CAP took place in 2003 to make EU agriculture more competitive and market-oriented and to provide less trade-distorting support to farmers. The critical aspects of the reform included the introduction of a Single Payment Scheme (SPS) that decoupled DP from production and a greater emphasis on preserving/improving environmental quality, higher food safety, and better animal welfare standards. Changes in agricultural policy instruments were accompanied by increased attention to the assessment of policy impacts. Uncertainty in the effects of the 2003 CAP reform, in conjunction with sustainability concerns, raised the need to provide a comprehensive IA. Consequently, a formal IA of the 2003 CAP reform was performed. This assessment involved a scenario analysis, where a range of policy alternatives was compared against a “baseline” or “reference” scenario reflecting the expected developments of the EU agriculture in a “status quo” while taking into account anticipated technological or societal developments as well as the policies already in place. Parallel to the official requirements from the EC on the ex-ante IA of policy initiatives, considerable progress was made on model development. In particular, while existing IA models were able to analyze production decisions and evaluate the impacts of price support, decoupling support from production represented a great challenge for policy modelers. Simultaneously, IA models required radical adaptations to be applied to the assessment of the environmental effects of policy (reforms). In the 2000s, many conventional IA models went through significant improvements that enabled them to better capture the interactions among policy incentives, farmer responses, and environmental effects at various spatial and temporal scales [16].

Model-based analyses of decoupling DP are numerous. Balkhausen et al. (2008) [82] reviewed the results of selected PE and GE models (AGLINK, AGMEMOD, CAPRI, Common Agricultural Policy SIMulation (CAPSIM), ESIM, FAPRI, GOAL, and GTAP) assessing the production and the land-use effects of decoupling DP. Although results are different across models, depending on their specification and assumptions, all models foresaw a decline in cereal production and an increase in fodder production as a consequence of decoupling. Moreover, it was assessed that, in presence of decoupled DP, production decisions were more determined by the signals coming from the market for agricultural output than by the CAP payments.

The focus on the environmental and sustainability performance of the 2003 CAP reform also posed a great challenge for conventional IA models, which were particularly capable of assessing the economic impacts of reforms but were less able to account for their environmental implications. Furthermore, due to more disaggregated analyses being required to quantify the complex interdependencies between agriculture and the environment, models capable of providing farm-level responses became more relevant. Farm-level approaches started to be widely used to ascertain the environmental implications of agricultural policies and to analyze the impacts of AEM [83], [18].

A further step towards decoupled DP took place in 2008 with the Health Check package. The existence and dismissal of milk quota, the abolition of compulsory set-aside, and the convergence in the levels of DP across and within EU Member States (MSs) (i.e., the external and internal convergence of DP) have been extensively modeled [16]. Other environmental concerns also influenced the development of IA models. Investigating issues connected with the production and provision on the market of bioenergy from agricultural biological matter is an example of additional areas of concern embraced by agro-economic models to answer new policy and research questions. The policy support to increasing the supply and demand for energy from renewable sources and the rapid development of biofuel markets throughout the 2000s motivated the introduction of new activities in agro-economic models to account for the food-energy interactions [16].

The 2013 CAP reform further strengthened the environmental objectives of the CAP by introducing the greening payment among the Pillar I measures. The reform also aimed to keep pursuing the external and internal convergence in DP, reducing the asymmetries in the distribution of support. The new policy measures, and more precisely the greening measures, were expected to have differentiated effects at the regional/farm level. Most of the agro-economic models widely used to conduct an IA of previous CAP policies were aggregate models, operating at the level of representative farms, regions, countries, or groups of countries, incapable of fully capturing the impacts of these new policy measures [84]. The need to develop modeling tools capable of analyzing the socio-economic and environmental impacts of agricultural policies at a much more disaggregated level became a crucial issue. Farm-level models have come to play an increasingly prominent role in IA studies. These models are better suited to investigate how many and which real farms benefit/lose out from agricultural policy reform. However, the disaggregated assessment faces important challenges related to extensive data requirements and higher complexity to extend the spatial coverage and to account for market feedback.

Summarizing, environmental and sustainability concerns increasingly shape agricultural policies. Climate change mitigation and the efficient management of natural resources such as water, soil, and air are significant challenges and will probably be the primary concern of upcoming agricultural policy design initiatives. Accordingly, models capable of exploring the socio-economic and environmental impacts of agricultural policies at regional and farm level will provide better information regarding the impact of policy measures and identify the farms that benefit/lose out from agricultural policy reforms [16].

2.4 Indicators for the policy IA of the CAP

The performance of the CAP in achieving its common objectives can be measured on the basis of indicators. The information provided by an indicator is a datum used to measure facts or opinions. Indicators are aggregates of data that allow the quantification (and simplification) of phenomena. Thus, in the following subsection the indicators that are defined by the CMEF, set up by the EC, to assess the performance of CAP are listed (Technical handbook on the CMEF of the CAP). The next subsection depicts the indicators for which the impacts of policies were assessed in farm models [12], and the last subsection presents the policy impact indicators provided by the three integrated assessment tools [78].

2.4.1 Indicators defined by the Common Monitoring and Evaluation Framework

As part of the CAP 2014-2020 and in accordance with Article 110 of Regulation (EU) No 1306/2013, a CMEF has been set up to measure the performance of the whole CAP (both Pillar I DP to farmers and market measures as well as Pillar II rural development measures). In the CMEF, the performance of the CAP measures is assessed in relation to the three general objectives of the latest CAP (e.g., viable food production; sustainable management of natural resources and climate action; balanced territorial development) and in the case of Pillar II in relation to the thematic objectives for the Europe 2020 strategy for smart, sustainable, and inclusive growth. The key tool employed in the CMEF is a set of indicators, which measures the degree of achievement of an objective in terms of resources mobilized, an output accomplished or an effect obtained, or to describe the context (economic, social, or environmental).

Four groups of indicators, listed in Regulation (EC) No 834/2014, were established:

- 16 impact indicators for general CAP objectives, which measure outcomes of policy interventions beyond immediate effects.
- A total of 65 results indicators, for both Pillar I (16) and Pillar II (25), as well as 24 target indicators for rural development measure the direct and immediate effects of interventions.
- A total of 84 output indicators measure activities directly enacted by the policy interventions in the areas of DP (36), markets (13), horizontal aspects (9, in areas such as cross-compliance, quality, organic farming, promotion, farm advisory system) and rural development (26).
- 45 context indicators measure general background trends in the economy, the agricultural sector, and the environment.

The following tables list the common impact, result/target, output, and context indicators. These different types of indicators are linked to the different levels of the objectives.

Impact indicators

The impact indicators for the CAP general objectives are presented in what follows.

Indicator No.	Indicator name
I.01	Agricultural entrepreneurial income
I.02	Agricultural factor income
I.03	Total factor productivity in agriculture
I.04	EU commodity price variability
I.05	Consumer price evolution of food products
I.06	Agricultural trade balance
I.07	Emissions from agriculture
I.08	Farmland birds index (FBI)
I.09	High nature value farming
I.10	Water abstraction in agriculture
I.11	Water quality
I.12	Soil organic matter in arable land
I.13	Soil erosion by water
I.14	Rural employment rate
I.15	Degree of rural poverty
I.16	Rural GDP per capita

Table 4 Impact indicators for the CAP general objectives

Source: Technical handbook on the CMEF of the CAP 2014 - 2020.

Results indicators

Pillar I results indicators are presented in the following table.

Indicator No.	Indicator name
R.01_PI	Share of direct support in agricultural income
R.02_PI	Variability of farm income • by type of farm • by economic size
R.03_PI	Value-added for primary producers in the food chain.
R.04_PI	EU agricultural exports • share of agricultural exports in world exports • share of final products in EU agricultural exports
R.05_PI	Public intervention: percentage of the volume of products bought in intervention storage out of total EU production
R.06_PI	Private storage: percentage of the volume of products in private storage out of total EU production
R.07_PI	Export refunds: percentage of the volume of products exported with export refunds out of total EU production
R.08_PI	EU commodity prices compared to world prices (broken down by product)
R.09_PI	Value of production under EU quality schemes compared to the total value of agricultural and food production
R.10_PI	Importance of organic farming • share of the organic area in the total utilized agricultural area (UAA) • share of organic livestock in total livestock
R.11_PI	Crop diversity • on-farm (number of farms by number of crops and size) • in a region
R.12_PI	Share of grassland in total UAA
R.13_PI	Share of ecological focus area (EFA) in agricultural land
R.14_PI	Share of the area under greening practices
R.15_PI	Net greenhouse gas (GHG) emission from agricultural soils
R.16_PI	Structural diversity • in absolute terms • in relative terms

Table 5 Pillar I result indicators

Source: Technical handbook on the CMEF of the CAP 2014 - 2020.

Result, target, and complementary result indicators for rural development focus areas are presented in the following tables. Complementary result indicators are marked with an asterisk (*).

Indicator No.	Indicator name
R.01_PII	Percentage of agricultural holdings with RDP support for investments in restructuring or modernization (focus area 2A)
R.02_PII	Change in agricultural output on supported farms/Annual Work Unit (AWU) (focus area 2A)
R.03_PII	Percentage of agricultural holdings with RDP supported business development plan/investments for young farmers (focus area 2B)
R.04_PII	Percentage of agricultural holdings receiving support for participating in quality schemes, local markets and short supply circuits, and producer groups/organizations (focus area 3A)
R.05_PII	Percentage of farms participating in risk management schemes (focus area 3B)

R.06_PII	Percentage of forest or other wooded area under management contracts supporting biodiversity (focus area 4A)
R.07_PII	Percentage of agricultural land under management contracts supporting biodiversity and/or landscapes (focus area 4A)
R.08_PII	Percentage of agricultural land under management contracts to improve water management (focus area 4B)
R.09_PII	Percentage of forestry land under management contracts to improve water management (focus area 4B)
R.11_PII	Percentage of forestry land under management contracts to improve soil management and/or prevent soil erosion (focus area 4C)
R.12_PII	Percentage of irrigated land switching to more efficient irrigation systems (focus area 5A)
R.13_PII	Increase in the efficiency of water use in agriculture in RDP supported projects (focus area 5A)
R.14_PII	Increase in the efficiency of energy use in agriculture and food-processing in RDP supported projects (focus area 5B) (*)
R.15_PII	Renewable energy produced from supported projects (focus area 5C)
R.16_PII	Percentage of Livestock Units (LU) concerned by investments in livestock management in view of reducing GHG and/or ammonia emissions (focus area 5D)
R.17_PII	Percentage of agricultural land under management contracts targeting reduction of GHG and/or ammonia emissions (focus area 5D)
R.18_PII	Reduced emissions of methane and nitrous oxide (focus area 5D) (*)
R.19_PII	Reduced ammonia emissions (focus area 5D) (*)
R.20_PII	Percentage of agricultural and forest land under management contracts contributing to carbon sequestration or conservation (focus area 5E)
R.21_PII	Jobs created in supported projects (focus area 6A)
R.22_PII	Percentage of the rural population covered by local development strategies (focus area 6B)
R.23_PII	Percentage of the rural population benefiting from improved services/infrastructures (focus area 6B).
R.24_PII	Jobs created in supported projects (LEADER) (focus area 6B)
R.25_PII	Percentage of rural population benefiting from new or improved services/information and communication technology infrastructures (focus area 6C)

Table 6 Rural development and complementary results indicators

Source: Technical handbook on the CMEF of the CAP 2014 - 2020.

Indicator No.	Indicator name
T.01_PII	Percentage of expenditure under Articles 14, 15 and 35 of Regulation (EU) No 1305/2013 in relation to the total expenditure for the RDP (focus area 1A)
T.02_PII	Total number of cooperation operations supported under the cooperation measure (Article 35 of Regulation (EU) No 1305/2013) (groups, networks/clusters, pilot projects) (focus area 1B)
T.03_PII	Total number of participants trained under Article 14 of Regulation (EU) No 1305/2013 (focus area 1C)
T.04_PII	Percentage of agricultural holdings with RDP support for investments in restructuring or modernization (focus area 2A)
T.05_PII	Percentage of agricultural holdings with RDP supported business development plan/investments for young farmers (focus area 2B)
T.06_PII	Percentage of agricultural holdings receiving support for participating in quality schemes, local markets, and short supply circuits, and producer groups/organizations (focus area 3A)
T.07_PII	Percentage of farms participating in risk management schemes (focus area 3B)

T.08_PII	Percentage of forest/other wooded areas under management contracts supporting biodiversity (focus area 4A)
T.09_PII	Percentage of agricultural land under management contracts supporting biodiversity and/or landscapes (focus area 4A)
T.10_PII	Percentage of agricultural land under management contracts improving water management (focus area 4B)
T.11_PII	Percentage of forestry land under management contracts to improve water management (focus area 4B)
T.12_PII	Percentage of agricultural land under management contracts to improve soil management and/or prevent soil erosion (focus area 4C)
T.13_PII	Percentage of forestry land under management contracts to improve soil management and/or prevent soil erosion (focus area 4C)
T.14_PII	Percentage of irrigated land switching to a more efficient irrigation system (focus area 5A)
T.15_PII	Total investment for energy efficiency (focus area 5B)
T.16_PII	Total investment in renewable energy production (focus area 5C)
T.17_PII	Percentage of LU concerned by investments in livestock management in view of reducing GHG and/or ammonia emissions (focus area 5D)
T.18_PII	Percentage of agricultural land under management contracts targeting the reduction of GHG and/or ammonia emissions (focus area 5D)
T.19_PII	Percentage of agricultural and forest land under management contracts contributing to carbon sequestration or conservation (focus area 5E)
T.20_PII	Jobs created in supported projects (focus area 6A)
T.21_PII	Percentage of the rural population covered by local development strategies (focus area 6B)
T.22_PII	Percentage of the rural population benefiting from improved services/infrastructures (focus area 6B)
T.23_PII	Jobs created in supported projects (LEADER) (focus area 6B)
T.24_PII	Percentage of rural population benefiting from new or improved services/information and communication technology infrastructures (focus area 6C)

Table 7 Rural development target indicators

Source: Technical handbook on the CMEF of the CAP 2014 - 2020.

Output Indicators

The output indicators for Pillar I DP, market measures, horizontal measures, and output indicators for Pillar II (rural development) are shown in the following tables.

Indicator No.	Indicator name
Basic payment scheme	
O.01_PI	Number of farmers
O.02_PI	Number of hectares (ha)
Single area payment scheme	
O.03_PI	Number of farmers
O.04_PI	Number of ha
Transitional national aid	
O.05_PI	Number of farmers
O.06_PI	Number of units for which transitional national aid is granted (ha/animals/other units)
Redistributive payment	
O.07_PI	Number of farmers
O.08_PI	Number of ha
Greening	

O.09_PI	Total number of farmers who have to apply at least one greening obligation
O.10_PI	Total number of ha declared by those farmers
Greening exemptions	
O.11_PI	Number of farmers exempted by: organic farmers/exempted from crop diversification/exempted from EFA obligation
O.12_PI	Number of ha declared by these farmers (organic farmers, exempted from crop diversification, exempted from EFA obligation)
Crop diversification	
O.13_PI	Number of farmers subject to crop diversification (with 2 crops; with 3 crops)
O.14_PI	Number of ha of arable land declared by farmers subject to crop diversification (with 2 crops; with 3 crops)
Permanent grassland	
O.15_PI	Number of farmers with permanent grassland counting for the ratio
O.16_PI	Number of ha covered by permanent grassland declared by the farmers counting for the ratio
O.17_PI	Number of farmers with permanent grassland in designated environmentally sensitive areas
O.18_PI	Number of ha covered by environmentally sensitive permanent grassland declared by these farmers
O.19_PI	Number of ha of designated as environmentally sensitive permanent grassland (total)
EFA	
O.20_PI	Number of farmers subject to EFA requirements
O.21_PI	Number of ha of arable land declared by farmers subject to EFA
O.22_PI	Number of ha declared by farmers as EFA, broken down by EFA type
Equivalence	
O.23_PI	Number of farmers applying equivalent measures (certification schemes or agri-environment-climate measures)
O.24_PI	Number of ha declared by farmers implementing equivalent measures (certification schemes or agri-environment-climate measures)
Payment for young farmers	
O.25_PI	Number of farmers
O.26_PI	Number of ha
Small farmers scheme	
O.27_PI	Number of farmers
O.28_PI	Number of ha
Voluntary coupled support	
O.29_PI	Number of beneficiaries of voluntary coupled support (broken down by sector)
O.30_PI	Quantities eligible (number of ha/ number of animals broken down by sector)
O.31_PI	Number of ha
O.32_PI	Number of animals
Payment for areas with natural constraints	
O.33_PI	Number of farmers
O.34_PI	Number of ha
National programs for the cotton sector	
O.35_PI	Number of farmers
O.36_PI	Number of ha

Table 8 Pillar I output indicators – DP

Source: Technical handbook on the CMEF of the CAP 2014 - 2020.

Indicator No.	Indicator name
Public intervention	
O.37_PI	Volume
O.38_PI	Duration
Private storage	
O.39_PI	Volume
O.40_PI	Duration
Export refunds	
O.41_PI	Volume of products exported with export refunds
Exceptional measure	
O.42_PI	[as appropriate]
Producer organizations	
O.43_PI	Percentage of production marketed by producer organizations and associations of producer organizations
School schemes	
O.44_PI	Number of final beneficiaries of the school milk scheme
O.45_PI	Number of final beneficiaries of the school fruit scheme
Wine sector	
O.46_PI	Number of ha of new vine plantings
O.47_PI	Number of ha of restructured vineyards
O.48_PI	Number of promotion projects in the wine sector
O.49_PI	Number of projects of investment and innovation measures

Table 9 Pillar I output indicators – Market measures

Source: Technical handbook on the CMEF of the CAP 2014 - 2020.

Indicator No.	Indicator name
Cross compliance	
O.50_PI	Number of ha subject to cross-compliance
O.51_PI	Share of CAP payments subject to cross-compliance
Quality policy	
O.52_PI	Geographical indications in the wine sector
O.53_PI	Number of new Protected Designations of Origin (PDO), Protected Geographical Indication (PGI), and Traditional Specialty Guaranteed (TSG) by sector
Organic farming	
O.54_PI	Number of ha (total and under conversion)
O.55_PI	Number of certified registered organic operators
Promotion policy	
O.56_PI	Number of programs (in and outside the EU)
O.57_PI	Number of new proposing organizations
Farm advisory system	
O.58_PI	Number of farmers advised

Table 10 Pillar I output indicators – Horizontal aspects

Source: Technical handbook on the CMEF of the CAP 2014 - 2020.

Indicator No.	Output Indicator
O.01_PII	Total public expenditure
O.02_PII	Total investment
O.03_PII	Number of actions/operations supported
O.05_PII	Total area (ha)
O.05_PII	Physical area supported (ha)
O.07_PII	Number of contracts supported
O.08_PII	Number of LU supported
O.09_PII	Number holdings participating in supported schemes
O.10_PII	Number of farmers benefiting from pay-outs
O.11_PII	Number of training days given
O.12_PII	Number of participants in training
O.13_PII	Number of beneficiaries advised
O.14_PII	Number of advisors trained
O.15_PII	Population benefiting from improved services/infrastructures (information technology or others)
O.16_PII	Number of European Innovation Partnership (EIP) groups supported, number of EIP operations supported, and number and type of partners in EIP groups
O.17_PII	Number of cooperation operations supported (other than EIP)
O.18_PII	Population covered by Local Action Group (LAG)
O.19_PII	Number of LAGs selected
O.20_PII	Number of LEADER projects supported
O.21_PII	Number of cooperation project supported
O.22_PII	Number and type of project promoters
O.23_PII	Unique identification number of LAG involved in a cooperation project
O.24_PII	Number of thematic and analytical exchanges set up with the support of National Rural Networks (NRN)
O.25_PII	Number of NRN communication tools
O.26_PII	Number of European Network for Rural Development activities in which the NRN has participated

Table 11 Pillar II output indicators

Source: Technical handbook on the CMEF of the CAP 2014 - 2020.

Context indicators

The context indicators are presented in the following table and those that incorporate CAP impact indicators are marked with an asterisk (*).

Indicator No.	Output Indicator
	Socio-economic indicators
C.01	Population
C.02	Age structure
C.03	Territory
C.04	Population density
C.05	Employment rate (*)
C.06	Self-employment rate
C.07	Unemployment rate
C.08	GDP per capita (*)
C.09	Poverty rate (*)

C.10	Structure of the economy
C.11	Structure of the employment
C.12	Labor productivity by economic sector
Sectoral indicators	
C.13	Employment by economic activity
C.14	Labor productivity in agriculture
C.15	Labor productivity in forestry
C.16	Labor productivity in the food industry
C.17	Agricultural holdings (farms)
C.18	Agricultural area
C.19	Agricultural area under organic farming
C.20	Irrigated land
C.21	Livestock units
C.22	Farm labor force
C.23	Age structure of farm managers
C.24	Agricultural training of farm managers
C.25	Agricultural factor income (*)
C.26	Agricultural entrepreneurial income (*)
C.27	Total factor productivity in agriculture (*)
C.28	Gross fixed capital formation in agriculture
C.29	Forest and other wooded land
C.30	Tourism infrastructure
Environment indicators	
C.31	Land cover
C.32	Areas facing natural and other specific constraints
C.33	Farming intensity
C.34	Natura 2000 areas
C.35	FBI
C.36	Conservation status of agricultural habitats
C.37	High nature value farming (*)
C.38	Protected forest
C.39	Water abstraction in agriculture (*)
C.40	Water quality (*)
C.41	Soil organic matter in arable land (*)
C.42	Soil erosion by water (*)
C.43	Production of renewable energy from agriculture and forestry
C.44	Energy use in agriculture, forestry and food industry
C.45	Emissions from agriculture (*)

Table 12 Context indicators

Source: Technical handbook on the CMEF of the CAP 2014 - 2020.

Indicators for which impacts of policies were assessed in farm models

Reidsma et al. (2018) [12] performed a systematic review of the use of farm models for policy IA, based on 202 studies from the period 2007-2015. In their review, around half of the studies assessed impacts on indicators in two different SD dimensions, usually economic and environmental. Slightly less than a quarter included only one SD dimension, usually the economic one, and slightly more than a quarter included in all three SD dimensions. In the economic dimension, gross margin is the most used indicator, and in many studies the calculation of gross margins was undertaken according to choices specific of the study or the author(s). The full list of economic indicators assessed in farm models is presented below.

SD dimension	Indicators
Economic	Gross margin, gross income, net income, household income, net present value, income from different sources, the potential increase in earned income, value-added (all per farm, ha or labor unit)
	Crop prices, minimum subsidy level, subsidy, variable costs (e. g., seeds, water, pumping, fertilizer, pesticides, biomass, N surplus disposal, bought feed, livestock, maintenance and management, harvest, fixed, capital), compliance costs per ha, marginal abatement costs
	Crop yields, crop/milk/meat/energy/protein/carbohydrates/fat production, exploitable, livestock, woodstock, energy supply curves
	Investment (in land, farm buildings, tractors, tillage machinery, harvesting machinery), operational capital, farm income-investment elasticity, household worth, net worth growth, farm fixed investment, debt-to-asset ratio, long term loans, option value
	Allocative efficiency, economic efficiency, output-input efficiency, economic water efficiency, irrigation productivity
	Risk, risk efficiency, uncertainty, insurance, economic sustainability, CAP independency, business diversification
	Shadow price
	Consumption, wealth
	Costs of measures, cost-effectiveness of measures
	Return to a governmental body, regional consumption, equity, distribution of family farm income, distribution of farm subsidies, farm contribution to GDP
	Value for EU farmers, value for the seed sector
	Land price, land rent, tenure fee
	Agricultural trade, trade of roughage, total demand, net export
	Farm structure, farm size change
	Adaptability (wooded area/total, farm area with pasture only, subsidies/revenue, LU cattle/LU sheep, LU swine/LU total, cows per bull, ewes per ram, sows per boar)
	Stability (farm area in ownership, LU/ha, land fixed capital per ha, machinery fixed capital per ha, livestock fixed capital per ha, autochthonous cows/ewes per total, opportunity costs of owned resources)
	Economic viability (available income per worker compared with the national legal minimum wage, economic specialization rate)
	Independence (financial autonomy, reliance on direct subsidies from the CAP, and indirect economic impact of milk and sugar quota)
	Transferability (total assets minus land value by non-salaried worker units)
	Efficiency (operating expenses as a proportion of total production value)

Table 13 Economic indicators for which the impacts of policies were assessed in farm models

Source: Reidsma et al. (2018) [12].

In the environmental dimension, crop areas and animal numbers are the most used indicators (although it can be argued whether they can be considered environmental indicators). Indicators on nutrient and water management are also frequently used, while a wide range of biodiversity-related indicators is available. The full list of environmental indicators assessed in farm models is depicted below.

SD dimension	Indicators
Environmental	Cropping system, crop areas, area of organic farming, area of irrigated farming, area of forests and pastures, area of (semi-natural) grassland, energy crop share, orchard and meadow area, share of low/high yield grassland, land-use for fallow/ livestock production/maintenance, AES area, area under botanic contract, area-wide cultivation, land abandonment (area in use), ecological buffer zones, land-use competition, dimension of fields
	Number of animals, livestock density index, stocking rate
	Farming intensity, grassland intensity, fodder area management
	Farm specialization, diversification, genetic diversity, agro-diversity
	N use, (in)organic N use, manure production, manure application, manure purchase, fertilizer management, fertilizer expenses, N uptake, seasonal available N, ammonia (NH_3) emissions, nitrous oxide (N_2O) emissions, methane (CH_4) emissions, carbon dioxide (CO_2) equivalent emissions, particulate matter (PM) emissions, NH_3 deposition, NH_3 deposition excess loads, NH_3 housing emissions, NH_3 application emissions, N deposition, N leaching, N runoff, N surplus, phosphorous (P) surplus, freshwater/marine/terrestrial N/P eutrophication, stream nitrate-N, nitrate-N load at site, P-load, nitrate reduction, N response, acidification, terrestrial/aquatic/human ecotoxicity, prevention of nitrate leaching, air quality, water quality
	Water use, water management, water use efficiency, water productivity, preservation of water resources, water use from collective networks/private wells, water accumulation, water balance, water stress index, water allocation, adoption of deficit irrigation techniques, dehydration of the soil, drainage, irrigation efficiency, aquifer recovery
	Global warming potential, GHG emissions, energy use, non-renewable energy use/demand, fossil energy use, fuel consumption, energy efficiency, energy dependence, biogas plant investment, adoption of biogas digester, adoption of energy crops, regional biomass supply, carbon sequestration
	Pesticide use, fungicide use, pesticide leaching, pesticide pollution, herbicide runoff, runoff of pesticide to surface water, pesticide risk, Predicted Environmental Concentrations (PECs) of the used pesticides, costs of each plant protection product, veterinary products
	Biodiversity (for selected taxonomic groups; e.g. amphibians, floral, skylark), natural value, landscape, landscape-scale biodiversity metrics, landscape based on L-function, wildlife habitat provided by cropped areas and green set aside, environmental amenity, habitat quality (for different target species), Shannon diversity index, community specialization index (CSI), community trophic index (CTI), species abundance, index of relative change in abundance and distribution of agricultural wildlife species, occupancy of species, potential aquatic biodiversity loss, reduction of potential terrestrial biodiversity, ordinal scale assessment of biodiversity that includes biotopes, species, biotope connectivity and the influence of land-use, bird population growth rate, bird reproductive success, total bird density, bird density five different species, bird list per farm, FBI, generalist bird index (GBI), bumblebees/ha, size of ecological compensation areas, number of farmers with botanic contract, average field size, species-area relationship, area of protected habitats according to the EC Habitats Directive, woodstock volume, measures to protect the natural heritage
	Countryside access and recreation, landscape and heritage, maintenance of cultural landscapes
	Soil quality, soil cover, soil organic carbon, organic matter input, organic matter management, soil erosion, (risk of) soil (N) loss, erosion control, risk of water erosion
	Feed self-sufficiency, feed import, feed production, animal feed, concentrates, feed source
	Resource use conservation, preservation of water and soil resources, efficient use of resources
	Area burnt
	Ozone formation (potential)
	Conversion to organic agriculture

Table 14 Environmental indicators for which impacts of policies were assessed in farm models

Source: Reidsma et al. (2018) [12].

Studies using social indicators usually focus on labor use, but several other indicators have been proposed and presented below.

SD dimension	Indicators
Social	Labor use (total/hired/family/men/women/harvest/seasonal/in mountain regions), labor productivity, labor intensity, labor allocation, off-farm employment, machinery use
	Family consumption expenditure, caloric self-sufficiency
	Public expenditure, cost-effectiveness of measures, net social costs, global value for society, value for farmers and consumers in the rest of the world, welfare
	Redistribution effects of payments, income distribution per farm types, income distribution per social groups
	(Average) farm size, farm size distribution, number of farms (total/single-holder/corporate), land ownership, abandoned land
	Nature area, landscape quality, cultural amenity, tourism, social valuation effects for environmental benefits, quality of life, odor, quality of the products and land (quality of foodstuffs produced, enhancement of buildings and landscape heritage, processing of non-organic waste, accessibility of space, social involvement)
	Organization of space (short trade, services, multi-activities, contribution to employment, collective work, probable farm sustainability)
	Animal welfare, animal health
	Food safety, milk quality parameters (total bacterial count, somatic cell count, coliform count, freezing point, urea-N, fat content, protein content, and penalty-points), seropositive pigs leaving the farm, carcass contamination after slaughter, PAHC of Salmonella
	Bankruptcy, sensitivity to technical and economic fluctuations, self-management (rented farm area, farm area with scrub only, farm area under crops, expenditure on animal feed, veterinary expenditure, intermediate consumption, reuse on-farm, resources used from environment/total resources needed by livestock)
	Ethics and human development (contribution to world food balance, training, labor intensity, quality of life, isolation, reception, hygiene, and safety)
	Population patterns, migration patterns
	Land rent, land demand
	Staying legal

Table 15 Social indicators for which impacts of policies were assessed in farm models

Source: Reidsma et al. (2018) [12].

Finally, only few studies used a comprehensive indicator framework comprising all SD dimensions (Gómez-Limón and Riesgo, 2009 [85]; Refsgaard and Johnson, 2010 [86]; Zahm et al., 2008 [87]; Zimmermann et al., 2011 [88]), while Manos et al. (2013) [89] specifically focused on sustainability, looking at labor effects and implications for the rural area.

2.4.2 Policy impact indicators provided by integrated assessment tools

The three integrated assessment tools (SEAMLESS-FT, SIAT, and MEA-Scope) presented previously, provide impact indicators for the three sustainability categories (economic, social, and environmental). Some indicators constitute primary model output and can be directly derived from the tools, while others were derived through further processing.

The following table presents the economic impact indicators provided by SEAMLESS-IF, SIAT and MEA-Scope tool.

Economic	**SEAMLESS-IF**	**SIAT**	**MEA-Scope tool**
	Agricultural income	Energy costs	Profit per ha
	Direct CAP payments	Gross domestic product	Rental prices per ha
	Export subsidy outlays	Inflation rate – consumer price index	Number of farms
	First Pillar CAP expenditure	Labor costs by sector	Change in farm size
	Intervention stock costs	Labor productivity	
	Money metrics	Net flow of energy products	
	Profits (accounting) of the agricultural processing industry	Net flow of traded goods by sector	
	Subsidies	Public expenditure	
	Tariff revenues	Value-added by sector	
	Terms of trade		
	Total agricultural inputs		
	Total agricultural outputs		
	Total costs		
	Total welfare		
	Value of farm production		
	Land shadow price		
	Net farm income		
	Percentage of debts in net farm income		
	Percentage of subsidies in net farm income		

Table 16 Economic impact indicators provided by the three integrated IA tools

Source: Uthes et al. (2010) [78].

The following table presents the environmental and social impact indicators provided by SEAMLESS-IF, SIAT, and MEA-Scope tool.

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	NH_3 volatilization	NH_3 emission from agriculture	NH_3 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 (fossile energy demand area, animal)	
		Global warming potential	
Biodiversity	Crop diversity	Terrestrial habitat at risk from eutrophication	Field hares
		Population trends of farmland birds	
		Dead wood	
		High nature value farmland	
		Spatial cohesion	
Social	Labor use institutional compatibility	Continuity of appreciated landscape heritage	Labor use
		Deviation of regional income	
		Deviation of regional unemployment rates	
		Employment rate by sector, gender, and age	
		Exposure to air pollution	
		Exposure to fire risk	
		Exposure to water pollution (N, P)	
		Migration	
		Self-sufficiency index for food (calories)	
		Self-sufficiency index for food (fat)	
		Self-sufficiency index for food (protein)	
		Recreational pressure from tourism	
		Unemployment rate by sector, gender, and age	
Others		Forest fire risk	

Table 17 Environmental and social impact indicators provided by the three integrated IA tools

Source: Uthes et al. (2010) [78].

2.5 Policy IA: summary remarks

Evaluation of public policies and intervention programs has received increasing attention over the past years. Most non-governmental organizations and public institutions, including the EC, evaluate whether their activities have the desired impact, whether spending is justified based on the performance of the interventions, and how planned actions and policies can be adjusted to improve outcomes [90]. In the EU, agriculture is one of the few sectors for which the most relevant and the majority of the policies are defined and managed at the EU level [91]. There is a wide cross-country variation in the priority objectives of agricultural policies, which also evolve through time in line with continuously changing societal demands. Any policy change is designed with the expectation of improving the current situation, but the extent to which this can be achieved needs to be carefully assessed [16].

Nowadays, the agricultural sector is facing continuous socio-economic and environmental challenges in a rapidly changing economic and institutional environment. Climate change and environmental concerns influence agriculture and shape the design of agricultural policies. Due to the manifold objectives of agricultural policies and the multitude of environmental impacts associated with agricultural production, IA requires an integrated approach to account for the interrelated economic, environmental, and social impacts at different temporal and spatial scales. Tools for integrated assessment combine models from different disciplines and provide a multitude of outcomes. Integrated assessment also needs methods for scaling up economic, environmental, and social variables from the farm level to higher aggregation levels. In addition, they require methods for scaling down data and baseline indicators from the administrative level (regional, national) to the farm level. Current agricultural policies require methods that are able to represent heterogeneity and to model farm-specific policy measures. Yet, these methods should be also able to capture interconnections between farms as well as market adjustments for inputs and outputs [16]. ABMs are able to consider heterogeneous agents and their interactions, along with feedback to simulate the emergent properties of a system. Thereby, ABMs allow the representation of agent-specific behavior covering individual preferences or motivations [69].

Environmental factors are another crucial issue. There is a diversity of environmental impacts (e.g., on natural resources such as soil and water, biodiversity, the landscape) and a wide range of agri-environmental policy measures. Despite the integration of environmental variables in IA tools, current models are still lacking the capability to simulate the environmental impacts of policy measures, and in particular those with a strong spatial component (e.g. biodiversity, landscape, and hydrology).

Data availability and accuracy are constraining factors in model development. Even more limitations arise from using environmental variables, which exhibit high spatial variability. Secondary data sources on the relationship between farming and environmental conditions are lacking, and collecting these data for a large number of regions may become extremely costly. However, spatial data are increasingly available and big data tools offer promising opportunities to improve data availability and processing.

The challenges encountered in the ex-ante IA of the latest CAP reforms have led to changes in impact models. Today, the rapid development of sophisticated modeling platforms has been possible through the collaboration of multidisciplinary teams worldwide. Notable advances have been achieved in database sharing and in the joint development and coding of models. Recent research on climate change and resource scarcity is a clear example and it shows how IA will increasingly rely on multi-model approaches capable of addressing more issues at a time.

2.6 References

1. ^ Radaelli, Claudio M. 2004. “The Diffusion of Regulatory Impact Analysis–Best Practice or Lesson-Drawing?” European Journal of Political Research 43 (5): 723–47.
2. ^ Renda, Andrea. 2006. Impact Assessment in the EU: The State of the Art and the Art of the State. Ceps.
3. ^ 1 2 Adelle, Camilla, and Sabine Weiland. 2012. “Policy Assessment: The State of the Art.” Impact Assessment and Project Appraisal 30 : 25–33.
4. ^ Boothroyd, Peter. 1995. “Policy Assessment.” Environmental and Social Impact Assessment, 83–126.
5. ^ Jacobs, Scott. 2006. “Current Trends in Regulatory Impact Analysis: The Challenges of Mainstreaming RIA into Policy-Making.” Jacobs and Associates 30.
6. ^ 1 2 Allio, Lorenzo. 2007. “Better Regulation and Impact Assessment in the European Commission.” Regulatory Impact Assessment: Towards Better Regulation, 72–105.
7. ^ Radaelli, Claudio M. 2007. “Whither Better Regulation for the Lisbon Agenda?” Journal of European Public Policy 14 (2): 190–207.
8. ^ Hertin, Julia, Klaus Jacob, and Axel Volkery. 2008. “Policy Appraisal.” Innovation in Environmental Policy?: Integrating the Environment for Sustainability 114.
9. ^ Jacob, Klaus, Julia Hertin, Peter Hjerp, Claudio Radaelli, Anne Meuwese, Oliver Wolf, Carolina Pacchi, and Klaus Rennings. 2008. “Improving the Practice of Impact Assessment.” Evaluating Integrated Impact Assessments.
10. ^ Russel, Duncan, and Andrew Jordan. 2009. “Joining up or Pulling Apart? The Use of Appraisal to Coordinate Policy Making for Sustainable Development.” Environment and Planning A 41 (5): 1201–16.
11. ^ Palumbo, Dennis J. 1987. The Politics of Program Evaluation. Vol. 15. SAGE Publications, Incorporated.
12. ^ 1 2 3 4 5 6 7 Reidsma, Pytrik, Sander Janssen, Jacques Jansen, and Martin K van Ittersum. 2018. “On the Development and Use of Farm Models for Policy Impact Assessment in the European Union–A Review.” Agricultural Systems 159: 111–25.
13. ^ Adelle, Camilla, Andrew Jordan, and John Turnpenny. 2012. “Proceeding in Parallel or Drifting Apart? A Systematic Review of Policy Appraisal Research and Practices.” Environment and Planning C: Government and Policy 30 (3): 401–15.
14. ^ Helming, Katharina, Katharina Diehl, Hanne Bach, Oliver Dilly, Bettina König, Tom Kuhlman, Marta Pérez-Soba, et al. 2011. “Ex Ante Impact Assessment of Policies Affecting Land Use, Part A: Analytical Framework.” Ecology and Society 16 .
15. ^ Vuuren, Detlef P van, Marcel Kok, Paul L Lucas, Anne Gerdien Prins, Rob Alkemade, Maurits van den Berg, Lex Bouwman, et al. 2015. “Pathways to Achieve a Set of Ambitious Global Sustainability Objectives by 2050: Explorations Using the IMAGE Integrated Assessment Model.” Technological Forecasting and Social Change 98: 303–23.
16. ^ 1 2 3 4 5 6 7 8 9 Blanco, Maria. 2016. “Policy Impact Assessment.” Farm-Level Modelling. Techniques, Applications and Policy. Oxfordshire: CABI, 1–13.
17. ^ Buysse, Jeroen, Guido Van Huylenbroeck, and Ludwig Lauwers. 2007. “Normative, Positive and Econometric Mathematical Programming as Tools for Incorporation of Multifunctionality in Agricultural Policy Modelling.” Agriculture, Ecosystems & Environment 120 : 70–81.
18. ^ 1 2 Schmid, Erwin, and Franz Sinabell. 2007. “On the Choice of Farm Management Practices after the Reform of the Common Agricultural Policy in 2003.” Journal of Environmental Management 82 (3): 332–40.
19. ^ Janssen, Sander, and Martin K Van Ittersum. 2007. “Assessing Farm Innovations and Responses to Policies: A Review of Bio-Economic Farm Models.” Agricultural Systems 94 (3): 622–36.
20. ^ Flichman, Guillermo. 2011. Bio-Economic Models Applied to Agricultural Systems. Springer Science & Business Media.

21. ^ Belhouchette, Hatem, Kamel Louhichi, Olivier Therond, Ioanna Mouratiadou, Jacques Wery, Martin van Ittersum, and Guillermo Flichman. 2011. "Assessing the Impact of the Nitrate Directive on Farming Systems Using a Bio-Economic Modelling Chain." Agricultural Systems 104 (2): 135–45.
22. ^ 1 2 Louhichi, Kamel, Argyris Kanellopoulos, Sander Janssen, Guillermo Flichman, Maria Blanco, Huib Hengsdijk, Thomas Heckelei, Paul Berentsen, Alfons Oude Lansink, and Martin Van Ittersum. 2010. "FSSIM, a Bio-Economic Farm Model for Simulating the Response of EU Farming Systems to Agricultural and Environmental Policies." Agricultural Systems 103 (8): 585–97.
23. ^ Jayet, Pierre-Alain, and Athanasios Petsakos. 2013. "Evaluating the Efficiency of a Uniform N-Input Tax under Different Policy Scenarios at Different Scales." Environmental Modeling & Assessment 18 : 57–72.
24. ^ Schönhart, Martin, Thomas Schauppenlehner, Erwin Schmid, and Andreas Muhar. 2011. "Integration of Bio-Physical and Economic Models to Analyze Management Intensity and Landscape Structure Effects at Farm and Landscape Level." Agricultural Systems 104 (2): 122–34.
25. ^ Brady, Mark, Konrad Kellermann, Christoph Sahrbacher, and Ladislav Jelinek. 2009. "Impacts of Decoupled Agricultural Support on Farm Structure, Biodiversity and Landscape Mosaic: Some EU Results." Journal of Agricultural Economics 60 (3): 563–85.
26. ^ Bamière, Laure, Petr Havlík, Florence Jacquet, Michel Lherm, Guy Millet, and Vincent Bretagnolle. 2011. "Farming System Modelling for Agri-Environmental Policy Design: The Case of a Spatially Non-Aggregated Allocation of Conservation Measures." Ecological Economics 70 (5): 891–99.
27. ^ Fernández, Francisco J, and Maria Blanco. 2015. "Modelling the Economic Impacts of Climate Change on Global and European Agriculture: Review of Economic Structural Approaches." Economics: The Open-Access, Open-Assessment E-Journal 9 (2015–10): 1–53.
28. ^ Rötter, Reimund, Heikki Lehtonen, Taru Palosuo, Tapio Salo, Janne Helin, Helena Kahiluoto, Jyrki Aakkula, Kirsti Granlund, Katri Rankinen, and Timothy Carter. 2009. "A Modelling Framework for Assessing Adaptive Management Options of Finnish Agricultural Systems to Climate Change." In Extended Abstracts, 138–39.
29. ^ Deppermann, Andre, Harald Grethe, and Frank Offermann. 2014. "Distributional Effects of CAP Liberalisation on Western German Farm Incomes: An Ex-Ante Analysis." European Review of Agricultural Economics 41 (4): 605–26.
30. ^ 1 2 Gocht, Alexander, and Wolfgang Britz. 2011. "EU-Wide Farm Type Supply Models in CAPRI–How to Consistently Disaggregate Sector Models into Farm Type Models." Journal of Policy Modeling 33 : 146–67.
31. ^ Listorti, Giulia, Egle Basyte-Ferrari, Szvetlana Acs, and Paul Smits. 2020. "Towards an Evidence-Based and Integrated Policy Cycle in the EU: A Review of the Debate on the Better Regulation Agenda." JCMS: Journal of Common Market Studies.
32. ^ Broughel, James. 2015. "What the United States Can Learn from the European Commission's Better Regulation Initiative." European Journal of Risk Regulation 6 (3): 380–81.
33. ^ Renda, Andrea. 2015. "Too Good to Be True? A Quick Assessment of the European Commission's New Better Regulation Package." A Quick Assessment of the European Commission's New Better Regulation Package (May 21, 2015). CEPS Special Report 108.
34. ^ Radaelli, Claudio M. 2018. "Halfway through the Better Regulation Strategy of the Juncker Commission: What Does the Evidence Say?" JCMS: Journal of Common Market Studies 56: 85–95.
35. ^ Golberg, Elizabeth. 2018. "'Better Regulation': European Union Style." Harvard Kennedy School, Mossavar-Rahmani Center for Business and Government, M-RCBG Associate Working Paper Series 98.

36. ^ Florio, Massimo, Stefano Forte, Chiara Pancotti, Emanuela Sirtori, and Silvia Vignetti. 2016. "Exploring Cost-Benefit Analysis of Research, Development and Innovation Infrastructures: An Evaluation Framework." Development and Innovation Infrastructures: An Evaluation Framework (February 2016).
37. ^ Beria, Paolo, Ila Maltese, and Ilaria Mariotti. 2012. "Multicriteria versus Cost Benefit Analysis: A Comparative Perspective in the Assessment of Sustainable Mobility." European Transport Research Review 4 (3): 137–52.
38. ^ Hermans, Caroline M, and Jon D Erickson. 2007. "Multicriteria Decision Analysis: Overview and Implications for Environmental Decision Making." In Ecological Economics of Sustainable Watershed Management. Emerald Group Publishing Limited.
39. ^ Tudela, Alejandro, Natalia Akiki, and Rene Cisternas. 2006. "Comparing the Output of Cost Benefit and Multi-Criteria Analysis: An Application to Urban Transport Investments." Transportation Research Part A: Policy and Practice 40 (5): 414–23.
40. ^ 1 2 3 4 5 6 7 8 9 10 11 12 Velasquez, Mark, and Patrick T Hester. 2013. "An Analysis of Multi-Criteria Decision Making Methods." International Journal of Operations Research 10 (2): 56–66.
41. ^ Jansen, Sylvia JT. 2011. "The Multi-Attribute Utility Method." In The Measurement and Analysis of Housing Preference and Choice, 101–25. Springer.
42. ^ Pöyhönen, Mari, and Raimo P Hämäläinen. 2001. "On the Convergence of Multiattribute Weighting Methods." European Journal of Operational Research 129 (3): 569–85.
43. ^ 1 2 Sabaei, Davood, John Erkoyuncu, and Rajkumar Roy. 2015. "A Review of Multi-Criteria Decision Making Methods for Enhanced Maintenance Delivery." Procedia CIRP 37: 30–35.
44. ^ 1 2 Zou, Xiaoxia, Roger Cremades, Qingzhu Gao, Yunfan Wan, and Xiaobo Qin. 2013. "Cost-Effectiveness Analysis of Water-Saving Irrigation Technologies Based on Climate Change Response: A Case Study of China." Agricultural Water Management 129: 9–20.
45. ^ Loi, Massimo, and Margarida Rodrigues. 2012. "A Note on the Impact Evaluation of Public Policies: The Counterfactual Analysis."
46. ^ Castaño, Javier, Maria Blanco, and Pilar Martinez. 2019. "Reviewing Counterfactual Analyses to Assess Impacts of EU Rural Development Programmes: What Lessons Can Be Learned from the 2007–2013 Ex-Post Evaluations?" Sustainability 11 (4): 1105.
47. ^ 1 2 Hermann, Barbara G, Carolen Kroeze, and Warit Jawjit. 2007. "Assessing Environmental Performance by Combining Life Cycle Assessment, Multi-Criteria Analysis and Environmental Performance Indicators." Journal of Cleaner Production 15 (18): 1787–96.
48. ^ 1 2 3 4 5 Paloma, y Sergio Gomez, Pavel Ciaian, Adriana Cristoiu, and Frank Sammeth. 2013. "The Future of Agriculture. Prospective Scenarios and Modelling Approaches for Policy Analysis." Land Use Policy 31: 102–13.
49. ^ Viaggi, Davide, Meri Raggi, and Sergio Gomez y Paloma. 2011. "Understanding the Determinants of Investment Reactions to Decoupling of the Common Agricultural Policy." Land Use Policy 28 (3): 495–505.
50. ^ Psaltopoulos, Demetris, Eudokia Balamou, Dimitris Skuras, Tomas Ratinger, and Stefan Sieber. 2011. "Modelling the Impacts of CAP Pillar 1 and 2 Measures on Local Economies in Europe: Testing a Case Study-Based CGE-Model Approach." Journal of Policy Modeling 33 : 53–69.
51. ^ Parappurathu, Shinoj. 2013. "Partial Equilibrium Models for Agricultural Policy Analysis." National Center for Agricultural Economic and Policy Research: New Delhi, India.
52. ^ Van Tongeren, Frank, Hans Van Meijl, and Yves Surry. 2001. "Global Models Applied to Agricultural and Trade Policies: A Review and Assessment." Agricultural Economics 26 (2): 149–72.
53. ^ 1 2 3 O'Donoghue, Cathal, O'Donoghue, and Pacey. 2017. Farm-Level Microsimulation Modelling. Springer.
54. ^ Buslei, Hermann, Stefan Bach, and Martin Simmler. 2014. "Firm Level Models: Specifically Firm Models Based upon Large Data Sets."

55. ^ Richardson, James W, Thia Hennessy, Cathal O'Donoghue, and others. 2014. "Farm Level Models." Contributions to Economic Analysis 293: 505–34.
56. ^ Shrestha, Shailesh, Andrew Barnes, and Bouda Vosough Ahmadi. 2016. Farm-Level Modelling: Techniques, Applications and Policy. CABI.
57. ^ Langrell, Stephen. 2013. Farm Level Modelling of CAP: A Methodological Overview. Publications Office of the European Union.
58. ^ Hennessy, Thia C, and Tahir Rehman. 2008. "Assessing the Impact of the 'Decoupling'Reform of the Common Agricultural Policy on Irish Farmers' off-Farm Labour Market Participation Decisions." Journal of Agricultural Economics 59 : 41–56.
59. ^ Sckokai, Paolo, and Daniele Moro. 2006. "Modeling the Reforms of the Common Agricultural Policy for Arable Crops under Uncertainty." American Journal of Agricultural Economics 88 : 43–56.
60. ^ Viaggi, Davide, Meri Raggi, and Sergio Gomez y Paloma. 2010. "An Integer Programming Dynamic Farm-Household Model to Evaluate the Impact of Agricultural Policy Reforms on Farm Investment Behaviour." European Journal of Operational Research 207 (2): 1130–39.
61. ^ De Cara, Stéphane, and Pierre-Alain Jayet. 2011. "Marginal Abatement Costs of Greenhouse Gas Emissions from European Agriculture, Cost Effectiveness, and the EU Non-ETS Burden Sharing Agreement." Ecological Economics 70 (9): 1680–90.
62. ^ 1 2 3 Ciaian, P, M Espinosa, S Gomez y Paloma, T Heckelei, S Langrell, K Louhichi, P Sckokai, A Thomas, and T Vard. 2013. "Farm Level Modelling of CAP: A Methodological Overview. European Commission, Joint Research Centre." Institute for Prospective Technological Studies.
63. ^ Hammond, Ross A. 2015. "Considerations and Best Practices in Agent-Based Modeling to Inform Policy." In Assessing the Use of Agent-Based Models for Tobacco Regulation. National Academies Press (US).
64. ^ Brown, Calum, Ken Brown, and Mark Rounsevell. 2016. "A Philosophical Case for Process-Based Modelling of Land Use Change." Modeling Earth Systems and Environment 2 (2): 50.
65. ^ Helbing, Dirk. 2012. Social Self-Organization: Agent-Based Simulations and Experiments to Study Emergent Social Behavior. Springer.
66. ^ An, Li. 2012. "Modeling Human Decisions in Coupled Human and Natural Systems: Review of Agent-Based Models." Ecological Modelling 229: 25–36.
67. ^ Magliocca, Nicholas R, Jasper Van Vliet, Calum Brown, Tom P Evans, Thomas Houet, Peter Messerli, Joseph P Messina, et al. 2015. "From Meta-Studies to Modeling: Using Synthesis Knowledge to Build Broadly Applicable Process-Based Land Change Models." Environmental Modelling & Software 72: 10–20.
68. ^ Kremmydas, Dimitris, Ioannis N Athanasiadis, and Stelios Rozakis. 2018. "A Review of Agent Based Modeling for Agricultural Policy Evaluation." Agricultural Systems 164: 95–106.
69. ^ 1 2 3 Huber, Robert, and others. 2018. "Representation of Decision-Making in European Agricultural Agent-Based Models." Agricultural Systems 167: 143–60.
70. ^ 1 2 3 Leeuwen, Eveline S van, Peter Nijkamp, and Piet Rietveld. 2005. "Regional Input-Output Analysis." In Encyclopedia of Social Measurement, 317–23. Elsevier.
71. ^ Karkacier, Osman, and Z Gokalp Goktolga. 2005. "Input–Output Analysis of Energy Use in Agriculture." Energy Conversion and Management 46 (9–10): 1513–21.
72. ^ McGregor, Peter G, and Iain H McNicoll. 1992. "The Impact of Forestry on Output in the UK and Its Member Countries." Regional Studies 26 : 69–79.
73. ^ Rotmans, Jan, and Marjolein Van Asselt. 1996. "Integrated Assessment: A Growing Child on Its Way to Maturity." Climatic Change 34 (3–4): 327–36.
74. ^ 1 2 Parson, Edward A. 1995. "Integrated Assessment and Environmental Policy Making: In Pursuit of Usefulness." Energy Policy 23 (4–5): 463–75.
75. ^ Harris, G. 2002. "Integrated Assessment and Modeling—Science for Sustainability." In Understanding and Solving Environmental Problems in the 21st Century, 5–17. Elsevier.

76. ^ Parker, Paul, and others. 2002. “Progress in Integrated Assessment and Modelling.” Environmental Modelling & Software 17 (3): 209–17.
77. ^ 1 2 Van Ittersum, Martin K, Frank Ewert, Thomas Heckelei, Jacques Wery, Johanna Alkan Olsson, Erling Andersen, Irina Bezlepkina, Floor Brouwer, Marcello Donatelli, and Guillermo Flichman. 2008. “Integrated Assessment of Agricultural Systems–A Component-Based Framework for the European Union (SEAMLESS).” Agricultural Systems 96 (1–3): 150–65.
78. ^ 1 2 3 4 5 6 Uthes, Sandra, Katharina Fricke, Hannes König, Peter Zander, Martin van Ittersum, Stefan Sieber, Katharina Helming, Annette Piorr, and Klaus Müller. 2010. “Policy Relevance of Three Integrated Assessment Tools—A Comparison with Specific Reference to Agricultural Policies.” Ecological Modelling 221 (18): 2136–52.
79. ^ Sieber, Stefan, Klaus Müller, Peter Verweij, Hördur Haraldsson, Katharina Fricke, Cesare Pacini, Karen Tscherning, Katharina Helming, and Torbjorn Jansson. 2008. “Transfer into Decision Support: The Sustainability Impact Assessment Tool (SIAT).” In Sustainability Impact Assessment of Land Use Changes, 107–28. Springer.
80. ^ Piorr, Annette, Fabrizio Ungaro, Arianna Ciancaglini, Kathrin Happe, Amanda Sahrbacher, Claudia Sattler, Sandra Uthes, and Peter Zander. 2009. “Integrated Assessment of Future CAP Policies: Land Use Changes, Spatial Patterns and Targeting.” Environmental Science & Policy 12 (8): 1122–36.
81. ^ Van Audenhove, Leo, Dorien Baelden, and Ilse Mariën. 2016. Quick-Scan Analysis of Multiple Case Studies.
82. ^ Balkhausen, Oliver, Martin Banse, and Harald Grethe. 2008. “Modelling CAP Decoupling in the EU: A Comparison of Selected Simulation Models and Results.” Journal of Agricultural Economics 59 : 57–71.
83. ^ Röhm, Ottmar, and Stephan Dabbert. 2003. “Integrating Agri-Environmental Programs into Regional Production Models: An Extension of Positive Mathematical Programming.” American Journal of Agricultural Economics 85 : 254–65.
84. ^ Louhichi, Kamel, Pavel Ciaian, Maria Espinosa, Liesbeth Colen, Angel Perni, and Sergio Gomez y Paloma. 2017. “Does the Crop Diversification Measure Impact EU Farmers’ Decisions? An Assessment Using an Individual Farm Model for CAP Analysis (IFM-CAP).” Land Use Policy 66: 250–64.
85. ^ Gómez-Limón, José A, and Laura Riesgo. 2009. “Alternative Approaches to the Construction of a Composite Indicator of Agricultural Sustainability: An Application to Irrigated Agriculture in the Duero Basin in Spain.” Journal of Environmental Management 90 (11): 3345–62.
86. ^ Refsgaard, Karen, and Thomas G Johnson. 2010. “Modelling Policies for Multifunctional Agriculture and Rural Development–a Norwegian Case Study.” Environmental Policy and Governance 20 (4): 239–57.
87. ^ Zahm, Frédéric, Philippe Viaux, Lionel Vilain, Philippe Girardin, and Christian Mouchet. 2008. “Assessing Farm Sustainability with the IDEA Method–from the Concept of Agriculture Sustainability to Case Studies on Farms.” Sustainable Development 16 (4): 271–81.
88. ^ Zimmermann, Albert, Daniel Baumgartner, Thomas Nemecek, and Gérard Gaillard. 2011. “Are Public Payments for Organic Farming Cost-Effective? Combining a Decision-Support Model with LCA.” The International Journal of Life Cycle Assessment 16 (6): 548–60.
89. ^ Manos, B, Th Bournaris, P Chatzinikolaou, J Berbel, and D Nikolov. 2013. “Effects of CAP Policy on Farm Household Behaviour and Social Sustainability.” Land Use Policy 31: 166–81.
90. ^ Colen, Liesbeth, Sergio Gomez y Paloma, Uwe Latacz-Lohmann, Marianne Lefebvre, Raphaële Préget, and Sophie Thoyer. 2016. “Economic Experiments as a Tool for Agricultural Policy Evaluation: Insights from the European CAP.” Canadian Journal of Agricultural Economics/Revue Canadienne d’agroeconomie 64 (4): 667–94.

91. ^ Britz, Wolfgang, Martin K van Ittersum, Alfons GJM Oude Lansink, and Thomas Heckelei. 2012. “Tools for Integrated Assessment in Agriculture. State of the Art and Challenges.” Bio-Based and Applied Economics Journal 1 (1050-2016–85718): 125–50.

3 Socio-Economic Impacts of Agriculture and Its Integration in Rural Society

This contribution reviews the extant literature on the topic of the socio-economic impacts of agriculture and its integration in rural society by focusing on establishing the most common determinants of succession in agriculture (also known as the "Young Farmer Problem"), the link between agriculture and rural employment as well as of the viability of farming. Among the many determinants, the role of the CAP - being the most relevant agricultural policy - is investigated.

3.1 Socio-economic, demographic and social trends in rural society: The Young Farmer Problem

The latest data available from Eurostat refers to the year 2016 and provides a picture of the number of farms per age category of the owner in Europe. Despite the EU enlargement, the number of farms has decreased over time due to farm consolidation. This overall trend has been determined mainly by the sharp decline in the number of farms owned by middle-age owners (i. e., 44-54 years old) while "young" owners (i. e., under 44 years old category) seemed to be on the rise only in the period 2007 - 2010. The figure below shows that, after a period of sharp decline, the number of farms owned by individuals over 65 increased slightly over the period 2013 - 2016, marking a divergence from both the overall and age-specific trends in the number of farms.

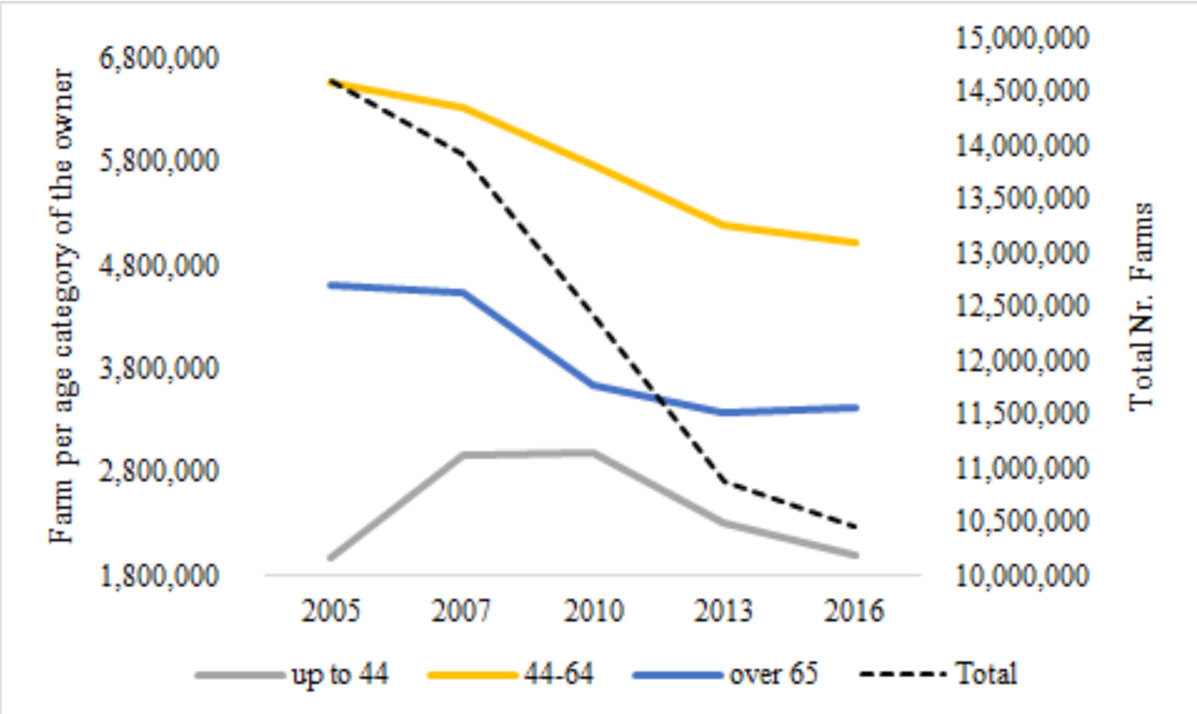

Figure 1 Age Distribution of the Farmer in Europe

Source: authors' elaboration onEurostat (online code ef_m_farmang)

Digging deeper into the EU distribution of farm ownership by age, it is evident that Portugal (52%), Cyprus (45%), Romania (44%), Italy (41%), Bulgaria (36%), UK (34%), and Greece (34%) rank above the EU-28 average share of over-65 farm owners. This evidence justifies the concern over the aging in the EU agricultural sector and its implications for the survival of the industry in the future.

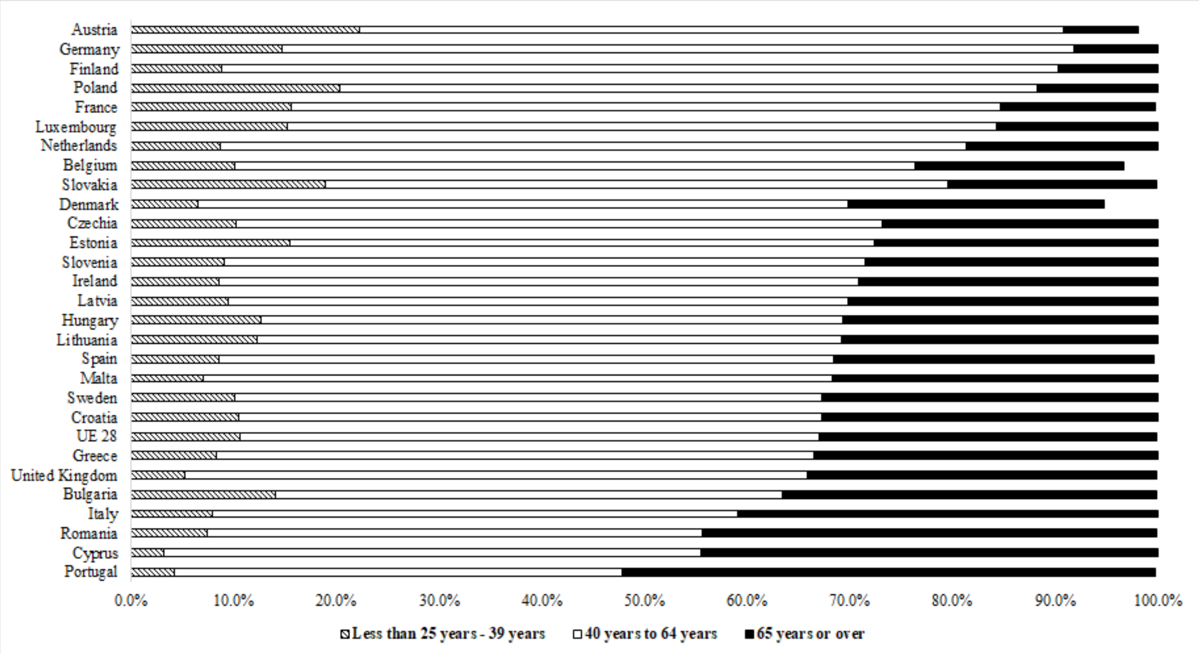

Figure 2 EU-28 and National Distribution of Farm Owners' Age, 2016

Source: authors' elaboration on Eurostat (online code ef_m_farmang)

In particular, the very low - and apparently continuously sharply declining number of farms owned by young people has sparked the investigation of the so-called "young farmer problem" (YFP). As described in Zagata et al. (2017)[1], the YFP consists of several topics: the restructuring of the agricultural sector, the aging of the farmer population, young farmers/new entrants and farm succession, and land abandonment. The latter gained substantial political importance since the '50s, which is when rural societies started to be integrated into a wider economic and social organization.

Land abandonment is defined as the cessation of any agricultural activity on a given surface of the land and its consequences span from environmental to economic. In fact, land abandonment together with other structural issues of the EU agricultural sector induced a shift of the CAP measures towards direct income support and rural development policy instruments. Especially with the Agenda 2000 reform, the EU agricultural policy embraced additional general objectives, namely providing environmental benefits and supporting the competitiveness of rural areas[2]. The following Fischler reform of the CAP in 2003 continued to support improving the environment by introducing the requirement of respecting the cross-compliance, maintaining the plots in Good Agricultural and Environmental Conditions, and following the Statutory Management Requirements defining higher standards for environmental maintenance and protection, animal welfare, and food security. LFAs have been identified by the EC as special areas that need additional support to avoid being abandoned (see Council Regulation 1698/2005, art. 50, 3).

As reported in Terres et al. (2013)[3], the EU enlargement towards the East embraced countries in transition from communist and socialist governments and regimes, which were undertaking a process of land privatization and the dismantling of collective farms. Moreover, while Western Europe seems not to be suffering significantly from this issue, Southern Europe is already flanked by it. The reasons of land abandonment are multiple and may include natural constraints, land degradation, socio-economic factors, demographic structure, and the institutional framework[4]. Land abandonment is a significant concern of policy-makers because of its negative effect on the social, economic, and environmental spheres. Another significant cause of land abandonment is trade policy reforms, as they reduce economic viability, inducing additional abandonment in more marginal agricultural areas. However, these model projections seem to be flawed and inaccurate also because of data availability, uncertainty over the future policy and socio-economic developments, the use of deterministic models, and the assumption that landowners' rationale is purely economic and of the short time lag considered in these models. Indeed, even if farming did not make a profit, operations may not be ceased for many social and cultural reasons. Three main blocks illustrate the drivers of land abandonment:

- Poor external conditions constraining the farming activity (i. e., environmental and biophysical factors);
- Weak farm viability and stability (i. e., the economic performance of farms, usually measured by the Farm Net Value Added). However, economics is not the only element driving farm-related decisions and additional elements must be taken into consideration. Some of these may be the share of CAP support on the total farm income, the volume of new investment as a proxy of dynamism, the age of the tenant and the presence of potential successors (in this regards, the volume of new investments may be used as a proxy for succession

  [5]), and the intensity of the use of land (i. e., gross margin/UAA) may be good indicators for incipient marginalization. External conditions, such as the presence of income and business opportunities outside the agricultural sector or the low rate of full-time employment on farms may also indicate that land abandonment is potentially an outcome

  [6]. On the other hand, the training of additional agricultural advisors may contribute to avoiding land abandonment.
- External factors: an unbalanced development across the sectors in the region together with the evolution of the labor market can entail labor transfers among sectors to the detriment of the agricultural one. The recognition and registration of PDO and PGI products may support the farming activity. Lastly, the conditions of the land market, including the land price, the use of land as well as the legal framework for land succession and purchasing are of utmost importance.

Due to the concern related to the decline of farm successions, which strictly relates to the weak generational renewal within the EU agricultural sector (see[7],[8],[9],[10],[11]), the YFP is a highly debated topic in the political agenda. Indeed, most of the farms across the EU are family-run and, typically, of a small to medium size. Hence, within-family farm succession is the main type of farm transfer in the agricultural sector (see[12],[11]).

The CAP of the EU supports young farmers via both its Pillar I and Pillar II subsidies and measures. Regarding the former, the Young Famers Payment is a compulsory scheme (see the Regulation (EU) No 1307/2013), requiring MSs to allocate up to 2% of the DP envelope. Most MSs opted for setting this payment at 25% of the average DP per hectare, limiting the payment entitlements or the number of hectares at the maximum possible of 90 ha/entitlements. This payment varies from 20 EUR/ha to more than 80 EUR/ha and approximately 4% of basic payment applicants benefited from it in 2015. Regarding the latter, support is given through Priority 2 (*Farm Viability and Competitiveness*) and Focus area 2B (*Facilitating the entry of adequately skilled farmers into the agricultural sector and generational renewal*) (see the Regulation (EU) No 1305/2013). It is worth noting that the endowment and relevance of a given Priority vary substantially from regions/MSs. The most common instrument for Priority 2 is Measure 6 - accounting for more than 90% of the budget allocated to Priority 2B - which supports young farmers via start-up grants, consisting of a maximum of € 70,000 over up to five years. While some MSs grant this support to very small farms, the majority of MSs addresses larger units which may be ten, or more, times the size of the smallest farms financed. Although conditions are different across MSs, farmers have to demonstrate the viability of their businesses in terms of a minimum number of AWUs employed a given size of the operations (expressed as Standard Output, hectares, or number of heads). Actually, the level of support (i. e., a lump-sum) is differentiated by location, size of the established holding, production specialization, amount of investment, provision of additional jobs, and "other". Zagata et al. (2017)[1] recommend continuing to support young farmers, incentivizing farm transfer and startup, as well as favoring access to land. Furthermore, Zagata et al. (2017)[1] identify the reduced and difficult access to capital, the lack of business skills and succession plans, as well as, finally, the need for differentiating the Young Farmers Payment for new entrants as the main hurdles to the successful installation of a young farmer . Zagata and Sutherland (2015)[13]proposed a research agenda in which the YFP is more consistently conceptualized to unveil the role of young farmers in innovation, thoroughly assess regional differences, and identify the process of farm succession, especially for new MSs. Zagata and Sutherland (2015)[13] described how the YFP is evident and consistent for countries in which farms are mainly small, such as Italy, Portugal, Romania, and Greece. On the other hand, countries like Germany, France, Switzerland, Finland, Austria, France, the Czech Republic, and Poland do not envisage any shortage of young farmers. This further highlights the significant variability of the characteristics of the EU farming sector and the different situations it has been in. Measure 112 was introduced by the EC with the 2007-2013 CAP reform to target the establishment of new farming units, disbursing subsidies for a total budget of roughly €5 billion. Measure 112 benefits individuals under 40 years of age who are willing to enter the farming sector by starting their first-in-time agricultural business, according to the business plan they have submitted to being awarded the relevant funding. Interestingly, Zagata and Sutherland (2015)[13] called for a more consistent and refined definition of the YFP, which should reflect this structural issue of small-scale farms mostly in Southern and Eastern European countries. Moreover, this problem is more serious in the marginal and mountainous areas, giving rise to regional differences within MSs which have to be accounted for.

The main areas of concern covered in this section are related to farm succession and the willingness to succeed in the family farm. The extant literature collects numerous studies on the topics, especially over the last five years, which - for the most part - are mainly devoted to understanding their social and cultural causes and impacts rather than focusing on the economic aspects.

Within the former category, Bertolozzi-Caredio et al. (2020)[7] investigated the succession dynamics in extensive livestock farming of two marginal areas in Spain (i. e., Sierra de Guadarrama (Autonomous Community of Madrid) and Hoya de Huesca (Aragón)) employing an iterative method in which interviews, transcription and data analysis feed each other sharping the focus of and improving the quality of the interviews. Data coding was the methodology applied to analyze the data collected. Bertolozzi-Caredio et al. (2020)[7] found that the succession process can be described as a three-steps-system formed by potentiality, willingness, and effectiveness. The willingness step is the pivotal one yet it attracts little attention from policymakers such that a significant share of potential successors does not complete it, hence failing the whole process. Furthermore, Bertolozzi-Caredio et al. (2020)[7] determine that four types of factors affect the succession process: individual, familial, institutional, and contextual. The individual dimension is central to the process, with the remaining factors contributing differently to succession dynamics: while the familial dimension strongly supports the possibility of succession and develops the successor's attributes, both the contextual and individual dimensions enter into the willingness step. Interestingly, concerning the institutional dimension, hence policies, they enter in the last step when the succession effectively takes place although they entail very weak influences in determining who the potential successors will be and on the willingness step. This may be due to the lack of non-monetary support to generational renewal and farmers being potentially unaware of the available policy instruments. Glauben et al. (2004)[14] studied the household and farm characteristics affecting farm succession as captured by the probability of succession, the likelihood of having a successor, and the timing of such succession in Upper Austria. Glauben et al. (2004)[14] found that the likelihood of the farm being transferred and to have an appointed successor is the highest for large and highly-specialized farms as well as the number of family members living on the farm significantly influencing succession plans. The age of the farm owner bears some influence on the probability of succession and on that of having appointed a successor. That is, they both increase with age and then decline again. Concerning the timing of succession, this is delayed as the age increases. Finally, Glauben et al. (2004)[14] concluded that these three aspects of farm succession are inter-related and hence not separable. Pindado et al. (2018)[15] investigated the role of human and social capital in determining the entrance of "new" agents in the European farming sector and established that part-time farmers are less prone to identify new business opportunities; hence, they start less competitive farms. Morais et al. (2017)[16] focused on Brazilian farms, especially on the intentions of the potential successors to take over the farm. Morais et al. (2017)[16] considered three constructs: attitude (the successors' evaluation), perceived norms (successors' perception of social norms), and perceived behavioral control (successors' perception over their own capability). Finally, Conway et al. (2017)[17] studied the transfers of family farms across generations in the Republic of Ireland, surfacing the additional issue that the old generation is reluctant to step aside and transfer the farm. Applying Bourdieu's theoretical framework of symbolic power and violence, Conway et al. (2017)[17] found that family-farm transfers put significant emotional stress on the old farmers delaying and hampering the succession. Accordingly, policy provisions should account for these power relations and the need for older tenants to retain or reassert their authority. Similarly, Conway et al. (2016)[18] stressed how policies should consider the emotional side of farm transfers, protecting the well-being of retiring farmers. Mishra et al. (2010)[19] studied farm succession in the US and found that the age of farmers, educational attainment of farm operators, off-farm work by the operator or operator and spouse, expected household wealth, and farm business location were important determinants for farm succession.

Summarizing the main results from the literature related to farm succession, Suess-Reyes and Fuetsch (2016)[20] offer the latest review on the topic. Investigating which farm characteristics increase the probability of succession, large farms are more likely to be transferred within the family ([21],[22],[14],[23]) mainly due to their potential for ensuring high earnings, hence providing good prospects to the potential successor ([14],[24]). Regarding farm specialization, the literature provides controversial results. On the one hand, Glauben et al. (2004)[14] point to the fact that more specialized — and often large — farms are more production-efficient and already have an appointed successor. On the other hand, it is claimed that diversified farms are associated with a high likelihood of transfer because of the risk-mitigating nature of diversification. Likewise, they are transferred earlier than specialized ones because of the less-specialized knowledge they require for running operations.

Inwood and Sharp (2012)[25] and Wheeler et al. (2012)[26] proved that the existence of a successor increases investments on the farm, fostering growth and adaptation to external events, while, on the opposite, lacking a successor leads to passive management styles, and accelerates the leasing-out of the farm, speeding up retirement and closure ([14],[22]). Mishra and El-Osta (2008)[12] showed that part-time farming and off-farm work (by the operator and the spouse) generate negative prospects for intra-family succession. The distance from the nearest urban center is a statistically significant determinant of the likelihood of boing taken over suggesting that farms located in remote rural areas experience a lower likelihood than less isolated ones[21].

Bohak et al. (2012)[27]unveiled that organic farms are more likely to be transferred because they operate full-time and organic farmers tend to be more engaged with their farming lifestyle. Nevertheless, these determinants are also those that shaped the decision to convert to organic production, hence questions regarding the causal nature of this result may arise.

Cavicchioli et al. (2015)[28], Kimhi and Nachlieli (2001)[29], Mishra and El-Osta (2008)[12] showed that the higher the parents' educational level, the more likely is that the farm will be transferred within the family, representing a sort of intellectual capital. Nonetheless, Mishra and El-Osta (2008)[12] and Mishra et al. (2010)[19] also pointed out how higher educational levels may delay succession planning, entailing additional investment to foster earnings. Nevertheless, concerning the educational level of the offspring, Aldanondo Ochoa et al. (2007)[21] and Hennessy and Rehman (2007)[30] showed that farm take-over is less likely the easier it is to find a more remunerative job in the labor market. However, as described by Cavicchioli et al. (2015)[28], holding high educational levels related to agriculture, as expected, increases the likelihood of farm succession, besides accelerating it, while non-agricultural studies may slow it down[22].

Regarding the age of the farmer, there is evidence claiming that the likelihood of succession increases with the age of the operator, even though at declining rates (e. g., [29],[19]). Indeed, Glauben et al. (2004)[14]found an inverse U-shaped relationship because, after reaching the age at which the likelihood of succession is at its peak, it decreases again.

The number of children affects positively the likelihood of succession, with a larger impact if they are males than females[14]. However, due to increasing competition among the young, it could be that a high number of potential heirs negatively affects the willingness to take over the farm[28].

On the economic and more CAP-related side, Pesquin et al. (1999)[31] investigated the reasons for the prevalence of intergenerational succession in the farming sector in Europe. They found that the intra-family succession allows the family to gain from the intergenerational risk-sharing. Furthermore, it provides an implicit insurance agreement, that is it acts as a pension fund when generations — retired parents and succeeding children — overlap, hence share income. The transition of the farm is smoother when it is inter-familiar, reducing transfer costs and lowering the taxes paid when transferring it.

Mishra and El-Osta (2008)[12] analyzed the impact of the USA governmental farming policy on succession decisions and the possibility of intra-family transfers of the farm. Mishra and El-Osta (2008)[12] and Key and Roberts (2006)[32] found that policies significantly influence succession decisions because government payments may ease liquidity constraints, lowering borrowing costs. Moreover, expecting government payments may increase farms' net worth given the positive impact they have on land values. Besides, farm wealth as well as the age and educational attainment of the farm operators shape the probability of a succession occurring. Especially, farm ownership, the education and marital status of the operator encourage family-based succession decisions. On the other hand, the presence of retirement income seems to prevent having an intra-family successor.

Bertoni and Cavicchioli (2016)[33] studied farm succession in horticultural farms in Italy. Besides testing the effects of well-established determinants of farm succession, i.e., farm, farmers, and family characteristics, Bertoni and Cavicchioli (2016)[33] considered also local labor market conditions such as the income gap between agricultural and non-agricultural activities and the population density around the farming unit. Bertoni and Cavicchioli (2016) indicated that both well-established and new factors influence the probability of succession with labor market conditions following the occupational choice theory only when less-inhabited areas are investigated. That is, the wider the gap between sectors the less likely it is that the farm succession will take place; on the other hand, in highly-populated areas the rural-urban effect is significant, which fosters succession. Alike, Cavicchioli et al. (2018)[34]recently studied horticultural farms in Italy, deepening the understanding of the factors driving the willingness to take over the farm by potential successors. Cavicchioli et al. (2018)[34] found that farm labor migration — as the outcome of the application of occupational choice theory — and local labor market conditions — proxied by the income gap between sectors, employment rate, and population density — had a non-linear negative relationship with the willingness to take over the farm. Indeed, increasing the income gap and population density had a U-shaped effect on succession. On the other hand, increasing employment rates generated a bell-shaped effect on succession. Proximity to wealthy areas may represent a factor boosting farm continuity, due to more opportunities for horticultural farms to benefit from higher income levels. On the other hand, above a certain threshold in the income and prosperity secured by being involved in non-agricultural sectors, the positive effect of the proximity to wealthy areas on succession vanishes and the relationship turns negative as expected.

Leonard et al. (2017)[11] described how European farms are aging at a fast pace given the evidence of the positive correlation between younger farmers and more efficient/innovation of farms ([5],[35],[36]). However, static land markets lead to capital accumulation because of fear of an uncertain financial condition in the future, hence the unwillingness to sell or transfer farm assets. This is further fostered by state assistance, i. e., DP, which makes older farmers remain on the farm since it is financially sustainable. The farming sector then consequently quickly ages. Agricultural policy has disregarded supporting the transfer of farms until the Early Farm Retirement Scheme of the CAP has been started to tackle the problem of aging farmers. This optional instrument did not exert a very significant effect ([37],[38]). These policy schemes intend to achieve transferring the farm at earlier stages by granting retired farmers a sufficient income, in the form of a pension for example, and making the farm business viable to attract, and hence support, the new entrant. This would decrease income uncertainty and consequently their perceived economic risk [39]. Albeit it can be generally argued that farmers are risk-averse, there is no specific study unveiling whether succession and inheritance are perceived as risky. Koundouri et al. (2009) [39] found that the main concerns of farmers related to succession and inheritance are the (in)ability of the farm to generate sufficient income to support both the entrant and the retiring farmers, and which part of the remaining income should be transferred to the farm before passing away. Interestingly, Koundouri et al. (2009) [39] found that receiving DP and a pension into the retirement years is in comport with the CAP rules, which delays the transfer of the farm until the death of the older holder.

As highlighted at the beginning of this section, Suess-Reyes and Fuetsch (2016)[20] reinforced the idea that related literature lacks a consistent theoretical framework, hampering the creation of connections between diverse results from different approaches and areas; hence slowing down the creation of a scientific discourse linking all these research efforts. This thought is shared by Leonard et al. (2017)[11] who stated how research to date has not informed much the agricultural policy.

3.2 Does the CAP foster employment on the farm and in rural areas?

Since there are not instruments directly aimed at preserving or stimulating agricultural employment, it is crucial to investigate the impact of both coupled and de-coupled CAP DP on farm labor. It is noteworthy that the literature on the impact of the CAP on farm employment cannot be conclusive due to the diversity of the structural characteristics of MSs, policy application, and also the diverse instruments analyzed.

Breustedt and Glauben (2007)[40] and Olper et al. (2014)[41] stated that the CAP instruments supporting income, investment, and training helped in maintaining agricultural jobs in rural areas but, depending on the instruments and how the CAP is implemented at both national and regional levels, it may result in some negative effects (e. g., [42],[43]). For example, Alexiadis et al. (2013)[44] support the idea that the CAP promoted mechanization, which would bear negative impacts on farm employment. The latter has been of particular interest since the CAP transition to DP. Indeed, decoupling provides support without requiring more work (but more land, rather), hence this reform could decrease farm employment ([45],[46]).

Psaltopoulos et al. (2006)[47] found positive effects of the MacSharry Reform of 1992 on rural employment via the reduction of rural migration into the cities in Greece, while Gohin and Latruffe (2006) [48], Elek et al. (2010) [49],Genius (2013)[50] found a negative impact of the 2003 Reform.

Regarding ex-ante studies, Helming and Tabeau (2018)[51] estimated the impact of the CAP reforms on farm employment up to 2020, indicating that reallocating the budget of Pillar I to coupled agricultural labor subsidy would increase the average employment in agriculture. Dwyer et al. (2018)[52] stated that they can infer CAP measures for young farmers for the planning period 2014-2020 to support the maintenance and the creation of employment in agriculture as they offer support to farm succession ensuring successful farm transfers. These results are obtained using a range of different methods of analysis, namely MCA, econometrics, and CGE models. It is worth noting that in special case studies, CAP measures help retain agricultural jobs in rural areas especially when they are targeted together with advising and training, improving the performances of both the employment and the business. Interestingly, Dwyer et al. (2018)[52] classified all the CAP measures which should impact generational renewal: for Pillar I measures included DP and payments for young farmers; for Pillar II mainly Priority 2, especially the Focus Area 2b "Generational Renewal", 2a "Restructuring", but also Priority 1, 3, 4, 5, and 6 (i. e., Measures 6.1, 4.1, 4.2, 6.2, 6.3, 6.4, 6.5, 7.3, 16, 9, 4.3, 8.1, 8.2, 8.6, 1.1, 1.2, 1.3, 2.1, 2.3, 10.1, 13.1, 13.2, 13.3, 7, 19, 11.3, 3.1, 3.2).

Dupraz and Latruffe (2015)[42]investigated French field crop farms over the period 1990-2007. They explored the determinants of the amount of family (unpaid), hired, and contract labor employed on the farm focusing especially on the role of the CAP reforms, namely those that occurred in 1992 (MacSharry Reform), 2000 (Agenda 2000), and 2003 (Fischler Reform), and the different types of CAP payments, i. e., DP, decoupled DP, agri-environmental, investment, and LFA payments. Relying on the French FADN dataset, and based on the farm profit maximization framework, Dupraz and Latruffe (2015)[42] employed a system of three equations, one for each type of labor, with a censored one. The results point to a weak effect of the MacSherry Reform despite the negative effect of crop subsidies on labor demand. On the contrary, both the 2000 and 2003 Reforms show significant negative effects on labor demand, except for the latter on hired labor. Concerning specific subsidies, area and Single Farm Payments both hamper the three different labor demand functions, while Pillar II instruments increase them. Therefore, Dupraz and Latruffe (2015)[42] unveil that the more decoupled the payments the lesser the labor demand. While such results may be generalized for other farms in the EU specialized in crop output, Pillar II measures may vary widely across MSs, and may generate opposite results depending on the reason why these subsidies were disbursed (e. g., farm conversion to organic or to more conservative practices, with the latter demanding smaller amounts of labor). Dupraz and Latruffe (2015)[42] concluded that the asset of the CAP 2014-2020 would have detrimental effects the farm labor demand, although this depends on the level of payments under Pillar I and Pillar II - as Pillar II may countervail the negative effects of Pillar I. Rizov et al. (2018)[53] investigated the influence of the CAP on the (indirect) generation of non-farm jobs in rural small and medium enterprises. They use a macroeconomic approach using firm data from the UK FAME dataset for the period 2006-2014. Using a firm employment function estimated using a Generalized Method of Moments (GMM) on both static and dynamic employment models, the quantitative evidence points to positive spillover effects of the CAP on non-farm job creation that are small but significant in economic terms. Interestingly, Pillar I payments entail stronger effects than Pillar II. Manos et al. (2009)[54] applied an MCA model to investigate the impact of tobacco diversification alternatives on employment in Greece—among other things. Estimating a farmers' utility function allows considering different farm behaviors (e. g., profit maximization, labor, the risk) and simulating different scenarios and policies, i. e., different levels of decoupling in the 2003 Reform context. Concerning labor, decoupling of tobacco payments provides a reduction of farm labor use claiming that farmers would switch to less profitable, less labor-intensive, and more mechanized crops. Petrick and Zier (2011)[55] conducted an econometric ex-post evaluation of CAP subsidies on farm labor in Germany counties for the period 1999-2006. Applying a difference-in-difference approach, Petrick and Zier (2011)[55] were able to estimate the impact of the full CAP portfolio of subsidies. They concluded that the null effect of LFA and investment aid payments on employment, besides decoupling, led to labor shedding as spending on more technologies, marketing, and the development of rural areas provoked job losses in the farming sector. On the contrary, AEM keep or induce the adoption of labor-intensive technologies.

Mattas et al. (2011)[56] estimated the CAP effects on employment in five EU regions belonging to Italy, Greece, UK, Sweden, and Germany. Applying PMP and IO models, they demonstrated that the CAP, in particular Pillar II subsidies, maintains the employment levels in both farm and non-farm sectors. Wier et al. (2002)[57] studied the effect of the Agenda 2000 Reform on a variety of elements, among which employment, in Denmark, via an integrated model system for the period 1999-2006. Wier et al. (2002)[57] found negative employment effects due to the switching towards more gross-margin-generating and less intensive crops.

Petrick and Zier (2012) [43], using a panel dataset of 69 German regions for the period 1994-2006, estimated the CAP impact on agricultural employment by estimating a dynamic labor demand model. Results suggest that agricultural employment slowly adjusts to external changes, and family labor does so at an even slower pace. Regarding policy instruments, neither DP, LFA nor AEM bear any effect on farm employment, while some significant and positive effects arise due to the disbursement of investment subsidies. Notably, they found that the decoupling of 2005 accelerated labor cuts. Petrick and Zier (2012) [43] concluded that the CAP has not been particularly effective in maintaining and creating jobs. Pufahl and Weiss (2009)[58]deployed a semi-parametric Propensity Score Matching approach to unveil the positive effects of the AES on input (labor) use in individual farms in Germany using accountancy panel datasets for the period 2000-2005. Olper et al. (2014)[41]studies the determinants of out-farm migration in 150 EU regions for the period 1990-2009 using the theory of occupational choice and labor migration decisions as well as estimating the associated empirical models by GMM. Olper et al. (2014)[41] found that the CAP generally has a positive and significant ability to maintain jobs in agriculture, despite an economic effect that is moderate and varied depending on the policy instrument analyzed. Olper et al. (2014)[41] stated that as long as the CAP was able to actually transfer income to farmers, it would reduce out-farm migration strongly. Indeed, using both static and dynamic representations, and accounting for potential payment endogeneity, Pillar I subsidies were found to be the most effective in retaining jobs, followed by Pillar II ones.

Key and Roberts (2006)[32]studied the role of US DP on farm businesses survival, paying special attention to farm size. Key and Roberts (2006)[32] found that subsidies have small but significant positive effects on farm survival. Ahearn et al. (2006)[59] investigated the effect of more decoupled payments that were introduced by the 1996 US Farm Act on the labor allocation in farm households, finding that government payments, both coupled and decoupled, entail negative effects on the participation of farm households to off-farm jobs. Ahearn et al. (2006)[59] explained how receiving coupled payments can be seen as an increment in farm wage rates; hence potentially increasing the use of labor. However, if the payment is coupled to a less labor-intensive agricultural product, the effect would be the opposite. El-Osta et al. (2004)[60]conducted a similar study using the ARMS database. Similarly, El-Osta et al. (2004)[60] concluded that government payments increase the volume of on-farm work to the detriment of off-farm jobs. This occurs independently regardless of the payments being tied to current or not-current production.

3.3 Defining and investigating farm viability

Viability in agricultural economics relates to a multifaceted concept embracing economic, environmental and social dimensions of farms and rural areas. Therefore, viability might be considered a synonymous of "sustainability". Viability shares with the concept of sustainability the multidimensional setting, ie the three pillars of sustainability, and the time frame, but in a wider perspective. According to Latruffe et al. (2016)[61], dealing with the concept of economic viability, economic sustainability is "viewed as economic viability, namely whether a farming system can survive in the long term in a changing economic context". We can argue that the viability concept can be applied both in short- and long-term domain, so that sustainability is conceivable as an embedded concept of viability. The following table reports a list of papers providing a definition of viability.

Location	Reference	Definition of viability
USA	Smale et al. (1986:14)[62, p.14]	A level of annual cash income sufficient to cover farm operating costs, meet the households minimum consumption needs, replace capital items at a rate that ensures constant serviceability of the capital stock, and finance loan retirement as scheduled
Ireland	Frawley and Commins (1996:21)[63, p.21]	A viable farm (is described) as one having (a) the capacity to remunerate family labor at the average agricultural wage, and (b) the capability to give an additional 5 percent return on non-land assets
Canada	Scott (2001:17)[64, p.17]	Broad goals are basic livelihood security for farmers, a return on investment sufficient to encourage investments in quality food production and responsible land stewardship
Spain	Argilés (2001:96)[65, p.96]	Farm viability defined as its ability to remunerate working time put in by family members over a long period at a comparable wage to that available from alternative work, and the contrary for non-viability
USA	Adelaja et al. (2004) [66]	A farm is defined as economically viable when it generates enough revenue from its operations to cover all variable and fixed costs of production, all appropriate family living expenses, and capital replacement costs
European Union	Abler (2004:9) [67, p.9]	Viability of rural areas can be interpreted as the capability to have an "economic value above and beyond their value-added in the goods and services they produce" [67, p.9]
Greece	Aggelopoulos et al. (2007:896) [68, p.896]	Viable farms are farms which render family farm income per used family human labor unit (HLU) higher than the reference income (the Ministry of Agriculture Development annually determines the reference income as equal to approximately 80 percent of the comparable income) and use at least 1 HLU
Ireland	Hennessy et al. (2008:17) [69, p.17]	An economically viable farm is defined as one having (a) the capacity to remunerate unpaid family labor at the average agricultural wage, and (b) the capacity to provide an additional 5 percent return on non-land assets – these include the capital value of machinery, livestock and production quotas
France	Zham et al. (2008:272) [70, p.272]	Viability involves, in economic terms, the efficiency of the production system and securing the sources of income of the farming production system in the face of market swings and uncertainties surrounding DP
European Union	Vrolijk et al. (2010:20) [71, p.20]	Financial Viability Categories (in the context of reduced subsidy payments in Europe): Category 1: farming provides a positive income higher than opportunity costs. Category 2: farming provides a positive income, but the rewards for the farmer's input of labor and capital are less than he/she could earn in other economic activities. Category 3: farming provides no positive income, but it still provides positive cash flow. Category 4: farming provides no positive income and no positive cash flow. Category 5: farm income has been negative during the reference period before the reduction of payments
Norway	Olsson et al. (2011:253) [72, p.253]	The concept of "rural viability" in this paper is used as a dimension of sustainable development, addressing economic, cultural, and environmental factors in the study area

Lithuania	Savickienė et al. (2015:413) [73, p.413]	The economic viability of a farm is its capability to survive, live, and develop by using the available resources
Scotland/Sweden	Barnes et al. (2014:4) [74, p.4]	Do not define farm economic viability, however, state: "Whilst viability must include the ability of business entities to meet their operating expenses and financial obligations, there must be some accommodation for future growth. Ultimately, studies on agricultural viability attempted to understand the criteria for failure at the farm level and identify factors which determine a switch from viable to non-viable and the consequences of consistent underperformance in the sector"[74, p.4]
USA	Graddy-Lovelace and Diamond (2017:74) [75, p.74]	This article emerges from a normative commitment to agrarian viability, defined as the ability of small and mid-sized growers to maintain a decent livelihood and farm in a way that does not degrade ecosystems or rural communities
Italy	Coppola et al. (2020:4) [76, p.4]	In presenting the methodological framework they state: "the farm viability has been analyzed distinguishing between the short and medium-long term. In the short term, a holding has been considered viable to the extent that it is able to ensure a level of income per family work unit at least equal to a given reference income. In the medium-long term, the level of income must also adequately remunerate all the factors owned by the farmer and his/her family at their opportunity cost. Only in this case, in fact, farmers will continue to invest in the sector in the medium-long term, contributing to maintaining a lively socio-economic fabric in rural areas" [76, p.4]

Table 18 Farm viability in the literature

Source: extended from O'Donoghue et al. (2016) [77]

Despite the cross-cutting meaning, most of the literature on this topic applies the concept of viability for evaluating the economic resilience of farms within their territory. In what follows, we propose a brief literature review of the main studies adopting FADN variables to assess economic viability.

O'Donoghue et al. (2016) [77] propose a comparative cross-country analysis using FADN integrated with the data of pilot cases originating from the EU FP7 research project FLINT (Farm-Level Indicators on New Topics in policy evaluation), with the aim to calculate a viability/vulnerability rate at farm level (Vrolijk et al., 2016) [78]. The main index adopted is the Family Farm Income (FFI), one of the economic variable of FADN, providing the remuneration to fixed factors of production of the farm (work, land, and capital) and remuneration to the entrepreneur's risks (loss/profit) in the accounting year (EC, 2015) [79]. The key issue in measuring the economic viability is the threshold definition, ie the minimum economic value beyond which the farm falls in the viability area. In this respect, Hennessy et al. (2008) [45] suggest using as a threshold the minimum agricultural wage defined by national public bodies, such as the Irish Labor Court. Unfortunately, this wage level is not available for all EU MSs, thus preventing cross-country comparisons. This drawback is solved by O'Donoghue et al. (2016) [77] by using the average paid wage calculated using FADN variables (total paid wage divided by total paid labor hours) and assuming that this wage level can approximate to the minimum wages defined nationally. Another issue in the viability analysis is the range of the viability indicators. Hennessy et al. (2008) [45] and Hanrahan et al. (2014) [80] consider viable the farms with an FFI exceeding the average agricultural wage and providing a 5 percent return on the capital invested in non-land capitals, such as machinery, livestock, and production quota. This an opportunity cost interpreted as an extra risk-free revenue to cope with, ie an opportunity cost of investing capital in a low-risk conservative investment, such as a bank account (Hennessy et al., 2008) [45]. Although they recognize the relevance for Ireland, O'Donoghue et al. (2016) [77] apply a condition on all own capital (land and non-land capital) using as reference cost of own capital a fixed percentage based on long-term European Central Bank interest rate. Farms that are not able to cover the cost of their own capital cannot contribute to their development in the long-term, but rather to their survival. O'Donoghue et al. (2016) [77] measure viability considering also two different measures of FFI: the FFI per family working unit and FFI per worked hour. The first measure evaluates the advantage to continue to invest in the farm activity, while the second one the advantage to spend one hour working on the farm. All these articulated procedures allow O'Donoghue et al. (2016) [77], following the approach of Hennessy et al. (2008) [45], to classify farms into three categories: viable, sustainable and vulnerable farms. While this approach identifies the degree of the economic viability of FADN farms, it misses identifying the issues affecting the vulnerable farms, such that further social and economic indicators are needed for a comprehensive assessment of viability at the farm level.

A viability measure based on FFI is proposed by Vrolijk et al. (2010) [71] with the aim to assess the farm viability after the change in the level of the CAP intervention. The study assesses a scenario where decoupled DP are abolished and a more extreme scenario, where all farm subsidies are removed. The study focuses on the EU-25 and the main source of information is the FADN. The viability analysis is purely financial and allowed to classify farms into 5 categories: 1) FFI is higher than the opportunity cost of own labor and own capital items (position to save money for farm investments); 2) absolute level of FFI above zero (farms with rather good perspectives of development); 3) FFI is negative after policy change, but postponing depreciation is an option (difficulty to invest); 4) negative FFI cannot be compensated by postponing depreciation (farms cannot invest); 5) FFI is negative before CAP change and worsens after the change (withdrawal perspective). Only farms present in FADN for three succeeding years have been included in the analysis. The study is of rather little meaningfulness in terms of methodology overview, but it is possible to see an approach similar, though more simplified, to that adopted by O'Donoghue et al. (2016) [77], where FFI is compared with the opportunity cost of capital and labor. Cost of own labor is calculated as the average of paid labor in a specific region (NUTS 2); although not specified, we assume the average value of paid labor is calculated from FADN data. While the cost of own capital is calculated as a fixed percentage of own equity (percentage based on 10 years government bonds retrieved through EUROSTAT data). Authors point out that the viability measure allows to evaluate the impact of CAP mechanisms on the survival possibility of farms, but it cannot provide in-depth insights on the structural, economic and financial reasons of economic, organizational inefficiency neither on the causes of farm poverty. According to Spicka et al. (2019) [81], the viability measure proposed by Vrolijk et al. (2010)[71]complies with the economic value-added theoretical approach of Chen and Dodd (1997) [82], which was at the base of the INFA Performance Indicator Diagnostic System (Neumaierova and Neumaier 2014) [83]. Actually, the INFA approach calculates the return on equity at the firm-level comparing it with the opportunity cost of the own capital.

According to Spicka et al. (2019) [81], the opportunity cost of labor should refer to the average wage in the economy or in the region because it represents the best alternative to the value of time spent in agricultural activities. Therefore, the average opportunity cost of labor calculated through FADN wages would not represent the suitable best alternative. The same authors sustain that FFI per family working unit cannot be applied to large farms that typically hire non-family workers and benefit from external professional services. Spicka et al. (2019) [81], recommend adopting another income indicator, such as the Farm Net Value Added (FNVA) per AWU (as defined by the SE425 according to the FADN Standard Results methodology). This FADN variable is suitable for comparing the economic viability of different typologies of farms (e. g., small vs. large farms, family vs. non-family farms). In this respect, "The economic viable farm is able to cover labor cost, land and capital cost by the FNVA". However, Spicka et al. (2019) [81] argue that FNVA per AWU is not a valid indicator of farm viability, so that it should be modified to measure the "potential income" per AWU, obtained as FNVA minus interest paid and rent paid (MFNVA). MFNVA should cover the paid wages, the unpaid workforce, including the opportunity cost of capital; moreover, MFNVA per AWU, can be compared with the threshold wage, ie the opportunity cost of labor. Another FADN economic variable that can support the economic viability measure is the cash flow. The standard economic variables SE526 (it considers the balance of current subsidies and taxes, including investments) and SE530 (SE526 + balance of operations of liabilities and assets) provides the information about the farms' cash flows. Spicka et al. (2019) [81] assert that SE530 criteria for evaluating farm viability are similar to the approach followed by the European Investment Bank to evaluate what it calls inappropriately "economic sustainability".

More recently, Coppola et al. (2020) [76] propose an economic viability indicator for Italian agriculture using FADN data for the three-year period 2015–2017. The objective of the paper is to evaluate farm viability in the short and medium-long term. Coppola et al. (2020) [76] define viable a farm in the short term when it is able to ensure to family workers a level of income greater than or equal to a reference income per AWU; while a farm is viable in the medium-long term when the level of income per family worker is able to cover the opportunity cost of labor and "to remunerate all the factors owned by the farmer and his/her family at their opportunity cost". Farm net income (FNI) is the FADN variable used for assessing the farm viability. In the short term, Coppola et al. (2020) [76] suggest obtaining the viability measure by operating the difference between the FNI at farm level and a reference income, obtained from the average annual net earnings of an Italian worker provided by EUROSTAT database. This difference is named viability index. In the medium-long term, farm viability is obtained by a ratio between FNI and Reference Net Income (RNI), obtained as the sum of the opportunity costs of all the farmer's family factors, i. e., (family labor hours in a year * hourly average agricultural wage) + (value of working capital * average annual return) + (value of land capital * average land rent). Hourly average agricultural wage, average annual return, and average land rent have been collected from the Italian Ministry of Labor and Social Policies, Italian Ministry of Economy and Finance, and FADN respectively. The results of the ratio between FNI and RNI is called by Coppola et al. (2020) [76] the Profitability Index (PI): "when PI is equal or higher than 1 the agricultural activity remunerates all the family factors at their opportunity costs and the farm can be considered viable in the medium-long term". It is noteworthy that the viability is tested according to two different policy scenarios: with CAP subsidies and without CAP subsidies. Furthermore, authors apply a multinomial logit model for detecting the factors (socio-demographic characteristics of the farmer, structural characteristics of the farm, and productive choices of the farmer) affecting the farm viability in the short and in the medium-long term. Coppola et al. (2020) [76], as well as Vrolijk et al. (2010) [71], admit that FADN cannot inform about the off-farm incomes of family members (eg pensions, rents), so that this factor can explain the reason why some unviable farms persist in the sector. Another important aspect on which authors insist is the level of dependence from public subsidies. The viability analysis allows demonstrating the extent to which the CAP payments affect the farm survival. Authors point out that without CAP payments, the role of farms size in economic viability significantly decreases, suggesting the need to refocus CAP towards structural change to ensure farm autonomy and stabilize rural communities.

3.4 References

1. ^ 1 2 3 L. Zagata et al., "Young farmers–Policy implementation after the 2013 CAP reform," Brussels: European Parliament, Policy Department for Structural and Cohesion Policies, 2017.
2. ^ P. Pointereau et al., "Analysis of farmland abandonment and the extent and location of agricultural areas that are actually abandoned or are in risk to be abandoned. European Commission Joint Research Centre," Institute for Environment and Sustainability, 2008.
3. ^ J. M. Terres, Nisini Scacchiafichi, Luigi, and E. Anguiano, "Assessing the risk of farmland abandonment in the EU," 2013. doi: LB-NA-25783-EN-N.

4. ^ FAO, "The Role of Agriculture and Rural Development in Revitalizing Abandoned/Depopulated Areas Document prepared under the supervision of the Policy Assistance Branch Regional Office for Europe," no. June, 2006.
5. ^ 1 2 C. Potter and M. Lobley, "Unbroken Threads? Succession and its Effects on Family Farms in Britain," Sociologia Ruralis, vol. 36, no. 3, pp. 286–306, Dec. 1996, doi: 10.1111/j.1467-9523.1996.tb00023.x.
6. ^ S. Rickebusch, M. Gellrich, H. Lischke, A. Guisan, and N. E. Zimmermann, "Combining probabilistic land-use change and tree population dynamics modelling to simulate responses in mountain forests," Ecological Modelling, vol. 209, no. 2–4, pp. 157–168, Dec. 2007, doi: 10.1016/j.ecolmodel.2007.06.027.
7. ^ 1 2 3 4 D. Bertolozzi-Caredio, I. Bardaji, I. Coopmans, B. Soriano, and A. Garrido, "Key steps and dynamics of family farm succession in marginal extensive livestock farming," Journal of Rural Studies, vol. 76, no. June 2019, pp. 131–141, 2020, doi: 10.1016/j.jrurstud.2020.04.030.
8. ^ R. J. F. Burton and H. Fischer, "The Succession Crisis in European Agriculture," Sociologia Ruralis, vol. 55, no. 2, pp. 155–166, Apr. 2015, doi: 10.1111/soru.12080.
9. ^ H. Fischer and R. J. F. Burton, "Understanding Farm Succession as Socially Constructed Endogenous Cycles," Sociologia Ruralis, vol. 54, no. 4, pp. 417–438, Oct. 2014, doi: 10.1111/soru.12055.
10. ^ J. G. Regidor and B. Sánchez-Reyes, "EU measures to encourage and support new entrants," A study by the European Parliament available at: http://www. europarl. europa. eu/studies, 2012.
11. ^ 1 2 3 4 B. Leonard, A. Kinsella, C. O'Donoghue, M. Farrell, and M. Mahon, "Policy drivers of farm succession and inheritance," Land Use Policy, vol. 61, pp. 147–159, Feb. 2017, doi: 10.1016/j.landusepol.2016.09.006.
12. ^ 1 2 3 4 5 6 A. K. Mishra and H. S. El-Osta, "Effect of agricultural policy on succession decisions of farm households," Review of Economics of the Household, vol. 6, no. 3, pp. 285–307, Apr. 2008, doi: 10.1007/s11150-008-9032-7.
13. ^ 1 2 3 L. Zagata and L. A. Sutherland, "Deconstructing the 'young farmer problem in Europe': Towards a research agenda," Journal of Rural Studies, vol. 38, pp. 39–51, Apr. 2015, doi: 10.1016/j.jrurstud.2015.01.003.
14. ^ 1 2 3 4 5 6 7 8 9 T. Glauben, H. Tietje, and C. R. Weiss, "Intergenerational Succession in Farm Households: Evidence from Upper Austria," Review of Economics of the Household, vol. 2, no. 4, pp. 443–462, Dec. 2004, doi: 10.1007/s11150-004-5656-4.
15. ^ E. Pindado, Sánchez, Mercedes, J. A. A. M. Verstegen, and T. Lans, "Searching for the entrepreneurs among new entrants in European Agriculture: the role of human and social capital," Land Use Policy, vol. 77, pp. 19–30, Sep. 2018, doi: 10.1016/j.landusepol.2018.05.014.
16. ^ 1 2 M. Morais, E. Binotto, and Borges, João Augusto Rossi, "Identifying beliefs underlying successors' intention to take over the farm," Land Use Policy, vol. 68, pp. 48–58, Nov. 2017, doi: 10.1016/j.landusepol.2017.07.024.
17. ^ 1 2 S. F. Conway, J. McDonagh, M. Farrell, and A. Kinsella, "Uncovering obstacles: The exercise of symbolic power in the complex arena of intergenerational family farm transfer," Journal of Rural Studies, vol. 54, pp. 60–75, Aug. 2017, doi: 10.1016/j.jrurstud.2017.06.007.
18. ^ S. F. Conway, J. McDonagh, M. Farrell, and A. Kinsella, "Cease agricultural activity forever? Underestimating the importance of symbolic capital," Journal of Rural Studies, vol. 44, pp. 164–176, Apr. 2016, doi: 10.1016/j.jrurstud.2016.01.016.
19. ^ 1 2 3 A. K. Mishra, H. S. El-Osta, and S. Shaik, "Succession decisions in US family farm businesses," Journal of Agricultural and Resource Economics, pp. 133–152, 2010.
20. ^ 1 2 J. Suess-Reyes and E. Fuetsch, "The future of family farming: A literature review on innovative, sustainable and succession-oriented strategies," Journal of Rural Studies, vol. 47, pp. 117–140, Oct. 2016, doi: 10.1016/j.jrurstud.2016.07.008.

21. ^ 1 2 3 A. M. Aldanondo Ochoa, V. Casanovas Oliva, and C. Almansa Saez, "Explaining farm succession: the impact of farm location and off-farm employment opportunities", Spanish Journal of Agricultural Research, vol. 5 no. 2, pp. 214-225, 2007.
22. ^ 1 2 3 T. Glauben, M. Petrick, H. Tietje, and C. Weiss, "Probability and timing of succession or closure in family firms: a switching regression analysis of farm households in Germany," Applied Economics, vol. 41, no. 1, pp. 45–54, Jan. 2009, doi: 10.1080/00036840601131722.
23. ^ Kerbler, Boštjan, "Factors affecting farm succession: The case of Slovenia," Agricultural Economics, vol. 58, no. 6, pp. 285–298, 2012.
24. ^ M. Calus, G. Van Huylenbroeck, and D. Van Lierde, "The relationship between farm succession and farm assets on Belgian farms," Sociologia ruralis, vol. 48, no. 1, pp. 38–56, 2008.
25. ^ S. M. Inwood and J. S. Sharp, "Farm persistence and adaptation at the rural–urban interface: Succession and farm adjustment," Journal of Rural Studies, vol. 28, no. 1, pp. 107–117, 2012.
26. ^ S. Wheeler, H. Bjornlund, A. Zuo, and J. Edwards, "Handing down the farm? The increasing uncertainty of irrigated farm succession in Australia," Journal of Rural Studies, vol. 28, no. 3, pp. 266–275, Jul. 2012, doi: 10.1016/j.jrurstud.2012.04.001.
27. ^ Z. Bohak, A. Borec, and T. Jernej, "Succession status of organic and conventional family farms in southwestern Slovenia," Društvena istraživanja, vol. 20, no. 4, pp. 1183–1199, 2012.
28. ^ 1 2 3 D. Cavicchioli, D. Bertoni, F. Tesser, and D. G. Frisio, "What Factors Encourage Intrafamily Farm Succession in Mountain Areas?," Mountain Research and Development, vol. 35, no. 2, p. 152, May 2015, doi: 10.1659/MRD-JOURNAL-D-14-00107.1.
29. ^ 1 2 A. Kimhi and N. Nachlieli, "Intergenerational Succession on Israeli Family Farms," Journal of Agricultural Economics, vol. 52, no. 2, pp. 42–58, 2001.
30. ^ T. C. Hennessy and T. Rehman, "An Investigation into Factors Affecting the Occupational Choices of Nominated Farm Heirs in Ireland," Journal of Agricultural Economics, vol. 58, no. 1, pp. 61–75, Feb. 2007, doi: 10.1111/j.1477-9552.2007.00078.x.
31. ^ C. Pesquin, A. Kimhi, and Y. Kislev, "Old age security and inter-generational transfer of family farms," European Review of Agricultural Economics, vol. 26, no. 1, pp. 19–37, 1999, doi: 10.1093/ERAE.
32. ^ 1 2 3 N. Key and M. J. Roberts, "Government Payments and Farm Business Survival," American Journal of Agricultural Economics, vol. 88, no. 2, pp. 382–392, 2006, doi: 10.1093/ajae/aap014.
33. ^ 1 2 D. Bertoni and D. Cavicchioli, "Farm succession, occupational choice and farm adaptation at the rural-urban interface: The case of Italian horticultural farms," Land Use Policy, vol. 57, pp. 739–748, Nov. 2016, doi: 10.1016/j.landusepol.2016.07.002.
34. ^ 1 2 D. Cavicchioli, D. Bertoni, and R. Pretolani, "Farm succession at a crossroads: The interaction among farm characteristics, labour market conditions, and gender and birth order effects," Journal of Rural Studies, vol. 61, pp. 73–83, Jul. 2018, doi: 10.1016/j.jrurstud.2018.06.002.
35. ^ M. Lobley, J. Baker, and I. Whitehead, "Farm Succession and Retirement: Some International Comparisons," Journal of Agriculture, Food Systems, and Community Development, vol. 1, no. 1, pp. 49–64, Aug. 2010, doi: 10.5304/jafscd.2010.011.009.
36. ^ P. Howley, O. Donoghue, Cathal, and K. Heanue, "Factors Affecting Farmers' Adoption of Agricultural Innovations: A Panel Data Analysis of the Use of Artificial Insemination among Dairy Farmers in Ireland," Journal of Agricultural Science, vol. 4, no. 6, p. p171, Apr. 2012, doi: 10.5539/jas.v4n6p171.
37. ^ J. Davis, P. Caskie, and M. Wallace, "Economics of farmer early retirement policy," Applied Economics, vol. 41, no. 1, pp. 35–43, Jan. 2009, doi: 10.1080/00036840600994211.
38. ^ T. Hennessy, CAP 2014-2020 tools to enhance family farming: opportunities and limits. European Parliament, Directorate-General for Internal Policies. 2014.

39. ^ 1 2 3 P. Koundouri, M. Laukkanen, S. Myyrä, and C. Nauges, "The effects of EU agricultural policy changes on farmers' risk attitudes," European Review of Agricultural Economics, vol. 36, no. 1, pp. 53–77, 2009.
40. ^ G. Breustedt and T. Glauben, "Driving Forces behind Exiting from Farming in Western Europe," Journal of Agricultural Economics, vol. 58, no. 1, pp. 115–127, Feb. 2007, doi: 10.1111/j.1477-9552.2007.00082.x.
41. ^ 1 2 3 4 A. Olper, V. Raimondi, D. Cavicchioli, and M. Vigani, "Do CAP payments reduce farm labour migration? A panel data analysis across EU regions," European Review of Agricultural Economics, vol. 41, no. 5, pp. 843–873, Apr. 2014, doi: 10.1093/erae/jbu002.
42. ^ 1 2 3 4 5 P. Dupraz and L. Latruffe, "Trends in family labour, hired labour and contract work on French field crop farms: The role of the Common Agricultural Policy," Food Policy, vol. 51, pp. 104–118, Feb. 2015, doi: 10.1016/j.foodpol.2015.01.003.
43. ^ 1 2 3 M. Petrick and P. Zier, "Common Agricultural Policy effects on dynamic labour use in agriculture," Food Policy, vol. 37, no. 6, pp. 671–678, Dec. 2012, doi: 10.1016/j.foodpol.2012.07.004.
44. ^ S. Alexiadis, C. Ladias, and N. Hasanagas, "A regional perspective of the Common Agricultural Policy," Land Use Policy, vol. 30, no. 1, pp. 665–669, Jan. 2013, doi: 10.1016/j.landusepol.2012.05.013.
45. ^ 1 2 3 4 5 T. C. Hennessy and T. Rehman, "Assessing the Impact of the 'Decoupling'' Reform of the Common Agricultural Policy on Irish Farmers' Off-farm Labour Market Participation Decisions,'" Journal of Agricultural Economics, vol. 59, no. 1, pp. 41–56, Jan. 2008, doi: 10.1111/j.1477-9552.2007.00140.x.
46. ^ R. B. Tranter et al., "Implications for food production, land use and rural development of the European Union's Single Farm Payment: Indications from a survey of farmers' intentions in Germany, Portugal and the UK," Food Policy, vol. 32, no. 5–6, pp. 656–671, Oct. 2007, doi: 10.1016/j.foodpol.2007.04.001.
47. ^ D. Psaltopoulos, E. Balamou, and K. J. Thomson, "Rural?Urban Impacts of CAP Measures in Greece: An Inter-regional SAM Approach," Journal of Agricultural Economics, vol. 57, no. 3, pp. 441–458, Sep. 2006, doi: 10.1111/j.1477-9552.2006.00059.x.
48. ^ A. Gohin and L. Latruffe, "The Luxembourg Common Agricultural Policy Reform and the European Food Industries: What's at Stake?," Canadian Journal of Agricultural Economics/Revue canadienne d'agroeconomie, vol. 54, no. 1, pp. 175–194, Mar. 2006, doi: 10.1111/j.1744-7976.2006.00044.x.
49. ^ Elek, Sándor, I. Fertő, and Forgács, Csaba, "The possible effects of the CAP Reform on farm employment in Hungary," Agricultural Economics Review, vol. 11, no. 2, pp. 29–34, 2010.
50. ^ M. Genius, "Production and Off-Farm Employment Decisions of Greek and Hungarian Farmers in the Light of the Last CAP Refrom," Agricultural Economics Review, vol. 14, no. 389-2016–23492, pp. 59–74, 2013.
51. ^ J. Helming and A. Tabeau, "The economic, environmental and agricultural land use effects in the European Union of agricultural labour subsidies under the Common Agricultural Policy," Regional Environmental Change, vol. 18, no. 3, pp. 763–773, Mar. 2018, doi: 10.1007/s10113-016-1095-z.
52. ^ 1 2 J. Dwyer et al., Evaluation Roadmap of the impact of the CAP on generational renewal, local development and jobs in rural areas. European Commission, 2019.
53. ^ M. Rizov, S. Davidova, and A. Bailey, "Employment effects of CAP payments in the UK non-farm economy," Eur Rev Agric Econ, vol. 45, no. 5, pp. 723–748, Dec. 2018, doi: 10.1093/ERAE.
54. ^ B. Manos, T. Bournaris, J. Papathanasiou, and P. Chatzinikolaou, "Evaluation of tobacco cultivation alternatives under the EU common agricultural policy (CAP)," Journal of Policy Modeling, vol. 31, no. 2, pp. 225–238, Mar. 2009, doi: 10.1016/j.jpolmod.2008.07.001.
55. ^ 1 2 M. Petrick and P. Zier, "Regional employment impacts of Common Agricultural Policy measures in Eastern Germany: a difference-in-differences approach," Agricultural Economics, vol. 42, no. 2, pp. 183–193, Mar. 2011, doi: 10.1111/j.1574-0862.2010.00509.x.

56. ^ K. Mattas, F. Arfini, P. Midmore, M. Schmitz, and Y. Surry, The impact of the CAP on regional employment: a multi-modelling cross-country approach. 2011.
57. ^ 1 2 M. Wier, J. M. Andersen, J. D. Jensen, and T. C. Jensen, "The EU's Agenda 2000 reform for the agricultural sector: Environmental and economic effects in Denmark," Ecological Economics, vol. 41, no. 2, pp. 345–359, May 2002, doi: 10.1016/S0921-8009(02)00024-1.
58. ^ A. Pufahl and C. R. Weiss, "Evaluating the effects of farm programmes: results from propensity score matching," European Review of Agricultural Economics, vol. 36, no. 1, pp. 79–101, Apr. 2009, doi: 10.1093/erae/jbp001.
59. ^ 1 2 M. C. Ahearn, H. El-Osta, and J. Dewbre, "The Impact of Coupled and Decoupled Government Subsidies on Off-Farm Labor Participation of U.S. Farm Operators," American Journal of Agricultural Economics, vol. 88, no. 2, pp. 393–408, May 2006, doi: 10.1111/j.1467-8276.2006.00866.x.
60. ^ 1 2 H. S. El-Osta, A. K. Mishra, and M. C. Ahearn, "Labor Supply by Farm Operators Under ?Decoupled? Farm Program Payments," Review of Economics of the Household, vol. 2, no. 4, pp. 367–385, Dec. 2004, doi: 10.1007/s11150-004-5653-7.
61. ^ L. Latruffe et al., "Measurement of sustainability in agriculture: a review of indicators," Studies in Agricultural Economics, 2016, doi: 10.7896/j.1624.
62. ^ M. Smale, W. E. Saupe, and P. Salant, "Farm family characteristics and the viability of farm households in Wisconsin, Mississippi, and Tennessee.," Agricultural Economics Research, 1986.
63. ^ J. P. Frawley and P. Commins, The changing structure of Irish farming: trends and prospects. Teagasc Dublin, 1996.
64. ^ J. Scott, "The Nova Scotia Genuine Price Index Soils and Agriculture Accounts – Farm Viability and Economic Capacity," in Nova Scotia. 1st Data release: Kings County Genuine Progress Index, GPI Atlant., Glen Haven NS, Ed. Canada, 2001.
65. ^ Argilés, Josep M., "Accounting information and the prediction of farm non-viability," European Accounting Review, 2001, doi: 10.1080/713764592.
66. ^ S. Adelaja, M. Lake, and S. Pennington, "Agricultural viability in the State of Michigan," Presentation at Michigan Land Use Summit, Michigan State University, 2004.
67. ^ 1 2 D. Abler, Multifunctionality, agricultural policy, and environmental policy. 2004.
68. ^ S. Aggelopoulos, V. Samathrakis, and A. Theocharopoulos, "Modelling the determinants of the financial viability of farms," Research Journal of Agriculture and Biological Sciences, vol. 3, no. 6, pp. 896–901, 2007.
69. ^ T. Hennessy and M. O'Brien, "Is off-farm income driving on-farm investment?," Journal of farm management, vol. 13, no. 4, pp. 235–246, 2008.
70. ^ Zahm, Fréd%[1]ric, P. Viaux, L. Vilain, P. Girardin, and C. Mouchet, "Assessing farm sustainability with the IDEA method - From the concept of agriculture sustainability to case studies on farms," Sustainable Development, 2008, doi: 10.1002/sd.380.
71. ^ 1 2 3 4 H. Vrolijk, C. De Bont, P. Blokland, and R. Soboh, "Farm viability in the European Union: assessment of the impact of changes in farm paymen," 2010.
72. ^ E. G. A. Olsson, K. Rönningen, S. K. Hanssen, and S. Wehn, "The interrelationship of biodiversity and rural viability: sustainability assessment, land use scenarios and Norwegian mountains in a European context," Journal of Environmental Assessment Policy and Management, vol. 13, no. 02, pp. 251–284, 2011.
73. ^ L. Jurgelaitienė, J. Savickienė, and A. Miceikienė, "Assessment of economic viability in agriculture," 2015.
74. ^ 1 2 A. P. Barnes, H. Hansson, G. Manevska-Tasevska, S. Shrestha, and S. Thomson, "The Influence of diversification on short-term and long-term viability in the Scottish and Swedish agricultural sector," 2014.
75. ^ G. Graddy-Lovelace and A. Diamond, "From supply management to agricultural subsidies—and back again? The U.S. Farm Bill & agrarian (in)viability," Journal of Rural Studies, 2017, doi: 10.1016/j.jrurstud.2016.12.007.

76. ^ 1 2 3 4 5 6 7 A. Coppola, A. Scardera, M. Amato, and F. Verneau, "Income Levels and Farm Economic Viability in Italian Farms: An Analysis of FADN Data," Sustainability, vol. 12, no. 12, p. 4898, 2020.
77. ^ 1 2 3 4 5 6 7 C. O'Donoghue, S. Devisme, M. Ryan, R. Conneely, P. Gillespie, and H. Vrolijk, "Farm economic sustainability in the European Union: A pilot study," Studies in Agricultural Economics, vol. 118, no. 3, pp. 163–171, Dec. 2016, doi: 10.7896/j.1631.
78. ^ H. Vrolijk, K. Poppe, and Keszthelyi, Szilárd, "Collecting sustainability data in different organisational settings of the European Farm Accountancy Data Network," Studies in Agricultural Economics, 2016, doi: 10.7896/j.1626.
79. ^ Europena Commission, No Titl): Definitions of Variables used in FADN standard results, doc RI/CC1750 (ex RI/CC 882). Brussel: European Commission, 2015.
80. ^ K. Hanrahan, T. Hennessy, A. Kinsella, B. Moran, and F. Thorne, "Farm Viability–A Teagasc National Farm Survey Analysis," 2014.
81. ^ 1 2 3 4 5 J. Spicka, T. Hlavsa, K. Soukupova, and M. Stolbova, Approaches to estimation the farm-level economic viability and sustainability in agriculture: A literature review. 2019.
82. ^ S. Chen and J. Dodd, "Economic Value Added (EVA Super TM): An Empirical Examination of a New Corporate Performance Measure," Journal of Managerial Issues, 1997.
83. ^ Neumaierová, Inka and I. Neumaier, "INFA Performance Indicator Diagnostic System," Central European Business Review, 2014, doi: 10.18267/j.cebr.73.

4 Environmental and Climatic Impacts of Agriculture

4.1 Key impacts of agriculture on the environment and climate

The agricultural sector is at the heart of the economies of many countries, especially those least-developed ones. It plays a strategic role in countries' economic development, providing not only food but also raw materials for industry. Progress in the agricultural sector is essential for growing the market for domestic manufactures, earn foreign exchange, and to obtain tax revenue. A key challenge for the agriculture sector in future years is to feed an increasing global population. As shown by the estimates provided in the report of the United Nations Department of Economic and Social Affairs World Population Prospects, the 2019 Revision, the world population, currently estimated at 7.6 billion, is expected to increase to approximately 10 billion over the next four decades [1]. The Food and Agriculture Organization (FAO) of the United Nations predicts that, in order to meet the increasing demand for food associated with the increase in population and to prevent famine, global food production will have to grow by at least 60 percent compared with the current level [2]. But increasing agricultural production might accentuate the already significant impact of agriculture on the environment. Therefore, in the context of agricultural policy reform, trade liberalization and multilateral, environmental, and sustainable agriculture are of major public concern.

The environmental impact of agriculture is the effect that different farming practices have on the ecosystems around them, and how those effects can be traced back to those practices. Some of the environmental issues that are related to agriculture are climate change, deforestation, dead zones, genetic engineering, irrigation problems, pollutants, soil degradation, and waste. Pollutants from farming include excessive nutrients, pesticides, sediments, pathogens, metals, and salts. For livestock agriculture, they include bacteria and pathogens from manure contaminating groundwater. While negative impacts are serious, agriculture can also positively impact the environment. This can be achieved, for instance, by trapping greenhouse gases within crops and soils or by mitigating flood risks through the adoption of certain farming practices. Of course, the environmental impacts of agriculture are as varied as the agricultural strategies employed around the world are diversified. Ultimately, the environmental impact depends on the production practices of the system used by farmers, but it also depends on external factors over which the farmer has no control. For example, the emissions into the environment due to climate variables such as rainfall and temperature. Therefore, it is in everyone's interest to be as sustainable as possible. As Barbier stated bib[3], to be sustainable, agriculture must be fair at the economic and social level; viable from the economic and environmental point of view; and also tolerable from a social and environmental perspective. From the environmental point of view, a farming activity is sustainable if its polluting emissions and its use of natural resources can be supported in the long term by the natural environment.

The environmental impact of agriculture involves a variety of factors. According to the OECD ‘Environmental Indicators for Agriculture Methods and Results’ [4], the environmental and climatic impacts of agriculture are reflected in:

- **Soil quality**

  To maintain agricultural productivity it is essential to maintain soil quality. Cultivated soil is constantly degrading and this degradation is related to either its physical (e.g. erosion, compaction), chemical (acidification, salinization) or biological (organic matter reduction) properties. Soil degradation processes can be linked to both changes in climate and management practices. For farmers, it is essential to sustain soil fertility, but they also should consider other key aspects of soil quality: preservation of the natural environment and protecting plant, animal, and human health. Because of this, governmental policies are being developed. They include investment and loans to promote conservation practices, and consulting services on soil management.

- **Water quality**

Agriculture can also influence the quality of water through agricultural pollutants. This applies to the contamination by nitrate (which can be dispersed to the surface and ground waters) and to pesticides. Infiltration of agricultural pollutants into the water can impair the quality of drinking water and pose a threat to the biosphere, excessive levels of agricultural pollutants lead to other problems like eutrophication.

- **Land conservation**

Land cover and land-use patterns reflect the interaction of human activities and the natural environment [5]. The basis of all agricultural activity is the availability of land and water resources. Using those resources can affect the flow of surface water and cause the loss of soil sediment from agricultural land. Impact related to off-farm sediment flows is particularly important in regions with alternating periods of drought limiting soil vegetation cover, followed by heavy rainfall. Also, altering the land cover changes its ability to absorb or reflect heat and light contributing to radiative forcing and climate change.

- **Greenhouse gases**

It is widely known that the increased atmospheric concentration of GHGs is contributing to the process of climate change and global warming. Agriculture is highly exposed to climate change as all of the farming activities depend directly on meteorological conditions. On the other hand, agriculture contributes to climate change by releasing greenhouse gases into the atmosphere - namely CH_4 from livestock and nitrous oxide (N_2O) from organic and mineral nitrogen fertilizers. The impact of climate change manifests in various factors: from changes that can be observed in rainfall patterns or rising temperatures, through variability in seasonality, to extreme weather events such as heatwaves, droughts, storms, and floods. Although the net impact of climate change on agricultural production is uncertain, it is likely that it will shift the suitable growing zones for individual crops. Adjustment to this geographical shift will involve considerable economic costs and social impacts. Monitoring whether the agriculture acts as a source or sink for GHGs is of importance to policy-makers, as they implement domestic strategies to meet international obligations to reduce GHG emissions. Data allowing to assess the level of contribution of agriculture to climate change, especially in comparison to other economic sectors, can help to develop proper policies leading to limiting the negative impacts related to GHG emissions.

There are two ways of dealing with climate change – either mitigating it or adapting to it[6]. While mitigation has the potential to reduce impacts of climate change, adaptation can reduce the damage of those impacts[7]. Applied together, both approaches can contribute to the development of societies that are more resilient to the threat of climate change. The agricultural sector can contribute to climate change mitigation by reducing the GHG emissions from arable fields and switching to crop varieties that act as carbon sinks, or by sequestering carbon while maintaining food production. On the other hand, adaptation means the application of strategies that lead to maintaining yield or even taking advantage of changing climate to obtain higher yields[8][9]. Regarding livestock, most of the methane emissions come from ruminants such as cattle and pigs, while poultry or fish have a far lower impact. Mitigation strategies include:

  - using biogas from manure;
  - genetic selection;
  - immunization;
  - rumen defaunation;

- outcompetition of methanogenic archaea with acetogens;
- introduction of methanotrophic bacteria into the rumen;
- diet modification;
- and grazing management.

In turn, adaptations at the farm level may include:

- adjustment of the timing of farm operations, such as planting or sowing dates and treatments;
- choosing crops and varieties better adapted to the expected length of the growing season and water availability, and more resistant to new conditions of temperature and humidity;
- adapting crops with the help of existing genetic diversity and new possibilities offered by biotechnology;
- using water more efficiently by reducing water losses, improving irrigation practices, and recycling or storing water;
- improving the effectiveness of pest and disease control through for instance better monitoring, diversified crop rotations, or integrated pest management methods;
- applying technical solutions, such as protecting orchards from frost damage or improving ventilation and cooling systems in animal shelters;
- improving soil management by increasing water retention to conserve soil moisture, and landscape management, such as maintaining landscape features providing shelter to livestock;
- or introducing more heat-tolerant livestock breeds and adapting diet patterns of animals under heat stress conditions.

Sectorial-level adaptation may include identification of vulnerable areas and sectors and assessment of needs and opportunities for changing crops and varieties in response to climate trends; supporting agricultural research and experimental production aiming at crop selection and development of varieties best suited to new conditions; and building adaptive capacity by awareness-raising and provision of salient information and advice on-farm management.

- **Biodiversity**

  Biodiversity is highly related to land use. The key area of concern regarding biodiversity lies in agriculture, as it is the human activity having the largest share in the total land area. Major causes of biodiversity losses are related to both the expansion of farm production and the intensification of input use. For instance, genetically modified crop varieties and livestock breeds, crop pollination, and soil fertility provided by microorganisms. In some cases, it may happen that non-native species are the cause of alien pests appearing and of the competition for livestock forage. Therefore, the main focus of policies related to biodiversity is placed on the protection and conservation of endangered species and habitats, but some countries have also begun to develop more holistic national biodiversity strategy plans, which incorporate the agricultural sector in biodiversity conservation.

- **Wildlife habitats**

  Land, including agricultural land, provides habitat for wildlife, both flora and fauna. However, agricultural activities affect wildlife habitats both directly, by the conversion of land to cropping or forage systems, and indirectly, by disturbances introduced to these habitats due to elevated levels of pollutants. As the wildlife habitats are sites of environmental and recreational value, policy actions have focused on protecting them. This is done by encouraging farmers to adopt management practices that benefit wildlife habitat preservation.

- **Landscape**

  Landscape can be defined as all the visible features of an area of land. Several characteristics can be attributed to landscapes. First of all, the landscape is composed of structures, for which appearance, environmental functions (e.g. habitats), land use types (e.g. crops), and man-made objects or cultural features (e.g. hedges) can be distinguished. Secondly, each landscape fulfills some functions, as it may be a place to live, work, visit, or it may provide various other environmental services. Finally, the landscape has a value, which can be related either with the cost of maintaining them by farmers or the recreational and cultural value society that is placed on it by society. Agricultural landscapes are the visible outcomes from the interaction between agriculture, natural resources and the environment, and encompass amenity, cultural, and other societal values. Therefore, the biggest challenge for policy-makers lies in judging the appropriate provision of landscape, together with its societal value, and assessment to what extent changes in policies will affect the agricultural landscape.

  The main goal which farmers want to achieve when adjusting their production practices (e.g. fertilization, tillage operations, sowing) is to increase production. Usually, with the intensification of methods of agricultural production, an increase in environmental pollution is observed. Nowadays, to protect natural environments, the limitation of environmental impacts of agriculture to an acceptable level is becoming an object of interest. Usually, these limitations are regulated by appropriate policies in order to reduce, for example, loss of quality of the source functions of natural capital for agriculture through phenomena such as erosion, the disappearance of beneficial predatory and parasitic invertebrates in crops or the decrease of soil organic matter[10][11][12]. That's why nowadays farmers, when adjusting production practices, must pay attention not only how to attain desired output (yield) but at the same time how to limit undesired emissions to the environment by finding an optimal balance between inputs based on available natural capital (soil, solar energy, rain, fossil energy) and those based on human-made capital (fertilizers, seeds, pesticides). The environmental impacts of agriculture are mainly connected with:

- **Use of fertilizers**

  The use of fertilizers, such as nitrogen, phosphorus, and potassium, is essential to agricultural production, as it provides nutrients necessary for plant growth and increased productivity. Likewise, excessive use of fertilizers can also have very negative environmental effects. Surplus of nutrients can affect surface and groundwater (eutrophication), air quality (acidification), and contribute to global warming (greenhouse effect). Soil runoff may lead to the formation of dead zones and sometimes they have to be bio-remediated. Also, if soils are being agriculturally used and nutrients are not replenished, it may lead to soil fertility reduction and impairing of agricultural sustainability through "soil mining" of nutrients.

- **Use of pesticides**

  Using pesticides is necessary to maintain or increase agricultural productivity, as it helps to control pests. However, the use of pesticides also poses risks, as they may become pollutants through misuse or ignorance. Pesticide use by farmers depends on a multitude of factors, such as climatic conditions, the composition and variety of crops, pest and disease pressures, farm incomes, pesticide cost/crop price ratios, pesticide policies, and management practices. The most widespread are synthetic pesticides. As over 98% of sprayed insecticides and 95% of herbicides reach a destination other than their target species, the environmental impact of pesticides is mostly related to the effect they have on non-target species, especially on humans and their health. Pesticides are also deadly dangerous to bees, which pollinate some of the crop plants. It is obvious that the risks vary greatly depending on pesticide's inherent toxicity (or hazard), way of application, mobility, and exposure time (persistence in the environment). Furthermore, pesticides can also leach through the soil to groundwater's, runoff can carry pesticides into aquatic environments, wind can carry them to other fields, grazing areas, or human settlements, as well as they can residue in food products. Also, if herbicides or pesticides stay in the topsoil, they can be carried away from farms to other places as a result of soil erosion. All of this may result in the death of non-targeted wildlife. Additionally, repeated application of the same pesticide increases pest immunity over time, while the negative impact on other species can reinforce the pest's reappearance. The positive aspect is that over time, pesticides have generally become less persistent and more species-specific which reduces the negative environmental footprint. Additionally, some of the most harmful pesticides have been banned in most countries. Pesticide indicators are potentially a useful tool to help policy-makers monitor and evaluate policies and also provide information concerning human and environmental pesticide risks.

- **Use of irrigation**

  It is estimated that irrigated land area occupies about 16% of the total agricultural area worldwide, with roughly 40% of the total yield coming from crop yield of irrigated land (which means that on average irrigated land produces 2.5 times more product than non-irrigated land). The environmental impact of irrigation is related to altered hydrological conditions caused by the installation and operation of the irrigation systems. In the case of the use of water wells we have to face the depletion of underground aquifers through overdrafting. Overall water level decrease may lead to land/soil subsidence, and, along the coast, to saltwater intrusion. Additionally, irrigation increases atmospheric moisture which induces atmospheric instabilities and increased downwind rainfall. In some cases, irrigation can modify the atmospheric circulation, delivering rain to different downwind areas. Other effects include waterlogging and soil salination. Over-irrigation can cause deep drainage from rising water tables that can lead to problems of irrigation salinity requiring water table control by some form of subsurface land drainage. On the other hand, under-irrigation can lead to increased soil salinity with the consequent buildup of toxic salts on the soil surface in areas with high evaporation. This requires either leaching to remove these salts or a method of drainage to carry the salts away. Irrigation with saline or high-sodium water may damage soil structure due to the formation of alkaline soil. All of this leads to ecological damage and other socio-economic impacts associated with the impairment of the natural and social conditions in river basins. While waterlogging and soil salination are usually very local, ecological and socioeconomic consequences may be more far-reaching.

- **Deforestation**

  One of the main causes of deforestation is to clear land for pasture or crops. In 2000 the FAO stated that deforestation can result from "a combination of population pressure and stagnating economic, social and technological conditions" [13]. According to the British environmentalist Norman Myers, 5% of deforestation is due to cattle ranching, 19% due to over-heavy logging, 22% due to the growing sector of palm oil plantations, and 54% due to slash-and-burn farming [14]. Deforestation results in many land damages. Forest is not only a habitat for millions of species, but also acts as a carbon sink (trees absorb carbon dioxide from the atmosphere). Trees removal not only causes the loss of habitat for various species, but also contributes to climate change in two ways – along with fewer trees less carbon dioxide is absorbed from the air, and with stump removal additional carbon dioxide from the soil is released into the atmosphere. When trees are removed, the soils tend to dry out quicker for two reasons – first because there are not enough trees to assist in the water cycle by returning water vapor back to the environment, and secondly because of no-shading effect. Deforestation and desertification are the major anthropogenic agricultural sources of carbon dioxide release. The removal of trees also causes extreme fluctuations in temperature.

4.2 Current state-of-the-art methods to assess or model environmental and climatic impacts of agriculture

The main goal of IA is to enhance our understanding of how factors and their changes will affect the considered area. IA can be used to measure the outcomes or to improve practices. It can be either backward-looking, related to the evaluation of past changes or already implemented policies (ex-post IA) or forward-looking, related to current and future changes, or planned regulations (ex-ante IA).

Agriculture is more and more often viewed as an activity having a multi-functional purpose. Its primary function as a tool for plant and animal production is nowadays supplemented by treating is a way of managing the countryside[15]. This complexity of farming activity should lead to the adoption of a holistic approach to environmental assessment[16]. Farming systems generate environmental impacts in the form of changes to the natural environment at different scales at the same time. Therefore, the environmental impacts of agriculture should be analyzed on a range of spatial scales, from the field to the national or even the supranational scale[4], with individual methods of assessment more suitable for each spatial scale. To illuminate the large and widespread impacts of agriculture, assessment at the global scale should be performed. On the other hand, the basic management unit of the agricultural system, at which farmers aim to optimize production, whilst minimizing inputs and polluting emissions, is a field[17] or livestock building[18], therefore the farm level should not be overlooked when carrying out analyses related with environmental impacts of agriculture. The scale over which the environmental impacts of agriculture are generally felt is related to the type of impact. The scale of various environmental impacts of agriculture is presented in Table 1 (adapted from the CGIAR report 2011).

Type of impact	Scale of Impact		
	individual farm	local	global
Land			
Salinization & waterlogging	x		
Nutrient depletion	x		
Loss of organic matter (soil erosion)	x	x	
Conversion of non-agricultural lands (deforestation)		x	x
Water			
Groundwater depletion		x	
Water conservation	x	x	
Pollution			
Human health	x	x	
Animal health	x	x	
Plant health	x	x	
Livestock			
Animal waste	x	x	
Animal diseases		x	x
Common property pasture degradation		x	
Biodiversity			
Loss of biodiversity		x	
In situ crop genetic diversity			x
Conversion of non-agricultural lands (deforestation)			x
Climate change			

GHG emissions from agriculture			x
Release of soil carbon			x
Reduced C sequestration			x

Table 19 Typology of environmental impacts of agriculture with scales over which those impacts are felt.

Source: Renkow (2011)[19]

A review of methods used for environmental IA of a farming region shows that a broad spectrum of different approaches exists. The environmental impact of agriculture is of main concern for these methods; nonetheless, some of them allow to evaluate also economic and social components of sustainability. They consist of:The variety of scales in the different agricultural activities raises the question of how to scale the results of environmental IA. This is not trivial as a management practice or technology may have a different impact in various locations which complicates the extent to which particular observed or projected environmental outcome can be up-scaled. There are a few basic approaches to address the scaling issue. An option relies on designating 'monitoring sites' at multiple locations, for which biophysical measurements are carried out to determine how environmental impacts vary across diverse agro-ecological zones. Such measurements carried out over a period of time allow to assess impacts felt globally, especially those related to global climate change or changes in biodiversity. An alternative method to assess off-site impacts at a fairly coarse spatial scale is to use innovations in the field of monitoring environmental changes, such as remote sensing and satellite imagery, and combine them with GIS-based spatial modeling techniques. Such methods are best suited to upscale impacts on soil and water quality up to a watershed or basin scale. Scaling to more general levels is achievable by using models that explicitly integrate economic and biophysical outcomes. This is due to the fact that crop growth models do not take into account the farmers behavioral responses to economic forces that are in turn affected by biophysical responses. Therefore, the models are not able to provide accurate predictions of environmental outcomes beyond a small scale. Only models in which a unified set of biophysical and economic drivers jointly influence biophysical and economic outcomes are able to take into account such interactions. The so-called 'agent-based' models allow a high level of aggregation where agents representing different types of households, livestock and landscapes are effectively connected by a set of sub-models simulating biological, agronomic, and economic processes. Other methods allowing to assess impacts at a geo-regional level rely on using biophysical models combined with aggregative economic models (like GTAP) or on combining linear programming models of economic surplus maximization and 'technical coefficient generators' for livestock and cropping activities with GIS-based spatial modeling. This type of approach allows to perform an ex-ante assessment of agricultural and agri-environmental policies and to assess land-use changes accompanying a variety of policy shocks in continental or global scale.

- **Environmental risk mapping (ERM)**

In the environmental risk mapping approach, it is assumed that risks connected with the environment are the outcome of both pressures, that the farmer exerts on the habitat in the form factors such as land use and land-use change, and habitat susceptibility to this pressure. The main objective of the ERM approach is to quantify an environmental risk associated with the regional farming practices by using a set of indicators, variables, and/or results from simulation models, depending on whichever is more appropriate to describe the studied feature[20]. The most important part of this method is the choice of criteria weighting techniques that are used to evaluate the risk. Weighting techniques vary in their degree of complexity from simple weighted linear combinations to very advanced fuzzy combination approaches[21]. The main drawback of the ERM is that the choice of a weighting method introduces an element of subjectivity into the risk mapping. Additionally, the ERM looks only into the environmental aspect of sustainability, while the economic and social components of sustainability are omitted. Various environmental impacts were investigated with the use of environmental risk mapping, among them the risk of nitrate leaching[21], of pesticide use[22], or of the transfer of phosphorus[23]. In ERM, Geographical Information Systems (GIS) are routinely used to obtain the spatial distribution of information[24]. The main advantage of ERM is that it can be rapidly applied to obtain a qualitative characterization of risk.

- **Life cycle analysis (LCA)**

  As the name of the method suggests, the main goal of LCA is the holistic evaluation of the impact that the life of the product (or service) has on the environment, starting from the extraction of the primary materials needed for its production, through the production and use, until the disposal of the product and its residues, using a small number of indicators. This multi-criteria assessment method was originally developed for industrial processes, especially for evaluation of the environmental gains in the bioenergy sector relative to fossil fuel use, where inventoried emissions relate primarily to the use of nitrogen fertilizers and the combustion of diesel fuel for machinery[25], and therefore LCA method has undergone a process of standardization[26][27], both in the terms of the impacts calculation[28] and the interpretation of the results[29].

  In recent years, there has been a growing interest in the use of the LCA method to evaluate the environmental impact of farming activities, both for crop[30][31]and animal production [32][33]. In LCA overall environmental impact of a farming region is assumed to be equal to the sum of the impacts calculated for each individual farm. To simplify and speed up the analysis is often assumed that farmer management practices are uniform within predefined classes and then these classes are used to estimate the results for farming region scale|[34]. Sometimes assessment of environmental impacts of a given crop on the regional scale are performed by calculating the value of a quantity related with a given impact for one ha, and then multiplying it by the total area on which considered crop is cultivated[35]. In LCA the scale of impact is distinguished depending on the distance between the impact source and the area affected by it. Both local, regional, and global impacts are considered[36], among them smell and noise (treated as local impacts, as they are felt over a few kilometers), eutrophication and acidification (both local and regional, as such phenomena can affect the environment not only close to, but also several hundred kilometers away from the source) or greenhouse effect and the use of non-renewable energy (global impacts). While the main focus of the LCA method is put on the environmental aspect of sustainability, economic and social viability can also be included in the analysis by adding the analysis of production costs and estimating how many workers may be involved in such production system.

  With this method, it is possible to quantify over a dozen potential environmental impacts, but in order to include all of them in the assessment, an analysis of the contributions of all resource uses and all potential emissions at all production stages and from all locations needs to be done. Contributions from various sources are summed up independently using linear models, regardless of their location or timing. It follows from the above that in obtained potential final impact specificity of local conditions, such as environmental sensitivity of the site or effects connected with thresholds, is usually not taken into account. In some specific applications localized impacts can be accounted for by the weighting of final impact based on regionalized factors, as, for example, in the case of the model calculating the index of water scarcity[37]. Another example of attempts to introduce regionalization to LCA is the land use IA with the use of the “Biotic Production Potential” indicator[38], developed during research related to agricultural LCA[39][40]. “Biotic Production Potential” indicator expresses the variations in carbon stocks, assuming that these variations are linked with changes in soil organic matter. Assessment of changes in soil organic matter allows evaluating the impacts on the life-supporting capacity of soils for agricultural or forestry production, as SOM indicates soil's capacity to supply various functions, particularly those relating to life and biological development, even if other aspects of soil quality also play a role[40]. Therefore the variations in carbon stocks are treated in this method of land use IA as dynamic soil attribute indicating various aspects of soil quality, such as cation exchange capacity and biological activity[41][42]. Many frameworks for land use IA, such as Simapro and OpenLCA, uses characterization factors that quantify variations in soil carbon levels based on the values and coefficients proposed by the IPCC[43]. Other methodologies use other quantities, such as soil compaction[44] or erosion resistance, groundwater recharge, mechanical, and physicochemical filtration[45][46].

Regardless of the above, LCA is usually used for providing an estimate of overall, non-localized impact.

- **Environmental impact assessment (EIA)**

  The EIA method was developed for those impacts related to emerging pollution sources located on the surroundings of a new industry or highway. The main assumption of this method is that the impact of human activity depends both on the pollution associated with that activity and the sensitivity of the environment in terms of various factors, such as biodiversity, housing, and tourism. In the agricultural sector EIA has been often used to evaluate the environmental impact of newly introduced practices or to help farmers assess the loss of sustainability of performed practices[47] This method takes into account various aspects of sustainability, both from the environmental, economic, and social point of view, so the impact of a new activity on the environment, the population, and the attractiveness of the neighborhood is simultaneously evaluated. In EIA, local impacts like noise, smell, dust, or smoke are the major concerns from the environmental point of view. Regional impacts have lower priority, but they are nonetheless included and evaluated, however, unlike in the LCA method, impacts resulting from the newly introduced practices are rarely assessed on a global scale[48]. As this method of environmental assessment is standardized, performing an assessment with the use of EIA requires comprising a series of steps from the scope definition and data collection, through monitoring, to decision-making by the IA authority and the experts.

- **Multi-agent system (MAS)**

  MAS, otherwise known as Agent-based models (ABM), are based on the concept of a system consisting of a group of agents interacting between each other in the environment surrounding them. Above means that the main objective of this approach is to model each agent's behavior, both towards the other agents and limited resources. This simulation framework takes into account micro-level constraints such as environmental externalities, limited adaptive capacity, and behavioral barriers to provide a local-level assessment, which makes it able to reflect the interaction dynamics taking place in the complex systems. The MAS approach stands out from the other three previously described methods in the complexity of the considered interactions, which allows determining whether the exploitation of a given resource is sustainable not only from the environmental but also from the social and economic points of view. A huge advantage of agent-based modeling is that it can include the use of external models to simulate various processes or estimate the consumption of natural resources. MAS focus on the regional level assessment and usually does not take into account assessments on the global or national scale.

  In the field of the agricultural economics MAS benefited from the knowledge gained during the development of Recursive Farm Programming Models. However, the degree of their complexity is significantly greater, as they simulate all individual farms, their spatial interactions, and the natural environment[49]. First agricultural MAS was developed by Balmann[50], who used farm linear programming, but it was soon followed by numerous other research, even to mention these introduced by Berger[51] or other authors[52][53][54][55]. For example, in an ABM developed by Berger[51], hydrologic and economic modules were linked to each other within a framework that could perform spatial analyses. The model was then used to assess the potential impacts of water-saving irrigation methods in rural Chile. In turn, an ABM introduced by Matthews[52] integrated modules simulating water balance, dynamics of the nutrients and organic matter decomposition with the module simulating responses of households to both economic and environmental variables. This model was used to evaluate potential soil fertility enhancing interventions in Nepal. Other MAS were used to study the impacts of, for example, manure management[56], or the co-evolution of human and landscape systems in response to forest protection zoning, agrochemical subsidies and agricultural extension[57]. In agricultural ABM models, each farm of the region has its own representation, which allows for upscaling of individual results to the regional scale and enhancing the analysis by an explicit incorporation of local resource markets, cooperation, social learning and other agent-agent interactions[49]. However, most of the MAS focus on the regional level assessment and do not take into account global or national scale.

Balbi and Giupponi[58], Patt and Siebenhüner[59], or Moss with his co-workers[60] found the agent-based models to be extremely useful in analyzing the impact of climate change on the agricultural sector, especially for planning adaptation measures. This is because they allow for performing an in-depth analysis of the impacts identifying not only the speed but also the extent of climate change adaptation, which other approaches to economic simulation of agriculture cannot or may not capture. Among them are, for example, the direct interaction among agents and between agents and the environment, straightforward modeling of learning processes, both individual and social, to cope with new environmental conditions, or micro-level constraints to adaptation such as economies of scale, hysteresis, and indivisibility of assets. Another advantage is that the modeling results can be viewed from both aggregate and a disaggregate perspective simultaneously. This means that one can analyze both changes in the agricultural supply of goods, the demand of resources and changes of land use and land cover in the region (at an aggregate level), as well as identify individual farms especially vulnerable to climate change by assessing their strategies of adaptation (at disaggregate level). While outcomes from aggregate level are requisite inputs to perform the biophysical assessment of feedbacks in climate, ecosystems and impacts on the provision of environmental services associated with them, and also to conduct an economic analysis of global or national food supply, combined perspective from both aggregate and disaggregate level is necessary to evaluate the effect of establishing different policies which are intended to support certain adaptation measures or mitigate adverse outcomes of adaptation on ecosystems with respect to effectiveness, efficiency, and equity. The aggregated and disaggregated level perspectives make ABM models able to perform not only ex-ante analyses assessing what possible outcomes might emerge under specific policy regimes or technology adoption scenarios, but also but it also enables to perform ex-post analyses, intended to predict what could be the outcome if certain policies or adaptation measures would not be introduced (or other would be imposed).

- **Multiple linear programming (MLP) approaches**

  MLP is another method utilizing the concept of indicators, which are used to describe a system. In the MLP approach three distinct steps can be featured. In the first step, an IO matrix is defined for each element of the system. The second step consists of defining a set of constraints to select possible routines. The last step is based on using linear optimization techniques to find such routines that either maximize or minimize indicators (depending on the effect we want to achieve), while fulfilling the constraints. For a farming system, this method is usually used to optimize the total production taking into account available management technologies (and optionally economic and social requirements), while at the same time trying to minimize the environmental impact[61][62]. When considering farming systems the IO matrix is used to link in animal or plant production in terms of needed inputs with emissions from production as an output, while a set of environmental, agronomic, social, and economic constraints is defined to limit the possible management methods. The application of the MLP approach allows for assessment of both single environmental impact such as erosion[63], or several impacts, such as emissions of greenhouse gases, eutrophication, and pesticides[64]. MLP method allows to perform the assessment on a farming region scale. To perform such an analysis, a classification of farms is performed to extrapolate the impacts of a specific sub-set of farms to the whole studied area. MLP can be also used as a part of an integrated platform to model economic and biophysical sustainability trade-offs. To build such a platform researchers from Wageningen used MLP in conjunction with technical coefficient generators to evaluate livestock and cropping activities, economic surplus maximization approach to maximize profit, and GIS-based spatial modeling to assess land-use changes accompanying a variety of policy shocks[64].

- **Agro-environmental indicators**

As Herdt and Steiner[65] pointed out, continuous increase of human-made inputs leads to increase of yield in most agroecosystems, but in the long term such actions may induce negative impacts related to the quality of the natural resources, leading to, for example, land degradation, and thus undermining the productive capacity. Because of that there is a need to assess whether current agroecosystems are sustainable in the long run. As the direct assessment or quantification of "environmental impact" or "environmental sustainability" is a hard task, a set of more specific objectives is required. This caused the establishment of numerous methods for the assessment of the environmental impacts of agriculture using a set of indicators, which serve as criteria to quantify the degree to which environmental issues (e.g. soil erosion, emission of greenhouse gasses, water quality) are still of concern[66]. The term "indicator" can be defined as a variable giving information about changes in other, difficult to access, variables or processes and which can be treated as a reference for making a decision[67]. Additionally, in the paper of Mitchell and his co-workers[68], we can read that "indicators are alternative measures that are used to identify the status of a concern when for technical or financial reasons the concern cannot be measured directly".

Indicator methods may take into account effects at various scales - local and regional impacts, or global impacts like the greenhouse effect. Such methods can serve farmers, local councils, catchment and land protection boards, policymakers and other decision-makers at the community, regional, national, and global levels[69][70]. They can be divided into two classes, either "means-based" (methods based on farmer production practices) or "effect-based" (methods based on the effects of farmer production practices have on the state of the farming system or on emissions to the environment, measuring attributes of the system directly). While means-based indicators cost less in data collection, they also do not allow for an actual evaluation of environmental impact. Also, validation of the means-based indicators is problematic. In the effect-based indicators the link with the objective is more direct and the choice of means or practices is left to the farmer. For this reason, the effect-based indicators are valued more highly by the stakeholders. Some of the commonly used indicators include:

- <u>The farmer sustainability index (FSI)</u>

  The FSI is an indicator reflecting ecological sustainability. It was introduced by Taylor and his co-workers[71], who took into account 33 farmer production practices for producing cabbage (Brassicca sp.). Each practice was assigned either a positive or negative score and they were summed up to form a single value - the FSI. In the FSI recent changes in practices are considered, so a farmer using practices leading to greater sustainability obtains a larger FSI than the farmer using exactly the same practices, but for a long time. This indicator was developed in Malaysia for policymakers and is suitable for assessing impacts on the local scale.

-Sustainability of the energy crops index

The sustainability of the energy crops index method extends the concept of LCA[72] by adding auxiliary indicators for each agricultural production system. It was developed by Biewinga and van der Bijl[35] to assess the ecological and economic sustainability of energy crops and was subsequently used to compare the production of energy crops in four regions in Europe. It can be used to make an assessment on both a local and global scale.

- LCA for agriculture (LCAA)

The LCA concept was also extended by applying it to agricultural production by Audsley and his co-workers[73]. They presented the results of a study performed in cooperation with seven other research groups from different European countries. This study identified methodological difficulties and proposed a harmonized approach based on case studies of three methods of wheat growing. The LCAA method was developed for assessments on a global scale but can be adapted for assessments on a local scale.

- LCA for environmental farm management (LCAE)

Rossier adapted the LCA approach to obtain a comprehensive method of evaluation of the farm environmental impact[74]. The LCAE method can be used it identify the main pollution sources and to assess possible alterations in farming methods. Rossier applied the LCAE method to assess the performance of 13 Swiss crops, animals, and mixed farms. The method was developed to perform an IA on a global scale, but the method can be adapted to a local scale as well.

- Ecopoints (EP)

The EP method was developed to assess farmer production practices and landscape maintenance by assigning scores to them. The method was used by Mayrhofer and his co-workers[75] for the Lower Austria region to determine how much money would farmers have to get to start implementing the guidelines related to the environment and landscape. The EP method was developed for IA at a local scale.

- Agro-ecological indicators (AEI)

The AEI method was introduced by Girardin and his co-workers[76] to evaluate the effects of farmer production practices on various components of the agroecosystems. The method adopts a classic environmental IA methodology, namely the interaction matrix, introduced by Leopold and his co-workers[77], and aggregated evaluation modules characterizing production practices impact on an environmental component to two classes of indicators: agro-ecological and environmental. Agro-ecological indicators reflect the impact of one production practice on all environmental components concerned, while environmental indicators reflect the impact of all production practices concerned with one environmental component. While the method was developed for assessment at a local and global scale, it was used mostly to perform an IA for France.

- Agro-ecological system attributes (AESA)

The AESA approach was developed by Dalsgaard and Oficial[78] as a “pragmatic framework for monitoring, modeling, analyzing, and comparing the state and performance of integrated agroecosystems”. The method was deeply rooted in the theory of ecosystems and the mass-balance modeling software ECOPATH was used as a structuring tool. The approach was applied to four Philippine smallholder rice (Oriza sp.) farms. It was developed for impact assessment at a local scale.

- Operationalizing Sustainability (OS)

Rossing and his co-workers[79] designed the OS method to design an environmentally friendly flower bulb production system in The Netherlands. This method considers two environmental and one economic objective together with various socio-economic constraints and uses interactive multiple goal linear programming to optimize the objectives at the farm level. Objectives are identified in interaction with growers and environmentalists. The OS method was developed for impact assessment at a local scale.

- Multi-objective parameters (MOP)

Vereijken[80] proposed the MOP method as a way to design integrated and ecological arable farming systems. “Multi-objective parameters” are indicators used to quantify a set of ecological, economic, and social objectives. The method was used for a European research network of experimental farms or pilot farms to obtain sustainable systems; the process was iteratively improved until the objectives were reached. The MOP method was developed for assessment at a local scale.

- Environmental management for agriculture (EMA)

The main goal of the method proposed by Lewis and Bardon is to introduce “a computer-based informal environmental management system for agriculture”[11]. Eco-ratings indicating environmental performance are produced on the base of comparison of actual farmer production practices supplemented by site-specific details and information about the best agricultural practice for that site. Environmental management for agriculture system incorporates modules to explore alternative scenarios. The system is used by farmers and their advisors in the UK. It was developed for assessment at a local scale, but can be adapted to be used on a global scale.

- Solagro diagnosis (SD)

The objective of the SD method proposed by Pointereau and his co-workers is to “evaluate of the environment at the farm level by means of a comprehensive, simple and rapid approach”[81]. In this method, four “integrative criteria” (which consider the number of farm production systems, both for crop and livestock, diversity of grown crops, input management and land management) are introduced, and performance levels are assigned to them. Pointereau used this method for 300 French farms. The method was developed for the assessment of all French agricultural production systems at both local and global scale.

- Indicators of farm sustainability (IFS)

The IFS method, introduced by Vilain[82], is based on assigning scores to farmer production practices and farmer behavior. It was developed for the French ministry of agriculture to evaluate the farms of 15 secondary schools for agricultural training involved in the promotion of sustainable agriculture, but it can be used to evaluate agro-ecological, socio-territorial, and economic sustainability for different types of farms. It was developed for impact assessment at both local and global scale.

- Environmental indicators for sustainable agriculture (ELISA)

  ELISA approach uses about 100 indicators defined according to the concept of the driving force/state/response (DSR)[83]. In the DSR indicators related to driving forces are used to characterize the negative or positive impacts of agricultural activities connected with land use and farming practices on the environment. In turn, state indicators assess the ecological state of habitats affected by agricultural activities, and response indicators characterize the response of society in regulatory terms to the state of the environment. Besides the DSR, the ELISA approach includes additionally the methods for combining indicators to obtain assessment criteria from several evaluation modules.

The evaluation methods using various agro-environmental indicators are based on a set of objectives. The term 'objective' is explicitly used in AEI, OS, MOP, and IFS methods, while other ones use a different term to name the same concept. They are named "environmental themes" in SEC and SD, "categories of environmental impact" in LCAA, "activity areas" in EMA, and "environmental impacts" in LCAE. To effectively evaluate environmental impact using methods of this type, a wide range of objectives covering both local and global effects should be taken into account. The number of objectives should be as small as possible to not become redundant and maintain feasibility, but sufficiently large to avoid the inadvertent creation of a new problem. Methods assessing simultaneously several environmental objectives are better suited to evaluate the environmental impact of farming activity than single-criterion approaches. Three classes of objectives can be distinguished, based on their type: input related, emission-related, and state of the system related. Table 2 (adapted from van der Werf[84]) presents which objectives are considered in the discussed agro-environmental indicators.

Objectives	**Methods**											
	FSI	**SEC**	**EP**	**LCAA**	**AEI**	**AESA**	**OS**	**MOP**	**EMA**	**SD**	**LCAE**	**IFS**
Input related												
Use of non-renewable energy		x		x	x				x	x	x	x
Use of other non-renewable resources		x		x	x							x
Soil erosion		x	x							x		
Land use		x		x		x					x	
Water use		x							x	x		x
Nitrogen fertilizer use	x		x						x			
Pesticide use	x		x				x		x			
Emission related												
Emission of greenhouse gases		x		x							x	
Emission of ozone-depleting gases		x									x	
Emission of acidifying gases		x		x							x	
Emission of nutrifying substances		x		x		x	x				x	
Emission of pesticides		x										
Emission of substances contributing to photo-chemical oxidant creation potential				x								
Emissions concerning terrestrial ecotoxicity				x							x	
Emissions concerning aquatic ecotoxicity				x							x	
Emissions concerning human toxicity				x							x	
Waste production and utilization		x									x	
System state related												
Landscape quality		x	x		x			x		x		x
Natural biodiversity		x			x			x	x	x		x
Agricultural biodiversity			x		x	x				x		x
Total system biomass						x						
Air quality					x			x				x

Water quality					x			x		x		x
Soil quality					x			x	x	x		x
Food (product) quality								x				
Animal welfare									x			

Table 20 Environmental objectives considered in indicator-based evaluation methods

Source: van der Werf and Petit (2002) [84]

The results obtained from indicator methods may be either in the form of values or scores. Scores have dimensionless units and can therefore not be balanced against other values or real-world observations. Indicators which express an impact in values that have units (both per kg of product or per unit of land area) are usually well-balanced and highlight the essential functions of agriculture, namely production and the occupation of the countryside.

The EIA approach based on agro-environmental indicators (AEI) is not allowing to assess environmental risk by spatial analysis like the environmental risk mapping (ERM) approach. It is also not standardized as others like life cycle analysis (LCA) or EIA, nor is basing on a representation of the behavior of the agents, as the multi-agent system (MAS) approach or on optimization models like the multiple linear programming (LP) approach. But the AEI method allows to obtain and map some indicators, such as contamination by pesticides, losses of nutrients or soil losses, when used in parallel with the ERM approach[83]. The environmental indicators can be complemented by economic indicators, such as the cost/benefit of a crop, or social indicators like food security[4][85].

- **Biophysical modeling**

  In some applications related to EIA of farming systems, process-based models can be used. This is especially true for the movement of sediments, nutrients and pesticides in the soil and habitat, determination of erosion risk factors or assessing agricultural emissions. These models can be also used to assess the soil impact aspects, for example the long-term effects of land use, or the impacts of alternative land-use scenarios. Process-based models can be divided into two classes. Some of the models are focused on the simulating of physicochemical and hydric processes occurring in the soil, such as erosion, water, or organic carbon levels (for example USLE/MUSLE/RUSLE, SWAT, GORCAM, RothC, ICBM, C-Tool). Other models are oriented on integrating various components to provide a full or almost a full agro-ecosystem simulation (for example CROPWAT, MISCANMOD, CENTURY, CERES-EGC, EPIC, SECRETS, GREET, BIOMA). Those two classes are intertwined with each other, for example USLE is used in EPIC, while CENTURY is used in GREET. The use of biophysical modeling to assess environmental impacts requires obtaining very detailed datasets, at a sufficiently detailed timescale (daily or even sub-daily). Data availability is often a limiting factor for biophysical modeling, as the process-based models must be initially calibrated. On the other hand, if the data is available, process-based models can simulate processes over long time periods, which allows the assessment of the variability and robustness of the results.

4.3 Key Performance Indicators (KPIs) related to the environmental and climatic IA of policies

Agri-environmental indicators are dedicated to measuring the linkages between the biophysical environment and human activities connected with agricultural production. These indicators can be used for improving the management of connections between various agents involved in the food chain. They also have to make it possible to consider the trade-offs between different management practices and their impact on the environment. An overview of the existing KPIs related to the environmental and climatic impact has been done in this chapter to facilitate their choice as input data in agent-based modeling within AGRICORE Suite. The indicators are always based on available measured or modeled data, therefore this overview also contains the description of the existing relevant information used for KPIs creation, contained in the existing EU databases. The overview on KPI provided in this section has been performed in the frame of WP5 of the AGRICORE project and its goal is to develop an impact assessment module (IAM) for the purpose of evaluating interrelations between agriculture and environmental issues including climate change challenges for food production. The IAM is aimed to deliver regional climatic patterns as an input to the agent-based models and to compute KPIs related to the environmental and climatic impact assessment of policies. In the extensive literature, there are still different approaches and numerous ambiguities for the evaluation of KPIs. Therefore, it was extremely important to overview the existing knowledge and to choose the KPIs that will be most suitable for agent-based modeling. The analyzed KPIs cover a broad range of issues including land conversion and habitat loss, wasteful water consumption, soil erosion and degradation, pollution, genetic erosion, and climate change.

The decisions about farm management take into account many factors that are connected with environmental aspects, including site-specific environmental conditions, environmental regulations or investments in research, and education. The complexity of the interactions between the agriculture and the environment and between the climate instability and required measures to adapt and mitigate to expected changes in climatic conditions make it difficult to precisely define physically-based indicators. The created indicators should be a basis on which policy-makers can have a picture of overall trends influencing socio-economic relations that may require specific actions. These indicators have to satisfy a set of criteria. Firstly, they should be able to sufficiently reflect changes in policies and farmer actions. Secondly, they should be analytically sound which means they should contain a scientific understanding of biophysical relationships and their interaction with farming activities. Additionally, the indicators should be based on measurable data of good quality, densely covering the area of interest. In some EU countries, data is available only nationally, in other sub-national data is also available. Therefore, the issues of spatial and temporal aggregation of the available data arise which is addressed in many reports [86] [87]. There are also differences in quality and data coverage and some disparities in absolute indicator levels between various countries. Existing databases of measured biophysical variables and research surveys frequently possess temporal gaps that should be addressed when planning their use. This refers especially to nutrient management indicators, pest management indicators, soil and land management indicators and biodiversity indicators [88] [89] [90].

The indicators that are related to the environmental and climatic impact assessment of policies should be easily interpretable by policy-makers, other stakeholders, and the wider public. This criterion is especially important in the context of selecting the most suitable KPIs for the IAM. Not properly-recognized disparities in absolute indicator levels between countries can lead to large inaccuracies in model predictability and in resulting recommendations for policy-makers. Varying methodologies and physical units of some biophysical values can also be a serious obstacle in the overall assessment of the trends in environmental performance. It is often spotted that some indicators remain difficult to understand without advanced biophysical knowledge, and it is often a serious challenge for specialists to elaborate uniform interpretation algorithms which could be used effectively by policy-makers. Additionally, in many cases, different indicator sets are needed when analyzing the overall farming system management and farm management aimed at specific practices (e.g. organic farming).

The development of the EU AEIs is a long-term project for monitoring the integration of environmental concerns into the CAP. A turning point in establishing the AEIs for the EU scale was the project: 'Indicator reporting on the integration of environmental concerns into agriculture policy' launched in the frame of the International Renewable Energy Agency (IRENA) in 2002 which was finalized at the end of 2005. The project aimed at developing and compiling the set of 35 indicators for EU-15, using the DPSIR model. In this model, social and economic developments drive (D) changes are identified that exert pressure (P) on the environment. This leads to changes in the state (S) of the environment, and consequently to impacts (I) on agriculture, and ecosystem functioning, and human services. As a final point, societal and political responses (R) occur that affect other parts of the system. The authors acknowledged numerous challenges for the EU scale implementation of the elaborated indicators mainly due to shortages in harmonization, quality, geographical coverage, and availability of data and existing limitations of the existing models to properly compute some of the indicators. These challenges were addressed in EU Commission Communication (COM) final 0508/2006. In this document, the EC proposed to maintain a core set of 28 indicators, which included 26 IRENA indicators and two new indicators covering new agri-environmental issues. The list of these indicators which was elaborated in close collaboration with MSs is presented in Table 3.

DPSIR			
Domain	**Subdomain**	**No.**	**Indicator (AEI)**
Responses	Public policy	1	Agri-environmental commitments
		2	Agricultural areas under Natura 2000
	Technology and skills	3	Farmers' training levels
	Market signals and attitudes	4	Area under organic farming
Driving forces	Input use	5	Mineral fertilizer consumption
		6	Consumption of pesticides
		7	Irrigation
		8	Energy use
	Land use	9	Land use change
		10.1	Cropping patterns
		10.2	Livestock patterns
	Farm management	11.1	Soil cover
		11.2	Tillage practices
		11.3	Manure storage
	Trends	12	Intensification/ extensification
		13	Specialization
		14	Risk of land abandonment
Pressures and benefits	Pollution	15	Gross nitrogen balance
		16	Risk of pollution by phosphorus
		17	Pesticide risk
		18	Ammonia emissions
		19	Greenhouse gas emissions
	Resource depletion	20	Water abstraction
		21	Soil erosion
		22	Genetic diversity
	Benefits	23	High nature value farmland
		24	Production of renewable energy
State/Impact	Biodiversity and habitats	25	Population trends of farmland birds
	Natural resources	26	Soil quality
		27.1	Water quality - Nitrate pollution
		27.2	Water quality - Pesticide pollution
	Landscape	28	Landscape - State and diversity

Table 21 The 28 AEIs identified in the Commission Communication COM(2006) 5081 with improvements performed in DireDate project report2

Source: European Commission (2006) and Euostat (2011)

Another step forward in developing AEIs for EU countries was the realization of the DireDate project with the aim to create a framework for setting up a sustainable system for collecting sets of data from farmers and other sources to determine the agreed 28 agri-environmental indicators. Within this project data requirements were defined and described, the methodologies elaborated for calculation of gas emissions and nutrient balances and the data collection, processing, and reporting systems in MSs were characterized. Lastly, recommendations for priority data collection were given. The reports from DireDate project became a keystone of AEIs assessment for the EU Commission.

The development and maintenance of the AEIs proposed by the EU Commission is a collaborative effort between the Directorate-General for Agriculture and Rural Development (DG AGRI), the Directorate-General for Environment (DG ENV), Eurostat, the Joint Research Centre (JRC), the European Environment Agency (EEA), and the Directorate-General for Health and Food Safety (DG SANTE). The Eurostat disseminates the available indicator fact sheets on the webpage: https://ec.europa.eu/eurostat/web/agriculture/agri-environmental-indicators which contains tables, graphs, and maps of the indicators or the raw dataset (data explorer). If the providers besides Eurostat exist they are indicated.

The changes in scale could affect the results of AEIs. Vinther et al. [91]proposed spatial scales for specific AEIs that were realistic, even at the NUTS 2 level. They suggested that a regional approach rather than a national approach is indispensable to capture the diversity in farming systems in a given territory and the environment. The authors suggest that the rate of change of the indicator should be the primary criterion for the frequency of data collection adjustment. They also propose that a chosen frequency of each indicator collection should be satisfactory to find its trends and spatial distribution but at the same time would not overwhelm the data provider. All of the EU AEIs are operational and deliver data at national and often at regional levels of decision[92] . For some indicators there is still insufficient frequency of evaluation and some regions are poorly covered. It was also indicated that some indicators (e. g., genetic diversity, migration of pests) still need substantial improvements in order to become fully operational[93] . According to Eurostat [94], for many indicators, only a short time period is covered which can limit the possibility of tracking the dynamics of their changes.

The data necessary for EU AEIs calculation is obtained by the surveys within EU MSs, direct measurements, and through modeling. There are three basic surveys of EU as existing data sources of EU Member States for the EU AEIs (Oenema et al. 2011):

1. **Farm Structure Survey (FSS)** which delivers statistical data on the structures of agricultural and horticultural enterprises in all Member States of the EU. The statistical data contains the number of farms, production sector, the form of ownership, land use, crop production, livestock production, farmers and other labor forces on farms, working hours spent on agricultural work, type and working hours outside the farm, secondary business activities on farms, organic production, machinery and equipment on farms, manure pits, and irrigated areas. The data under the FSS is carried out on a regular rather than an annual basis. This reflects the reality that changes in structural developments are difficult to identify on a year-to-year basis

   [95].

2. **Survey on Agricultural Production Methods (SAPM)**. The SAPM is a one-off supplement to the FSS focusing on production methods and management. It was carried out for the first time in 2010 to collect data at the farm level on AEM. The SAPM includes questions on the following topics: tillage methods (conventional tillage; conservation tillage; zero tillage), soil conservation and actions against erosion and nutrient leaching (soil cover in winter, crop rotation, anti-erosion measures for arable land and permanent crops), animal grazing (grazing on the holding; common land grazing), animal housing (places for cattle; pigs; laying hens), nutrients (availability of soil tests; manure application; application of solid/farmyard manure; application of slurry; the percentage of the total manure produced and exported from the holding), manure storage and treatment facilities, plant protection (type and area of plant protection methods, use of pesticide application equipment, treatment decision techniques), and irrigation (area of irrigated crops, methods of irrigation, source and volume of water used for irrigation). The legal basis for the SAPM is Regulation 1166/2008 of November 19, 2008, on farm structure surveys and the survey on agricultural production methods, which repealed Council Regulation 571/88.

3. **Farm Accountancy Data Network (FADN)**. Launched in 1965 (Regulation No 79/65/EEC of the Council), the FADN is an instrument for evaluating the income of agricultural holdings and the impacts of the CAP. The FADN creates a network for the collection of accountancy data on the incomes and business operation of agricultural holdings in 28 EU Member States. It covers over 81 thousand agricultural holdings. The responsibility for FADN data collection rests in the Liaison Agencies in each Member State. The FADN system is based on the annual surveys of microeconomic data carried out in and harmonized for all EU countries (the same bookkeeping principles). The farm return consists of several groups of accountancy data, including: general information about the farm, type of occupation, labor, number and value of livestock, livestock purchases and sales, costs of farm production, land and buildings, dead stocks, circulating capital, debts, value-added tax (VAT), grants and subsidies, production (excluding livestock), quotas and other rights, selected direct payments, details of purchase and sales of livestock. Kelly et al.

   [96] found that the FADN has a considerable potential to provide robust answers to complex emerging policy questions, especially when used in combination with other data (whether they are collected in complementary surveys or through integration with other databases). It has been also shown that some economic, environmental and social critical aspects at the farm level could be considered as an indirect proxy of farmers' innovation needs [97]

   [98].

Measurements and observations which can be used for the determination of indicators related to the environmental and climatic impact assessment are being gathered for the elements of the soil-plant-atmosphere system and natural ecosystems under the auspices of the EU Commission, FAO and other organizations within numerous projects dedicated to specific aspects of natural systems. An important reference point to host all relevant soil data and information at the European level is the European Soil Data Centre (ESDAC) [https://esdac.jrc.ec.europa.eu/]. The datasets are organized in 4 categories:

1. the European Soil Database (ESDB), datasets that have been derived with the help of the ESDB and general European datasets that contain soil properties,
2. datasets that are related to soil threats (erosion, soil organic carbon, landslides, compaction, salinization, soil biodiversity, contaminated sites, soil sealing, etc.),
3. soil point data (distributed in separate databases: LUCAS, SPADE, SPADE2, etc.),
4. data that stem from projects.

The ESDAC also contains some Eurasia and global soil datasets. Some ESDAC datasets can be freely downloaded; others are accessible after prior registration. Also, the ESDAC creates maps and projections of soil properties for EU territory including:

- European map of soil suitability: suitability of soil as a platform for most human activities; covers 28 European countries with a resolution of 1km.
- Soil Organic Carbon Projections: for current and future conditions with the use of 4 Global Climate Models (GCMs) and the Fifth Assessment Report (AR5) Representative Concentration Pathway (RCP) scenarios; covers 26 European countries with a resolution of 1km.
- Soil Erosion Risk Assessment in Europe (MESALES model): covers 28 countries at a scale of 1: 1 million.
- Soil Erosion by Water: covers 28 European countries with a resolution of 100 m.
- Soil Erosion by Wind: covers 28 European countries. Themes are: soil erosion by the wind in European agricultural soils (resolution 1 km), land susceptibility to wind erosion (resolution 500 m), and Wind erosion susceptibility of soils (resolution 500 m).

- Potential Threats to Soil Biodiversity: covers 27 European countries with a resolution of 500 m.
- In recent years the EU has developed physical properties datasets (silt, clay, sand and coarse fragments) for the EU, and maps of derived products (bulk density, available water capacity) using the Land Use and Cover Area frame Survey (LUCAS) topsoil database (Ballabio et al. 2016). The same database was used to create maps of soil chemical properties: pH, cation exchange capacity (CEC), calcium carbonates ($CaCO_3$), C:N ratio, nitrogen (N), phosphorus (P) and potassium (K) (Ballabio et al. 2019) and soil organic carbon content (Yigini and Panagos, 2016).

Meteorological time series are used as indicators of fluctuations in the general atmospheric circulation and climate systems. They are also essential inputs to the crop production models in simulations of climate change adaptation and mitigation [99][6]. The quality of meteorological time series is very important, because climate change analyses are highly sensitive to inhomogeneity of the data, incorrect, unreliable values, and irregularities [100] [101]. Meteorological data on changes in weather and climate extremes, as well as the daily dataset needed to monitor and analyze these extremes were collected in the European Climate Assessment & Dataset (ECA&D) project. The basic meteorological activities within EU are also performed by EUMETNET which groups 31 European National Meteorological Services. EUMETNET activities include weather and climate observing systems, data processing, basic forecasting products, research, development, and training. The extensive database of weather conditions on EU territory is created by the European Centre for Medium-Range Weather Forecasts (ECMWF) which also produces and disseminates weather forecast data for the National Meteorological and Hydrological Services of ECMWF Member and Co-operating States and their authorized users. Some data is available under license and some are publicly available. The ECMWF Centre has one of the largest supercomputer facilities and meteorological data archives in the world.

An important source of historical data of weather parameters is reanalysis projects which aim to assimilate historical atmospheric observational data spanning an extended period, using a single consistent assimilation scheme to provide a consistent reprocessing of meteorological observations in a physically consistent manner. Weather reanalysis systems use multiple sources of information (ground data, satellite and aerial data) and computer modeling [102][103] [104]. The output of the reanalysis is gridded datasets of studied meteorological elements for specific periods. Two main objectives of the reanalysis of weather datasets are to improve the available observational record for the early 20th century and to prepare datasets and assimilation tools for global reanalysis. The leading reanalyses systems are:

- MERRA, MERRA-2 from the National Aeronautics and Space Administration [105],
- CERA-20C, ERA-15, ERA-20C, ERA-40, and ERA-Interim from the ECMWF [106] [107]
- NOAA-CIRES 20th Century Reanalysis (20CRV2c) supported by the National Oceanic and Atmospheric Administration (NOAA) as well as the Cooperative Institute for Research in Environmental Sciences (CIRES) and the U.S. Department of Energy (DOE) [108], regional NCEP North American Regional Reanalysis (NARR), CFSR (Climate Forecast System Reanalysis), NCEP-DOE or NCEP-NCAR elaborated in the National Centers for Environmental Prediction (NCEP) [109] [110
- Japanese 25-year Reanalysis (JRA-25) [111] from the Japan Meteorological Agency (JMA).

A special role in the context of building the agricultural performance indicators on the base of the meteorological data is played by the AgMERRA reanalysis system created within the Agricultural Model Intercomparison and Improvement Project [112]. It has been designed to give careful consideration to agricultural areas and the climatic factors which are known to be critical for crop development (e.g., mean growing season biases, seasonal cycles, interannual variability, and sub-seasonal extremes) while also focusing on reducing biases of greater importance to agricultural production (e.g., daily precipitation distributions and solar radiation). AgMERRA has been produced by combining state-of-the-art reanalyses (NASA's Modern-Era Retrospective analysis for Research and Applications, MERRA) with observational datasets from in situ observational networks and satellites (2324 observational stations in farm areas). The AgMERRA datasets are stored at 0.25°×0.25° horizontal resolution (~25km), except from the data of mean, minimum and maximum air temperature which possess the resolution of 0.5°×0.5° horizontal resolution (~50km).

Another important source of weather data is the WorldClim database (https://worldclim.org/data/worldclim21.html) which contains gridded climate data that can be used for mapping and spatial modeling. WorldClim version 2 contains average monthly climatic gridded data for the period 1970-2000 with different spatial resolutions, from 30 seconds (~1 km2) to 10 minutes (~340 km2). The dataset includes the main climatic variables (monthly minimum, mean and maximum temperature, precipitation, solar radiation, wind speed, and water vapor pressure) as well as 19 derived bioclimatic variables (annual mean temperature, mean diurnal range, isothermality, temperature seasonality, max. temperature of the warmest month, min. temperature of the coldest month, temperature annual range, mean temperature of wettest quarter, mean temperature of driest quarter, mean temperature of warmest quarter, mean temperature of coldest quarter, annual precipitation, precipitation of wettest month, precipitation of driest month, precipitation seasonality (coefficient of variation), precipitation of wettest quarter, precipitation of driest quarter, precipitation of warmest quarter, precipitation of coldest quarter).

AgCFSR (described in [112] follow the example of other climate forcing datasets created by the hydrologic modeling community [113] [114], but were designed giving careful consideration to agricultural areas and the climatic factors known to be critical for crop development (e.g., mean growing season biases, seasonal cycles, interannual variability, and sub-seasonal extremes) while also focusing on reducing biases of greater importance to agricultural production (e.g., daily precipitation distributions and solar radiation). These datasets are produced by combining state-of-the-art reanalyses (NCEP's Climate Forecast System Reanalysis, CFSR) with observational datasets from in situ observational networks and satellites (2324 observational stations in farm areas).

4.4 Which environmental and climatic impacts of agriculture could be considered and how can they be modeled

4.4.1 General environmental modeling framework

Environmental modeling may involve a broad set of methodologies, especially when links between agriculture and the environment have to be taken into account. A comprehensive set of modeling approaches consists of [115][116][117]:

- Qualitative/descriptive models that include participatory mapping, socio-cultural methods, and surveys with open-ended questions that are used to elicit individuals' perceptions.
- Mapping is typically used for visualization of provision levels using techniques such as hot-spot mapping, biophysical models, integrated mapping-modeling approaches, and land-use scoring approaches.
- Statistical techniques include a broad range of classical data analysis methods. Starting from regression and/or correlation methods or multivariate analyses (Principal Component Analysis (PCA) and Multiple Correspondences Analysis (MCA)).

- Data-driven modeling (DDM) which is based on machine learning. Such techniques as: artificial neural networks, decision trees, random forests, decision rules, and Bayesian networks belong to this group.
- Integration techniques (semantic meta-modeling): The Unified Modelling Language is emerging as a de-facto standard for modeling object-oriented systems. Semantic meta-modeling is a technique that enables the flexible integration of models to overcome the service-by-service modeling approach.
- Biophysical modeling approaches trying to describe environmental processes on the basis of the physical description of soil processes linked with some kind of modeling of the plants-soil-environment continuum.

The impact of agriculture on the environment involves multiple processes and phenomenon which are cross-connected, depend on each other or forms chains of dependencies. E. g., tillage practices impact water retention, which influences runoff, on which soil erosion and pesticide transport are dependent on. Often these processes are modeled independently but it would be a huge advantage to model them as they really occur in the environment, i.e., as a net of cross dependent phenomena.

Different approaches could be used for that purpose but one of them seems to be especially well suited for such application – Bayesian networks (BN).

4.4.2 Bayesian networks for modeling the impact of agriculture on the environment

Since 2014, Bayesian networks have been introduced and applied to understand the interactions among multiple environmental factors [118]. This modeling approach may be used for quantitative analyses and may be used also for integrated modeling of dependencies between different environmental factors

Bayesian networks are currently a popular modeling tool used for very different fields of investigation where expert system features are mixed with elements of data modeling, e.g., medical diagnoses, communication networks, logistic processes assessment, any kind of risk management (pipelines failure prediction, maritime accidents analysis, mining risk management, and prediction), and also environmental modeling. There is enormous scope for their application to environmental models, including those for natural resource management, species and community modeling, management models, integrated models, social models, and risk assessment [119].

Generally, the exceptional ability of BN to integrate information/knowledge and data from a broad set of sources is very important for modeling the interactions between multiple systems. On the other hand, the statistical nature of BN allows incorporating uncertainties of inputs directly in models which, consequently, allow estimating the result's uncertainty.

Bayesian networks represent a modeled system as a network of interactions between components allowing estimation of the outcome based on the set of input variables. All cause-effects dependencies within the modeled system are defined explicitly, usually in the form of some sort of statistical/data-driven modeling model ranging from simple probability-based models, through different kinds of regression modeling, to more advanced artificial intelligence models.

Used for environmental modeling, BN models should follow a general workflow to ensure model quality and robustness:

- define model purpose
- specify modeling context (scope and resources)

- conceptualize the system, specify data, and other prior knowledge
- select model features and families
- decide how to find the model structure and parameter values
- select estimation performance criteria and techniques
- identify model structure and parameters
- conditional verification and diagnostic testing
- quantify uncertainty
- model evaluation and testing

Within BN specifics, some additional issues/model properties should be taken into consideration. For instance, model conceptualization in BN modeling means synthesizing existing knowledge and building of the influence diagram which is a basis for the network of interactions definition. The main purpose of this step is to provide a visual representation of the drivers linked to other variables and outputs. As a result, a set of variables influencing outputs directly or indirectly is determined, together with processes which link them. The initially defined conceptual model should be reviewed by the panel of experts to look if potential elements need changes [119].

The next step in BN modeling is structuring the model. The general conceptual model may be modified/restricted to suit the special aims of BN modeling. Based on one conceptual model describing the system in question, more than one BN structural model may be derived for different purposes. At the phase of structuration, some links from conceptual models may be neglected explicitly if they have a much lower impact than others. This stem may be automated, when structural learning scoring algorithm is used, which searches for a structure based on the maximization of the defined model's structural entropy function [120]. All nodes finally included in the model have to influence the outcomes, otherwise they should be removed. BN are based on directed acyclic graphs; as a result, BN can't contain cyclic loops.

Variables appearing in BN modeling may be categorical, boolean, discrete, or continuous. In most cases, continuous variables have to be discretized to be incorporated into the model. This may potentially lead to decreasing the accuracy of the overall model. A crucial step in such cases is the correct choice of the number of intervals used for discretization. Proper selection of these intervals allows the balance between model accuracy and complexity [121]. Two commonly used techniques for that purpose are: first, a simple equal-width technique when min-max range is divided equally to a predefined number of uniform intervals. Alternatively, a data-aware approach, known as equal-frequency, divides parameter input space in accordance with equality of expected data in each interval. Some BN modeling software packages (e.g. commercial Analytica and Hugin, or GPL licensed R/bnlearn package) allow using continuous variables directly.

The core of BN modeling are conditional probabilities (CP) which are a statistical measure of dependence between nodes (representing variables and/or processes). BN networks are very flexible in CP considered in the model as they may be taken from different sources (datasets from field monitoring or laboratory studies; process equations derived from peer-reviewed studies or models; datasets, derived from models; information elicited from experts or stakeholders).

4.4.3 Uncertainty and validation in agriculture environmental modeling

The estimation of uncertainty of models is very important for their practical use. It allows for quantification of the error which accompanies estimations made by models. This, in turn, translates into the lack of confidence that a decision-maker has about the possible results in a real scenario. Unfortunately, in practical applications of environmental modeling, the uncertainty estimation is rather scarce. Based on a review of almost 200 modeling studies from the last decade [118], only 16% used some kind of uncertainty quantification. The most commonly applied methods were matrices and probability distributions in association with uncertainty types related to classification errors and natural variability.

Validation of models is a procedure to evaluate if a model provides correct results. This procedure typically needs additional data not used during a model elaboration. This is the reason why in practical applications it is not always used. Due to typically very complicated and often unclear dependence between factors/processes involved in environmental modeling they are sometimes substituted by extremely simplified models based on scarce available data related to the modeled phenomenon. In many situations, this data used for the model elaboration is the only available data. Therefore, validation cannot be done. According to about half of the presented studies lack validation. For other, most commonly applied validation strategies are: an adjustment of the field data samples, Cohen's Kappa coefficient, and concordance measures.

4.4.4 Software tools used for BN environmental modeling

If Bayesian networks are used for modeling the impact of agriculture on the environment, two software platforms seem to be the most suitable: R and Python. Both of them are scripting languages. R is a specialized scripting language developed especially for statistical analysis, visualization, and modeling. R is developed for years and is accompanied by a huge set of modules/libraries devoted to virtually any data modeling technique. In relation to BN, some libraries are also available. One of them – bnlearn – seems to be one of the most advanced tools. It allows a full set of BN related operations: graph creation, graph separation, decomposition of the global distribution, decomposition of the global distributions definition, adjacency matrix creation, finding the skeleton, finding the moral graph, and many others. Despite the great flexibility of the R environment, it may also have some shortcomings which should be considered. R is known to be not as effective (in terms of computation speed) as comparable compiled programs or even Python-based scripting programs. Second, it lacks the universal parallel computing module. Parallel computing, i.e. SMP parallelism, is supported in R by the use of add-ons libraries but not all data analysis tasks, especially related to the bnlearn library operation, could be sped up this way.

The second modelling environment to be considered is Python, which per se is another general use scripting language. Some Bayesian networks library packages are available for Python. Two of them seem to be developed enough to be considered: pgmpy and pomegranate. The latter has already SMP processing incorporated by using the third party library – joblib. Other potentially important computing features of the pomegranate package is the possibility of GPU computing on compatible hardware.

Both of the considered software systems are professional grade free license packages.

4.4.5 Environmental impacts of agriculture to be considered in modeling

Agriculture affects many different environmental processes. In fact, environmental/agricultural processes form cross connected nets of dependencies. Identifying these cross connections and understanding them is indispensable to correctly model environmental services.

4.4.5.1 Soil

Agricultural production may impact soil quality sometimes leading to its degradation. There are estimations that in certain circumstances soil degradation decreased environmental services by more than 50% during the last 60 years [122]. Globally, one third of land is affected by soil degradation. Soil degradation not only affects food production, which is a direct influence, but also may have negative impact on economic growth in case of agriculture dominated economies.

Soil provides very important ecological services: food, feed, climate, moderation by C cycling, waste disposal, water filtration, and cycling of the elements among others. Soil's degradation processes reduce soil quality leading to reduction of the ecosystem functions. Basically, there are three types of soil degradation processes: physical, chemical, and biological. All three may be related to agricultural production.

Physical soil degradation is almost exclusively related to changed soil pore geometry and continuity which impact soil water transport processes. This, combined together with increasing rain shortages and/or extreme rain events, may lead to soil dryness, increased runoff, and wind erosion. Chemical soil degradation may be related to adverse changes of naturally occurring chemical processes in the soil-plant environment. But chemical soil degradation may be also linked to the direct introduction of environment pollutants. Soil biological degradation reflects depletion of the soil organic carbon (SOC) pool, loss in soil biodiversity, a reduction in soil C sink capacity, and increased greenhouse gas (GHG) emissions from the soil into the atmosphere.

Once the soil environment is disturbed it leads consequently to soil quality reduction unless recovering actions are taken [123].

The main indicator of the soil quality is a SOC pool [124]. Other chemical indicators are: pH, CEC, lack of any toxicity, nutrients availability. Example indicators related to soil physical properties are: pore continuity, water content at plant-available capacity, aggregates stability, and soil water conductivity.

4.4.5.2 Cropping diversity

Monocropping is the practice of growing the same crop for a long time on the same plot of land. Such practice causes reduced nutrients content leading to decreased soil fertility and yields. Agro-ecosystems temporal diversity stays in opposition to the monocropping practice. Despite the obvious positive impact of diversity on soil's fertility, it may also have a positive role in mitigating the weather variations leading to increased yield. Especially in hot and dry conditions diversity shows positive impacts on yield while for wet and cool weather conditions its impact is not so significant [125].

Understanding the role of diversity on the functioning of agro-ecosystems and crop yield responses to environmental stresses may help design cropping systems able to maintain good crop quality under abnormal weather scenarios. Positive crop diversity impacts include: increase yields over time, lower risk of crop failure, and mitigation of yield loss due to hot/dry conditions.

4.4.5.3 Synthetic fertilizers on soil health

All plants need basic elements for proper growth. Nitrogen (N), phosphorus (P) and potassium (K) have key impacts on healthy and productive crops. Nutrients, when in balance, form the basis for healthy soil. Despite basic N P K nutrients, other macro- and micro-nutrients are needed for optimal – plant growth oriented – soil conditions.

The main indicator of soil biological health is the diversity of soil biota species. Potential methods for influencing the soil biota involve the use of management practices such as mulching, compost application, and synthetic nitrogen application [126]. One of the crucial components of soil biota are soil nematodes which are the most numerous and diverse organisms found in agricultural soils [127]. Synthetic fertilizers have been shown to have a large impact on soil microorganisms. In compost-treated soil, the total nematode density has been found to increase [128]. Recent studies suggests that synthetic nitrogen fertilizers may decrease soil's microbiological (i.e. fungi and bacteria) diversity and may affect the natural microbiological composition in a pathological manner [129].

The other issue related to application of fertilizers is excessive use. Despite most common problems related to accumulation of fertilizers in soil, leading to build-up of salt and possible chemical contamination of food products, excess of fertilizers may impact environment directly by water contamination including ground water [130]. As a result over-fertilization leads to changes in the biodiversity and causes greenhouse gas emissions. Over-fertilization is also counterproductive as it may negatively affect productivity and fruit or crop quality while increasing costs of agricultural production [131][132]. Excessive usage of fertilizers may also cause health problems for consumers. Drinking nitrate contaminated groundwater or consuming high nitrate-containing vegetables may lead to serious pathological conditions in the human population [133].

4.4.5.4 Pesticide residues in soil and water

Usage of pesticides is a common, and often indispensable, practice in agriculture. Once chemicals enter the environment, they are subject to many physio-chemical and bio-chemical processes. They may impact substantially the environment if not treated adequately. Pesticides usage have to be considered together with tillage systems as different tillage are linked with specific pesticides practices. Also, changes in tillage intensity leads to changes in soil physical and chemical properties, modifying soil processes and pesticides fate.

Once pesticides are applied, they are subject to three processes: interception in soil, degradation, and transfer. These processes are directly linked to soil, water, and yield quality.

Pesticides interception is dependent on: type of crop, the stage of the crop at the pesticide application, and the type of pesticide itself. Other effects which may impact interception is the existence of mulch [134]. Plant residues existing in soil, especially when conservation tillage is in use, cause higher pesticide adsorption. If more than 30% of soil surface is mulched, more than half of the applied dose would be intercepted[135]. The organic carbon (OC) content is another soil characteristic positively correlated with pesticides' interception rate. A major source of organic carbon in soil is decomposition of plant residues. Usually, the concentration of OC decreases with soil depth. As OC particles are adsorbing pesticides, its concentration is also depth dependent. Pesticides interception is also dependent on soil's pH. There is observed negative correlation between pH and pesticides' adsorption ratio. Pesticides already absorbed in soil, may be released when soil chemical condition will change and desorption processes will be more likely.

Understanding pesticide degradation processes is a key factor for understanding pesticide persistence in soil and its transport. Degradation is directly linked with environmental risk assessment for pesticides. There are two major paths of degradation: biotic—where soil micro-organisms, bacteria, and fungi are involved; and abiotic—based purely on physio-chemical soil's processes. Biotic pesticide degradation is considered to be far more important [136].

The last soil's pesticides related phenomenon to be considered is their transfer, an important factor, leading to contamination of other environmental components. It is important process as transferring pesticides dependently on their mobility and stability will contaminate other environmental components. Three transport transport processes need to be considered: volatilization, leaching, and runoff.

Volatilization is the process of losing pesticides from the soil in their gaseous state. Soil related factors that affect pesticides volatilization are: soil moisture, soil temperature, and organic carbon content. Furthermore, tillage also influences pesticides volatilization [137]. Conservation tillage is connected with higher volatilization ratios. Depending on chemical in question, and soil water content, volatilization ratio may be even three times higher for conservational tillage. The volatilization ratio depends on the meteorological conditions – primarily the temperature. The higher the temperature, the higher the volatilization rate.

The excess of pesticides in soil causes leaching, which in turn leads to contamination of groundwater resources. Besides pesticides availability, leaching is tightly connected to soil water transport processes. Soil hydraulic parameters together with meteorological conditions governs this phenomenon. An additional important factor is solubility of the compound in question. More soluble chemicals will be subject to stronger leaching. Solubility is influenced by the soil's pH and an increase of pH increases substantially the solubility of the selected pesticides. The influence of tillage in leaching is not clear. Different studies presents contradictory conclusions [134].

The role of runoff is important as it is directly related to potential contamination of surface waters. The mechanism is simple, excess of rainfall over infiltration rate forms surface flow, contaminating creeks, rivers or lakes. Runoff is generally a very adverse phenomenon which should be avoided if possible. Minimization of runoff enhances soil water retention, improving plants condition. This would be especially important in the context of changing climate reality. In fact, In fact, major reasons for applying in practice conservation tillage are, mitigation of runoff and erosion.

Detailed runoff modelling is possible within the framework of soil hydrology. Nevertheless simplified methods are also used for runoff quantification, e.g., the runoff curve number approach [138], estimating runoff based on simple field related indices.

Pesticide transport phenomenon may be modelled using numerous tools, among them four are pointed by FOCUS (FOrum for Co-ordination of pesticide fate models and their USe) working group as preferable for risk assessment for pesticide registration purposes on the European level [139]: MACRO [140], PEARL [141], PELMO [142] and PRZM [143]. These models were also the highest ranked among thirteen compared models in the independent pesticide leaching models comparison study (Siimes and Kämäri, 2003). All of these models allows for modelling of: pesticide leaching, soil water flow and surface runoff. Some of them: PELMO and PRZM allows also for erosion estimation. All of these models are 1D models simulating processes in one specific location based on accurate physical description. Usage of them for areas, needs repetition of calculations in representative points and integration or averaging of partial results.

4.4.5.5 Livestock production

Industrial agriculture, especially livestock farming may be very straining for the environment. The stress caused by livestock production is expected to increase together with consumer's demand for more animal products. Nutrient losses from animal production are inevitable, but they can, to some extent, be prevented or at least controlled.

Despite expected products, side products as: urine, feces, fermentation and respiration gases are also generated, leading to contamination of environment and greenhouse gases emission. From a biochemical point of view, livestock production is a chain of biochemical nutrients processes [144]. Within this chain, different components are involved: energy, soil, water, plants, animals, and manure. In the cycling of carbon, nitrogen, and carbon dioxide such processes as: photosynthesis, nitrogen fixation, nitrification, mineralization and denitrification are involved.

The type of animal production systems, together with intensity, are important factors influencing stress on the environment.

Manure related soil contamination may lead to contamination of surface waters due to runoff. Soil may accumulate only limited amounts of manure and excess may be transported further leading to fertilization of surface waters and causing algae to proliferate rapidly. This may impact the aquatic environment as when algae die they decompose, and dissolved oxygen is removed from the water, making it difficult for other aquatic organisms to survive. Nitrate excessive concentrations may lead to eutrophication and contamination of drinking water.

Not only the aquatic environment is affected by livestock production, but also generated gases affect air quality. Direct air pollution usually is not a problem in terms of environmental hazards, but it may affect very badly human life quality due to uncomfortable odors if they live in the proximity of livestock farms. The other phenomenon related to livestock production is greenhouse gasses emissions. While carbon dioxide emissions from livestock production are not so important due to low global warming potential (GWP) and low emission, methane is far more important. Methane GWP is high and it is estimated that around 20% of methane emissions come from ruminants and animal wastes [144]. The last gas emitted due to livestock production is ammonia, related to manure. Animals diet and/or manure related farm management practices can lead to released ammonia reduction. Due to zero GWP, livestock ammonia emission does not impact global warming, but after deposition to land, can increase acidification and nutrient-N soil enrichment [141].

One of possible modelling tools for quantification of greenhouse gas (GHG) emissions of feed production and utilization on a farm level may be FeedPrint. The model was developed at Wageningen University and is currently still maintained and developed[145]. It allows for calculation of greenhouse gas emissions of the whole feed production chain. Methodology applied there is consistent with IPCC requirements on calculating GHG emissions.

4.4.5.6 Soil erosion

Tillage practices (conventional tillage, conservation tillage) impacts many soil related factors. One of the most important is the impact on the soil erosion which leads in a long time spans to agricultural land degradation.

Conservation tillage not only reduces soil disturbance due to agricultural processes in comparison to conventional practices but also causes much higher (~30%) soil covering with residues after planting [146]. Conservation tillage influences also runoff from agricultural lands [147]. Reduced runoff leads to higher water retention and availability for plants. Which most likely is a reason for usually observed in case of conservation tillage decrease of soil erosion. Details of tillage, e.g. planting in rows which usually resulting bare soil in between (for potatoes or white beet) may cause higher vulnerability of soil to erosion [138].

Reduced soil erosion rate is linked also with other soil and environment quality indicators. Some authors connects with reduced soil loss ratio decreasing plant nutrient losses [148]. Pesticide interception is also impacted by tillage practice. Due to higher sorption capabilities of organic remainders accompanying conservation tillage, pesticides residues leaching to soil water/runoff is lower [134].

Mentioned earlier pesticide leaching models: PELMO and PRZM, are based on hydrological sub-models and estimate runoff as one of outcomes, are also capable for erosion rate estimation.

4.5 References

1. ^ U. N. D. of Economic and S. A. P. Division, World Population Prospects 2019: Data Booklet. New York, USA: UN, 2019.
2. ^ FAO, Climate change and food security: Risks and responses. Rome, Italy: FAO, 2016.
3. ^ E. B. Barbier, “The Concept of Sustainable Economic Development,” Environmental Conservation, vol. 14, no. 2, pp. 101–110, 1987.
4. ^ 1 2 3 OECD, Environmental Indicators for Agriculture: Methods and Results, Vol. 3. Paris, France: OECD Publishing, 2001, p. 416.
5. ^ F. Alonso-Pérez, A. Ruiz-Luna, J. Turner, C. A. Berlanga-Robles, and G. Mitchelson-Jacob, “Land cover changes and impact of shrimp aquaculture on the landscape in the Ceuta coastal lagoon system, Sinaloa, Mexico,” Ocean & Coastal Management, vol. 46, no. 6–7, pp. 583–600, Jan. 2003.
6. ^ 1 2 M. Ruiz-Ramos, R. Ferrise, A. Rodríguez, I. J. Lorite, M. Bindi, T. R. Carter, S. Fronzek, T. Palosuo, N. Pirttioja, P. Baranowski, S. Buis, D. Cammarano, Y. Chen, B. Dumont, F. Ewert, T. Gaiser, P. Hlavinka, H. Hoffmann, J. G. Höhn, F. Jurecka, K. C. Kersebaum, J. Krzyszczak, M. Lana, A. Mechiche-Alami, J. Minet, M. Montesino, C. Nendel, J. R. Porter, F. Ruget, M. A. Semenov, Z. Steinmetz, P. Stratonovitch, I. Supit, F. Tao, M. Trnka, A. de Wit, and R. P. Rötter, “Adaptation response surfaces for managing wheat under perturbed climate and CO 2 in a Mediterranean environment,” Agricultural Systems, vol. 159, pp. 260–274, Jan. 2018.

7. ^ A. Rodríguez, M. Ruiz-Ramos, T. Palosuo, T. R. Carter, S. Fronzek, I. J. Lorite, R. Ferrise, N. Pirttioja, M. Bindi, P. Baranowski, S. Buis, D. Cammarano, Y. Chen, B. Dumont, F. Ewert, T. Gaiser, P. Hlavinka, H. Hoffmann, J. G. Höhn, F. Jurecka, K. C. Kersebaum, J. Krzyszczak, M. Lana, A. Mechiche-Alami, J. Minet, M. Montesino, C. Nendel, J. R. Porter, F. Ruget, M. A. Semenov, Z. Steinmetz, P. Stratonovitch, I. Supit, F. Tao, M. Trnka, A. de Wit, and R. P. Rötter, "Implications of crop model ensemble size and composition for estimates of adaptation effects and agreement of recommendations," Agricultural and Forest Meteorology, vol. 264, pp. 351–362, Jan. 2019.
8. ^ N. Pirttioja, T. Carter, S. Fronzek, M. Bindi, H. Hoffmann, T. Palosuo, M. Ruiz-Ramos, F. Tao, M. Trnka, M. Acutis, S. Asseng, P. Baranowski, B. Basso, P. Bodin, S. Buis, D. Cammarano, P. Deligios, M. Destain, B. Dumont, F. Ewert, R. Ferrise, L. François, T. Gaiser, P. Hlavinka, I. Jacquemin, K. Kersebaum, C. Kollas, J. Krzyszczak, I. Lorite, J. Minet, M. Minguez, M. Montesino, M. Moriondo, C. Müller, C. Nendel, I. Öztürk, A. Perego, A. Rodríguez, A. Ruane, F. Ruget, M. Sanna, M. Semenov, C. Slawinski, P. Stratonovitch, I. Supit, K. Waha, E. Wang, L. Wu, Z. Zhao, and R. Rötter, "Temperature and precipitation effects on wheat yield across a European transect: a crop model ensemble analysis using impact response surfaces," Climate Research, vol. 65, pp. 87–105, Sep. 2015.
9. ^ S. Fronzek, N. Pirttioja, T. R. Carter, M. Bindi, H. Hoffmann, T. Palosuo, M. Ruiz-Ramos, F. Tao, M. Trnka, M. Acutis, S. Asseng, P. Baranowski, B. Basso, P. Bodin, S. Buis, D. Cammarano, P. Deligios, M.-F. Destain, B. Dumont, F. Ewert, R. Ferrise, L. François, T. Gaiser, P. Hlavinka, I. Jacquemin, K. C. Kersebaum, C. Kollas, J. Krzyszczak, I. J. Lorite, J. Minet, M. I. Minguez, M. Montesino, M. Moriondo, C. Müller, C. Nendel, I. Öztürk, A. Perego, A. Rodríguez, A. C. Ruane, F. Ruget, M. Sanna, M. A. Semenov, C. Slawinski, P. Stratonovitch, I. Supit, K. Waha, E. Wang, L. Wu, Z. Zhao, and R. P. Rötter, "Classifying multi-model wheat yield impact response surfaces showing sensitivity to temperature and precipitation change," Agricultural Systems, vol. 159, pp. 209–224, Jan. 2018.
10. ^ D. Pimentel and N. Kounang, "Ecology of Soil Erosion in Ecosystems," Ecosystems, vol. 1, no. 5, pp. 416–426, Sep. 1998.
11. ^ 1 2 K. LEWIS and K. BARDON, "A computer-based informal environmental management system for agriculture," Environmental Modelling and Software, vol. 13, no. 2, pp. 123–137, Apr. 1998.
12. ^ T. Kätterer and O. Andrén, "Long-term agricultural field experiments in Northern Europe: analysis of the influence of management on soil carbon stocks using the ICBM model," Agriculture, Ecosystems & Environment, vol. 72, no. 2, pp. 165–179, Feb. 1999.
13. ^ A. Marcoux, Population and deforestation. Rome, Italy: Sustainable Development Department,Food and Agriculture Organization of the United Nations (FAO), 2000.
14. ^ J. Hance, "Tropical deforestation is 'one of the worst crises since we came out of our caves," Mongabay.com / A Place Out of Time: Tropical Rainforests and the Perils They Face, 2008.
15. ^ OECD, Multifunctionality: Towards an Analytical Framework. Paris, France: OECD Publishing, 2001, p. 160.
16. ^ C. . Smith, G. . McDonald, and R. . Thwaites, "TIM: Assessing the sustainability of agricultural land management," Journal of Environmental Management, vol. 60, no. 4, pp. 267–288, Dec. 2000.
17. ^ M. Benoît, "Un indicateur des risques de pollution nommé BASCULE (Balance Azotée Spatialisée des systèmes de CUlture de l'Exploitation)," Courrier de la Cellule Environnement, vol. 18, pp. 23–28, 1992.
18. ^ CORPEN, Estimation des rejets d'azote-phosphore – potassium – cuivre et zinc des porcs. Influence de la conduite alimentaire et du mode de logement des animaux sur la nature et la gestion des de´jections produites. Paris, France: Comite´ d'ORientation pour des Pratiques agricoles respectueuses de l'ENvironnement, 2003, p. 41.
19. ^ M. Renkow, "Assessing the environmental impacts of CGIAR research: toward an analytical framework," in Measuring the impacts of agricultural research: theory and

applications to CGIAR research, Rome, Italy: CGIAR Independent Science and Partnership Council, 2011, pp. 1–33.
20. ^ A. L. Heathwaite, “Making process-based knowledge useable at the operational level: a framework for modelling diffuse pollution from agricultural land,” Environmental Modelling & Software, vol. 18, no. 8–9, pp. 753–760, Oct. 2003.
21. ^ 1 2 J. ASSIMAKOPOULOS, D. KALIVAS, and V. KOLLIAS, “A GIS-based fuzzy classification for mapping the agricultural soils for N-fertilizers use,” The Science of The Total Environment, vol. 309, no. 1–3, pp. 19–33, Jun. 2003.
22. ^ A. Finizio and S. Villa, “Environmental risk assessment for pesticides,” Environmental Impact Assessment Review, vol. 22, no. 3, pp. 235–248, May 2002.
23. ^ J.-Y. Bouchardy, “Méthodologie pour la spatialisation des zones sensibles à la pollution diffuse agricole par le phosphore, à l’aide de la télédétection et des systèmes d’informations géographiques (S. I. G.),” Grenoble, France, 1992.
24. ^ K. Chen, R. Blong, and C. Jacobson, “MCE-RISK: integrating multicriteria evaluation and GIS for risk decision-making in natural hazards,” Environmental Modelling & Software, vol. 16, no. 4, pp. 387–397, Jun. 2001.
25. ^ D. Cocco, P. Deligios, L. Ledda, L. Sulas, A. Virdis, and G. Carboni, “LCA Study of Oleaginous Bioenergy Chains in a Mediterranean Environment,” Energies, vol. 7, no. 10, pp. 6258–6281, Sep. 2014.
26. ^ ISO 14040: Environmental management — Life cycle assessment — Principles and framework. Geneva, Switzerland, 2000, p. 20.
27. ^ ISO 14044: Environmental management — Life cycle assessment — Requirements and guidelines. Geneva, Switzerland, 2006, p. 46.
28. ^ ISO 14042: Environmental Management – Life Cycle Assessment – Life Cycle Impact Assessment. Geneva, Switzerland, 2000, p. 16.
29. ^ ISO 14043: Environmental Management – Life Cycle Assessment – Life Cycle Interpretation. Geneva, Switzerland, 2000, p. 18.
30. ^ B. Mattsson, “Environmental Life Cycle Assessment (LCA) of agricultural food production,” Alnarp, Sweden, 1999.
31. ^ F. Brentrup, J. Küsters, H. Kuhlmann, and J. Lammel, “Application of the Life Cycle Assessment methodology to agricultural production: an example of sugar beet production with different forms of nitrogen fertilisers,” European Journal of Agronomy, vol. 14, no. 3, pp. 221–233, May 2001.
32. ^ G. Haas, F. Wetterich, and U. Köpke, “Comparing intensive, extensified and organic grassland farming in southern Germany by process life cycle assessment,” Agriculture, Ecosystems & Environment, vol. 83, no. 1–2, pp. 43–53, Jan. 2001.
33. ^ C. Cederberg, “Life Cycle Assessment (LCA) of animal production,” Goteborg, Sweden, 2002.
34. ^ R. Dalgaard, N. Halberg, I. S. Kristensen, and I. Larsen, “An LC inventory based on representative and coherent farm types,” in Proceedings of the Fourth International Conference on LifeCycle Assessment in the Agri-food Sector, Bygholm, Denmark, 2004, pp. 98–106.
35. ^ 1 2 E. E. Biewinga and G. van der Bijl, Sustainability of Energy Crops in Europe: A Methodology Developed and Applied. Utrecht, The Netherlands: Centre for Agriculture & Environment, 1996, p. 209.
36. ^ G. Gaillard, P. Crettaz, and J. Hausheer, “Inventaire environnemental des intrants agricoles en production végétale,” Comptes-rendus de la station federate de recherches en économie et technologie agricoles, vol. 46, pp. 1–53, 1997.
37. ^ S. Pfister, A. Koehler, and S. Hellweg, “Assessing the Environmental Impacts of Freshwater Consumption in LCA,” Environmental Science & Technology, vol. 43, no. 11, pp. 4098–4104, Jun. 2009.

38. ^ M. Brandão and L. M. i Canals, "Global characterisation factors to assess land use impacts on biotic production," The International Journal of Life Cycle Assessment, vol. 18, no. 6, pp. 1243–1252, Feb. 2012.
39. ^ L. M. i Canals, "Contributions to LCA methodology for agricultural systems, site-dependency and soil degradation impact assessment.," Barcelona, Spain, 2003.
40. ^ 1 2 L. Milà i Canals, J. Romanyà, and S. J. Cowell, "Method for assessing impacts on life support functions (LSF) related to the use of 'fertile land' in Life Cycle Assessment (LCA)," Journal of Cleaner Production, vol. 15, no. 15, pp. 1426–1440, Oct. 2007.
41. ^ D. W. Reeves, "The role of soil organic matter in maintaining soil quality in continuous cropping systems," Soil and Tillage Research, vol. 43, no. 1–2, pp. 131–167, Nov. 1997.
42. ^ N. Brady and R. Weil, The nature and properties of soils, 13th edn. Upper Saddle River, New York: Pearson Prentice Hall, 2002, p. 960.
43. ^ IPCC, Guidelines for National Greenhouse Gas Inventories. Vol 4 Agriculture, Forestry and Other Land Use. WMO/UNEP, 2006.
44. ^ M. Núñez, A. Antón, P. Muñoz, and J. Rieradevall, "Inclusion of soil erosion impacts in life cycle assessment on a global scale: application to energy crops in Spain," The International Journal of Life Cycle Assessment, vol. 18, no. 4, pp. 755–767, Nov. 2012.
45. ^ R. Saad, M. Margni, T. Koellner, B. Wittstock, and L. Deschênes, "Assessment of land use impacts on soil ecological functions: development of spatially differentiated characterization factors within a Canadian context," The International Journal of Life Cycle Assessment, vol. 16, no. 3, pp. 198–211, Feb. 2011.
46. ^ R. Saad, T. Koellner, and M. Margni, "Land use impacts on freshwater regulation, erosion regulation, and water purification: a spatial approach for a global scale level," The International Journal of Life Cycle Assessment, vol. 18, no. 6, pp. 1253–1264, Apr. 2013.
47. ^ P. J. B. Duffy, "EIA AS A CATALYST TO SUSTAINABLE DEVELOPMENT IN MOZAMBIQUE," Impact Assessment, vol. 10, no. 3, pp. 67–72, Sep. 1992.
48. ^ M. Lenzen, S. A. Murray, B. Korte, and C. J. Dey, "Environmental impact assessment including indirect effects—a case study using input–output analysis," Environmental Impact Assessment Review, vol. 23, no. 3, pp. 263–282, May 2003.
49. ^ 1 2 T. Berger, P. Schreinemachers, and J. Woelcke, "Multi-agent simulation for the targeting of development policies in less-favored areas," Agricultural Systems, vol. 88, no. 1, pp. 28–43, Apr. 2006.
50. ^ A. Balmann, "Farm-based modelling of regional structural change: A cellular automata approach," European Review of Agricultural Economics, vol. 24, no. 1, pp. 85–108, Jan. 1997.
51. ^ 1 2 T. Berger, "Agent-based spatial models applied to agriculture: a simulation tool for technology diffusion, resource use changes and policy analysis," Agricultural Economics, vol. 25, no. 2–3, pp. 245–260, Sep. 2001.
52. ^ 1 2 R. Matthews, "The People and Landscape Model (PALM): Towards full integration of human decision-making and biophysical simulation models," Ecological Modelling, vol. 194, no. 4, pp. 329–343, Apr. 2006.
53. ^ P. Schreinemachers, T. Berger, and J. B. Aune, "Simulating soil fertility and poverty dynamics in Uganda: A bio-economic multi-agent systems approach," Ecological Economics, vol. 64, no. 2, pp. 387–401, Dec. 2007.
54. ^ K. Happe, A. Balmann, K. Kellermann, and C. Sahrbacher, "Does structure matter? The impact of switching the agricultural policy regime on farm structures," Journal of Economic Behavior & Organization, vol. 67, no. 2, pp. 431–444, Aug. 2008.
55. ^ M. Graubner, A. Balmann, and R. J. Sexton, "Spatial Price Discrimination in Agricultural Product Procurement Markets: A Computational Economics Approach," American Journal of Agricultural Economics, vol. 93, no. 4, pp. 949–967, Jul. 2011.
56. ^ R. Courdier, F. Guerrin, F. Andriamasinoro, and J.-M. Paillat, "Agent-Based Simulation of Complex Systems: Application to Collective Management of Animal Wastes," Journal of

Artificial Societies and Social Simulation, vol. 5, no. 3, pp. 1–4, 2002, [Online]. Available: https://ideas.repec.org/a/jas/jasssj/2001-20-2.html.
57. ^ Q. B. Le, S. J. Park, and P. L. G. Vlek, "Land Use Dynamic Simulator (LUDAS): A multi-agent system model for simulating spatio-temporal dynamics of coupled human–landscape system," Ecological Informatics, vol. 5, no. 3, pp. 203–221, May 2010.
58. ^ S. Balbi and C. Giupponi, "Reviewing Agent-Based Modelling of Socio-Ecosystems: A Methodology for the Analysis of Climate Change Adaptation and Sustainability," SSRN Electronic Journal, 2009.
59. ^ A. Patt and B. Siebenhüner, "Agent Based Modeling and Adaptation to Climate Change," Vierteljahrshefte zur Wirtschaftsforschung, vol. 74, no. 2, pp. 310–320, Apr. 2005.
60. ^ S. Moss, C. Pahl-Wostl, and T. Downing, Integrated Assessment, vol. 2, no. 1, pp. 17–30, 2001.
61. ^ J. J. Stoorvogel, "Integration of computer-based models and tools to evaluate alternative land-use scenarios as part of an agricultural systems analysis," Agricultural Systems, vol. 49, no. 4, pp. 353–367, Jan. 1995.
62. ^ B. A. M. Bouman, H. G. P. Jansen, R. A. Schipper, A. Nieuwenhuyse, H. Hengsdijk, and J. Bouma, "A framework for integrated biophysical and economic land use analysis at different scales," Agriculture, Ecosystems & Environment, vol. 75, no. 1–2, pp. 55–73, Aug. 1999.
63. ^ P. J. Agrell, A. Stam, and G. W. Fischer, "Interactive multiobjective agro-ecological land use planning: The Bungoma region in Kenya," European Journal of Operational Research, vol. 158, no. 1, pp. 194–217, Oct. 2004.
64. ^ [1] [2] B. A. . Bouman, R. . Schipper, A. Nieuwenhuyse, H. Hengsdijk, and H. G. . Jansen, "Quantifying economic and biophysical sustainability trade-offs in land use exploration at the regional level: a case study for the Northern Atlantic Zone of Costa Rica," Ecological Modelling, vol. 114, no. 1, pp. 95–109, Dec. 1998.
65. ^ R. W. Herdt and R. Steiner, "Agricultural sustainability: concepts and conundrums," in Agricultural sustainability: economic, environmental and social considerations, 1995, p. 257.
66. ^ J. W. Hansen, "Is agricultural sustainability a useful concept?," Agricultural Systems, vol. 50, no. 2, pp. 117–143, Jan. 1996.
67. ^ R. Gras et al., "Le fait technique en agronomie. Activité agricole, concepts et méthodes d'étude," in INRA. Editions L'Harmattan. Chapitre 4: Les méthodes, 1989, p. 183.
68. ^ G. Mitchell, A. May, and A. McDonald, "PICABUE: a methodological framework for the development of indicators of sustainable development," International Journal of Sustainable Development & World Ecology, vol. 2, no. 2, pp. 104–123, Jun. 1995.
69. ^ OECD, Environmental indicators for agriculture, Conceptsand Framework, Vol. 1. Paris, France: OECD Publishing, 1999, p. 48.
70. ^ C. King, J. Gunton, D. Freebairn, J. Coutts, and I. Webb, "The sustainability indicator industry:where to from here? A focus group study to explore the potential of farmer participation in the development of indicators," Australian Journal of Experimental Agriculture, vol. 40, no. 4, p. 631, 2000.
71. ^ D. C. Taylor, Z. A. Mohamed, M. N. Shamsudin, M. G. Mohayidin, and E. F. C. Chiew, "Creating a farmer sustainability index: A Malaysian case study," American Journal of Alternative Agriculture, vol. 8, no. 4, pp. 175–184, Dec. 1993.
72. ^ R. Heijungs et al., Environmental Life Cycle Assessment of products. Part I. Guide; Part II. Backgrounds. Leiden, The Netherlands: Centre of Environmental Science, 1992.
73. ^ E. Audsley et al., "Harmonisation of environmental life cycle assessment for agriculture," Silsoe, UK, 1997.
74. ^ D. Rossier, "L'écobilan, outil de gestion écologique de l'exploitation agricole?," Revue Suisse d'Agriculture, vol. 31, no. 4, pp. 179–185, 1999.
75. ^ P. Mayrhofer, C. Steiner, E. Gärber, and E. Gruber, Regionalprogramm Ökopunkte Niederösterreich. Informationsheft. Wien, Austria, 1996.

76. ^ P. Girardin, C. Bockstaller, and H. Van der Werf, "Assessment of potential impacts of agricultural practices on the environment," Environmental Impact Assessment Review, vol. 20, no. 2, pp. 227–239, Apr. 2000.
77. ^ L. B. Leopold, F. F. Clark, B. B. Hanshaw, and J. R. Balsley, "A procedure for evaluating environmental impact," 1971.
78. ^ J. P. T. Dalsgaard and R. T. Oficial, "A quantitative approach for assessing the productive performance and ecological contributions of smallholder farms," Agricultural Systems, vol. 55, no. 4, pp. 503–533, Dec. 1997.
79. ^ W. A. H. Rossing, J. E. Jansma, F. J. De Ruijter, and J. Schans, European Journal of Plant Pathology, vol. 103, no. 3, pp. 217–234, 1997.
80. ^ P. Vereijken, "A methodical way of prototyping integrated and ecological arable farming systems (I/EAFS) in interaction with pilot farms," Perspectives for Agronomy - Adopting Ecological Principles and Managing Resource Use, Proceedings of the 4th Congress of the European Society for Agronomy, pp. 293–308, 1997.
81. ^ P. Pointereau et al., Le diagnostic agri-environnemental pour une agriculture respectueuse de l'environnement. Trois méthodes passées à la loupe. Travaux et Innovations. Paris, France, 1999.
82. ^ L. Vilain, De l'exploitation agricole à l'agriculture durable: Aide méthodologique à la mise en place de systèmes agricoles durables. Dijon, France: Educagri éditions, 1999, p. 155.
83. ^ 1 2 D. M. Wascher, Agri-environmental Indicators for Sustainable Agriculture in Europe. Tilburg, The Netherlands: European Center for Nature Conservation, 2000, p. 240.
84. ^ 1 2 H. M. . van der Werf and J. Petit, "Evaluation of the environmental impact of agriculture at the farm level: a comparison and analysis of 12 indicator-based methods," Agriculture, Ecosystems & Environment, vol. 93, no. 1–3, pp. 131–145, Dec. 2002.
85. ^ G. Rasul and G. B. Thapa, "Sustainability of ecological and conventional agricultural systems in Bangladesh: an assessment based on environmental, economic and social perspectives," Agricultural Systems, vol. 79, no. 3, pp. 327–351, Mar. 2004.
86. ^ {"format":"ieee","doi":"http://dx.doi.org/10.1787/9789264181151-en ","cacheKey":"http://dx.doi.org/10.1787/9789264181151-en :ieee:170"}
87. ^ {"format":"ieee","doi":"https://doi.org/10.2800/53480.","cacheKey":"https://doi.org/10.2800/53480.:ieee:170"}
88. ^ A. Elshorbagy, G. Corzo, S. Srinivasulu, and D. P. Solomatine, "Experimental investigation of the predictive capabilities of data driven modeling techniques in hydrology - Part 1: Concepts and methodology," Hydrology and Earth System Sciences, vol. 14, no. 10, pp. 1931–1941, Oct. 2010.
89. ^ M. G. Erechtchoukova, P. A. Khaiter, and P. Golinska, Eds., "Sustainability Appraisal: Quantitative Methods and Mathematical Techniques for Environmental Performance Evaluation," EcoProduction, 2013.
90. ^ C. Bockstaller, L. Guichard, D. Makowski, A. Aveline, P. Girardin, and S. Plantureux, "Agri-environmental indicators to assess cropping and farming systems. A review," Agronomy for Sustainable Development, vol. 28, no. 1, pp. 139–149, Mar. 2008.
91. ^ F. Vinther et al., Data requirements, availability and gaps in agri-environment indicators (AEIs) in Europe. Publications Office of the European Union, 2011.
92. ^ C. Van Beek, S. Pietrzaket, H. Heesmans, and O. Oenema, Characterisation of data collection—processing—reporting for agri-environmental policies in Member States of the European Union. Publications Office of the European Union, 2011.
93. ^ G. L. Velthof and J. Selenius, Agri-environmental indicators: recommendations for priority data collection and data combination. Publications Office of the European Union, 2011.
94. ^ L. Wilson et al., Direct and indirect data needs linked to the farms for agri-environmental indicators. Publications Office of the European Union.
95. ^ K. Utvik, M. Colantonio, C. Gengler, A. Begolli, and M. Da Silva, Agriculture, Forestry and Fishery Statistics: 2019 Edition. Publications Office of the European Union, 2019.

96. ^ E. Kelly, L. Latruffe, Y. Desjeux, M. Ryan, S. Uthes, A. Diazabakana, E. Dillon, and J. Finn, "Sustainability indicators for improved assessment of the effects of agricultural policy across the EU: Is FADN the answer?," Ecological Indicators, vol. 89, pp. 903–911, Jun. 2018.
97. ^ H. Vrolijk, K. Poppe, and S. Keszthelyi, "Collecting sustainability data in different organisational settings of the European Farm Accountancy Data Network," Studies in Agricultural Economics, vol. 118, no. 3, pp. 138–144, Dec. 2016.
98. ^ A. Arzeni, E. Ascione, P. Borsotto, V. Carta, T. Castellotti, and A. Vagnozzi, "Analysis of farms characteristics related to innovation needs: a proposal for supporting the public decision-making process," Land Use Policy, vol. 100, p. 104892, Jan. 2021.
99. ^ S. Asseng, F. Ewert, C. Rosenzweig, J. W. Jones, J. L. Hatfield, A. C. Ruane, K. J. Boote, P. J. Thorburn, R. P. Rötter, D. Cammarano, N. Brisson, B. Basso, P. Martre, P. K. Aggarwal, C. Angulo, P. Bertuzzi, C. Biernath, A. J. Challinor, J. Doltra, S. Gayler, R. Goldberg, R. Grant, L. Heng, J. Hooker, L. A. Hunt, J. Ingwersen, R. C. Izaurralde, K. C. Kersebaum, C. Müller, S. Naresh Kumar, C. Nendel, G. O'Leary, J. E. Olesen, T. M. Osborne, T. Palosuo, E. Priesack, D. Ripoche, M. A. Semenov, I. Shcherbak, P. Steduto, C. Stöckle, P. Stratonovitch, T. Streck, I. Supit, F. Tao, M. Travasso, K. Waha, D. Wallach, J. W. White, J. R. Williams, and J. Wolf, "Uncertainty in simulating wheat yields under climate change," Nature Climate Change, vol. 3, no. 9, pp. 827–832, Jun. 2013.
100. ^ F. Ewert, D. Rodriguez, P. Jamieson, M. . Semenov, R. A. . Mitchell, J. Goudriaan, J. . Porter, B. . Kimball, P. . Pinter, R. Manderscheid, H. . Weigel, A. Fangmeier, E. Fereres, and F. Villalobos, "Effects of elevated CO2 and drought on wheat: testing crop simulation models for different experimental and climatic conditions," Agriculture, Ecosystems & Environment, vol. 93, no. 1–3, pp. 249–266, Dec. 2002.
101. ^ H. Hoffmann, P. Baranowski, J. Krzyszczak, M. Zubik, C. Sławiński, T. Gaiser, and F. Ewert, "Temporal properties of spatially aggregated meteorological time series," Agricultural and Forest Meteorology, vol. 234–235, pp. 247–257, Mar. 2017.
102. ^ A. D. Kennedy, X. Dong, B. Xi, S. Xie, Y. Zhang, and J. Chen, "A Comparison of MERRA and NARR Reanalyses with the DOE ARM SGP Data," Journal of Climate, vol. 24, no. 17, pp. 4541–4557, Sep. 2011.
103. ^ A. Boilley and L. Wald, "Comparison between meteorological re-analyses from ERA-Interim and MERRA and measurements of daily solar irradiation at surface," Renewable Energy, vol. 75, pp. 135–143, Mar. 2015.
104. ^ C. W. Frank, S. Wahl, J. D. Keller, B. Pospichal, A. Hense, and S. Crewell, "Bias correction of a novel European reanalysis data set for solar energy applications," Solar Energy, vol. 164, pp. 12–24, Apr. 2018.
105. ^ R. Gelaro, W. McCarty, M. J. Suárez, R. Todling, A. Molod, L. Takacs, C. A. Randles, A. Darmenov, M. G. Bosilovich, R. Reichle, K. Wargan, L. Coy, R. Cullather, C. Draper, S. Akella, V. Buchard, A. Conaty, A. M. da Silva, W. Gu, G.-K. Kim, R. Koster, R. Lucchesi, D. Merkova, J. E. Nielsen, G. Partyka, S. Pawson, W. Putman, M. Rienecker, S. D. Schubert, M. Sienkiewicz, and B. Zhao, "The Modern-Era Retrospective Analysis for Research and Applications, Version 2 (MERRA-2)," Journal of Climate, vol. 30, no. 14, pp. 5419–5454, Jul. 2017.
106. ^ P. Poli, H. Hersbach, D. P. Dee, P. Berrisford, A. J. Simmons, F. Vitart, P. Laloyaux, D. G. H. Tan, C. Peubey, J.-N. Thépaut, Y. Trémolet, E. V. Hólm, M. Bonavita, L. Isaksen, and M. Fisher, "ERA-20C: An Atmospheric Reanalysis of the Twentieth Century," Journal of Climate, vol. 29, no. 11, pp. 4083–4097, May 2016.
107. ^ D. P. Dee, M. Balmaseda, G. Balsamo, R. Engelen, A. J. Simmons, and J.-N. Thépaut, "Toward a Consistent Reanalysis of the Climate System," Bulletin of the American Meteorological Society, vol. 95, no. 8, pp. 1235–1248, Aug. 2014.
108. ^ L. C. Slivinski, G. P. Compo, J. S. Whitaker, P. D. Sardeshmukh, B. S. Giese, C. McColl, R. Allan, X. Yin, R. Vose, H. Titchner, J. Kennedy, L. J. Spencer, L. Ashcroft, S. Brönnimann, M. Brunet, D. Camuffo, R. Cornes, T. A. Cram, R. Crouthamel, F. Domínguez-Castro, J. E. Freeman, J. Gergis, E. Hawkins, P. D. Jones, S. Jourdain, A. Kaplan, H. Kubota, F. L. Blancq, T. Lee, A. Lorrey, J. Luterbacher, M. Maugeri, C. J. Mock, G. W. K. Moore, R. Przybylak, C.

Pudmenzky, C. Reason, V. C. Slonosky, C. A. Smith, B. Tinz, B. Trewin, M. A. Valente, X. L. Wang, C. Wilkinson, K. Wood, and P. Wyszyński, “Towards a more reliable historical reanalysis: Improvements for version 3 of the Twentieth Century Reanalysis system,” Quarterly Journal of the Royal Meteorological Society, vol. 145, no. 724, pp. 2876–2908, Aug. 2019.

109. ^ {"format":"ieee","doi":"https://doi.org/10.1175/1520-0477(1996)077<0437:TNYRP>2.0.CO;2","cacheKey":"https://doi.org/10.1175/1520-0477(1996)077<0437:TNYRP>2.0.CO;2:ieee:170"}

110. ^ S. Saha, S. Nadiga, C. Thiaw, J. Wang, W. Wang, Q. Zhang, H. M. Van den Dool, H.-L. Pan, S. Moorthi, D. Behringer, D. Stokes, M. Peña, S. Lord, G. White, W. Ebisuzaki, P. Peng, and P. Xie, “The NCEP Climate Forecast System,” Journal of Climate, vol. 19, no. 15, pp. 3483–3517, Aug. 2006.

111. ^ K. ONOGI, J. TSUTSUI, H. KOIDE, M. SAKAMOTO, S. KOBAYASHI, H. HATSUSHIKA, T. MATSUMOTO, N. YAMAZAKI, H. KAMAHORI, K. TAKAHASHI, S. KADOKURA, K. WADA, K. KATO, R. OYAMA, T. OSE, N. MANNOJI, and R. TAIRA, “The JRA-25 Reanalysis,” Journal of the Meteorological Society of Japan. Ser. II, vol. 85, no. 3, pp. 369–432, 2007.

112. ^ 1 2 A. C. Ruane, R. Goldberg, and J. Chryssanthacopoulos, “Climate forcing datasets for agricultural modeling: Merged products for gap-filling and historical climate series estimation,” Agricultural and Forest Meteorology, vol. 200, pp. 233–248, Jan. 2015.

113. ^ J. Sheffield, G. Goteti, and E. F. Wood, “Development of a 50-Year High-Resolution Global Dataset of Meteorological Forcings for Land Surface Modeling,” Journal of Climate, vol. 19, no. 13, pp. 3088–3111, Jul. 2006.

114. ^ G. P. Weedon, S. Gomes, P. Viterbo, W. J. Shuttleworth, E. Blyth, H. Österle, J. C. Adam, N. Bellouin, O. Boucher, and M. Best, “Creation of the WATCH Forcing Data and Its Use to Assess Global and Regional Reference Crop Evaporation over Land during the Twentieth Century,” Journal of Hydrometeorology, vol. 12, no. 5, pp. 823–848, Oct. 2011.

115. ^ E. M. Bennett, G. D. Peterson, and L. J. Gordon, “Understanding relationships among multiple ecosystem services,” Ecology Letters, vol. 12, no. 12, pp. 1394–1404, Oct. 2009.

116. ^ L. Brilli, L. Bechini, M. Bindi, M. Carozzi, D. Cavalli, R. Conant, C. D. Dorich, L. Doro, F. Ehrhardt, R. Farina, R. Ferrise, N. Fitton, R. Francaviglia, P. Grace, I. Iocola, K. Klumpp, J. Léonard, R. Martin, R. S. Massad, S. Recous, G. Seddaiu, J. Sharp, P. Smith, W. N. Smith, J.-F. Soussana, and G. Bellocchi, “Review and analysis of strengths and weaknesses of agro-ecosystem models for simulating C and N fluxes,” Science of The Total Environment, vol. 598, pp. 445–470, Nov. 2017.

117. ^ A. Chlingaryan, S. Sukkarieh, and B. Whelan, “Machine learning approaches for crop yield prediction and nitrogen status estimation in precision agriculture: A review,” Computers and Electronics in Agriculture, vol. 151, pp. 61–69, Aug. 2018.

118. ^ 1 2 C. A. R. Agudelo, S. L. H. Bustos, and C. A. P. Moreno, “Modeling interactions among multiple ecosystem services. A critical review,” Ecological Modelling, vol. 429, p. 109103, Aug. 2020.

119. ^ 1 2 S. H. Chen and C. A. Pollino, “Good practice in Bayesian network modelling,” Environmental Modelling & Software, vol. 37, pp. 134–145, Nov. 2012.

120. ^ D. Heckerman, D. Geiger, and D. M. Chickering, Machine Learning, vol. 20, no. 3, pp. 197–243, 1995.

121. ^ D. Nash and M. Hannah, “Using Monte-Carlo simulations and Bayesian Networks to quantify and demonstrate the impact of fertiliser best management practices,” Environmental Modelling & Software, vol. 26, no. 9, pp. 1079–1088, Sep. 2011.

122. ^ J. D. León and N. W. Osorio, “Role of Litter Turnover in Soil Quality in Tropical Degraded Lands of Colombia,” The Scientific World Journal, vol. 2014, pp. 1–11, 2014.

123. ^ R. Lal, “Restoring Soil Quality to Mitigate Soil Degradation,” Sustainability, vol. 7, no. 5, pp. 5875–5895, May 2015.

124. ^ R. Jandl, M. Rodeghiero, C. Martinez, M. F. Cotrufo, F. Bampa, B. van Wesemael, R. B. Harrison, I. A. Guerrini, D. deB Richter, L. Rustad, K. Lorenz, A. Chabbi, and F. Miglietta,

"Current status, uncertainty and future needs in soil organic carbon monitoring," Science of The Total Environment, vol. 468–469, pp. 376–383, Jan. 2014.
125. ^ A. C. M. Gaudin, T. N. Tolhurst, A. P. Ker, K. Janovicek, C. Tortora, R. C. Martin, and W. Deen, "Increasing Crop Diversity Mitigates Weather Variations and Improves Yield Stability," PLOS ONE, vol. 10, no. 2, p. e0113261, Feb. 2015.
126. ^ G. L. Herren, J. Habraken, L. Waeyenberge, A. Haegeman, N. Viaene, M. Cougnon, D. Reheul, H. Steel, and W. Bert, "Effects of synthetic fertilizer and farm compost on soil nematode community in long-term crop rotation plots: A morphological and metabarcoding approach," PLOS ONE, vol. 15, no. 3, p. e0230153, Mar. 2020.
127. ^ T. Bongers and H. Ferris, "Nematode community structure as a bioindicator in environmental monitoring," Trends in Ecology & Evolution, vol. 14, no. 6, pp. 224–228, Jun. 1999.
128. ^ L. . Bulluck, K. . Barker, and J. . Ristaino, "Influences of organic and synthetic soil fertility amendments on nematode trophic groups and community dynamics under tomatoes," Applied Soil Ecology, vol. 21, no. 3, pp. 233–250, Oct. 2002.
129. ^ J. Zhou, X. Jiang, D. Wei, B. Zhao, M. Ma, S. Chen, F. Cao, D. Shen, D. Guan, and J. Li, "Consistent effects of nitrogen fertilization on soil bacterial communities in black soils for two crop seasons in China," Scientific Reports, vol. 7, no. 1, Jun. 2017.
130. ^ "Effects of Fertilizer Broadcasting on the Excessive Use of Inorganic Fertilizers and Environmental Sustainability," Sustainability, vol. 10, no. 3, p. 759, Mar. 2018.
131. ^ M. Ahmed, M. Rauf, Z. Mukhtar, and N. A. Saeed, "Excessive use of nitrogenous fertilizers: an unawareness causing serious threats to environment and human health," Environmental Science and Pollution Research, vol. 24, no. 35, pp. 26983–26987, Nov. 2017.
132. ^ S. A. Weinbaum, R. S. Johnson, and T. M. DeJong, "Causes and Consequences of Overfertilization in Orchards," HortTechnology, vol. 2, no. 1, p. 112b–121, Jan. 1992.
133. ^ M. H. Ward, "Too Much of a Good Thing? Nitrate from Nitrogen Fertilizers and Cancer," Reviews on Environmental Health, vol. 24, no. 4, Jan. 2009.
134. ^ 1 2 3 L. Alletto, Y. Coquet, P. Benoit, D. Heddadj, and E. Barriuso, "Tillage management effects on pesticide fate in soils. A review," Agronomy for Sustainable Development, vol. 30, no. 2, pp. 367–400, Apr. 2010.
135. ^ P. A. Banks and E. L. Robinson, "The Influence of Straw Mulch on the Soil Reception and Persistence of Metribuzin," Weed Science, vol. 30, no. 2, pp. 164–168, Mar. 1982.
136. ^ V. O. Biederbeck, C. A. Campbell, and J. H. Hunter, "Tillage effects on soil microbial and biochemical characteristics in a fallow-wheat rotation in a Dark Brown soil," Canadian Journal of Soil Science, vol. 77, no. 2, pp. 309–316, May 1997.
137. ^ C. Bedos, P. Cellier, R. Calvet, E. Barriuso, and B. Gabrielle, "Mass transfer of pesticides into the atmosphere by volatilization from soils and plants: overview," Agronomie, vol. 22, no. 1, pp. 21–33, Jan. 2002.
138. ^ 1 2 S. Sittig, R. Sur, D. Baets, and K. Hammel, "Consideration of risk management practices in regulatory risk assessments: evaluation of field trials with micro-dams to reduce pesticide transport via surface runoff and soil erosion," Environmental Sciences Europe, vol. 32, no. 1, Jun. 2020.
139. ^ J. M. Marín-Benito, L. Mamy, M. J. Carpio, M. J. Sánchez-Martín, and M. S. Rodríguez-Cruz, "Modelling herbicides mobility in amended soils: Calibration and test of PRZM and MACRO," Science of The Total Environment, vol. 717, p. 137019, May 2020.
140. ^ N. Jarvis and M. Larsbo, "MACRO (v5.2): Model Use, Calibration, and Validation," Transactions of the ASABE, vol. 55, no. 4, pp. 1413–1423, 2012.
141. ^ 1 2 F. van den Berg, A. Tiktak, G. B. M. Heuvelink, S. L. G. E. Burgers, D. J. Brus, F. de Vries, J. Stolte, and J. G. Kroes, "Propagation of Uncertainties in Soil and Pesticide Properties to Pesticide Leaching," Journal of Environmental Quality, vol. 41, no. 1, pp. 253–261, Jan. 2012.

142. ^ M. Klein, "Statistical distribution of pesticide concentrations in leachate results of a Monte-Carlo analysis performed with pelmo," Chemosphere, vol. 35, no. 1–2, pp. 379–389, Jul. 1997.
143. ^ R. F. Carsel, L. A. Mulkey, M. N. Lorber, and L. B. Baskin, "The Pesticide Root Zone Model (PRZM): A procedure for evaluating pesticide leaching threats to groundwater," Ecological Modelling, vol. 30, no. 1–2, pp. 49–69, Oct. 1985.
144. ^ 1 2 S. Tamminga, "Pollution due to nutrient losses and its control in European animal production," Livestock Production Science, vol. 84, no. 2, pp. 101–111, Dec. 2003.
145. ^ T.V. Vellinga, H. Blonk, M. Marinussen, W.J. van Zeist, I.J.M. de Boer, and D. Starmans, "Methodology used in feedprint: a tool quantifying greenhouse gas emissions of feed production and utilization," Livestock Research, Report 674, 2013.
146. ^ A. Klik and J. Rosner, "Long-term experience with conservation tillage practices in Austria: Impacts on soil erosion processes," Soil and Tillage Research, vol. 203, p. 104669, Sep. 2020.
147. ^ F. E. Rhoton, M. J. Shipitalo, and D. L. Lindbo, "Runoff and soil loss from midwestern and southeastern US silt loam soils as affected by tillage practice and soil organic matter content," Soil and Tillage Research, vol. 66, no. 1, pp. 1–11, Jun. 2002.
148. ^ L. L. McDowell and K. C. McGregor, "Plant nutrient losses in runoff from conservation tillage corn," Soil and Tillage Research, vol. 4, no. 1, pp. 79–91, Feb. 1984.

5 Ecosystem Services

5.1 Ecosystem services—the concept and evolution

According to the Millennium Ecosystem Assessment Report[1], the structure and functioning of ecosystems in the world have changed significantly over the years. These changes occurred faster in the second half of the 20th century than at any other time in human history. It was thirty years after 1950 that many more areas were transformed into arable fields than in the years between 1700 and 1850. The authors of the report indicate that arable systems (areas where at least 30% of the landscape is arable), account for a quarter of the earth's surface. The report shows rapid changes in land use as a result of deforestation in the continent of South America, north-eastern Europe, Asia, and central Africa over the years 1980-2000. Since 1960, the amount of retained water has increased fourfold, while 3-6 times more water is found in reservoirs than in natural rivers. Freshwater intake from open reservoirs and watercourses has doubled—agriculture is the largest consumer of water in the world by far and consumption accounts for 70% of freshwater. Flows of reactive (bioavailable) nitrogen in terrestrial ecosystems have doubled since 1960, while phosphorus flows have tripled. More than half of all synthetic nitrogen fertilizers used on our planet have been since 1985. The concentration of carbon dioxide in the atmosphere increased by about 32% (from about 280 ppm in 1750 to 376 ppm in 2003) mainly due to the burning of fossil fuels and land-use changes. About 60% of this increase (60 ppm) has been in recent years. Since 1959, people have a significant impact on the diversity of life on Earth, but unfortunately, most of these changes mean a loss of biodiversity. By 1990, more than two-thirds of the surface area of 2 of the 14 major terrestrial biomes in the world and more than half of the surface area of 4 other biomes were transformed mainly for agricultural purposes. The number of animal species on our planet is decreasing—in recent centuries the rate of extinction of species has increased up to 1,000 times compared to background indicators typical of the history of the planet. Genetic diversity has dropped worldwide, especially among crop species. Most of the above changes in our planet's ecosystems occurred to meet the dramatic increase in demand for food, water, wood, in bedding, and fuel. However, some of them were inadvertently the result of activities unrelated to the use of ecosystem services, such as road and port construction, urban development, and discharge. Still, most changes in the ecosystem were the direct or indirect result of changes made to meet the growing demand for ecosystem services. In particular, the growing demand for food, water, wood, fiber, and fuel. The demand for ecosystem services increased very clearly in the years 1960–2000 when the world's population reached 6 billion and the global economy increased more than six times. To meet this demand, it was necessary to increase food production by about two and a half times, and water consumption doubled. Wood harvest has tripled, hydropower capacity doubled, and wood production increased by more than half. The growing demand for ecosystem services has been met both by consuming an increasing part of the available supply (e.g., by channeling more irrigation water or capturing more fish from the sea), and by increasing the production of some services, such as crops and livestock. The latter has been achieved through the use of new technologies (such as new plant varieties, fertilization, and irrigation), as well as by increasing the managed area for services in the case of plant and animal production and aquaculture.

The concept of ecosystem services, which first appeared in the 1980s, is becoming increasingly influential [2]. As the MEA Report (Assessment, 2005) defines, ecosystem services are 'the benefits ecosystems provide to human well being'. The term has been joined by related terms such as 'environmental services' or 'ecological services'; however, 'ecosystem services' remains the most common term in the scientific literature[3]. The importance and application of this concept are rapidly evolving as stakeholders such as researchers, policymakers, and managers examine the benefits that ecosystems provide to people[4].

The concept of ecosystem services was born from early concerns about environmental degradation to formal knowledge, policies, and research focused on valuing and protecting valuable ecosystems. Four key stages of institutionalization were identified as part of the discussion on ecosystem services, which followed the publication of key documents at the national level to interest and research on a global scale [5]. A clear distinction between the ecosystems and the services they provide is still at a very basic level, but, as the authors say, the increase in discourse is increasingly affecting the perception of the value of ecosystems. According to Golley[6], the term "ecosystem" refers to complex interactions between living and inanimate environmental components in a pristine or natural state. Braat and de Groot[7], by formulating the term "services", drew attention to how individual ecosystems provide services to people and how people influence these services. This concept was met with a wave of criticism because of its anthropocentric orientation, ignoring the internal values of nature[8] and excluding more demanding forms of environmental ethics[9].

Schröter et al.[10]argue that this anthropocentric orientation of ecosystem services has facilitated the mainstreaming of the concept, creating a convincing rationale for policymakers to conserve and use ecosystems sustainably and address the problem of ecosystem degradation. The expansion of disciplines dealing with this topic has led to a different kind of criticism. Some of the allegations are technical, e.g., concerns about the limitations of ecosystem services to take into account uncertainty, and reversibility[11], confusion of ecosystem functions, and services[12], and consequently, the possibility of double-counting for the valuation of ecosystem services[13].

However, others reflect the involvement of new disciplines that have different interests than ecology and economics. According to Jackson and Palmer[14], a common problem is prioritizing economic values, which has led to the exclusion/marginalization of other ecological and socio-cultural values. Fairhead et al.[15]expressed concerns that setting the price for nature may lead to separation, commodification, and ultimately exploitation of the environment—and not to a closer relationship with it. Other authors who are closer to biological sciences are afraid of perceiving the weak links between biodiversity management and the provision of ecosystem services[16]. That anthropocentric focus can have a detrimental effect on species[12].

Fisher et al.[17] indicate that there are concerns about insufficient attention to poorer communities and the many values and services provided by ecosystems. On the other hand, Bommarco et al. [18] emphasized the potential of using this concept to pursue sustainable development, resilience, and food security. Therefore, extending ecosystem services to other disciplines raises new challenges and questions and creates new research paths when ecosystem services appear as a global project to specifically rebuild human-environment relationships.

Chaudhary et al. [5] identified a discursive-institutional spiral that illustrates how academic and some key non-academic actors have contributed to the development of the concept of ecosystem services over time. The authors of the spiral concept indicate that the combination of ecology and economics has created a pace for global actions on environmental issues that none could achieve by itself. Another interesting observation that comes from the spiral concept is the growing range of disciplines and institutions involved in the discourse of ecosystem services. Organizations as diverse as non-profit, government, intergovernmental, community, networks, and academic environments at all levels embrace this concept.

The history of the appearance and different aspects of the term ecosystem services is presented in a very detailed way in a book by Potschin, M. and R. Haines-Young[19]. The authors discussed widely the different points of view of the subject presented in the literature. Several of commentators have noted the problems of defining exactly what an ecosystem service is. Despite their differences, they all agreed that there is some kind of ‘pathway’ for delivering ecosystem services that go from ecological structures and processes at one end through to the well-being of people at the other. Therefore, the ecosystem services are described by the authors as a ‘cascade’ illustrated in Figure 1.

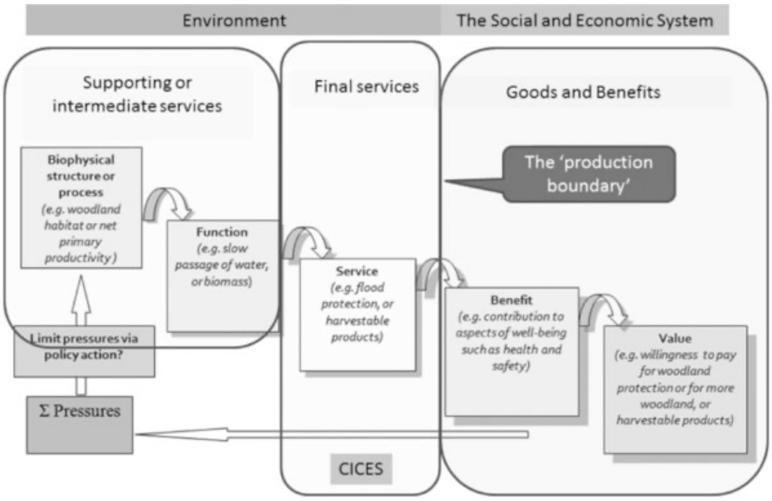

Figure 3 The cascade model

Source: authors' elaborations on Potschin and Haines-Young[20]

5.2 Ecosystem services classifications

Schmidt et al. [21] evaluated the ecosystem services approach in agricultural literature. The authors prepared an open, accessible database to analyze ecosystem services indexed in the literature with an agricultural context. It gives an overview of the assimilation of the ecosystem services concept across several scientific disciplines that deal with agriculture, the scale, and regions of studies. Further, the authors evaluated how the relation of agriculture to ecosystem services is conceptualized. This database enables potential users to get better insights into the application of the ecosystem services approach on agricultural research questions and whether new or different findings can be generated in comparison to conventional disciplinary research.

Typology and classification of Ecosystem Services were the subjects of the OpenNess Project[22]. The goal of that project was not to replace other classifications but to facilitate cross-comparisons. The hierarchical structure allows for easier comparison of research undertaken in different thematic and spatial resolutions. Currently, it only deals with services that are somewhat dependent on life processes, but, if necessary, it can be extended to include various abiotic natural products.

According to Mustajokia et al.[23], various classification frameworks have been developed for assessing ecosystem services, including the Millennium Ecosystem Assessment[24], The Economics of Ecosystem and Biodiversity[25], and The Common International Classification of Ecosystem Services[26]. The former is the most recent one where ecosystem services are classified into three sections: 1) provisioning services, 2) regulation and maintenance services and 3) cultural services. The sections are then separated into divisions describing the main types of output or process and these are further split into groups based on biological, physical, and cultural type or process. The lowest level is the class level, which provides a detailed classification into biological or material outputs and bio-physical and cultural processes that can be linked back to concretely identifiable service sources. The services on the class level can be measured by class type, which are the individual entities of the ecosystem services.

5.2.1 Ecosystem services by MEA (2003)

According to MEA[24], ecosystem services are categorized in many different ways, including by:

- functional groupings, such as regulation, carrier, habitat, production, and information services;
- organizational groupings, such as services that are associated with certain species, that regulate some exogenous input, or that are related to the organization of biotic entities

  [27]; and
- descriptive groupings, such as renewable resource goods, non-renewable resource goods, physical structure services, biotic services, biogeochemical services, information services, and social and cultural services.

For operational purposes, one can classify ecosystem services along functional lines within the MA, using categories of provisioning, regulating, cultural, and supporting services. However, some of the categories overlap.

5.2.1.1 Provisioning Services

These are the products obtained from ecosystems, including:

- Food and fiber. This includes the vast range of food products derived from plants, animals, and microbes as well as materials such as wood, jute, hemp, silk, and many other products derived from ecosystems.
- Wood, dung, and other biological materials serve as sources of energy.
- Genetic resources. This includes the genes and genetic information used for animal and plant breeding and biotechnology.
- Biochemicals, natural medicines, and pharmaceuticals. Many medicines, biocides, food additives such as alginates, and biological materials are derived from ecosystems.
- Ornamental resources. Animal products, such as skins and shells, and flowers are used as ornaments, although the value of these resources is often culturally determined. This is an example of linkages between the categories of ecosystem services.
- Freshwater is another example of linkages between categories—in this case, between provisioning and regulating services.

5.2.1.2 Regulating Services

These are the benefits obtained from the regulation of ecosystem processes, including:

- Air quality maintenance. Ecosystems both contribute to chemicals and to extract chemicals from the atmosphere, influencing many aspects of air quality.
- Climate regulation. Ecosystems influence climate both locally and globally. For example, on a local scale, changes in land cover can affect both temperature and precipitation. On the global scale, ecosystems play an important role in climate by either sequestering or emitting greenhouse gases.
- Water regulation. The timing and magnitude of runoff, flooding, and aquifer recharge can be strongly influenced by changes in land cover, including, alterations that change the water storage potential of the system such as the conversion of wetlands or the replacement of forests with croplands or croplands with urban areas.
- Erosion control. Vegetative cover plays an important role in soil retention and the prevention of landslides.
- Water purification and waste treatment. Ecosystems can be a source of impurities in freshwater but also can help to filter out and decompose organic wastes introduced into inland waters and coastal and marine ecosystems.

- Regulation of human diseases. Changes in ecosystems can directly change the abundance of human pathogens, such as cholera, and can alter the abundance of disease vectors, such as mosquitoes.
- Biological control. Ecosystem changes affect the prevalence of crop and livestock pests and diseases.
- Ecosystem changes affect the distribution, abundance, and effectiveness of pollinators.
- Storm protection. The presence of coastal ecosystems such as mangroves and coral reefs can dramatically reduce the damage caused by hurricanes or large waves.

5.2.1.3 Cultural Services

These are the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences including:

- Cultural diversity. The diversity of ecosystems is one factor influencing the diversity of cultures.
- Spiritual and religious values. Many religions attach spiritual and religious values to ecosystems or their components.
- Knowledge systems (traditional and formal). Ecosystems influence the types of knowledge systems developed by different cultures.
- Educational values. Ecosystems and their components and processes provide the basis for both formal and informal education in many societies.
- Ecosystems provide a rich source of inspiration for art, folklore, national symbols, architecture, and advertising.
- Aesthetic values. Many people find beauty or aesthetic value in various aspects of ecosystems, as reflected in the support for parks, “scenic drives,” and the selection of housing locations.
- Social relations. Ecosystems influence the types of social relations that are established in particular cultures. Fishing societies, for example, differ in many respects in their social relations from nomadic herding or agricultural societies.
- Sense of place. Many people value the “sense of place” that is associated with recognized features of their environment, including aspects of the ecosystem.
- Cultural heritage values. Many societies place a high value on the maintenance of either historically important landscapes (“cultural landscapes”) or culturally significant species.
- Recreation and ecotourism. People often choose where to spend their leisure time-based in part on the characteristics of the natural or cultivated landscapes in a particular area.

Cultural services are tightly bound to human values and behavior, as well as to human institutions and patterns of social, economic, and political organization. Thus, perceptions of cultural services are more likely to differ among individuals and communities than, say, perceptions of the importance of food production. Supporting services are those that are necessary for the production of all other ecosystem services. They differ from provisioning, regulating, and cultural services in that their impacts on people are either indirect or occur over a very long time, whereas changes in the other categories have relatively direct and short-term impacts on people. Some services, like erosion control, can be categorized as both a supporting and a regulating service, depending on the time scale and immediacy of their impact on people. For example, humans do not directly use soil formation services, although changes in this would indirectly affect people through the impact on the provisioning service of food production. Similarly, climate regulation is categorized as a regulating service since ecosystem changes can have an impact on local or global climate over time scales relevant to human decision-making (decades or centuries), whereas the production of oxygen gas (through photosynthesis) is categorized as a supporting service since any impacts on the concentration of oxygen in the atmosphere would only occur over a very long time. Some other examples of supporting services are primary production, production of atmospheric oxygen, soil formation and retention, nutrient cycling, water cycling, and provisioning of habitat.

5.2.2 The Economics of Ecosystems and Biodiversity approach

'The Economics of Ecosystems and Biodiversity' (TEEB) study was commissioned by the G8+5 and launched in 2007 by Germany and the EU Commission. It builds on the analysis of the Millennium Ecosystem Assessment and takes the analysis further by demonstrating the economic significance of biodiversity loss and ecosystem degradation in terms of negative effects on human well-being.

To make the economic value that nature provides visible, we need to estimate and disclose values for nature's goods and services (or so-called 'ecosystem services'). These estimated values can inform policy choices, executive actions, business decisions, and consumer behavior.

TEEB suggests a tiered approach to analyzing problems and ascertaining suitable policy responses. We find that, at times, it suffices simply to recognize the value – be it intrinsic, spiritual, or social. Recognition can stimulate policy response. At other times, policymakers may need to demonstrate the economic value of service in order to respond – wetland conservation near Kampala, for example, was taken up as an alternative to reclaiming land for agriculture because of the wetland's natural sewage treatment function. TEEB also focuses on instruments that capture value by rewarding and supporting good conservation – through measures such as payment for ecosystem services (PES).

Evaluations of any kind are a powerful 'feedback mechanism' for a society that has distanced itself from the biosphere, upon which its very health and survival depend. Economic valuations, in particular, communicate the value of ecosystems and biodiversity and their largely unpriced flows of public goods and services in the language of the world's dominant economic and political model.

TEEB does not propose that placing a value on ecosystem services means that they should be traded on the market. Such decisions are socially and ethically complicated. TEEB does not suggest placing blind faith in the ability of markets to optimize social welfare by privatizing the ecological commons and letting markets discover prices for them. What TEEB offers is a toolkit for integrating good stewardship because it's good economic practice (TEEB 2010).

5.2.3 The Common International Classification of Ecosystem Services (CICES)

This classification is widely used for mapping, ecosystem assessment, and natural capital ecosystem accounting. Based on the experience gained in using it since the first version was published in 2013, it has been updated for version 5.1. This policy brief summarizes what has been done and how the classification can be used. Both the original and the new version of CICES defines ecosystem services as the contributions that ecosystems make to human well-being[28]. CICES focuses on the 'final' outputs of ecosystems and seeks to identify the materials and properties of ecological systems that can be used by people in beneficial ways. CICES has been designed to capture the ways the science community has sought to describe ecosystem services, and following common usage, recognizes that the main categories of ecosystem outputs to be provisioning, regulating, and cultural services. To deal with the fact that people work at different spatial and thematic scales, CICES describes these service types through a five-level hierarchy, where each level is progressively more detailed and specific. However, the scope of the classification is comprehensive, aiming to include all that can really be considered as an ecosystem service. To highlight the 'purposeful' nature of the ecosystem service, in the CICES new version 5.1, the definition of each service consists of two parts, one of which describes the biophysical production of the ecosystem (i.e. what the ecosystem does) and the other describes the contribution it brings with some benefits (i.e., how people use this production).

5.3 Various approaches to ecosystem service indicators

According to Burkhard et al.[29], as cultural services are very difficult to grasp and value, they are reduced to "recreation and aesthetic value" and the intrinsic value of biodiversity. The first term was generated because appropriate indicators like visitors numbers are easily available; the second one because, from the authors' point of view, the lack appreciation of nature and species diversity as such (besides their contribution to human welfare) are considerable drawbacks in many of the available concepts of ecosystem services. The authors show typical patterns of ecosystem service distributions around urban areas. As the approach is new and still rather general, there is great potential for improvement, especially with regard to a data-based quantification of the numerous hypotheses, which were formulated as a base for the assessment. Moreover, the integration of more detailed landscape information on different scales will be needed in the future to take the heterogeneous distribution of landscape properties and values into account. Therefore, the purpose of the paper was to foster critical discussions on the methodological development presented. So, a new methodology to evaluate ecosystem service provisions of different land cover and land use types in relation to human activities was presented. One must bear in mind, that the assessments and the table/map compilations have been mainly based on expert evaluation up to now. The successive substitution of these expert assessments by real or model data, constituting the major task and work plan in the future, will reveal whether this method and the hypotheses made will stand or if they have to be modified. However, the assessment of the capacities of different ecosystems or land cover/land use types to provide ecosystem services seems to be very promising. The coupling with GIS and spatial displaying of ecosystem services‘ distributions in maps have a very high potential for landscape analysis and management. Maps of landscapes‘ capacities to provide ecosystem services give an idea about potentials, possible conflicts, and limits in environmental management. The integration and analysis of further landscape data, like land use information (types and intensities), biotic information (additional vegetation data, fauna, habitats), and abiotic information (soil types, elevation models, climate data, hydrological information), in the assessment process, open further opportunities. The conceptual framework shows the current steps of analysis (CORINE data, expert judgments, and exemplary quantitative assessments), future integration of additional data sources, and further quantifications. During the conceptual work on the assessment framework and within our case studies it became obvious, that the conditions, structures, problems, spatial and temporal scales we want to address are more diverse than expected. The opinions of Zurlini and Girardin[30] should be underlined, who argue that the impacts of land-use intensity on ecological functioning often depend on spatial scales much larger than a single field or land use. The land cover classes, ecosystem services, and respective indicators suggested here may not have the capacity to cover all topics and scales in general. Therefore, Burkhard et al.[29] suggest them as a core set of ecosystem services and land cover/use types with respective potential indicators. It is apparent, that CORINE data with their coarse resolution of at least several hundreds of meters do not have the potential to represent natural conditions on a local scale. Therefore in the individual studies, supplementary case study-specific ecosystems and land cover/use types needed to represent the particular circumstances at the individual study site have to be integrated. Moreover, temporal dynamics and processes taking place on different scales should be taken into account. The same should be done for ecosystem services, where there are further significant components not being covered by the list presented here, it is simple to include additional topics by integrating further ecosystem services.

A problem that requires a separate methodological analysis is the definition and measurement of cultural services. According to Norton et. al[31], cultural services are defined as the non-material benefits that people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experience. They include, for example, knowledge systems, social relations, and aesthetic values[1]. Whereas many studies try to recognize the importance of considering cultural services in evaluating land use options, there are only a few that have attempted to provide measures of them. Feld et al.[32] argue that whilst there are now numerous indicators for the majority of ecosystem services, there are very few for cultural services. According to Nelson et al.[33], this may in part be due to the fact that these services require very different measures to those generally used by biophysical scientists[34][35][36][37]. Most approaches used by quantitative scientists to measure/value cultural services have included economic methods or methods using habitat extent or use. Other authors[38][39] argue that in other cases no measures are attempted as a result of cultural services falling outside of the sphere of markets and therefore becoming invisible in traditional economic analyses. The presented study of Norton et. al[31] has indicated the potential for using a mix of qualitative and quantitative data to provide measures of cultural ecosystem services at a national scale. The qualitative research was able to identify particular landscape characteristics/features which correlated to a range of cultural ecosystem services including, a 'sense of history' or identity, spiritual benefits, inspiration, and places for escapism, relaxation, education, and recreational activities.

With the usage of the data from a national survey on the landscape[40], it was possible to quantify those landscape characteristics/features and, using the stratification underlying that survey, to provide mapped national estimates of cultural services. At a national level, the importance of all landscapes, for delivering cultural services and the fact that people value what they experience at a local level, is reflected by the relatively narrow range of scores across England[40]. However, what requires essential highlighting are the key issues that may affect the validity of these cultural service measures including the lack of measures concerning the built environment; the importance of distant views in the provision of cultural services; and, for the specific exercise described here, some incompatibilities in the scales at which quantitative and qualitative data are collected. However, this exercise does demonstrate the value of linking qualitative and quantitative information to provide measures of cultural ecosystem services which can aid policy decisions about land use options.

From another point of view, Satz et al.[41] believe that cultural services should be characterized as activities producing a large number of intangible and non-market benefits (e.g., social cohesion), that can in turn hold or have assigned different kinds of value (e.g., moral, religious, aesthetic). Chan et al. [42] develop such definitions; they think that for a fuller explanation of such characterization it is necessary to consider that a given non-material benefit provided by an ecosystem can be associated with different values and those values may have different weights for the individual.

The concept of culture is based on the eco-services definition is much debated and differently defined. Definitions tend to treat culture as an adjective rather than as a noun which then modifies particular dimensions of culture, such as belief systems, symbolic expressions, or identified assets and institutions. Ingold[43] and Turner et al.[44] think that normally, this realignment shifts 'culture' from being a 'thing' to also include processes.

In turn, Basso[45], Marsden[46], and Koehler[47] described cultural asset as a set of goods marked by people's histories (from important sites, to place names, to territories claimed or pending through Treaty, rights, and title). Roth[48] and Sahlins[49] define also cultural practices or institutions—for example, systems of naming, marriage or descent, kinship (human and non-human), as well as the organization of the human-natural world.

In the opinion of Satz et. al[41], five important challenges need to be addressed to make the case that cultural ecosystem services can be included in environmental assessment:

- how to account for interconnected benefits;
- incommensurability with other ecosystem services;
- how to deal with the plurality of values that people attach to ecosystem services;
- the question of the relevant unit of analysis;
- the worry that even if it is possible to include them in deliberation, focusing on cultural services will take us away from the ecosystem services whose protection is most important to human health and welfare.

We raise each challenge and offer responses below. Unless these challenges are answered, the case for integrating cultural services is considerably weakened.

According to Chan et al. [50], there is exist problem of double counting is not unique to cultural services measurement. Considering the four service categories put forth in the (Millennium Ecosystem Assessment 2005a): provisioning, regulating, supporting, and cultural one can see that many of these service flows have the potential to be double-counted. For example, the value of pollination services is eventually embodied in the value of harvested crops. To minimize the danger of double counting, it is important to clearly define the services one is attempting to account for and to recognize ecosystem complexity and interconnectedness.

Jim Boyd[51] suggests that we direct our attention to "final ecosystem services" that are embodied in the end product that gets valued. However, such an approach may be more complicated for cultural ecosystem services than for other ecosystem services, but Boyd's guideline does provide a potential solution to the double-counting problem. He offers the example of an angler, for whom an end product might be a "particular lake or stream or perhaps a particular species population in that water body"[51]. Because the angler in this example does not make choices directly about, for instance, the forest that contributes to the stream's water quality, the purification service would not be independently valued in this calculation of the stream's services to him. Tallis et al. [52] in turn, believe, that it is justified "getting specific" about ecosystem services definition: not employing broad categories of services but rather focusing on very specific definitions services explaining the background of their existence (e.g., "not hunting", but "religious rituals satisfied by hunting").

It is sometimes argued that cultural values cannot be compared with other values. In the introductory quotation, the tribal member can be interpreted as arguing that no amount of money can be equal to the value that the land has for him as an inheritance from his ancestors. If we generalize his stance to metrics other than money and if there is additionally no way that we can rank the way he values land in comparison to other goods, then it will be difficult to incorporate his evaluation into our decision-making. In its strongest sense, to say that a value A is incommensurable with a value B is to say that A and B cannot be compared: we cannot say when confronted with the choice between these two values that one value is better, worse or the same as the other[53]. In such cases, incommensurability is thought to entail incomparability. Some people seem to think that truly incommensurable values—values understood as completely incomparable—defeat the possibility of rational decision-making. If we really cannot compare two values at all, then it might seem that all that is left for us to do is flip a coin. In such cases, it would seem, our particular choices cannot be justified. If the values people attach to cultural services are incommensurable with other values, then cultural values would seem impossible to include in our overall assessments of an ecosystem's value.

Nevertheless, Simon[54] thinks that decisions can be evaluated in substantive or procedural terms. Decisions are substantially justified when they are rational in terms of some particular concrete goal: for example when they maximize an agent's overall preferences. Decisions can also be justified in procedural terms—by how they came about, regardless of whether or not they conform to some substantive value The first approach examines decisions in terms of substantive objectives such as promoting sustainability, promoting human well-being, or achieving better management of a resource. The second approach examines the procedures that were involved in the decision-making process itself, focusing on public processes of inclusion and deliberation.

At the same time, ecosystem service calculations and estimates may prove helpful as inputs for more deliberative processes of decision-making. When limited to a specific geographic and cultural context, it is possible to discuss cultural and other ecosystem services in ways that are meaningful to local residents and stakeholders. Consider a hypothetical example: suppose upstream and downstream residents of an important river have begun negotiations; the downstream participants demand a cessation of upstream forestry to protect in-stream water quality, while upstream participants believe they have a traditional right to engage in forestry activities and demand compensation if they are to be asked to alter their practices. At this point, in a particular context with particular decisions at stake, cultural ecosystem services can be cited as support for negotiations. This might include not just economic issues, but also a careful inventory of sacred places and other places of great cultural value as a support for a negotiation. If the goal is to have an appropriate process for decision-making, and if cultural ecosystem services involve important values that must be taken into account, they are more likely to receive due attention if they are sought and articulated at a local level, with specific possible actions and interventions on the table. In such situations, sensitive study of local cultural values can provide important inputs into negotiations, allowing participants to compare pluses and minuses of various options. As we have suggested, report cards can sometimes be generated which allows participants to rank different scenarios according to different values.

Hence, presented in a paper of Satz et. al [41], findings concluded that while the incorporation of cultural ecosystem services into environmental assessment has faced certain challenges, these challenges are not insurmountable. Although there is a plurality of values associated with these complex and multi-faceted services, many of these values may be partially ranked against each other. Value pluralism does not entail that some things have infinite value and it does not mean that making trade-offs is impossible. Although cultural values are intangible, we can design ways to deal with the problem of over-counting them. Finally, some cultural values can be more or less adequately captured in economic terms (such as recreation), while others will likely require other metrics and tools.

An interesting next contribution in the area of eco-services definitions, measures, and indicators can be found in Wiliams et al. [55] where the authors attempted to analyze this problem in the view of the wetland and its impact on differentiated climatic zones and on satisfying differentiated human needs.

According to the study, wetlands provide various ecosystem services such as provisioning, regulating, supporting, and cultural services which may be directly or indirectly beneficial to humans. How such wetlands are managed is partly determined by human perceptions of their value. However, climatic variability and climate change put the continued provision of such ecosystems under stress. The result is that certain ecosystem services may be provided to differing extents during anomalously wet or dry years. There is thus uncertainty in the values ascribed to wetlands by people during varying climatic phases. This statement is based on understanding how people perceive the functioning of wetlands within our current climate against a background of climatic variability and climate change.

Wiliams et. al[55] analyzed people’s perceptions regarding the functioning of wetlands and ecosystem services provided during dry and wet years as an indication of how climatic variability and climate change impact people's perceptions. The data concerning this survey was collected in the wetlands of the Agulhas Plain in the Nuwejaars Catchment where five wetlands were classified and scored using the WETEcoServices tool. Also, five semi-structured interviews and three participatory mapping exercises with landowners were also undertaken. The study reports on the landowners’ awareness of wetland ecosystems, ecosystem services, climatic variability, and climate change. The WETEcoService benefits and landowners' perceptions of ecosystem services vary, as the WETEcoService direct and indirect ecosystem services are either effective or ineffective in dry and wet years. The study recommends that the ecosystem services landowners perceive, as important to their interest, guaranteeing their participation in catchment management. WET-EcoService benefits can inform landowners and managers about ecosystem services degradation and whether their conservation methods are either positively or negatively impacting wetlands.

Within a discussion of the findings Asah et al.,[56] concluded that the WET-eco-services benefits consist of both direct and indirect ecosystem services as being effective or ineffective in dry and wet years. In comparison, the landowners' perceptions highlight the importance or the effectiveness of the ecosystem services that are directly beneficial to them. The authors found that this is confirmed through landowners' perceived benefits provided by wetlands measured with the likeliness of their participation in activities or measures taken for the continuous supply of their important ecosystem services. Landowners' perceptions of certain ecosystem services can be either positively or negatively influenced by previous experiences. The WET-EcoService tool can create awareness and assist landowners in seeing the practicality in the ecosystem services they consider as important that will be impacted by climatic variability and climate change. That is why the benefits of WET-EcoService usage can assist them in making adaptive strategies to respond effectively to climatic variability and climate change impacts[57]. The outcomes of the study substantiate the argument that it is important to understand people's perceptions of wetland ecosystem services, especially landowners in the Nuwejaars Catchment practicing sustainable agriculture and conserving wetlands. Kaplowitz and Kerr[58] state that the perceptions of people are essential as it shows which ecosystem services landowners consider as important as well as whether the effects of climatic variability and climate change are the only impacts affecting the ecosystem services. Agricultural practices in the catchment can contribute to the effectiveness and opportunities of the ecosystem services provided. The agricultural factors such as the extent of sediment sources (cultivated lands and gravel roads, amount of biocides and fertilizers, point and non-point sources, and land-use practices in the catchment contribute to the effectiveness and opportunity. However, landowners did not openly acknowledge that their agricultural practices may contribute to wetland ecosystems or downstream uses but often only pointed to climatic variability or climate change as causing changes in the benefits. Elum et al.[59] argue that South Africa's weather has considerably changed as well as rainfall. Although, landowners are aware of the changes in the region and believe that changes in the wetland ecosystems are only caused by climatic variability or climate change. Similarly to the IPCC (The Intergovernmental Panel on Climate Change) definition of climate change is more empirically based on the finding that landowners of the Nuwejaars Catchment are aware of wetland ecosystems. Even more, they and the benefits provided is an indication that the landowners understand the importance of wetland ecosystem services and the benefits provided. However, they mostly consider provisioning, supporting, and cultural ecosystem services to be important compared to regulating ecosystem services. The Nuwejaars Wetland Special Management Area recommends considering sustainable agricultural activities a priority; previously this was not important to landowners until their traditional agriculture was under pressure. Therefore, the study recommends landowners to have a connection to the landscape and their perceived important ecosystem services are nearer to their interest in catchment management what can guarantee their active participation in this process[55].

The results from WETEcoService tool usage can inform landowners and managers on which ecosystem services are ineffective or degraded and provide landowners with information on how their conservation methods are either positively or negatively impacting wetlands.

Increasing food production without further harming biodiversity is a key challenge of contemporary societies. Rega et al.[60] through a complex modeling chain, the forecast for 2040: 1) the total energy content of agricultural production; 2) total nitrogen surplus, an approximation of the overall impact of agriculture on the environment; and 3) an indicator measuring the ability of agricultural systems to support biodiversity. In their analysis, they presented both aggregated results (at the EU level) and spatial assessments in an accurate resolution (1 km^2). They used scenarios developed by Paterson et al.[61], describing different socioeconomic, cultural, political, and technological changes in the EU. The scenarios were derived from the storylines of the marker scenarios developed by the International Panel on Climate Change (IPCC), described in the Special Report on Emission Scenarios (SRES)[62]. The original SRES scenarios (named A1, A2, B1, and B2) were reviewed, adapted, and extended to better reflect development pathways that influence land use in Europe. These four scenarios, and others derived from them, have already been used in several recent studies on land systems to explore land change trajectories in the EU[63]; to identify pathways to visions of desired future land use in Europe as expressed by stakeholders[64] to assess future ecosystem service delivery[65][66], and to study the effect of nature protection policies on land use and agricultural production in Europe[67]. The scenarios consider a wide range of drivers of land-use change, the main ones being population growth, GDP change, trade policies, food demand/dietary requirements, environmental policies, regulations on land-use change, and changes in the CAP.

The results obtained by Rega et al.[60] show that a strong neoliberal approach to agriculture (full liberalization, the abolition of subsidies) will lead to an increase in the efficiency of outlays on use and a reduction in the impact of nitrogen outlays; however, a large part of Europe's agricultural areas will be abandoned, leading to an absolute decline in production and an increase in land homogenization and polarization, which will negatively affect the ability of agricultural areas to support biodiversity. Protectionist and sovereign policies will maintain high absolute production and arable land but at the expense of less efficient use of inputs and a greater impact on the environment and biodiversity. In a scenario characterized by environmentally friendly practices, multi-functional landscapes, and location, a significant reduction in the environmental pressure of agriculture (compared to other scenarios) can be achieved with a minimal decrease in agricultural production. The results presented by Rega et al.[60] indicate that agricultural and land-use policies aimed at maintaining production in large rural areas, multi-functionality, and diversification of agricultural landscapes can contribute to the joint achievement of biodiversity conservation and high food production.

Olander et al.[68] indicate that public policy increasingly demands insight into the social consequences of environmental policy and drivers of human behaviors that affect the environment. Social consequences can provide potent justifications for environmental protection and management. Hence, human preferences and related behaviors are the keys to understanding both the cause of and solutions to most environmental challenges. Yet, often the indicators measured by biophysical scientists do not correspond with factors relevant to human preferences and behavior. Olander et al.[68] deal with the following:

- develops a set of principles to guide the further identification of linking indicators;
- describes linking indicators' role in benefit-cost analysis; environmental accounting; and communication of ecological status, trends, and management outcomes;
- compares their features with those of more commonly collected ecological measures; and
- reviews empirical evidence pertinent to the further identification, definition, and performance of linking indicators, primarily from the point of view of conducting the monetary valuation of ecological outcomes.

It deserves emphasis that the relative desirability of alternative indicators (in terms of their ability to communicate or contribute to more accurate social welfare evaluation of natural resource outcomes) can be evaluated empirically. In the section Boyd et al. (2018) describe several ways to do this empirical evaluation. However, even empirically sophisticated practitioners have given relatively little attention to the "which indicators work best" issue. Open questions identified by the review—such as the most appropriate units of account, most appropriate indicators of nonuse benefits, and approaches to aggregation—would benefit greatly from the more deliberate empirical examination. Such studies would not only help improve the accuracy and salience of ecosystem services assessments but also lead to greater consensus among practitioners around preferred indicators. The greater consensus would advance the standardization of indicator protocols—a desirable goal because of the need to compare, aggregate, integrate, and transfer monitoring and evaluation results across the nation's ecological and social landscapes.

For any team of natural resource or environmental policy evaluators, the Authors recommend, at a minimum, conceptual development of an ecological and social production framework that describes (1) causal linkages between biophysical outcomes in an ecological system and (2) linkages between biophysical outcomes and social outcomes. Linked production frameworks have several virtues described below.

First, the identification of causal relationships leading to ecological and social outcomes using this framework can facilitate the identification of diverse beneficiaries affected by ecosystem changes. According to the literature, one can highlight the significant degree to which the value of natural resource outcomes can depend on their location, type of use or enjoyment, timing, and other beneficiary-specific factors. Ecosystem beneficiaries are diverse and draw value from nature in diverse ways, from consumptive natural resource uses to recreation, aesthetic enjoyment, and ethical and stewardship motivations. This diversity generates a corresponding diversity in linking biophysical measures. Accordingly, an initial broad recommendation is that analysts identify linking indicators in reference to what may be heterogeneous (e.g., demographically, geographically) sets of stakeholders affected by natural resource conditions.

Second, production frameworks permit ecological outcomes (and their indicators) to be differentiated based on the degree to which they directly, versus indirectly, matter to social welfare. The central hypothesis presented by the Authors is that production frameworks help isolate "linking indicators" more proximate to social welfare and that those indicators will (1) be more meaningful and understandable to lay audiences and (2) lead to more accurate and interpretable monetary valuations of ecological outcomes.

Third, production frameworks help identify and organize the full set of models, expertise, and data needed to relate intermediate ("nonlinking" or "distal") ecological outcomes to linking indicators and resource management options, stressors, and conservation actions. Again, however, the review of the literature suggests that the desirability of linking indicators is empirically understudied and should, therefore, be treated as a theoretical hypothesis, rather than as an unequivocal, generalizable fact. The authors strongly advocate more explicit empirical testing of this hypothesis. In the meantime, the burden of proof, in their view, lies with advocates of distal outcomes as the most appropriate linking indicators, because, by definition, distal outcomes require one to know (or speculate about) additional ecological production relationships to understand the effects of ecological changes on human welfare. In contrast, indicators that are directly proximate to (or directly affect) human welfare are ideally suited as arguments or variables in behavioral or valuation models, because these indicators do not require any further ecological "translation" to identify changes that are directly relevant to people.

Ecosystem assessment and monitoring require the development and application of suitable indicators, i.e. they need to be (i) reliable and capable of simplifying complex relationships, (ii) quantifiable and transparent to enable easy communication, and (iii) fit indication. These requirements are scarcely fulfilled in current ecosystem assessment and monitoring efforts to address the requirements of international biodiversity conventions. Feld et al. (2010) present and test a set of seven criteria towards an improved framework for ecosystems indication with particular emphasis on the indication of biodiversity and ecosystem services:

- the purpose of indication,
- indicator type according to the EEA's Driver-Pressure-State-Impact-Response scheme,

- direct/indirect linkages to biodiversity and ecosystem services,
- spatial scale and scalability across scales,
- the applicability of benchmarks/reference values,
- availability of data and protocols,
- applicability of remote sensing.

The criteria have been tested using 24 indicators of ecosystem assessment and monitoring at the global, continental, and regional scale. The authors suggest that more effort should be spent on the expansion of direct biological indicators of biodiversity and the development of thresholds or benchmarks. Justifiable benchmark values of a specific component of biodiversity (e.g., structural and functional diversity) or of specific processes underlying ecosystem functions and services (e.g., productivity, decomposition rate) would offer a sound basis for the assessment of both components. To streamline future indication and to better address the implementation of biodiversity conventions, a concerted effort is required at the international level. This would include the coordination of related activities (e.g., monitoring, indicator development, ecosystem management) and the provision of financial resources. The European Water Framework Directive may serve as an example of such a concerted effort. Since 2000, the directive has driven and supported the development of new indication systems towards an integrated assessment and management of European waters—rivers, lakes, marine, and groundwaters. A tremendous amount of research has been funded by the European Commission, but also by individual countries, to develop novel indicators and to render assessment results comparable between the Member States. A 'European Biodiversity or Ecosystem Service Directive' (see also Harrison et al. [69]) might provide the appropriate framework to foster and coordinate biodiversity indication and monitoring at the pan-European scale, in particular, to improve our tools and knowledge, specifically to:

- measure structural and functional components of diversity in all ecosystems at relevant spatial scales,
- set comparable reference thresholds/quality targets for components of biodiversity;
- identify and measure key ecosystem functions and processes,
- identify the linkage of these functions/processes to ecosystem service provision (incl. provisioning, regulating and supporting services),
- identify (critical) service provision rates needed to sustain human well-being,
- assess the status and trends of biodiversity and ecosystem services in all ecosystems (e.g., by O/E ratios), and
- develop cost-effective, easily understandable, broadly applicable, and integrated multi-metric indicators of biodiversity and ecosystem services to address policymakers, decision-makers, and the public.

Summarizing a problem of indicators and measures useful for ecosystem services analysis, assessment, and shaping there is wise to notice, as follows.

The creation of appropriate indicators and measures for the analysis and assessment of eco-services is inherent in the proper definition of these services conditioned by the needs of their stakeholders, such as politicians responsible for eco-services, agricultural entrepreneurs, or residents of a given geographical area. Referring to measuring the value of cultural services, there are objective methodical difficulties to quantify them, e.g. aesthetic, artistic, folk, cultural heritage (e.g. singing, folk dance, folklore, tourism, other intangible values, etc.). It is emphasized that it is necessary to express what is more or less important for stakeholders and what can be methodologically presented in models by hierarchically assigning different weights to various variables depending on the goals of individual eco-services stakeholders, e.g., agricultural producers, local communities, a given country or global community. This can be expressed in a large number of models describing eco-services to provide solutions to a particular problem. Those models are very diverse both in terms of input data, processing methods, and the possibility of obtaining specific solutions. This greatly complicates the possibility of their functional integration in such a way as to obtain synergistic effects supporting the development of eco-services both in the regional and global dimensions. Certain hopes are created here for IT opportunities—such as Big Data exploration and the use of hybrid models of searching for optimal solutions as well as satisfying end-users.

5.4 Methods for evaluating the impact of land use on ecosystem services

5.4.1 Impact of construction of models and methods on an evaluation of land use influence on ecosystem services

Kenenth et al. [70] presented a practical approach to the usefulness of eco-services tools for their users in making specific decisions. The authors showed practical limitations of their applications such as high labor intensity for setting and verifying input data. Also, the scope of substantive eco-services models is very diverse in the sense of the research space (geographical area and the research problem), but also the conflicting interests and goals of the beneficiaries of eco-services cause problems with models' integration and practical solving of climatic and environmental problems. According to Kenneth et al.[70] differentiated models could be integrated through Big Data and corresponding ontologies and semantics to let obtain useful information for stakeholders solutions concerning analysis, assessment, and change of eco-services. For example, tool developers indicated that future versions of ARIES, EcoServ, Envision, InVEST, and other models intend to link to existing, peer-reviewed ecological and biophysical process models. This would be a major step forward for ecosystem service modeling but requires substantial work on model semantics, inputs, and outputs to build linkages between the models. The authors also concluded that a broad trade-off exists between using new ecosystem service tools and using existing mapping or modeling approaches that are locally known and trusted by decision-makers. According to Smart et. al. [71], such trade-off is also partly related to the scale: while some generalized models may be highly effective at the national and regional level, they may be ineffective at the local level if they cannot incorporate accurate high-resolution data while accounting for local influences on ecosystem service supply, demand, and value. In such cases, locally developed models may better account for fine-scale analysis.

In Fox and Hendler[72] and, Villa[73], it is stated that although modelers typically recognize the need for more data, such data also need to be better organized and accessible to model users when they seek to choose and parameterize a model. Although it is an ambitious goal, semantic meta modeling offers a path forward in improving ecosystem service quantification in an era of Big Data. The authors described 17 ecosystem services tools against eight evaluative criteria like quantification and uncertainty, time requirements, the capacity of independent application, level of development and documentation, scalability, generalizability, and non-monetary and cultural perspectives. Next, they rate their performance against eight evaluative criteria that can measure their readiness for widespread application in the public—and private—sector decision making. Afterward, the authors describe each of the tools′ intended uses, services modeled, analytical approaches, data requirements, and outputs as well as time requirements to run seven tools in a first comparative concurrent application of multiple tools to a common location – the San Pedro River watershed in southeast Arizona, USA and northern Sonora, Mexico. Finally, they presented potential pathways to reduce the resource requirements for running ecosystem services models, which are essential to facilitate their more widespread use in environmental decision making.

Authors conclude that strategic investment could lower barriers to tool use in the public and private sector settings. In their opinion, strategic investment in such systems could be supported by Federal agencies, philanthropic foundations, or industry groups to support the public and private sector ecosystem service-based decision making. Although in some cases higher quality local data may exist and stakeholders may trust locally collected data over "pre-wired" data. For many other cases, well-documented data obtained from credible sources can provide significant advances in modeling.

According to Posner et al.[74], ecosystem services support human livings and economies but are declining in many places. They argue that ecosystem service assessments estimate the benefits that nature provides to people and can be used to evaluate trade-offs in impacts and changes resulting from land-use decisions that can affect the capacity of decision-makers to make sustainable land-use decisions. On the other hand, the authors believe, that the actual impact of such projects on decision-maker attitudes is almost entirely unstudied. For this reason, studies aimed to eliminate the knowledge gap and answer the question of how decision-makers' understanding and attitudes about ecosystem services changed "pre-" and "post-" assessments. The authors used a mixed-methods approach to evaluate the impact of the initiative and the subsequent valuation reports on decision-makers in Santa Cruz and Santa Clara Counties, USA[75][76],[77] and including regression models to estimate the treatment effect of the assessment, as well as interviews and direct observations to further understand how decision-makers responded to the assessment.

5.4.2 Analysis of the perception of the problem of the impact of land management on the development of eco-services by decision-makers

Regression results showed small increases relative to the comparison group in decision-maker understanding of ecosystem services and perceived relevance of ecosystem services to their work. Interviews showed that decision-makers learned specific ways they could use ecosystem services in conservation and development decisions and they believed that doing so would improve outcomes. The findings suggest barriers on how ecosystem services assessments impact decision-makers. In the interviews, decision-makers described a need to vet and refine the methods underpinning ecosystem services valuation before they could use the results to enact new policies. A significant challenge lies on how to effectively integrate "new" ways of valuing land into existing decision processes and tools such as cost-benefit analysis. Another challenge in impacting decisions lies in the potential mismatch between the scale of county-wide ecosystem services assessments and the scale of individual property-level decisions. These issues warrant consideration by those involved in ecosystem services assessment and/or policy. Despite the challenges associated with using ecosystem services knowledge, the processes of the county-wide assessments did affect how decision-makers thought about longer-term, regional planning. Decision-makers appreciated having additional ways to communicate with people about the value of conservation.

These results show how ecosystem services assessments can facilitate a conceptual shift in the minds of decision-makers, which is a necessary ingredient for subsequent policy impact. Impact evaluation studies of this type – that estimate a counterfactual and explore rival explanations for observed outcomes – are needed to truly understand whether ecosystem service projects impact decision-makers and, ultimately, produce outcomes for environmental and human well-being.

Bateman et al.[78] argue that land-use decisions are based largely on agricultural market values. However, such decisions can lead to losses of ecosystem services, such as the provision of wildlife habitat or recreational space, the magnitude of which may overwhelm any market agricultural benefits. In Bateman et al. [78], the authors described key issues of the research project forming part of the UK National Ecosystem Assessment and they estimate the value of these net losses. The authors use spatially explicit models in conjunction with valuation methods to estimate comparable economic values for these services, taking into account climate change impacts. Next, global change scenarios were used to produce the land-use change which was linked to several ecosystem service indicators and provide maps of ecosystem services provision for a 10 km^2 grid of Europe. The socio-economic scenarios were used to project developments in a macro-scale adaptive capacity. Next, changes in the stratified ecosystem service provision compared to baseline conditions reflect the potential impact of a given location.

Policies that recognize the diversity and complexity of the natural environment can target changes to different areas to radically improve land use in terms of agriculture and greenhouse gas emissions, recreation, and wild species habitat and diversity. Authors show that, although decisions that focus solely on agriculture reduce overall ecosystem service values, highly significant value increases can be obtained from targeted planning by incorporating all potential services and their values and that this approach also conserves wild-species diversity.

5.4.3 Selected findings from research on the evaluation of the impact of land use on ecosystem services development

Some other assessments in this research area are also very interesting. In the opinions of Metzger et al.[79], biomes can be used to stratify ecosystem service indicators from the global model IMAGE[80]. There are two limitations to applying the complete vulnerability framework to other modeling studies: both a quantitative stratification and some measure of adaptive capacity need to be available. For European assessments, this should not pose too much of a problem, as the datasets used in the presented study could be used. For other regions, such datasets may need to be developed. Application of the vulnerability framework to global change impacts in the arctic region is currently under discussion. Both the modeled changes in ecosystem service provision and the adaptive capacity index form top-down projections that ignore regional heterogeneity. In a flood-prone area in Germany, it has recently been shown that ‘‘perceived adaptive capacity’’ is a major determinant of whether people will take adaptation measures or not. It seems that more place-based studies could better take into account the individual nature of vulnerability. One possible consistent method of analysis would be to assess impacts on detailed random sample areas. For such sample areas, it would also be possible to develop more detailed, regional land-use change scenarios, by combining high-quality regional ancillary data sources, as discussed in Metzger[79], for the impacts of shifting environments in four sample regions. Such regional scenarios can provide the detail required for analyzing impacts on biodiversity or nature conservation. By constraining these scenarios with top-down European scenarios, European and global socioeconomic trends can be taken into account. Hence, the necessity for a work methodology of ecosystem services considering separately regional and global contexts should be underlined.

In turn, Lawlera et al.[81] created Ecosystem Service models. They modeled soil carbon storage for all land uses. Additionally, for forest and urban areas, we accounted for above- and below-ground biomass carbon storage, but not for other land-use types. To estimate forest biomass carbon, the authors made several simplifying assumptions. They assumed that all privately owned forests would be managed with even-aged rotations, which were determined by the Faustmann formula, and that all age classes were evenly represented in the landscape. The forest biomass carbon was then assessed based on the Forest Inventory and Analysis (FIA) estimates for forest types in each county and allometric curves of tree growth[82]. Soil carbon estimates to a soil depth of 30 cm for each land-use type in a county were based on carbon stock estimates from Bliss et al.[83] There were also estimated kilocalories productions on private croplands in 2051 as a function of observed 2001 yields and observed 2001 crop-planting patterns on the landscape [Haim en al. 2011]. The authors assumed a 6% increase in yield every 5 years across the entire nation and all crops. In addition, there were modeled time-invariant timber yields from private forests based on average yield data from FIA and the rotation length that was estimated as part of the biomass carbon assessment. To assess species responses to land-use change, Lawlera et al. quantified the amount of change in habitat area individually for 194 terrestrial vertebrate species, which were chosen for their ecological or social importance: amphibians (because of their sensitivity to environmental change), influential species (in terms of their ecological role, e.g., top predators, keystone species, and ecosystem engineers), game species (because of their importance to hunters and land managers), and at-risk birds (categorized by the American Bird Conservancy (30) as "vulnerable" or "potential concern"). Next, there were quantified habitat areas for each species under current and future land-use conditions based on species' geographic range and habitat associations. For birds, they used only portions of the range that were used for breeding or year-round residency. Considered species–habitat associations were based on a land cover classification of ecological systems[84] cross-walked to the land-use categories used in the econometric model. Across the contiguous United States, for each species, areas of current (2001) land use/land cover (LULC) were given a score of 1 if they were a prime habitat and a score of 0 otherwise. For simulated future LULC, the authors used the land-use transition probability matrices generated by the econometric land-use model under each of our scenarios. The summation of the potential habitat values within a species' range in 2051, compared with the summed habitat value of current land cover, quantified the impact of future land-use change on a given species. For each species, there were compared the projected change in habitat area resulting from each policy scenario and summarized results by our four species groups.

Lawlera et al. [81]projected a large increase in croplands (28.2 million ha) under a scenario with high crop demand mirroring conditions starting in 2007, compared with a loss of cropland (11.2 million ha) mirroring conditions in the 1990s. Projected land-use changes result in increases in carbon storage, timber production, food production from increased yields, and >10% decreases in habitat for 25% of modeled species. They also analyzed policy alternatives designed to encourage forest cover and natural landscapes and reduce urban expansion. Although these policy scenarios modify baseline land-use patterns, they do not reverse powerful underlying trends. The presented research concluded that In the US analysis, the emphasis was placed on the analysis of three alternative policies that are an incentive to maintain and expand forest cover, protect natural habitats, and limit urban sprawl. It is necessary to underline the conclusion that policy interventions, in the opinion of the authors, need to be aggressive to significantly alter underlying land-use change trends and shift the trajectory of ecosystem service provisions.

Huabin Hu et al.[85] reported changes in ecosystem services in relation to land use and land cover over an 18-year period (1988–2006) in the Menglun Township, Xishuangbanna, Southwest China. They used Landsat TM/ETM and Quickbird data sets to estimate changes in ten land use and land cover categories and generalized value coefficients to estimate changes in the ecosystem services provided by each land category. The results showed that over the 18-year period, the land use and land cover in the study area experienced significant changes. Rubber plantations increased from 12.10% of total land cover to 45.63%, while forested area and swidden field decreased from 48.73% and 13.14% to 27.57% and 0.46%, respectively. During this period, the estimated value of ecosystem services dropped by the US $11.427 million (~27.73%). Further analysis showed that there were significant changes in ecological functions such as nutrient cycling, erosion control, climate regulation, and water treatment as well as recreation. The findings let conclude that an abrupt shift in land use from ecologically important tropical forests and traditionally managed swidden fields to large-scale rubber plantations result in a great loss of ecosystem services in this area. Further, the study suggests that the provision of alternative economic opportunities would help in maintaining ecosystem services and that appropriate compensation mechanisms need to be established based on rigorous valuation. A positive solution to this problem may be the experience of Puerto Rico, where they started to recover forests when the economy moved from agriculture and changes in the structure of the economy [86][81]. In a view of mentioned above the findings, there is a question, first how to develop a comparison with ecological compensation, e.g. by usage of carbon dioxide eligible services to protect tropical forests (Laurance 2007b). Secondary, how to make social impact assessment, in connection with the rigorous valuation of these ecosystem services (Boyd 2007). Hence, there is obvious, based on the previous two research, that effectiveness of ecosystem services development depends both on the rigorous valuation of these ecosystem services and aggressive intervention policy as well. It seems that the political systems of a given country or group of countries can have an impact on the positive or negative effects of the introduction and spreading of ecosystem services.

Franciska et al. [87] quantified, across four countries of contrasting climatic and soil conditions in Europe, how differences in soil food web composition resulting from land-use systems (intensive wheat rotation, extensive rotation, and permanent grassland) influence the functioning of soils and the ecosystem services that they deliver. They argue that intensive wheat rotation consistently reduced the biomass of all components of the soil food web across all countries. Soil food web properties strongly and consistently predicted processes of C and N cycling across land-use systems and geographic locations, and they were a better predictor of these processes than land use. Next, processes of carbon loss increased with soil food web properties that correlated with soil C content, such as earthworm biomass and fungal/bacterial energy channel ratio, and were greatest in permanent grassland. In contrast, processes of N cycling were explained by soil food web properties independent of land use, such as arbuscular mycorrhizal fungi and bacterial channel biomass. Such quantification of the contribution of soil organisms to processes of C and N cycling across land-use systems and geographic locations shows that soil biota needs to be included in C and N cycling models and highlights the need to map and conserve soil biodiversity across the world.

Franciska et al. [87] also generated statistical models for each ecosystem service using spatial filters, soil properties, land use, and soil food web characteristics.

5.5 The EU and global databases used for ecosystem services modeling

This section presents selected entry points to reference data and information related to biodiversity in Europe, as developed and managed by a range of initiatives and projects, and land cover information. The focus of the section is set on information infrastructures supported by the European Union. There are several data portals listed on the Biodiversity Information System for Europe (BISE) that are cross-cutting with biodiversity.

5.5.1 The Biodiversity data center (BDC)

It is managed by the European Environment Agency (EEA) provides access to data and information on species, habitat types, and sites of interest in Europe and related products for biodiversity indicators, and assessments. Priority is given to policy-relevant data and information for European and national institutions, professionals, researchers, and the public. Biodiversity data and information will also be provided by the other eight data centers due to the cross-cutting nature of biodiversity. These are as follows: air pollution, climate change, water, and land use, soil, forest, natural resources, and waste.

5.5.2 The Global Biodiversity Information Facility (GBIF)

It is an international network and research infrastructure funded by the world's governments and aimed at providing anyone, anywhere, open access to data about all types of life on Earth. https://www.gbif.org/

5.5.3 Copernicus

It is previously known as GMES (Global Monitoring for Environment and Security), which is the European Programme for the establishment of a European capacity for Earth Observation. So far the most relevant services in the context of Biodiversity Information System for Europe (BISE) are land monitoring, climate change, and marine environmental monitoring. https://www.copernicus.eu/en

5.5.4 The Group on Earth Observations Biodiversity Observation Network (GEO BON)

It is the biodiversity arm of the Global Earth Observation System of Systems (GEOSS). Some 100 governmental and non-governmental organizations are collaborating through GEO BON to make their biodiversity data, information, and forecasts more readily accessible to policymakers, managers, experts, and other users. A formal listing and description of all the Earth observation systems, data sets, models, and other services, and tools that together constitute the Global Earth Observation System of Systems can be found at the GEASS registry. https://geobon.org/

5.5.5 LifeWatch

It constructs and brings into operation the facilities, hardware, software, and governance structures for all aspects of biodiversity research. It consists of: facilities for data generation and processing; a network of observatories; facilities for data integration and interoperability; virtual laboratories offering a range of analytical and modeling tools; and a Service Centre providing special services for scientific and policy users, including training and research opportunities for young scientists. https://www.lifewatch.eu/

5.5.6 EMODnet

The European Marine Observation and Data Network (EMODnet) consists of more than 160 organizations assembling marine data, products, and metadata to make these fragmented resources more available to public and private users relying on quality-assured, standardized, and harmonized marine data which are interoperable and free of restrictions on use. EMODnet is currently in its second development phase with the target to be fully deployed by 2020. http://www.emodnet.eu/

5.5.7 EuMon

It is wide monitoring methods and systems of surveillance for species and habitats of Community interest. The EuMon portal provides information on biodiversity monitoring in Europe, national responsibilities, and biodiversity coverage of the Natura 2000 network. Policy briefs for these topics are also available. It also provides a support tool called BioMAT for the design and analysis of monitoring schemes. http://eumon.ckff.si/index1.php

5.5.8 Natura 2000

It is the key instrument to protect biodiversity in the European Union. It is an ecological network composed of sites designated under the Birds Directive (Special Protection Areas or SPAs) and the Habitats Directive (Sites of Community Importance or SCIs, and Special Areas of Conservation or SACs).

The European database of Natura 2000 sites consists of a compilation of the data submitted by the Member States of the European Union. This European database is generally updated once a year to take into account any updating of national databases by the Member States. However, the release of a new EU-wide database does not necessarily mean that a particular national dataset has recently been updated.

The descriptive data in the European database are based on the information that national authorities have submitted, for each of the Natura 2000 sites, through a site-specific standard data form (SDF). In addition to other site-specific information, the standard data form provides the list of all species and habitat types for which a site is officially designated.

The spatial data (outlining the boundaries of sites) submitted by each Member State are validated by the European Environment Agency (EEA) (Table 1).

Any problems identified through the above validation procedures in the national datasets are brought to the attention of the Member States concerned. However, it remains up to the Member States to decide whether to submit a revised dataset before the European database is updated. The EEA, therefore, cannot guarantee that all inconsistencies detected in national datasets are removed in the European dataset.

Please note that some Member States have submitted sensitive information that has been filtered out of this database. The following Member States have submitted sensitive information: Austria, Belgium, Cyprus, Estonia, Finland, France, Germany, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Poland, Portugal, Slovakia, Spain, Sweden, and United Kingdom. This concerns mainly species associated with specific sites. All reference to these species has been removed from the related sites. If this sensitive information is necessary to your field of research, please contact the Member State administrations individually. You can find a compiled list of national or regional Natura 2000 websites at the following address:http://ec.europa.eu/environment/nature/natura2000/db_gis/index_en.htm#sites

There are specific terms and conditions related to the use of downloaded boundary data within the United Kingdom. If you intend to use the UK data, you must first agree to the end user license http://www.jncc.gov.uk/page-5232.

Metadata	
Geographic coverage	Austria, Belgium, Bulgaria, Croatia, Cyprus, Czechia, Denmark, Estonia, Finland, France, Germany, Greece, Hungary, Ireland, Italy, Latvia, Lithuania, Luxembourg, Malta, Netherlands, Poland, Portugal, Romania, Slovakia, Slovenia, Spain, Sweden, United Kingdom
Scale of the data set	1:100,000
Rights	EEA standard re-use policy: unless otherwise indicated, re-use of content on the EEA website for commercial or non-commercial purposes is permitted free of charge, provided that the source is acknowledged (https://www.eea.europa.eu/legal/copyright). Copyright holder: Directorate-General for Environment (DG ENV).There are specific terms and conditions relating to the use of downloaded boundary data within the United Kingdom. If you intend to use the UK data, you must first agree to the end user license http://www.jncc.gov.uk/page-5232
Coordinate reference system	EPSG:3035
Data sources	Unit Nature & Biodiversity, DG Environment, European Commission of the Member States of the European Union
Owners	Directorate-General for Environment (DG ENV)
Processors	European Environment Agency (EEA)
GIS Data	
Natura 2000 - Spatial data	Natura 2000 End 2019 — Shapefile Natura 2000 End 2019 — OGC Geopackage INSPIRE compliant metadata set

Table 22 Natura 2000 - database characteristics

Source: authors' elaboration on European Environment Agency

5.5.9 Land Use and Land Cover Area frame Survey (LUCAS)

LUCAS is an in-situ area frame survey, which means that the data are gathered through direct observations made by surveyors in the field. Land cover data can also be obtained by interpreting satellite images or orthophotos, as is done in the Corine land cover inventory.

LUCAS data are available at a 2km grid that includes around 1 million points all over the EU. During the LUCAS 2018 survey, a sample of around 240,000 of these points was visited on the spot by 750 field surveyors, whilst another 98,000 points were photo-interpreted. The points were selected based on stratification information.

The land cover/use statistics derived from the LUCAS survey are unique as they are fully standardized to use the same definitions and methodology and are comparable among the MSs.

Types of land cover and visible land use are broken down into harmonized LUCAS categories. The full supporting documents for the survey comprise a field form, where all the measured variables are listed, and detailed field surveyors' instructions, which describe quality control procedures. The full description of the statistical data set is available in the land cover/use statistics metadata.

As in the 2009 and 2015 surveys, the LUCAS 2018 survey includes a soil module, where a topsoil sample is collected at 10% of the points. The objective of the soil module is to improve the availability of harmonized data on soil parameters in Europe. The LUCAS soil module was implemented in cooperation with the Directorate-General for Environment and the Joint Research Centre of the European Commission.

5.5.10 CORINE Land Cover

CORINE Land Cover (CLC), is a project for the uniform classification of the most important forms of land cover that was initiated by the European Union Commission. CORINE stands for Coordination of Information on the Environment. Since the mid-1980s, digital satellite images of Member States have been recorded and evaluated for the use of space for this program. Particular attention is paid to changes in use and the connection with environmental problems. Data as well as the maps developed from it are the basis for the determination of biotope types. The data are checked by the European Environment Agency in Copenhagen, and the first two recording epochs, 1990 - 2000 especially from Landsat 7, are already available to the public as digital maps in scales of 1: 100,000. The third registration with the reference year 2006, which has a higher resolution, was completed in January 2010. CORINE land cover data with the reference year 2012 are currently available from 2014. It has a wide variety of applications underpinning various community policies in the domains of the environment, but also agriculture, transport, spatial planning, etc.

5.6 Main features of the models and analytical tools used for evaluating ecosystem services

Researchers, modelers, and policy-makers have developed several ecosystem services valuation (ESV) tools to help quantify services. These tools can examine alternate scenarios, uncover connections, develop conservation strategies, and build coalitions. The various ESV tools have different emphases and strengths. In below Table 2 the selected tools reviewed by Snell[88] are presented.

Name	**InVest**
Sources	http://www.naturalcapitalproject.org/invest/ http://ecosystemsknowledge.net/invest
Background	InVest was developed as a partnership between Stanford University, the University of Minnesota, The Nature Conservancy, and the World Wildlife Fund. It is a suite of free open-source software models.
About the model/tool	InVest has an iterative engagement strategy that places an emphasis on stakeholder engagement. It has a strong spatial component and returns maps as outputs. The scale is flexible and allowing the model to be used at the local or global levels. It analysis ecosystem services related to regulation, provisioning, and culture and it is designed to work with terrestrial, freshwater, and marine ecosystems. The model is based on production functions and includes service supply, as well as the locations and activities of people who benefit from eco-services. The tools can be used independently or as a script tool within ArcGIS (geographic information system for working with maps and geographic information maintained by the Environmental Systems Research Institute) or QGIS (is a free and open-source cross-platform desktop geographic information system application that supports viewing, editing, and analysis of geospatial data); however, an intermediate level of GIS is required. The model includes research issues like carbon, coastal blue carbon, coastal vulnerability, crop pollination, fisheries, habitat quality, habitat risk assessment, managed timber production, marine fish aquaculture, marine water quality, nearshore waves and erosion, offshore wind energy, recreation, reservoir hydro-power production, scenic quality, sediment retention, water purification, and wave energy.
Limitations	Like many tools, InVest may be limited by local data access and quality. It may be oversimplified and it can be time-consuming to use.
Data requirements	GIS data and tables in CSV format can be used as inputs and maps are generated as outputs.
Training and support	InVest is well documented. The limitations and methodologies are outlined. There are training videos available online, along with a forum.
Name	**TESSA**
Sources	http://tessa.tools/ http://www.birdlife.org/worldwide/science/Toolkit_for_Ecosystem_Service_Site_Based_Assessment/How_TESSA_is_different_from_other_tools
Background	TESSA was developed in the UK, and it was used throughout the world for site-specific scoping in conservation projects. It is designed to use local knowledge and stakeholder engagement and to be relatively accessible to those without in-depth technical knowledge. It is not a spatially explicit model, but TESSA aims to help "non-experts" evaluate several ecosystem services "quickly, cheaply, but robustly and estimate the difference between the current state, and plausible alternatives"
About the model/tool	TESSA (Toolkit for Ecosystem Services Site-Based Assessment) is specifically developed for conservation planning at the site scale (100-100,000 ha). It has a participatory emphasis and has mostly been used in the United Kingdom. It requires some understanding of both scientific and socio-economic methods along with computer and mathematical skills, but it does not require any in-depth technical knowledge and relies on a comparatively simple model using information gathered locally. TESSA is rapid, robust, and provides guidance for low-cost methods. It does not focus on spatial techniques or outputs but does provide an opportunity for the comparative valuation and visualization of the impact of decision making. TESSA requires a computer with an internet connection, field equipment, and staff/or volunteers to carry out the analysis. Ecosystem services valued include harvested wild goods, global climate regulations, cultivated goods, nature-based rec, water (provision and quality), cultural, coastal protection, pollination (the last three are still in development). TESSA is made up of an eight-step process, with stakeholder engagement included throughout. The eight steps include: 1. Scoping. 2. Identifying and engaging with decision-makers.

	3. Preliminary scoping appraisal. 4. Determining the alternative statements. 5. Collecting data for the alternative state. 6. Selecting methods. 7. Data analysis. 8. Communicating results. The toolkit includes: step by step guidance for scoping and appraisal, decision trees/flow charts to help select the most appropriate methods based on site characteristics, information about 50 different methods for assessing ecosystem services, guidance/tips about assessing benefits across local, national and global communities, guidance about how to disaggregate values at the local level to determine inequities, templates, and examples, guidance on data synthesis.
Limitations	TESSA is not a spatial tool. It is designed for small scales and it does not measure all services, but it is designed more for scoping.
Data requirements	Data requirements will vary depending on the project and methods selected. Often uses primary data collected in the field.
Training and support	TESSA has strong support online with case studies, documentation, and webinars.
Name	**ARIES**
Sources	http://aries.integratedmodelling.org/
Background	ARIES (Artificial Intelligence for Ecosystem Services) was developed in 2007. It hopes to "quantify the benefits that nature provides to society in a manner that accounts for dynamic complexity and its consequences" (http://aries.integratedmodelling.org/?page_id=632). The tool is a new methodology and web application meant to assess ecosystem services (ES) and illuminate their values to humans to make environmental decisions easier and more effective. By creating ad-hoc, probabilistic models of both provision and usage of ES in a region of interest and mapping the actual physical flows of those benefits to their beneficiaries ARIES helps discover, understand, and quantify environmental assets, and what factors influence their value according to explicit needs and priorities.
About the model/tool	It uses modular model components that are most appropriate for each situation The underlying software is k.LAB, which is specifically designed to examine socioeconomic and environmental modeling problems. k.LAB is networked, which allows researchers to share models. However, ARIES requires significant technical knowledge. The tool can be used for spatial mapping and qualification of ES, spatial economic valuation of ES, natural capital accounting, optimization of payment schemes for ES, conservation planning, spatial policy planning, and forecasting of change in ES provision. The tool requires the k.LAB software tool environment. The specific ecosystem services modeled include carbon sequestration and storage, riverine flood regulation, coastal flood regulation, nutrient regulation, sediment regulation, water supply, fisheries, pollination, aesthetic value, open space proximity, and recreation. The specific ecosystem services modeled include carbon sequestration and storage, riverine flood regulation, coastal flood regulation, nutrient regulation, sediment regulation, water supply, fisheries, pollination, aesthetic value, open space proximity, and recreation.
Limitations	ARIES currently requires experienced modelers to consult for application.
Data requirements	GIS data and maps make up the inputs. Outputs include maps, quantitative data, and an environmental asset portfolio.
Training and support	Aries is well supported online. There are several workshops offered and custom training is available.
Name	**Co$ting Nature**

Sources	http://www.policysupport.org/costingnature http://ecosystemsknowledge.net/coting-nature
Background	Co$ting Nature was developed by Kings College London, Ambio TEK, and UNEP-WCMC. It is intended for conservation/development NGOs, governmental/non-governmental policy analysts, agriculture/industry, and education and research. It is applicable to a range of land uses.
About the model/tool	Co$ting Nature is web-based and spatially explicit. The spatial datasets are of 1 ha or 1 km² resolution, and based on the data maps are created. It is a free (for non-commercial use), open-access web-based tool. GIS software is helpful for analysis of output maps but is not necessary. The following services are modeled: water quantity, water quality, water provisioning, carbon storage and sequestration• recreation, biodiversity, conservation priority, threats, and pressures. Data are provided with the tool, but users may provide additional or more specific data. Time requirements for the tool are considered to be low, but no estimate of working days is available. Co$ting Nature calculates a baseline for current ESV (1950-2000). Scenarios, policy interventions, etc. can then be calculated and compared to the baseline.
Limitations	The model may be too simple for some uses. It does not currently support the mapping of the valuation and trade-offs associated with individual services.
Data requirements	Basic data are included in the tool. Users may supply their own more detailed data.
Training and support	Extensive videos and training are available online. Users can make suggestions and design the future of the tools.
Name	**EcoMetrix**
Sources	http://www.ecometrixsolutions.com/ecometrix.html
Background	EcoMetrix is a proprietary decision support system from the EcoMetrix Solutions Group. The tool balances robustness with ease of use. EcoMetrix develops a conceptual model for each function examined. The tool is designed to be used by ESG professionals (EcoMetrix Solutions Group) professionals generally at the site scale.
About the model/tool	EcoMetrix is based on algorithms for determining ecosystem function scores describing how well each relevant function is performed. These algorithms are developed for the EcoMetrix data-base in a four-step process. Each function to be examined has a corresponding conceptual model, which outlines the key attributes to functional performance. The conceptual model illustrates how physical attributes are connected to carry out the service. The conceptual model is developed by EcoMetrix. Measurement units are then selected for each attribute. The units of measure can be either quantitative or qualitative. These measures then are used to calculate scoring curves to show how a site's ecosystem functional performance will change with respect to changes in the various attributes. The functional performance scoring algorithms consist of an aggregation of the individual attributes identified in the conceptual model. These are connected to the scoring tables in the EcoMetrix database. Weights may be incorporated to capture ecological priories, regional differences, policy goals, etc. Additionally, the individual function measures are used to calculate the performance of the ecosystem. This performance is defined as a gain or loss of services. This measure can then be used to calculate economic or non-economic values.
Limitations	EcoMetrix is a proprietary tool so analysis and data collection would not occur in-house. As a result, projects may be more costly.
Data requirements	The conceptual models, which are developed as part of the analysis, determine the specific data needs.
Training and support	No training or other support are available, since EcoMetrix is a proprietary tool. ESG professionals create models, collect data, and conduct analysis.

Name	**ESII**
Sources	http://www.ecometrixsolutions.com/esii-tool.html http://www.esiitool.com/
Background	ESII (Ecosystem Services Identification and Inventory) tool was designed by TNC, Dow Chemical Company, and the EcoMetrix Solutions Group. It is designed for rapid and inexpensive analysis for communities, organizations, or businesses, and it can identify and estimate values for ES. It is designed for those without in-depth ecological training. Although it is still in development, early users are welcome. There is no cost for version one. Although it has not been well tested in marine environments, it is designed to be used in a broad range of geographies. It does not calculate a monetary value for the resources, but it does generate values that can be used in such valuation.
About the model/tool	There are two parts of the ESII tool: a web-based project workspace and an iPad app for data collection in the field. Beyond the app, no third party software is required. ESII follows these five 5 steps: 1. Identify the site. 2. Set up the project workspace. 3. Collect data with the app through questions and photos. 4. Review data and identify missing data. 5. Run models and examine results. Ecosystems Services modeled include aesthetics (noise and visuals), air quality (nitrogen and particulates), climate regulations, carbon uptake, erosion control, mass wasting, flood mitigation, water quality (nitrogen and sediment), water provisioning, and water quality control. Other ecosystem services will be added in the future.
Limitations	ESII does not provide monetary values and it is not well tested in marine environments.
Data requirements	Site-specific data are collected in the field through photos and a questionnaire.
Training and support	There are an online forum and strong information on the website. Some initial training is recommended. Additional support services, including personalized support and workshops/training sessions, are available for a fee.
Name	**ESR**
Sources	http://www.wri.org/publication/weaving-ecosystem-services-into-impact-assessment
Background	ESR (Ecosystem Services Review for Impact Assessment) is a spreadsheet methodology that has been used internationally and at multiple scales. It is primarily a screening tool.
About the model/tool	ESR is a six-step spreadsheet methodology that analyzes the impacts and dependencies on ecosystem services of a project. It includes environmental and social impacts. Additionally, it identifies strategies to mitigate project impacts on ES and ways to manage dependencies. The outputs include a list of services, the identification of key services and stakeholders, the assessment of project impacts and dependencies, and the determination of mitigation measures. The open-source tools are available for download. It is mostly a qualitative tool and not spatially explicit. It is relatively quick to use, although no time estimate is available. Sub-models include: atmosphere, lithosphere, hydrosphere, biosphere, and anthroposphere There are 4 outputs: 1. A list of ES. 2. Identification of priority ES and key stakeholders. 3. Assessment of potential impacts and connections within priority ES. 4. Potential measures to mitigate project impacts.
Limitations	ESR is mainly qualitative and does not provide a monetary valuation.

Data requirements	Most data are qualitative and gathered through stakeholder engagement or secondary data. Other useful data sources include censuses, historical texts, land cover maps, resource-specific data, etc.
Training and support	ESR is well documented online.
Name	**MIMES**
Sources	http://www.natureserve.org/conservation-tools/ecosystem-based-management-toolsnetwork/mimes.html
Background	MIMES (Multi-scale Integrated Models of Ecosystem Services) was developed by UVM and is managed by AFORDable futures LLC. It is currently under revision. It takes a systems approach and includes stakeholder involvement. MIMES has been used internationally and its three objectives are[89]: 1. A suite of dynamic ecological-economic computer models specifically aimed at integrating our understanding of ecosystem functioning, ecosystem services, and human well-being across a range of spatial scales. 2. Development and application of new valuation techniques adapted to the public goods nature of most ecosystem services and integrated with the modeling work. 3. Delivery of the integrated models and their results to a broad range of potential users.
About the model/tool	MIMES is an iterative set of models that can be used at multiple scales. It is spatially explicit and can provide a monetary valuation of ES. It is designed for both land and marine applications. According to Bagstad et al. [90], MIMES is open source, but requires the commercial modeling software SIMILIE and contracting a modeling group to develop a model. As of 2013, it was considered by Bagstad et al. [90] to be time-consuming to run. MIMES examines the dynamics of ES, how ES are linked to human welfare, how the value of ES might change under different situations.
Limitations	Some models are still in development. Resources are limited. The use of MIMES would require hiring an experienced systems modeler. While MIMES is highly scalable, local models would need to be adapted or developed.
Data requirements	MIMES requires relevant spatial data. Data requirements are imposed by the eco-system, specific location, and spatial scale.
Training and support	There are some web resources for MIMES, including a webinar. However, much of the information has a theoretical focus. Specific supporting resources are limited.
Name	**MIDAS**
Sources	http://people.bu.edu/suchi/midas/index.html http://www.seaplan.org/blog/project/midas/
Background	MIDAS (Marine Integrated Decision Analysis System) was developed to assist in the management of Marine Managed Areas (MMAs). MIDAS is a graphic user interface between MIMES and the needs of ocean mangers and stakeholders. It is opensource, web-based, and spatial. There is an emphasis on coastal areas and the ocean and stakeholder interaction. MIDAS has three objects: 1. Determine the socio-economic, governance, and ecological effects of MMAs. 2. Determine the critical ecological, socioeconomic, and governance factors, and time that affects MMA efforts. 3. Provide management tools for predicting the influence of MMA on ecological, socioeconomic, and governance variables along with the outputs that illustrate the results of different management decisions or actions.
About the model/tool	Stakeholder discussions provided the inputs for the model in the fifteen critical determining factors, 5 for each of the three following categories: governance, socioeconomic, and ecological. These ratings are input via drop-down menus.

	1. Governance Constituency Development Funds: stakeholder involvement; stakeholder compliance with rules and regulations; management operations; support from government agencies; empowerment. 2. Socio-Economic: perceived threat due to developments; perception of local extractive resources; non-extractive alternative livelihoods; socio-economic benefits from the establishment of MMAs; perception of seafood availability. 3. Ecological: level of fishing effort; relative change in habitat extent; habitat quality-of-life; herbivory; focal species abundance These inputs are visualized into four outcomes or indexes: governance, livelihood, ecological health and resilience, and MMA effectiveness.
Limitations	MIDAS is limited to marine systems. It is designed to be used along with MIMES.
Data requirements	Information is gathered at public meetings.
Training and support	There is limited, dated information available about MIDAS online.
Name	**Envision**
Sources	http://envision.bioe.orst.edu/
Background	Envision is a spatially explicit alternative futures modeling tool developed by Oregon State University. It was also known as Evoland.
About the model/tool	It was developed and tested for the Pacific North West, it has also been used in Colombia and New Zealand. The tool is designed for the landscape scale and has an emphasis on agent-based modeling. It is open-source. Although it is primarily a scenario modeling tool, it can provide some monetary valuation. It also allows for non-monetary ranking of preferences. It depends on different “plug-ins” to run the models, and users can create custom “plug-ins”. Envision requires Windows and it must be customized for each location, which means that it is both costly and time-consuming. Bagstad et al.[91] report that new applications cost 100,00-150,000 USD and take about one year.
Limitations	Envision is time-consuming and costly to apply in new areas. Data availability is also a challenge.
Data requirements	New locations must supply all necessary data. This includes land use, land cover, ecological, and economic data.
Training and support	It comes with several tutorials and there are some additional support resources available online, along with a developer's guide.
Name	**SolVES**
Sources	http://solves.cr.usgs.gov/
Background	SolVES was developed by the United States Geological Survey (USGS) and the Geosciences and Environmental Change Science center to assess the social values of ecosystem services. It has been used is coastal areas as well as forests.
About the model/tool	SolVES is a toolbox for ArcGIS. As a result, it requires ArcGIS and intermediate GIS knowledge. It is spatially explicit. The goal of SolVES is to quantify perceived social values, what stakeholders think “ought to be”. Thus, it has an emphasis on cultural services, including aesthetics and recreation. It does not provide monetary values, but it does rank them according to preferences. A 10 point social values metric, the Value Index, is calculated through a combination of spatial and non-spatial responses to public value surveys. It also takes into account measurable environmental traits and metrics. SolVES currently measures aesthetic appreciation, recreation, spiritual experience and identity, tourism. It is designed to work on

	the landscape or watershed scale and it is relatively fast to use once data are collected. The outputs include maps of the social values of ecosystem services. Months to years may be necessary to collect the required survey data.
Limitations	It requires specifically formatted data. The survey data can be time-consuming to collect and code.
Data requirements	It requires environmental data in raster format. Community responses to survey data must be collected and associated with raster environmental data.
Training and support	The tool is well documented online.
Name	**ESValue**
Sources	www.entrix.com
Background	ESValue is a proprietary model developed by Cardno Entrix. It has been previously used by the Frenchman Bay Partners (FBP).
About the model/tool	ESValue is a spreadsheet-based model and depends on rankings in a survey. It establishes stakeholder preferences and relative values for ecosystems rather than monetary values. Stakeholder involvement is an important part of ESValue. It is well suited for comparisons. It is designed for the landscape to site-level scale.
Limitations	There is not much support online. Spreadsheets may not be intuitive.
Data requirements	Data are collected through surveys at public meetings.
Training and support	ESValue is a proprietary model. There is not much online support. Personal training or support may be available for a price.
Name	**EMDS**
Sources	http://1726-4482.el-alt.com/
Background	EMDS (Ecosystem Management Decision Support) is a spatial decision support system made up of several tools. It is designed to be used at several geographic scales. It was developed by the United States Forest Service under a contract with Mountain View Business Group and it is still in development. EMDS has been used internationally.
About the model/tool	It is a proprietary tool and an add-on to ArcMap. It is designed to be used for planning, but not necessarily for valuation. EMDS has been applied to study carbon sequestration, conservation, the design and siting of ecological reserves, ecosystem sustainability, forest management, hydrology, land classification, landscape evaluation, landscape restoration, pollution, social issues in natural resource management, soil impacts, urban growth and development, watershed analysis, wetlands management, wildlife habitat management, and wildland fire danger. It uses the Netweaver Logic Engine and Priority Analyst to model decision making and planning implications. Netweaver is useful in situations when data might be incomplete. It also allows the for evaluation of missing data.
Limitations	Like all tools, EMDS depends on the quality of the data. The tool is still in development and new features will be available in the future.
Data requirements	Data requirements depend on the resources evaluated. Spatial data, formatted for ArcGIS is required.
Training and support	There are good documentation and strong online support with a forum to share issues.

Name	EnviroAtlas
Sources	https://www.epa.gov/enviroatlas https://toolkit.climate.gov/tool/enviroatlas
Background	EnviroAtlas was developed by the United States Environmental Protection Agency (EPA) and partners. It is still under development. It is an interactive tool designed for a variety of users to explore the benefits people receive from ecosystems. It includes both web-based components and tools to use within GIS. Downloaded data can, in turn, be used in other tools. It is not an accounting tool, but it is meant to aid in the evaluation of ecosystem services, including social value. Little technical knowledge or scientific background is necessary.
About the model/tool	There are seven benefit categories: clean air, clean, plentiful water, natural hazard mitigation, climate stabilization, recreation, culture, and aesthetics, food, fuel materials, and biodiversity conservation. These are further divided into supply, demand, and drivers of change. Data are available at both the watershed level and the census block level. It relies on land cover data, along with census and other publicly available environmental and economic data. There are several statistical and analytical tools to analyze the data. Maps, charts, and graphs are the outputs.
Limitations	Some data may be at a too coarse resolution. The data are adequate for examining the current state only.
Data requirements	Data are available through the web-based tool; however, data are very limited for Alaska and Hawaii.
Training and support	EnviroAtlas is well supported online with the user's guide, videos, and tutorials.

Table 23 Characteristics of models and analytical tools used for evaluating ecosystem services

Source: authors' elaborations on Snell[88]

5.7 References

1. ^ 1 2 M. E. Assessment, Ecosystems and human well-being, vol. 5. Island press Washington, DC:, 2005.
2. ^ E. Gómez-Baggethun, R. de Groot, P. L. Lomas, and C. Montes, “The history of ecosystem services in economic theory and practice: From early notions to markets and payment schemes,” Ecological Economics, vol. 69, no. 6, pp. 1209–1218, Apr. 2010, doi: 10.1016/j.ecolecon.2009.11.007.
3. ^ D. J. Abson et al., “Ecosystem services as a boundary object for sustainability,” Ecological Economics, vol. 103, pp. 29–37, 2014.
4. ^ R. Haines-Young and M. Potschin, “Methodologies for defining and assessing ecosystem services,” 2009.
5. ^ 1 2 S. Chaudhary, A. McGregor, D. Houston, and N. Chettri, “The evolution of ecosystem services: A time series and discourse-centered analysis,” Environmental Science & Policy, vol. 54, pp. 25–34, 2015.
6. ^ F. B. Golley, A history of the ecosystem concept in ecology: more than the sum of the parts. Yale University Press, 1993.
7. ^ L. C. Braat and R. De Groot, “The ecosystem services agenda: bridging the worlds of natural science and economics, conservation and development, and public and private policy,” Ecosystem services, vol. 1, no. 1, pp. 4–15, 2012.
8. ^ K. H. Redford and W. M. Adams, “Payment for ecosystem services and the challenge of saving nature,” Conservation biology, vol. 23, no. 4, pp. 785–787, 2009.
9. ^ K. Jax et al., “Ecosystem services and ethics,” Ecological Economics, vol. 93, pp. 260–268, 2013.

10. ^ M. Schröter et al., "Ecosystem services as a contested concept: a synthesis of critique and counter-arguments," Conservation Letters, vol. 7, no. 6, pp. 514–523, 2014.
11. ^ Y. E. Chee, "An ecological perspective on the valuation of ecosystem services," Biological conservation, vol. 120, no. 4, pp. 549–565, 2004.
12. ^ 1 2 D. J. McCauley, "Selling out on nature," Nature, vol. 443, no. 7107, pp. 27–28, 2006.
13. ^ R. S. De Groot, M. A. Wilson, and R. M. Boumans, "A typology for the classification, description and valuation of ecosystem functions, goods and services," Ecological economics, vol. 41, no. 3, pp. 393–408, 2002.
14. ^ S. Jackson and L. R. Palmer, "Reconceptualizing ecosystem services: Possibilities for cultivating and valuing the ethics and practices of care," Progress in Human Geography, vol. 39, no. 2, pp. 122–145, 2015.
15. ^ J. Fairhead, M. Leach, and I. Scoones, "Green grabbing: a new appropriation of nature?," Journal of peasant studies, vol. 39, no. 2, pp. 237–261, 2012.
16. ^ B. Ridder, "Questioning the ecosystem services argument for biodiversity conservation," Biodiversity and Conservation, vol. 17, no. 4, pp. 781–790, 2008.
17. ^ J. A. Fisher et al., "Strengthening conceptual foundations: analysing frameworks for ecosystem services and poverty alleviation research," Global Environmental Change, vol. 23, no. 5, pp. 1098–1111, 2013.
18. ^ R. Bommarco, D. Kleijn, and S. G. Potts, "Ecological intensification: harnessing ecosystem services for food security," Trends in ecology & evolution, vol. 28, no. 4, pp. 230–238, 2013.
19. ^ M. Potschin, R. Haines-Young, R. Fish, and K. Turner, "Ecosystem services in the twenty-first century," in Routledge Handbook of Ecosystem Services, Routledge, 2016, pp. 1–9.
20. ^ M. B. Potschin and R. H. Haines-Young, "Ecosystem services: exploring a geographical perspective," Progress in Physical Geography, vol. 35, no. 5, pp. 575–594, 2011.
21. ^ M. Schmidt et al., "Evaluation of the ecosystem services approach in agricultural literature," One ecosystem, vol. 2, p. e11613, 2017.
22. ^ R. Haines-Young and M. Potschin, "Typology/classification of ecosystem services," OpenNESS Ecosystem Services Reference Book. EC FP7 Grant Agreement, no. 308428, 2014.
23. ^ J. Mustajoki, H. Saarikoski, V. Belton, T. Hjerppe, and M. Marttunen, "Utilizing ecosystem service classifications in multi-criteria decision analysis–Experiences of peat extraction case in Finland," Ecosystem Services, vol. 41, p. 101049, 2020.
24. ^ 1 2 J. Alcamo, "Ecosystems and human well-being: a framework for assessment," 2003.
25. ^ P. Sukhdev, The economics of ecosystems and biodiversity. na, 2008.
26. ^ R. Haines-Young and M. Potschin, "CICES V4. 3 Common International Classification of Ecosystem Services, Report prepared following consultation on CICES Version 4, August-December 2012. EEA Framework Contract No EEA," EEA Framework Contract No EEA, 2013.
27. ^ J. Norberg, "Linking Nature's services to ecosystems: some general ecological concepts," Ecological Economics, vol. 29, no. 2, pp. 183–202, May 1999, doi: 10.1016/S0921-8009(99)00011-7.
28. ^ R. Haines-Young and M. Potschin-Young, "Revision of the common international classification for ecosystem services (CICES V5. 1): a policy brief," One Ecosystem, vol. 3, p. e27108, 2018.
29. ^ 1 2 B. Burkhard, F. Kroll, F. Müller, and W. Windhorst, "Landscapes' capacities to provide ecosystem services-a concept for land-cover based assessments," Landscape online, vol. 15, pp. 1–22, 2009.
30. ^ G. Zurlini and P. Girardin, "Introduction to the special issue on 'Ecological indicators at multiple scales,'" Ecological Indicators, vol. 6, no. 8, pp. 781–782, 2008.
31. ^ 1 2 L. R. Norton, H. Inwood, A. Crowe, and A. Baker, "Trialling a method to quantify the 'cultural services' of the English landscape using Countryside Survey data," Land use policy, vol. 29, no. 2, pp. 449–455, 2012.

32. ^ C. K. Feld et al., “Indicators of biodiversity and ecosystem services: a synthesis across ecosystems and spatial scales,” Oikos, vol. 118, no. 12, pp. 1862–1871, 2009.
33. ^ E. Nelson et al., “Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales,” Frontiers in Ecology and the Environment, vol. 7, no. 1, pp. 4–11, 2009.
34. ^ J. A. Angulo-Valdés and B. G. Hatcher, “A new typology of benefits derived from marine protected areas,” Marine Policy, vol. 34, no. 3, pp. 635–644, 2010.
35. ^ Y. I. Zhang, S. Singh, and B. R. Bakshi, “Accounting for ecosystem services in life cycle assessment, Part I: a critical review,” Environmental science & technology, vol. 44, no. 7, pp. 2232–2242, 2010.
36. ^ B. Martín-López, E. Gómez-Baggethun, P. L. Lomas, and C. Montes, “Effects of spatial and temporal scales on cultural services valuation,” Journal of Environmental Management, vol. 90, no. 2, pp. 1050–1059, 2009.
37. ^ R. Costanza et al., “The value of the world’s ecosystem services and natural capital,” nature, vol. 387, no. 6630, pp. 253–260, 1997.
38. ^ S. M. Swinton, F. Lupi, G. P. Robertson, and S. K. Hamilton, Ecosystem services and agriculture: cultivating agricultural ecosystems for diverse benefits. Elsevier, 2007.
39. ^ L. Pejchar and H. A. Mooney, “Invasive species, ecosystem services and human well-being,” Trends in ecology & evolution, vol. 24, no. 9, pp. 497–504, 2009.
40. ^ 1 2 N. England, “Experiencing landscapes: Capturing the cultural services and experiential qualities of landscape (Natural England Commissioned Report NECR024),” Sheffield, UK: Natural England, 2009.
41. ^ 1 2 3 D. Satz et al., “The Challenges of Incorporating Cultural Ecosystem Services into Environmental Assessment,” AMBIO, vol. 42, no. 6, pp. 675–684, Oct. 2013, doi: 10.1007/s13280-013-0386-6.
42. ^ K. M. Chan, T. Satterfield, and J. Goldstein, “Rethinking ecosystem services to better address and navigate cultural values,” Ecological economics, vol. 74, pp. 8–18, 2012.
43. ^ T. Ingold, The Perception of the Environment: Essays on Livelihood, Dwelling and Skill - Tim Ingold - Google Książki. .
44. ^ N. J. Turner, M. B. Ignace, and R. Ignace, “Traditional Ecological Knowledge and Wisdom of Aboriginal Peoples in British Columbia,” Ecological Applications, vol. 10, no. 5, pp. 1275–1287, 2000, doi: 10.1890/1051-0761(2000)010[1275:TEKAWO]2.0.CO;2.
45. ^ K. H. Basso, Wisdom Sits in Places: Landscape and Language Among the Western Apache. UNM Press, 1996.
46. ^ S. Marsden, “Adawx, Spanaxnox, and the Geopolitics of the Tsimshian,” BC Studies: The British Columbian Quarterly, no. 135, pp. 101–135, 2002.
47. ^ E. M. Koehler, “Repatriation of Cultural Objects to Indigenous Peoples: A Comparative Analysis of U.S. and Canadian Law,” International Lawyer (ABA), vol. 41, p. 103, 2007, [Online]. Available: https://heinonline.org/HOL/Page?handle=hein.journals/intlyr41&id=117&div=&collection=.
48. ^ C. F. Roth, Becoming Tsimshian: The social life of names. University of Washington Press, 2011.
49. ^ M. Sahlins, “What kinship is (part one),” Journal of the Royal Anthropological Institute, vol. 17, no. 1, pp. 2–19, 2011.
50. ^ K. M. Chan et al., “Cultural services and non-use values,” Natural capital: Theory and practice of mapping ecosystem services, pp. 206–228, 2011.
51. ^ 1 2 J. Boyd, “Nonmarket benefits of nature: What should be counted in green GDP?,” Ecological Economics, vol. 61, no. 4, pp. 716–723, Mar. 2007, doi: 10.1016/j.ecolecon.2006.06.016.
52. ^ H. Tallis, Natural capital: theory and practice of mapping ecosystem services. Oxford University Press, 2011.
53. ^ J. Raz, The Morality of Freedom. Clarendon Press, 1986.

54. ^ H. A. Simon, "Rationality as Process and as Product of Thought," The American Economic Review, vol. 68, no. 2, pp. 1–16, 1978, [Online]. Available: https://www.jstor.org/stable/1816653.
55. ^ 1 2 3 S. Williams, "Perceptions of wetland ecosystem services in a region of climatic variability," 2018, [Online]. Available: http://etd.uwc.ac.za/xmlui/handle/11394/6599.
56. ^ S. T. Asah, A. D. Guerry, D. J. Blahna, and J. J. Lawler, "Perception, acquisition and use of ecosystem services: Human behavior, and ecosystem management and policy implications," Ecosystem Services, vol. 10, pp. 180–186, 2014.
57. ^ D. Y. Ayal and W. Leal Filho, "Farmers' perceptions of climate variability and its adverse impacts on crop and livestock production in Ethiopia," Journal of Arid Environments, vol. 140, pp. 20–28, 2017.
58. ^ M. D. Kaplowitz and J. Kerr, "Michigan residents' perceptions of wetlands and mitigation," Wetlands, vol. 23, no. 2, pp. 267–277, 2003.
59. ^ Z. A. Elum, D. M. Modise, and A. Marr, "Farmer's perception of climate change and responsive strategies in three selected provinces of South Africa," Climate Risk Management, vol. 16, pp. 246–257, 2017.
60. ^ 1 2 3 C. Rega, J. Helming, and M. L. Paracchini, "Environmentalism and localism in agricultural and land-use policies can maintain food production while supporting biodiversity. Findings from simulations of contrasting scenarios in the EU," Land Use Policy, vol. 87, p. 103986, 2019.
61. ^ J. Paterson, M. Metzger, and A. Walz, "The VOLANTE scenarios: framework, storylines and drivers," Download: http://www. volante-project. eu/documents/104-deliverables. html, 2012.
62. ^ N. Nakicenovic, "IPCC special report on emissions scenarios," http://www. data. kishou. go. jp/climate/cpdinfo/ipcctar/spm/scenario. htm, vol. 28, 2000.
63. ^ J. Stürck et al., "Simulating and delineating future land change trajectories across Europe," Regional Environmental Change, vol. 18, no. 3, pp. 733–749, 2018.
64. ^ P. J. Verkerk et al., "Identifying pathways to visions of future land use in Europe," Regional environmental change, vol. 18, no. 3, pp. 817–830, 2018.
65. ^ M. A. Mouchet et al., "Bundles of ecosystem (dis) services and multifunctionality across European landscapes," Ecological Indicators, vol. 73, pp. 23–28, 2017.
66. ^ M. A. Mouchet et al., "Ecosystem service supply by European landscapes under alternative land-use and environmental policies," International Journal of Biodiversity Science, Ecosystem Services & Management, vol. 13, no. 1, pp. 342–354, 2017.
67. ^ H. Lotze-Campen et al., "A cross-scale impact assessment of European nature protection policies under contrasting future socio-economic pathways," Regional Environmental Change, vol. 18, no. 3, pp. 751–762, Mar. 2018, doi: 10.1007/s10113-017-1167-8.
68. ^ 1 2 L. P. Olander et al., "Benefit relevant indicators: Ecosystem services measures that link ecological and social outcomes," Ecological Indicators, vol. 85, pp. 1262–1272, 2018.
69. ^ P. A. Harrison et al., "Identifying and prioritising services in European terrestrial and freshwater ecosystems," Biodiversity and Conservation, vol. 19, no. 10, pp. 2791–2821, 2010.
70. ^ 1 2 K. J. Bagstad, D. J. Semmens, S. Waage, and R. Winthrop, "A comparative assessment of decision-support tools for ecosystem services quantification and valuation," Ecosystem Services, vol. 5, pp. 27–39, 2013.
71. ^ S. M. Smart et al., "Exploring the Future: Phase 1-scoping current and future use of spatial Decision Support Tools (sDST) for integrated planning for land-use, biodiversity and ecosystem services across England," Final Report to Defra, Project code WC0794, 2012.
72. ^ P. Fox and J. A. Hendler, "Semantic escience: encoding meaning in next-generation digitally enhanced science.," The Fourth Paradigm, vol. 2, 2009.
73. ^ F. Villa, "Bridging scales and paradigms in natural systems modeling," in Research Conference on Metadata and Semantic Research, 2010, pp. 1–7.

74. ^ S. M. Posner, E. McKenzie, and T. H. Ricketts, "Policy impacts of ecosystem services knowledge," Proceedings of the National Academy of Sciences, vol. 113, no. 7, pp. 1760–1765, 2016.
75. ^ M. Bamberger, "Introduction to mixed methods in impact evaluation," Impact Evaluation Notes, vol. 3, no. 3, pp. 1–38, 2012.
76. ^ J. W. Creswell and J. D. Creswell, Research design: Qualitative, quantitative, and mixed methods approaches. Sage publications, 2017.
77. ^ K. E. Newcomer, H. P. Hatry, and J. S. Wholey, Handbook of practical program evaluation. John Wiley & Sons, 2015.
78. ^ 1 2 I. J. Bateman et al., "Bringing ecosystem services into economic decision-making: land use in the United Kingdom," science, vol. 341, no. 6141, pp. 45–50, 2013.
79. ^ 1 2 Mj. Metzger, M. D. A. Rounsevell, L. Acosta-Michlik, R. Leemans, and D. Schröter, "The vulnerability of ecosystem services to land use change," Agriculture, ecosystems & environment, vol. 114, no. 1, pp. 69–85, 2006.
80. ^ B. Eickhout, "The IMAGE 2.2 implementation of the SRES scenarios; A comprehensive analysis of emissions, climate change and impacts in the 21st century," RIVM Rapport 481508018, 2001.
81. ^ 1 2 3 H. R. Grau, T. M. Aide, J. K. Zimmerman, J. R. Thomlinson, E. Helmer, and X. Zou, "The ecological consequences of socioeconomic and land-use changes in postagriculture Puerto Rico," BioScience, vol. 53, no. 12, pp. 1159–1168, 2003.
82. ^ J. E. Smith, L. S. Heath, K. E. Skog, and R. A. Birdsey, "Methods for calculating forest ecosystem and harvested carbon with standard estimates for forest types of the United States," Gen. Tech. Rep. NE-343. Newtown Square, PA: US Department of Agriculture, Forest Service, Northeastern Research Station. 216 p., vol. 343, 2006.
83. ^ N. B. Bliss, S. W. Waltman, and L. West, "Detailed mapping of soil organic carbon stocks in the United States using SSURGO," AGUFM, vol. 2009, pp. B51F-0367, 2009.
84. ^ P. Comer et al., "Ecological Systems of the United States: A Working Classification of US Terrestrial Systems (NatureServe, Arlington, VA)," Accessed July, vol. 21, p. 2009, 2003.
85. ^ H. Hu, W. Liu, and M. Cao, "Impact of land use and land cover changes on ecosystem services in Menglun, Xishuangbanna, Southwest China," Environmental monitoring and assessment, vol. 146, no. 1–3, pp. 147–156, 2008.
86. ^ E. H. Helmer, "Forest conservation and land development in Puerto Rico," Landscape Ecology, vol. 19, no. 1, pp. 29–40, 2004.
87. ^ 1 2 F. T. de Vries et al., "Soil food web properties explain ecosystem services across European land use systems," Proceedings of the National Academy of Sciences, vol. 110, no. 35, pp. 14296–14301, Aug. 2013, doi: 10.1073/pnas.1305198110.
88. ^ 1 2 M. Snell, "Review of Ecosystem Services Valuation Tools," 2016.
89. ^ R. Boumans and R. Costanza, "The multiscale integrated Earth Systems model (MIMES): the dynamics, modeling and valuation of ecosystem services," Issues in Global Water System Research, vol. 2, pp. 10–11, 2007.
90. ^ 1 2 K. J. Bagstad, D. J. Semmens, S. Waage, and R. Winthrop, "A comparative assessment of decision-support tools for ecosystem services quantification and valuation," Ecosystem Services, vol. 5, pp. 27–39, 2013.
91. ^ K. J. Bagstad, D. Semmens, R. Winthrop, D. Jaworski, and J. Larson, "Ecosystem services valuation to support decision making on public lands: a case study for the San Pedro River, Arizona," USGS Scientific Investigations Report, vol. 5251, 2012.

6 Agricultural Output and Input Markets and Their Interlinkages[2]

6.1 Agriculture and its Input and Output Markets

Several distinguishing features of the agricultural sector make it quite special in comparison to non-agricultural sectors. Agriculture's impact on the land market through changes in land-use and land-cover; the sector's multi-dimensional linkages with the environment; being the main source of income in rural areas and being the main driver of bio-economy are among the distinguishing features of the agricultural sector.

The negative externalities on the environment that arise as a result of the relationship between the agricultural sector and the environment on various grounds and that harm agriculture itself in return are an important result of the multi-dimensional linkages between agriculture and environment. Land is an indispensable factor for agricultural production. The decision of land-use and the choice of land-cover creates prominent impacts on the landscape and the environment compared to the impact of non-agricultural sectors. Therefore, the agricultural sector is probably the key factor in land markets. The sector has strong interactions with factors such as soil, water, and air which are quite influential in agricultural production. However, wrong agricultural practices harm these factors in return. Another distinguishing feature of the agricultural sector is its engagement with organic species, which raises issues of animal and plant health, biodiversity, and animal welfare. Negative environmental externalities arising from agricultural production have a widespread structure such as nutrients runoff and agro-chemical losses in soil, air, and water instead of being point-sourced. Hence, it is not possible to take source (point)-based pollution preventive measures as in non-agricultural sectors. Nutrient and agro-chemical flows into the biological system trigger biological transformation processes which embody spatially and temporally changing characteristics. Last but not the least, nitrogen, phosphorus, and ammonia emissions to the ground, surface water, and airplay a significant role in climate change.

From the economic point of view, the development level of countries also affects particularly the structure of the sector and farms as well as farm management practices. As a result, there is heterogeneity among agricultural enterprises which determines agent behavior in the sector. While small scale and mostly family-operated farms, are common in developing countries, large scale, and professionally operated farms, are common in developed countries. Therefore, the sources of farm heterogeneity in countries of different development levels do differ as well.

As already pointed out, agriculture is the key source of income in rural areas. Therefore, regardless of whether the country is developed or not, rural and agricultural policies are interrelated. As opposed to non-agricultural sectors, agriculture is highly integrated with cultural heritage, tourism, rural economy, and - in a wider perspective - it is at the center of bio-economy [1]. Agriculture in developing countries provides food security and absorbs unemployment. With the integration of particularly developed countries' agricultural sectors into international markets, spillover effects of agricultural policies on developing countries' markets occur as well.

Based on the above multi-dimensional and multi-functional structure of the agricultural sector, impact assessment becomes quite a challenge and specific tools are needed to do the task. Literature offers a diverse set of approaches and tools - each of which is highly specialized. These tools consider different temporal properties (time horizon and choice of static/dynamic settings),

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spatial resolution levels (plot, farm, parcel, region, and country), integrated components (biophysical, environmental, and social), and other characteristics (e.g., policy instruments).

The structure of the review is as follows. Section 2 provides a general overview of the output and input markets in the EU and Section 3 summarizes the institutional framework regarding the agricultural sector. Section 4 introduces the main modeling approaches used for the agricultural sector analyses together with the main characteristics of some well-known partial equilibrium and agent-based modeling platforms. In section 5, some clues about the features that the agent-based model to be used in AGRICORE are derived based on findings from the comparison of modeling platforms given in section 4.

6.2 The rationale for analyzing the modeling and behavior of output and production factors

6.2.1 A general overview of land use, farm holdings, and production in the EU agriculture

Agriculture is primarily the main user of land for agricultural activities in the EU. The average farm size is 16.1 ha in the EU-28 (in 2013). While 66% of holdings have a size smaller than 5 ha, only 7% are larger than 50 ha. Farms with 50 ha or more of the agricultural land cover 68% of the total agricultural land and farms having less than 5 ha occupy only 6.2%. The largest share of land is managed by farms in the upper-medium economic size class. In the EU-28, the average standard output per farm was EUR 30 536 in 2013 while the average economic size in the EU-15 is seven times as high when compared to farms in the EU-N13. The average standard output per farm has increased due to either a shift to higher output values agricultural activities or an increase in yields and/or prices [2].

On the one hand, family farms hold about 97% of all holdings and the holder is also the farm manager who manages only 67% of the agricultural land in the EU-28. The rest is corporate farms and group holdings. On the other hand, tenant farmers operated more than 43% of the land in the EU-28. Regarding farm activities, about 34% of all holdings in the EU-15 are specialized in permanent crops, granivores, and mixed production systems. Bigger farms tend to specialize in field cropping and grazing livestock while farming activities are mixed in the smaller farms. Farms specialized in horticulture, permanent crops or granivores take up a very small amount of agricultural land [2].

Production of agricultural commodities in most EU countries has increased for more than 15 years, except for the production of beef, sheepmeat, and sugar. The EU produces 143 million tons of soft wheat on average annually. Pork production increased 8% in last 15 years and poultry production has increased by more than 30%. As a result of the bovine spongiform encephalopathy (BSE) crisis, the impact of decoupling direct payments in 2005, and the decline of dairy herds beef production shrunk by 9% for the last 15 years. Since milk quota ended and milk prices in 2013-2014 were high, milk production increased rapidly afterwords. Most of the milk in the EU is used to produce cheese. Production of skimmed milk powder (SMP) increased and whole milk powder (WMP) production declined since 2000. After removing the sugar quota in October 2017 sugar production increased by 25%. The EU is self-sufficient for most agricultural commodities except for sheep meat, sugar and maize and to a lesser extent beef [3].

The EU agriculture sector is undergoing a steady structural change. Farms are getting larger and more productive and farm dependence on labor is declining since family members provide about 75% of the labor. There are still vast numbers of very small farms, primarily ran in a part-time fashion and often by elderly farmers. In fact, agriculture is the sector in which it is most common for people to continue working after the age of 65 in Europe. Young farmers are the best-trained group of EU-farmers and hold bigger farms [4].

The used agricultural area has remained largely stable over the last decades. Agricultural land has not been abandoned on a large-scale. Therefore, the production base is maintained. Since the most suitable land is already in use, a new entrant into farming will often take over an existing farm. Thus, land may be difficult to find if it is not inherited. The higher proportion of rented land among young farmers indicates a desire to increase the size of the farming operation, which is constrained by the lack of suitable land [5].

Agriculture in the EU can be summarized as follows: it is anticipated that the total agricultural land use continues to decline due to the demand from other sectors[6]. The number of farms decreases and the used agricultural area is stabilized while the standard output (SO) is increasing. The share of young farmers is low and middle-aged farmers have the highest agricultural income in the EU. Also, land values are higher for older farmers than for the young ones who also own less land. Most market-oriented farmers rent more land than they own and that trend is increasing. Land rents make up roughly 5% of the total costs and it is young farmers who invest the most among all age groups. Regarding capital, young and old farmers have the lowest on average while liabilities for young farmers are low and declining. Also, younger farmers have higher debt-to-asset ratios than older ones and have a higher return on assets than older ones do [5].

Yields in agriculture will grow more slowly than in the past. Consumer demand is increasing for local, organic, or other certified products, and the demand for organic food is expected to boost EU supply in the short term. The land used for agriculture is expected to decline; however, the overall production will increase due to higher yields. The EU cereals market will also grow and the demand for feed and industrial uses of cereals will increase. Competition in the cereal market in the world is high. Therefore, EU exports will increase moderately. Additionally, production of protein crops is expected to grow strongly in the medium term due to a high demand for plant-protein products and the area for oil-seeds will decline slightly, which will not be the case for sugar beet as it is expected it will not change in the medium term [6].

More intensified olive oil production is expected and EU exports will also increase. However, wine production and domestic use will decline. Although the EU's apple production remains stable due to increasing yields. Peaches and nectarines production will decline slightly since the area grown is decreasing. Consumers prefer fresh juices and that would increase orange production. Fresh tomatoes production is expected to remain relatively stable. The use of palm-based biodiesel is restricted and this is expected to reduce the available supply of biofuels significantly [6].

Milk production grows moderately. Yields will increase and dairy herds will decline reducing the gas emissions. Changes in consumer demands will shift the market in terms of production systems and dairy products. New products such as adult nutrition will add value to the sector. Global import demand will increase for dairy products in the world as the population continues to grow. Most of the milk produced will be channeled into cheese processing because the global demand and domestic industrial uses are increasing. Demand for butter could also rise. The production of skimmed milk powders will grow further as a result of increased export demand and adult nutrition. Annual meat consumption is expected to decline. Pork for exports is projected to increase although consumption in the EU will be lower. Total cow herds could also decline due to the increase in profitability. It is anticipated that new trade opportunities could increase in EU beef exports [6].

Without regulation, on the basis of current trends, with a decline in the number of farmers, the concentration and specialization of farms across Europe will continue. The amounts of capital and the workforce will increasingly be employed in the farms. It is anticipated that the number of farms could fall by around 40% between 2010 and 2025 in France [7].

6.2.2 A general overview of input markets in the EU agriculture

In this section, an overview of developments in the labor market, investments and fertilizer market is given. The land market is not included as it will be explained in a separate section under Deliverable 5.1.

6.2.2.1 Labor market

The characteristics of factor markets in the EU are not necessarily uniform since the widespread conditions in country levels or at a more localized national level influence factor markets. In other words, factor markets are heterogeneous in the context of agriculture across the EU and candidate countries.

The average number of workers employed per farm is 1.5 annual work units (AWUs) in the EU-28 in 2015. However, AWUs varied significantly across the Member States, ranging from 15.5 AWUs in Slovakia to 1.1 AWUs in Greece. The average number of workers per horticultural farm was about 2.5 times larger than that in permanent crops except for wine farms which require the lowest labor input [3].

Loughrey et al,[8] indicated that the maximum hours of work vary across selected countries in the EU-27 and in Croatia and Macedonia. The maximum hours of work in most countries is 40 hours per week. However, this number is larger in Croatia, Ireland, the UK, and the Netherlands. In most countries, except for Greece, Ireland, Macedonia, and Slovakia where hiring is 'relatively easy', the hiring and firing of employees in agriculture is 'relatively difficult'. This trend changes in Belgium, Ireland, Macedonia, and Slovakia where firing is "relatively easy".

Countries have minimum wage legislation except for Finland, Germany, Italy, and Sweden. Some of these countries have a minimum pay at the industry level. In the case of Italy, for example, there are 15 regional, 8 industry-level and 100 agreements at the province level. In Belgium, Macedonia, the Netherlands, Poland, Slovenia, and Slovakia the minimum wage is applied to monthly incomes. The minimum wage varies based on the job experience (such as Belgium and Greece), age, or education. Although there are exceptions, payments for unemployment are generally for one year. Nevertheless, in Belgium and Ireland, the duration of payments is indefinite. Furthermore, income tax wedge varies across countries. It is usually between 30-45% of the gross wage for low wage earners. The highest tax wedge is in Belgium, France, and Germany and the lowest is in the UK and Ireland [9].

Most countries have a system of agricultural qualifications. The level of education is above average in the UK and below average in Poland. Belgium, Germany, Ireland, the Netherlands, and Slovakia have active labor market measures for farm employees. Contrary to this, Greece, Italy, Macedonia, Poland, Slovenia, and Sweden have these measures for farm operators. Foreign workers in agriculture are relatively uncommon either from within the other EU Member States or outside of the EU with exceptions for the labor market in Belgium, Ireland, and the Netherlands. However, foreign workers in France and Macedonia have increased [9].

Based on a labor market rigidity/flexibility index, agricultural labor markets are the most flexible in Macedonia, Greece, and Italy and the least flexible in France, the Netherlands, and Belgium since the wage levels are the highest. The difference is a result of the wage-setting mechanism and labor mobility in the countries. For most countries, the labor market flexibility score is not much different [9].

Shutes [10] estimated the labor supply curves for all Member States, Croatia, and Turkey. The results show that the new member and candidate countries have systematically lower average wages than the EU-15 countries and are often less labor-constrained. Younger individuals at the age of 15–24 responses to an economic stimulus are generally more mobile and may leave agriculture for non-farm jobs. The main outflows from agriculture are however associated with those over 55 years old. They are more likely to exit agriculture. The retirement of the older farmers composed the largest outflows from the sector. People with low levels of education stay in the farm labor market. Self-employed individuals and family-workers are less likely to exit agriculture since the self-employed individuals have specific capital assets or other personal motives for agriculture whereas family-workers are tied to the family responsibilities and contribute to a 'surplus of labor' in agriculture. Labor market conditions constitute important pull factors for attracting labor out of agriculture. Due to the individuals' response to market incentives and regional labor market conditions, a high wage differential between the non-farm and farm sectors also increases the likelihood of a sectoral switch [11].

Heterogeneity of the farm structures in the EU-15 has different impacts on the outflows of labor from agriculture. For instance, higher rates of farm exit occur among small farms in Hungary. Very small farms, and especially subsistence farms, in Italy and Poland play a buffer role and thus prevent major outflows of labor. Olper et al, [12] found strong support that CAP subsidies reduce the rate of off-farm migration since they have a positive effect on the income to farmers. Decoupling does not significantly affect the off-farm labor supply in Ireland but the relationship is significantly negative in Italy. In addition, the rate of off-farm migration and the convergence per capita productivity growth across-sector are positively related [9]. In Greece, agricultural support measures have a negative effect on family and hired labor demand which are substitutes. Decoupled payments and crops subsidies have a significant impact on these labor sources and rural development payments affect on-farm labor negatively. Farm size and the age of farm operators also have a significant impact on farm labor [13].

Petrick [14], indicates that production elasticities for labor, land, and fixed capital are very low. On the other hand, the elasticity of materials is above 0.6 for most of the countries. Therefore, shadow prices for the three fixed factors are very low. In the EU arable farming, land, labor, and fixed capital are not among the bottleneck factors. The availability of working capital is the most effective way to increase agricultural productivity. The share of agriculture in the overall employment is about 4%, around 22 million people, a full- time equivalent of about 9 million. Agricultural labor input shows a long-term downward trend. The sole holders' families provide 83% of all agricultural labor input in the inmost Member States except for Slovakia, the Czech Republic, Hungary, Estonia, and Denmark where the share of family labor was below 50 %. Most of the agricultural employment comes from farms in intermediate economic size classes. As the number of farms declines, most jobs were lost in small size farms concerning mostly the smallest farms [2].

EU farmers are getting older. About 56% of farmers are older than 55 years, having the lowest average farm size in the EU. On the other hand, only 6% are younger than 35 years, managing the largest holdings. Less than one-third of all holdings (about 13%) are managed by women in the EU-27 and 40% of these farmers are older than 65 years [2]. The share of younger farmers in the EU is only 5.6% of all European farms while more than 31% of all farmers are older than 65. This fact questions the future competitiveness of European agriculture and guaranteed food production [5].

6.2.2.2 Investments

Farm output price and government support uncertainty have a strong effect on the investment decisions of a farmer in physical capital (farm buildings (FB) or machinery and equipment (ME)). Subsidies might support the budget and credit access, diminishing risk and revenue uncertainties resulting in higher physical investment. Subsidies influence farm loans non-linearly. Large farms use subsidies to increase long-term loans and small farms for short-term loans. Coupled and decoupled subsidies tend to affect loans differently. The positive impact of subsidies may hold although the crowding-out effect cannot be completely excluded. The results suggest that the impact of the CAP on agricultural credit markets is complex and varies by credit type and size of the farm and by type of subsidy. Findings indicate that CAP subsidies offset the credit tightening in the financial crisis and, they correct credit market imperfections stabilizing agricultural production. On the other hand, Viaggi, [15], discusses that CAP payments do not affect the investment in the majority of cases (about half of the farms).

Dudu and Kristkova[16] explain Pillar II payments on the total factor productivity in the agricultural sector using human capital, physical capital, and agro-environmental and rural development. They suggest that regions receiving higher Pillar II payments for these measures increase productivity while payments related to rural development do not have a significant impact on productivity. The results do not change among the Member States, date of access to the European Union, spatial characteristics or size of the countries.

The estimation results showed that the substitution elasticity between capital, land, and labor is highly significant and robust with values far from unity. The results confirmed significant positive effects of physical, human capital, and agro-environmental payments on factor-augmenting technical change in agriculture. It has been found that human capital subsidies stimulate labor-augmenting technical change, whereas physical capital subsidies increase capital-augmenting technical changes. Agro-environmental payments are in turn important in stimulating land-augmenting technical change. This shows that labor-saving technical changes have occurred in European agriculture and is consistent with the processes occurring in other industries of the economy [16].

6.2.2.3 Fertilizers

Common Agricultural Policy (CAP) reforms shifting from price support to decoupled payments have lowered fertilizer use below the economic optimal amount reducing the fertilizer use strongly. Fertilizer use stabilized in the last years but adapting the application of nutrients according to plant needs would increase productivity and reduce fertilizer use.

The EU produces 9 % of the nitrogen, 3 % of the phosphate, and 8 % of the potassium of global production. The market share of urea in the nitrogen-based fertilizer market is lower in the EU and in North America compared with the use in Asia. The price of nitrogen-based fertilizers is highly related to energy prices. On the other hand, the price of rock-based fertilizers such as phosphate and potassium are less correlated to energy prices. The consumption of fertilizers has stabilized in the past decade in the EU. The market value of fertilizers has been increasing by 3 % annually for the last decades, although declining in some years. The EU represents 10 % of the total use of the global volume of fertilizers used. Due to specifics and structures of individual markets, prices of similar fertilizer products within the EU can differ widely between various geographical and local markets. FADN data indicates that fertilizer costs account for around 10 % of the intermediate consumption in 2016 [17].

Fertilizer import prices in 2018 were 40 % higher than before that price peak. Also the volatility in energy prices, and therefore fertilizer prices has been high. EU imports most of the mineral fertilizers. About 6 million tons of nitrogen (N) based products including ammonia are imported each year. The amount of phosphate (P) fertilizers imported is around 1 million tons annually. EU imports 2 million tons of potassium (K) fertilizers. The EU is a net importer of fertilizer [17].

Nitrogen accounts for more than two-thirds of the total use of N, P, and K. 26 % of the fertilizers is applied on wheat and 25 % on coarse grains.16 % on grassland and 11 % on oilseeds. Fertilizers applied to specialized crops such as potatoes, sugar beet, permanent crops are relatively low. Organic matter, such as manure is also used as fertilizer. The application rate per hectare varies considerably between different crops. Although wheat is grown on 15 % of the agricultural land, 26 % of the total amount of fertilizers is used for wheat. Additionally, although 6 % of the agricultural land is used for oilseeds, it represents 11 % of the fertilizer use. Lastly, fertilized grassland covers 18 % of the land and 16 % of fertilizer [17].

The cost of seed in cereals in the EU varies to a large extent between the Member States. Seed cost accounts for about 10% of the total operating costs in Ireland while it accounts for about 23% in Romania. Seed cost for wheat is about 10.5% on average between 2008 and 2018. Contrary to this, fertilizer cost for wheat varied between 22% and 28% in the same period. Fertilizer cost in cereal production was about 16% in Belgium while it is as high as 40% in Lithuania. The irrigated area in cereal production accounts for less than 1% and decreasing steadily [18].

6.3 Institutional factors affecting the output and production factors markets that might have been addressed in modeling exercises

6.3.1 Existence of market power

While agricultural markets are referred to as examples of competitive markets, they are probably not. In fact, the emphasis is likely to be on other dimensions of product quality and differentiation, particularly in light of the significantly increased concentration in food production [19] and food retail [20] [21]. According to Sexton[22], the crucial point is not to focus only on concentration when considering departing from perfect competition in modern agricultural markets. Rather, it is important to recognize and evaluate jointly the trends towards increased concentration and vertical coordination along with an increased focus on product quality and differentiation. Depending on the commodity, relevant procurement markets for agricultural products may be located in a geographical range due to high transport costs, which means that the concentration ratios at national level may vastly underestimate the buyer concentration level for raw agricultural products on the relevant geographical markets. Worldwide, leading food retailers have become the dominant players in the food chain.

McCorriston[20] quite explicitly indicated in his study that anti-competitive behavior in EU agricultural and food marketing systems is multi-dimensional, i.e., it is not only about measuring, at one point in the system, the nature of horizontal competition between companies or whether a limited number of processing companies can use vertical market power over agricultural suppliers. Instead, he asserted that a range of potentially anti-competitive practices should be focused on such, as food processors having to pay for access to retail shelf space (slotting allowances), market penetration of private-label products of retailers, and other vertical market coordination restrictions. This view of competition on the agriculture and food marketing system was motivated by the perceived increased market intensity of EU retailers in the 1990s, and by concerns about how imperfect competition could interfere with vertical linkages in successive phases of the agricultural and food marketing scheme, thereby affecting the transfer of exogenous price changes.

While a healthy market features an 'ecosystem' consisting of stakeholders of varying sizes who can compete among each other, market power can simply be defined as the ability of strong players to execute or affect others' actions and this is a major concern of the agricultural policy-making process. The existence of the leading companies that can coordinate the whole value chain is a prominent feature of many modern agricultural market governance forms. Large and powerful leading companies may usually use their power to make a profit and interest from the weaker organized companies [23]. As a result of decoupling subsidies and, in general, CAP reforms over the last 20 years, farmers are now more sensitive than they were just a few decades ago to this challenge [24].

On the other hand, the bargaining power can be defined as "the power to acquire a deal from another party by threatening to impose cost or withdraw profit unless the party makes the deal." [25]. In theory, both market and bargaining power may lead to lower prices or surplus transfers. The key difference is that this outcome is obtained by buying/supplying market power, while bargaining control uses the threat of withdrawal from the deal. The main difference is that market power often dictates a lower level of trade relative to the total competition, although in the case of bargaining power this is not always true [23].

The existence of market power and bargaining power in agricultural markets are largely empirically tested by looking at the imperfect price transmission along the supply chain in the literature. Price transmission analysis results reveal asymmetry sources as significant fixed costs, adjustment costs, inventory management, and perishable products [26] [27] [28] [29]. In their study, in which the existence of buyer's power was estimated, Madau et al.,[26] indicated that a distortionist behavior by retailers and food companies have helped to widen the price gap among farmers and retailers and called for further research to assess the power and causes of buyers. The importance of price transmission problems throughout the food chain is due to possible social losses, particularly to weaker farmers and consumers due to higher concentrations in manufacturing and retail stages [30]. Other studies highlighted or analyzed, the role of farming policy in reducing negotiating power imbalances [24] [31]. Also, there are some studies that investigated how over time the CAP of chain-level counterbalancing instruments has worked, particularly if they have contributed to improvements in efficiency, farmers' income, and consumer welfare.

The new CAP focuses more on helping farmers improve their bargaining positions with other players in the food supply chain by better coordinating the commodity industry and with a few restricted derogations from EU competition law. Producer organizations in the fruit and vegetable sector since 2001 and in the milk sector since 2011 have been legally encouraged in this respect. 2013 CAP reform allowed the Member States to recognize producer organizations, producer organizations associations, and the interbranch organizations other than those in certain regions where recognition has become mandatory (e.g. milk, olive oil, fruit and vegetables, hops, wine). In the context of Pillar II, rural development programs aid can be provided for setting up producer groups as well as short supply chains and cooperation. Derogations from competition law allow farmers in some industries to collectively negotiate contracts and to jointly sell and set prices, volumes, and other conditions through accepted organizations. This derogation applies to the supply of milk, olive oil, beef, cereals, and certain other arable crops for example in circumstances and in safeguards when producer organizations, through other common economic activities (e.g. joint processing, joint transportation/storage or joint quality control) create significant efficiencies. Member States are permitted to introduce in their legal systems the compulsory use of written agreements with a number of standard clauses. These rules apply to all but the milk and sugar sectors where different sectoral rules apply [32].

6.3.2 General institutional and policy framework

6.3.2.1 Transaction costs

Transaction costs can have a significant impact on agricultural land markets. Overall, two types of transaction costs are differentiated. The first type is the explicit transaction costs which are associated with the operating costs of renting or purchasing a plot of agricultural land. This includes costs for registration, notary fees, etc. These costs are generally more prominent on the sales market. The second type of transaction costs is the implicit transaction costs that are also associated with the rent and purchase of agricultural land. These costs include fees for search and negotiation. All such costs are especially prevalent in new Member States' (MS') land markets, characterized by severe imperfections on land markets due to the dominance of large-scale corporate farms.

Explicit transaction costs. Taxes on agricultural land sales and purchases can have effects on land supply and demand, thus agricultural land pricing. Structural changes in the agricultural sector can be hindered by high land transaction costs because they restrict the reallocation of land from less efficient farms on highly efficient farms. Furthermore, when there are only low costs regarding the purchase of agricultural land, it is possible that non-agricultural investors can make more purchasing for speculative purposes.

The high transaction costs associated with the purchasing of agricultural land have driven in many countries to the formation of a gray market. In Belgium, for example, the high administrative costs have provided an incentive for the buyer of agricultural land to pay the seller a part of the purchase price without paying any tax (envelope payment). By comparing auction and private sales data for the 1990–2004 period provided by "FOD Economie, KMO and Middenst, and en Energie", the envelope payment can approximately be estimated to differentiate between the price paid in both public and private auction (by mutual and private contracts). This shows that nearly 20% of the purchase price (in an envelope) is paid in black money. It is essential to mention that the buyer is encouraged to restrict the envelope payment, as the buyer may be fined by the registration office if the selling price varies too much from the average regional agricultural land sales prices.

There are other 'administrative' costs in relation to the transfer of agricultural land in addition to registration fees, such as notary fees and other taxes and administrative charges. When considering these costs, land transaction costs in the new MS are relatively high in comparison with the old MS and range from 10 % to 30% of the value of the land transaction [33] [34].

Even though transaction costs on the agricultural land sales market is more explicit, there can also be transaction costs on the rental market. In general, a lease agreement is a contractual arrangement between two parties, but it must be registered in certain situations. As in France, Ireland, Italy, Germany, the Netherlands and Hungary, that can be voluntary or mandatory. There are also contracts, such as long-term (> 12 years) rentals in France, and long-term *arenda* contracts in Bulgaria that have to be approved by a notary.

Implicit transaction costs. In particular, the new MS involves high, implicit transaction costs, which are strongly linked with the process of privatization and land reform that began in the early 1990s. The process involves three significant implicit costs:

- Imperfect competition in agricultural land markets.
- Property rights imperfections (for example, unresolved ownership and co-ownership).
- High withdrawal cost and equivocal boundaries.

After the transition, agricultural land was allocated to former owners. Most of these new owners are not or will not be active in agriculture and may retire or decide to live in urban areas. For example, in Hungary 'passive owners' (a group comprising village-based pensioners, non-cooperative landowners and non-villagers) obtained about 71% of their privatized land in the land reform process [35]. In several cases, they decided to rent the land they received to the past users of the land, especially to large-scale enterprise farms. This pattern is expressed in the high proportion of rented land within some new MSs and in the strong correlation between farm structure and agricultural land utilization: more land (e.g. Slovakia) is rented in countries where corporate farmers use greater land. The hegemony of big corporate farms in the land market gives rise to imperfect competition. Large farming corporations utilize their market power on local or regional land markets to promote land prices and the terms of rental contracts.

As a result, transaction costs generally lead to decreased land prices, whereas the CAP policy has the potential to reverse this impact, as subsidies are capitalized on land prices and increase the prices. According to Ciaian and Swinnen[36], if competition between corporate farms and individual farms exists, corporate farms' dominance of the land market and transaction costs will not influence the fact that subsidies are capitalized on land prices. But if agricultural subsidies are allocated unequally, for example, because small farmers have trouble meeting subsidy requirements, then small farmers will be net losers, while large corporate farmers and landowners will benefit.

6.3.2.2 Monitoring and evaluation

In addition, the CAP corresponds to three main goals that incorporate the smart, sustainable, and inclusive growth priorities of Europe 2020. The CAP's success is assessed against the following general aims. The first aim is to ensure viable food production to result in food safety by improving EU agriculture's competitiveness while also providing the means to respond to market disruptions and food chain function challenges faced by the sector. The second aim is environmental management and climate action of natural resources to ensure long-term sustainability and growth of the EU agriculture through the safeguarding of natural resources on which agriculture depends. Also, balanced territorial development is another main objective of CAP to lead to socio-economic development in rural areas while promoting the necessary conditions for the preservation of structural diversity across the EU.

All CAP pillars contribute to these main targets. The general goals are split into specific objectives, some common to Pillar I (widely agricultural income and support to the market) and Pillar II (rural development), while others are connected either to Pillar I or rural development.

Direct payments provide protection of the incomes of farmers against specific pressures to which agriculture is exposed (e.g. price and weather). They constitute a substantially steady share of farmers' income (46% in 2015 in the EU-27). The new payment layers are now better focused, trying to cover the particular needs of young farmers, small-scale farmers, specific sectors or territories in need, and the environment. Such adjustments to the framework of direct payment systems—along with regulations expressly dealing with redistribution—should result in a more equal distribution of payments. As subsidies are largely isolated from production, farmers base their output decisions on market signals instead of trying to optimize subsidy payments. The stabilizing impact of direct payments is reinforced by market instruments that are currently operating at a 'safety net' level, rather than always controlling the EU market as they did once.

From the period of 2007–2013, the cross-compliance program has connected all direct payments (as well as some wine market and some rural development payments) with a number of environmental and climate change legal criteria. In addition, the 'greening' layer of the direct payment system has since 2015 enhanced farmers' diversification of crop rotations and the conservation of the permanent grasslands and environmental benefits. For the duration of 2014-2020, the policy for rural development continues to give – as in the 2007-2013 period – various types of area-related payments aligned with management requirements which have demonstrated a positive effect on biodiversity, soil, water, and air in both farming and forestry sectors. Support for environmental benefits through organic farming is available, among other items. Support for knowledge creation, research, collaboration, and creativity can make a major contribution to environmental improvements.

The related instruments of Pillar I and rural development focus on specific objectives include farm income and income fluctuations, improving the competitiveness in the agricultural sector, stabilization of the market, consumer needs, providing public goods and environmental protection, mitigation of climate change and adaptation and sustaining diverse agriculture. In particular, market measures enable the safety net to be sustained and to meet customer demands in times of market instability or crisis. Both goals are often assisted by a variety of horizontal instruments. Overall, these steps contribute to the sustainability of the EU integrated agriculture. Direct payments improve farmers' income and sustain it, improve productivity and lead to environmentally sustainable public goods, and mitigate and respond to climate change.

Every program concerning rural development in Pillar II should be focused on an intervention logic that shows the goals and areas of focus are included and which interventions are scheduled to contribute to a selected focus. There are six rural development priorities (specific goals), each divided into a number of focus areas. One overarching goal, namely the transfer of expertise and innovation, which contributes to the general CAP goals by the other five priorities, is assisted by five priorities. These five priorities can be listed as:

- Improving farm viability and competitiveness in all forms of agriculture in all regions and encouraging innovative farming, and forest management technologies.
- Encouraging the organization of the food chain, including farm products processing and marketing, animal welfare, and farm risk management.
- Conservation, protection, and enhancement of agricultural and forestry habitats.
- Fostering the efficient use of resources and endorse a transition to a low-carbon and climate-resilient agricultural economy.

- Enhancing social inclusion, poverty reduction, and rural economic development.

6.3.2.3 Institutional framework—land market

In their study Ciaian et al., [37] indicate that the general conclusion of the studies which analyzed the agricultural policy measures in the literature is that farmers' incomes are (increased) affected by agricultural policies, although their effects differ. Besides the immediate first-order effect of rising farmer incomes, most of the agricultural policies introduced often lead to second-order changes. For instance, agricultural subsidies affect not simply the employed factor award, but also the factor of demand, the inter-sectoral factor allocation, and the factor of ownership through altered farmers' incentives. One strand of the literature analyzing policy effects of second-order takes into account the policy implications for land prices, land leases, and land taxes.

When farm subsidies favor landowners rather than producers, there may be negative effects. The growth that is induced by policies on land prices, for example, may negatively affect the efficiency in the agricultural sector. Then farmers have to fund higher initial (primary) investment and bear the consequences of policy changes affecting investment returns, the entry barrier is increasing for potential new farmers. Existing farmers are also facing higher expansion costs. As a result, the number of transactions of land between different owners is decreased and the average production costs in the agricultural sector are increased.

Furthermore, the benefits of support will only help those who are landowners at the time the support was created, depending on the particular implementation process. Subsequent entrants with a higher price purchase of land will benefit less from policy support. This means that many active farmers receive no subsidies or receive just a portion of the benefits. In fact, it means that when the policy objective is intergenerational equity, future support rates will be raised, land prices will be further inflated, and a spiraling circle of subsidies could not be sustained.

Eventually, future reform attempts to minimize support may be made more difficult by the possible effects on land values. Expectations of potential levels of funding for subsidies play a significant role in deciding land prices. If land support policies are capitalized into land prices, current landowners will impede future policy changes due to vested interests.

Capitalization of coupled subsidies. The main findings from the literature of coupling policy impacts can be summarized as follows (with area payments combined in the EU before the Single Payment Scheme (SPS)):

- When the availability of land is fixed, area payments are completely capitalized into the prices of property.
- Coupled production subsidies are completely capitalized on land prices, where the elasticity of supply of non-land inputs is either perfectly elastic or factor proportions are calculated in addition to zero land supply elasticity.
- The advantages of coupled subsidies are shared between land and other competitive factors in other circumstances and customers if the demand elasticity is not perfectly elastic.
- The effect of agricultural policy on land prices (e.g. the complete capture of subsidies) can be very high.

Capitalization of decoupled subsidies. The key contributions of the theoretical literature on decoupled policy impacts are summarized in the following points:

- Fully decoupled agricultural policies have no effect on land values if the markets are perfect.
- Decoupled policies may only impact land values when (some) imperfection of the market occurs (e.g. transaction costs or land market credit restrictions).

- The intended result depends on many factors, such as the kind of policy, elasticities of supply and demand, legislation, subsequent policy steps, market imperfections, opportunity costs of land use incentives, and institutions and expectations determinants of subsidy capitalization.

The outcomes of the policies implemented in terms of income distribution, inter-sectoral factor allocation, and productivity are influenced by many factors. The factors related to policy (determinants) are the policy type, specifics of implementation, and associated measures. The major exogenous determinants of comparative advantage (endowment and technology) are factor supply and substitution elasticities, and inter-sectoral substitution possibilities (land-use alternative options). Land market determinants involve market imperfections, land market institutions and legislation, and transaction costs. In addition, the impact of the agricultural support policies introduced depends on the time scale and sensitivity dynamics of the policies being studied by policymakers.

In general, the policy goal of increasing farmers' income can be tackled through different policies, such as input subsidies, export subsidies, decoupled payments, input quota, and production quota. One important finding of the theoretical review is the degree to which subsidies are capitalized in land values depending on the policy type. This result relates not only to decoupled versus coupled policies but also to the significant variations between different coupling policies.

The rate of subsidy capitalization also depends on the specifics of the policy implementation. For example, the capitalization of subsidies into land values can vary based on whether they are available for a certain duration or "open-end." Benefits can be reached by landowners, however, they may not be capitalized on land prices unless they are expected to continue in the future. Furthermore, profits can be easily capitalized at land prices even though the benefits are not transferred to land per se.

6.3.2.4 Institutional framework—farm employment

Agricultural employment in the EU has been decreasing gradually over the last 15 years from 13.1 million AWUs in 2003 to 9.1 million AWUs in 2018. In the EU-27, a remarkable decrease of 30 % over the past 15 years has been observed. At the same time, the number of small and medium-sized farms has decreased and the number of larger farms (over 100 hectares) is growing, which indicates that the agricultural sector is consolidating. Nevertheless, the picture is not universal in the EU as the number of farms (Czech Republic, Slovakia) and other countries' agricultural labor market (Greece, Slovenia, Malta and in a lesser degree, Cyprus, Romania, and Lithuania) recently increased marginally in a number of Member States.

Looking at this phenomenon from a national point of view, many other regions across Europe stand out much better with increased farm labor (Corsica, East Wales, Alentejo, etc.). Similarly, there is not a clear West-East and North-South division in the EU: many parts of Europe are predominantly family farm models (Ireland and Northern Ireland, central Europe (including Bavaria, Austria, Northern Italy, Slovenia, and Croatia), the Atlantic (northern Portugal and Northern Spain) and Romania, Greece, Poland, and Croatia). In addition, depending on temporary labor is not a special Mediterranean agricultural custom, but it is also seen in Flanders, the Netherlands, and West Germany in Europe.

The quality of life for farmers and their families in rural areas, the aging population of farm managers, the urban-rural income gap and consequent "brain drain" by young skilled workers to more competitive economies, difficult access to loans and lack of targeted investment, shortages of jobs during peaks in season, and employment for immigrant workers to meet this need are the major challenges for agricultural sectors. Some regions are also affected by an inadequate land cadastre that prevents farm transfers beyond the family circle, while others show a persistent technological and innovational lagging of family farms.

Farmers should perform various activities on and off-farm, to minimize their reliance on one source of income, to increase their revenues, and thus to ensure the profitability of their holdings. These involve on-farm diversification (including processing and/or selling agricultural outputs) in short food supply chains, agro-tourism, and production of renewable sources of energy and other out of farm activities. Yet these two options remain restricted at the EU level, as only 1 out of 20 farmers have been diversified in the EU and the majority of farm managers still spend their entire time on agricultural activities in many EU countries. Further expansion of the diversification of farming is hampered by difficult access to land, bad weather, low tourist potential, and relative isolation of some rural areas.

Using mathematical forecast models, it is possible to predict the short-term production of farming-related variables and forecast future values within a range of probable values (trust intervals) that represent the uncertainty associated with future policies and external influencing factors. More specifically, it is predicted that a further decline in agricultural employment is expected at the European level in line with the agricultural outlook of the European Commission for 2030. The number of farms operated by young farmers is steeply declining – already substantially lower than those of older farmers.

The effect of CAP on agricultural and rural employment is complex, as numerous European evaluations have shown. The schemes and acts of the first and second pillars of the CAP (the direct payments respectively and rural development measures) have had diverse, often conflicting effects on the labor force of the farmers, depending on investment's size and nature, on the use of the farm managers' payments (for example, recruitment of additional staff or replacement by mechanization).

6.3.3 Price control/input or output subsidies

In practical terms, world agricultural prices pursued a downward trend until the 2000s. During this time, agricultural price changes were very disconnected from the development of other commodity prices except for the peak of the oil crisis during 1973-1974. Agricultural prices began to rise from 2000 along with energy and fertilizer prices but at a much slower rate. Between 1999 and 2008, agricultural prices rose by 58% while energy and fertilizer prices multiplied, respectively, by three and four. Agriculture is extremely energy-intensive, leading to significant increments in production costs.

Since the peak in all commodity prices in 2008, agricultural prices tracked oil and fertilizer demand patterns more closely. Nonetheless, the recent price drop for agriculture was more constrained. Between 2008 and 2017, agricultural prices fell by 10 % compared with energy and fertilizer prices which decreased by around 40% and 60% respectively. Whilst agricultural prices are currently just 42% higher than in 1997, fertilizers and electricity prices are still about 90% and 130% higher respectively. Table 1 summarizes the developments in output prices in the EU.

Cereals	From around EUR 120/ton before 2007, world and EU cereal prices have risen to 240 EUR/ton between 2008 and 2012. This rise was caused by higher energy and fertilizer prices, increased demand for production of biofuels, and crop failures impacting global supply during 2010 and 2012. Since, subsequent world harvests have led to a decrease in cereal prices at approximately 150-160 EUR/ton.
Sugar	Along with the reform of the EU's common market organization for sugar in 2006 and the decrease of EU reference price to EU R400/ton in 2009, the EU's white sugar price slightly decreased and remained stable at almost 100 EUR/ton higher than the reference price by 2011. A global supply shortage during this period sometimes resulted in world prices to be higher than the EU price. In 2011, EU prices increased very rapidly and stayed at a high level of 700 EUR per hectare until early 2013. While tariffs restrict imports from more competitive producers of sugar cane, the existence of a quota and the strong concentration of processors may explain this substantial increase in EU domestic prices amid declining global prices. The EU and world harvests in 2014/2015 have brought the EU sugar price down to EUR 400/ton and the gap

	between EU and international prices narrowed significantly. In 2016, lower world stocks brought EU prices up to approximately EUR 500/ton. Thanks to an increase in the region (linked to the quota elimination in October 2017) and strong returns and high sugar prices, EU sugar production reached a record high level in 2017/2018. As a result of the surplus of global supplies, prices have decreased considerably to below EUR 400/ton in the EU since January 2018.
Milk	Prior to 2004, the EU's raw milk price for skimmed milk powder and butter was fluctuating around an average of EUR 31 per 100 kg seasonally. Between 2003 and 2009, EU milk equivalent support prices were down 23 %, while the EU and world milk prices began converging in 2008 to EUR 35/100 kg. This rise was due to the general increase in commodity prices and the reduction in milk production in Oceania. The worst milk crisis followed in 2009 when the EU's average annual price decreased to EUR 26.5/100 kg due to a sharp increase in milk production, particularly in Oceania. Despite this crisis, milk prices steadily rose to EUR 37.3/100 kg in 2014. During this time, world consumption continued to grow faster in particular accelerated by strong Chinese demand and imports. The sudden fall in Chinese buying and the introduction of, in August 2014, the Russian import ban, in the sense of increasing surplus, led to a dramatic drop in prices to EUR 28.4/100 kg in 2016. In 2017, market growth recovered slightly as a result of high global demand, and by 2017, the EU milk price averaged EUR 34.9/100 kg.
Beef	After the decrease in price in 2001, owing to the mad cow and foot-and-mouth disease crisis, the EU beef price increased slowly but steadily over the next ten years, from an average price level of about EUR 2 500/ton to EUR 3 800/ton in 2012–2013. In spite of the Russian import ban and the re-structuring of the EU dairy market, beef prices remained fairly steady between 2014 and 2017, although in the same period US prices showed a substantial increase because of the domestic shortfall.
Pig meat	The EU average pig meat prices have been fluctuating between EUR 1 400 and 1 600 per ton over the last 15 years. After the high price of pig meat in 2012-2013 as a result of the new EU welfare rules and a dramatic decrease in the pig herd, production again increased and there was a fall in prices caused by Russian sanitary and economic bans. The export boom to China led to a rebound in pig meat prices in 2016.
Poultry	EU poultry prices have shown a gradually growing trend in the last 15 years, driven by a steady rise in demand, from EUR 1 400 to nearly EUR 2 000 per ton. In 2016, EU poultry prices fell to EUR 1 800/ton due to domestic oversupply and Brazil's export pressure. In 2017, the EU price stayed at this point.

Table 24 Price developments in EU agriculture

Source: European Commission "Price developments in the EU"

The change in average annual input and output price indices for the EU countries over the period of 2010-2015 is presented in Figure 1. Except for Slovakia, Croatia, United Kingdom, and Belgium input prices have increased in all countries over the period and the increasing rate is above the output price increase in Poland, Denmark, Sweden, Germany, and Finland. It is observed that in the countries represented to the left of Poland in Figure 1, output prices have increased more than the increase in input prices and for Slovakia, Netherlands, Croatia, Luxembourg, Austria, Portugal, Lithuania, United Kingdom, Latvia, and Belgium output prices have fallen down.

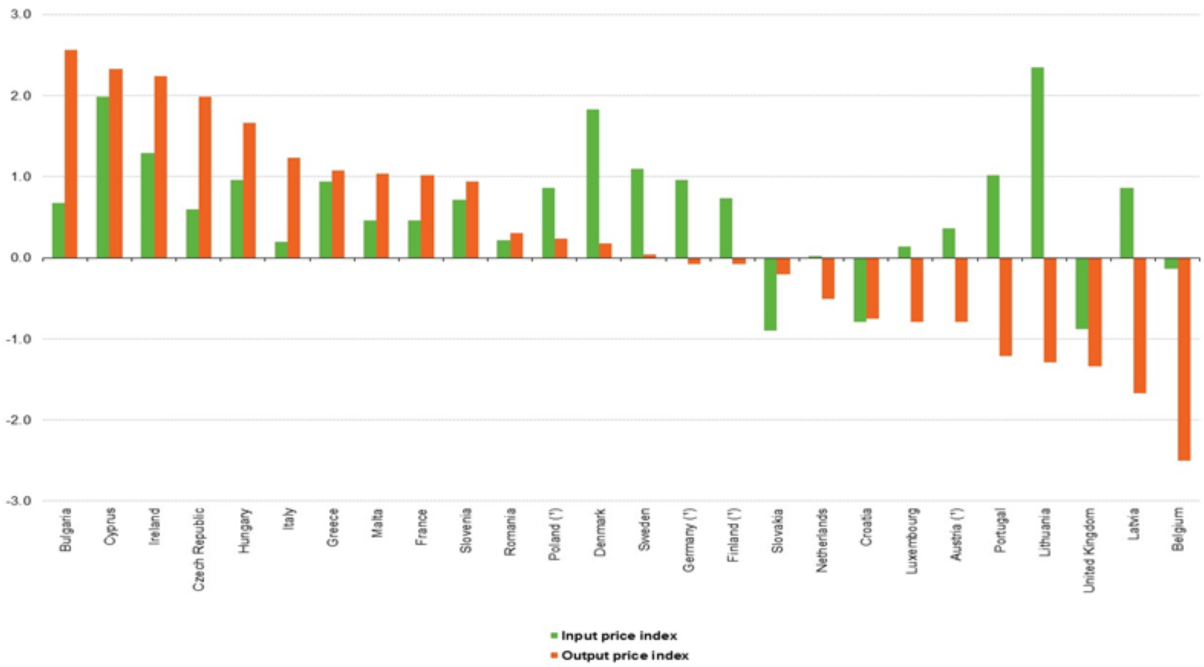

Figure 4 Change in deflated price indices of agricultural input and output

Source: Eurostat (online data codes: apri_pi10_ina and apri_pi10_outa)

EU prices for agricultural commodities in 2017 were on average 13% higher than world prices. The difference between the EU and world prices has decreased over the past 10 years from 30-40% to about 10%. With the subsequent CAP changes (shift from price support to income support), the gap between EU prices and world prices (particularly in the cereal and dairy sectors more than in the meat and sugar sectors) narrowed.

In the last two decades, much has changed in the EU agricultural policy. The CAP reform started in earnest with the 1992 MacSharry reform, initiated during the Uruguay Round negotiations on the liberalization of agricultural trade. The center of the strategy introduced by this reform was to decrease support prices whereas farmers were compensated by partially coupled direct payments. Another significant milestone was the 2003 reform of the CAP Fischler Mid-Term Review which started the significant transition of these partially coupled payments into mainly decoupled direct payments. In the current CAP reform, which occurred in 2013, a portion of these farmers' payments was allocated to environmental and climate-friendly activities in an attempt to "green" the CAP. There are now three elements of agricultural support in the EU: market management (which now mainly is the safety net supports when price levels fall to crisis levels or market disturbances resulting from consumer confidence losses); support to farm incomes (provided by direct payments and border protection); and support for rural development. Figure 2 presents subsidies minus taxes as a share of agricultural value-added in 2015. On average, net subsidies reach about 29% of agricultural value added in the EU (28).

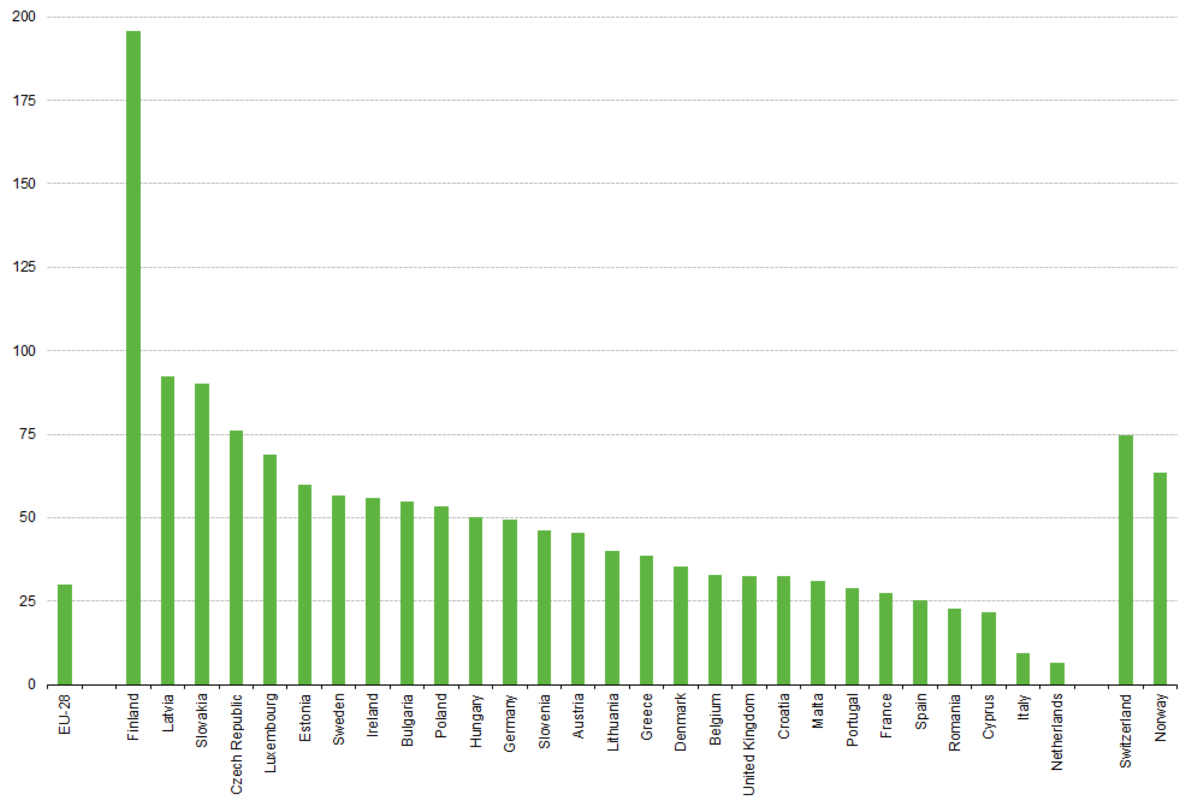

Figure 5 Subsidies less taxes in the agricultural sector, 2015

Source: Eurostat (online data code: aact_eaa01)

6.3.4 Trade policies

As of 2013, the EU-28 has become the world leader in the agri-food trade. The EU was the leading agri-food exporter and importer in that year, with exports amounting to €122 billion and imports worth €104 billion in 2014. Agri-food exports constitute 7% of EU exports and the trade surplus in agri-foods is nearly 80% of the overall trade surplus of the EU. In the previous decade, America and the EU have competed with Brazil and China for the global leadership in agri-food exports; on the import side, the EU is by far the world's leader followed by the US and China.

The EU agri-food trade structure is different than that of other major traders, such as the United States. Primary products and commodities do not take a large share in EU exports, while final products such as processed food, beverage, and non-edible products account for more than two-thirds of EU exports and approximately 35% of imports. Over the last decade, the trade structure has not changed substantially, following subsequent EU enlargement and CAP reforms.

In 2014, wine, cider, and vinegar and spirits and liqueurs (with each accounting for 8% of EU agri-food exports) are the most exported products: around one-third of the exports are sold on the US market. On the contrary, wheat and infant food and other cereals are also of considerable importance (they each account for 5% of the total agri-food exports). Former exports are mainly made to North African countries while China and Russia are the most important markets for the latter. The exports of wheat, as well as wine and spirits, increased in comparison with the period 2004-2006 by around 2% to the current 5%.

6.3.4.1 Most-favoured-nation (MFN) tariffs

The Customs Union is an essential part of the Common Commercial Policy under the sole competence of the EU. The 1994 World Trade Organization (WTO) Agricultural Agreement called for the elimination at that time of the conventional variable import levels and other controls and import charges. This implies the transformation in the future of all legislation limiting the imports of agricultural goods into customs duties.

The basic average MFN tariff rate, including that of the ad valorem equivalents of non-ad valorem tariff rate is 6.4%. 25% of the tariff lines are duty-free in the EU WTO schedule. Since agricultural duties were enforceable only at the end of the Uruguay Round under the General Tariff and Trade Agreement (GATT), industrial goods were subject to lower MFN tariffs than agriculture (based on definitions of WTO). The average rate applied for agricultural products in 2014 decreased from 15.2% in 2011 to 14.4% in 2014. This represents a rise in agricultural products' prices and the resulting reduction of non-ad valorem tariff rates for these goods in the ad valorem equivalents (AVES). Agricultural products have a higher overall level of protection and a higher variation in tariff lines.

The EU imposes a variety of different forms of tariffs: the ad valorem rates are the most commonly used (approximately 70% of agricultural tariff lines at HS-6) and paid as a percentage of the amount of cost-insurance-freight (cif) customs value. Also, there are many other specific tariffs that are measured per kilogram, liter or animal head), compound tariffs (sum of a particular item and an ad valorem), or combinations of different and compound tariffs, such as Max or Min. Around 11% of the overall tariff lines, mainly for agricultural goods, are non-ad valorem. The dynamic tariff mechanisms such as entry price systems and the Meursing Table continue to challenge agricultural imports. Non-ad valorem rates tend to better protect on average than ad valorem rates. In addition, not only do EU tariffs include ad valorem and certain elements, but also seasonal variations and tariffs that differ with the import price.

The majority of EU duty-free imports (and 43 percent of the total value of EU agri-food imports) involve products that are already completely liberalized under the WTO Agreement, according to EU Commission data[4]. Most other EU duty-free imports are liberalized by bilateral agreements (19% of the value of all EU agri-food imports). 12% of EU duty-free imports are subject to the "Generalised Scheme of Preferences (GSP)" scheme, including the "everything but arms (EBA)" scheme, duty-free tariff-rate quota (TRQs) (GATT and bilateral), and imports from the inward processing regime (3% of each).

The aggregation of tariffs plays a significant role in addressing the protective effect of MFNs. The simple average used in past tables is of little economic significance since it gives a highly important product the same weight when compared with a marginal product.

The trade-weighted average is also highly limited[38]. There are several theoretically sound aggregators, including Anderson and Neary's Trade Restrictiveness Index (MTRI) (2005). This is the only tariff alternative that will hold trading volume until all current tariffs have been abolished.

6.3.4.2 Assessing the trade impacts of EU TRQs

The assessment of the effect of EU TRQs is difficult because it requires a very complex method. To be able to model TRQs, two tariffs, one quota, the administration method, and three alternative regimes must be taken into account. In reality, three different situations can be defined depending on market conditions.

When imports are below the quota-and the quota has been underfilled, the quota tariff is mandatory. If imports are identical to the quota, the quota is compulsory and the unit rent depends on the domestic price. When imports surpass the quota, the out of quota tariff is binding and the unit rent refers to the difference between the out and in-quota tariffs.

The EU or the exporting country must, under the last two regimes, allocate import rights under the quota. Most papers do not specifically model TRQs, they transform TRQs into AVEs. The most common assumption is that of Mac Map-HS6 [39]. During the absence of the quota, the in-quota tariff is used; if the quota is binding, the average tariffs for in-quota and non-quota tariffs are calculated; when imports are greater than the quota, the rent equivalent to the difference between these two tariffs is used for out-quota tariffs. This solution may have a variety of drawbacks. [40] proved that in the presence of fixed trade costs, simple averages' usage of the two tariffs can be deceptive and contribute to an overestimate of the AVE. Instead, they suggest that the usage of weighted averages will be more acceptable.

The most important point is that if AVE is used for balance models to ex-ante tests, the implicit presumption is that exogenous shocks will not lead to a change in TRQ; partial trade liberalization is expected to a priori not require a move, for example, from a quota-binding scheme to a tariff-binding out-of-quota regime. Also because of the difficulties in handling change in the scheme, many studies simulate only a complete TRQ liberalization scenario.

The key message that emerges from the debate on the effect on world market distortions of the EU's agricultural trade policy is that in recent years, the MFN EU tariff profile has not changed: adjustments to the simple average tariff represent the adjustments in ad valorem tariff equivalents triggered by changes in unit prices. Nevertheless, by means of preferential agreements as well as cuts in bilateral tariffs, market access for agricultural products has increased. The EU has entered into trade agreements with a number of significant trading partners, such as the USA, and agreements are concluded with others, including Canada. This has also continued to enforce its GSP and GSP+ schemes and its all-but-arms scheme for the least developed countries. The cumulative effect of the various preferential arrangements already in place or currently under negotiation and would result in a MFN trading with only a few countries and territories. Nonetheless, a small number of products continue to apply to import and export licenses, tariff rate quota (TRQs), and unique protections.

6.3.5 Impacts of bioenergy policies

The European Commission has developed a long-term European Union renewable energy strategy to improve energy supply security and decrease greenhouse gas (GHG) emissions. The medium-term goals address bioenergy targets for 2020 with at least a 21% share of total electricity consumption in renewable energy and with at least a 10% share of biofuel in overall fuel consumption. The European Commission has also published a comprehensive biomass action plan provided that bioenergy from forestry and agriculture can contribute significantly. A significant increase in biomass power plantations has been noted across Europe in recent years in reaction to a shifting political environment and changing market conditions. Simultaneously, the indirect effect of increased energy crop production on land use is increasingly concerned.

Along with the directives, the EU farmers have to decide where to sell their products, whether on the market for food, feed or biofuel. Because the EU's commitment to double the use of renewable energy by 2020, which would dramatically increase the demand for biomass, the energy market is likely to become more relevant. The EU Agricultural Policy has increased support for the development and use of bioenergy in rural areas: renewable energy and climate change are goals for which the EU has increased significantly the available resources. Renewable energy support of EU can take many forms, ranging from investments in physical infrastructure to investments in human resources (such as training). Some relevant themes of EU funded projects (through programs for rural development) can be listed as follows:

- Development of biogas plants.
- Planting trees for short-rotation coppicing.
- Installation of heating systems running on straw, wood pellets, or timber of low value.
- Establishment of perennial grass for energy.
- Crushing oilseeds on the farm to use as fuel for agricultural machinery.

Moreover, the EU encourages the Member States to make sustainable use of more wood from forests and to use wood more efficiently. The Directive on renewable energy (2009/28/EC) mandates that 20% of the EU's energy needs come from renewable energies by 2020 and contains a transport target of 10% of biofuels.

6.4 The current state-of-the-art theoretical methods to assess or model output and production factors markets

The current state-of-the-art empirical methodologies used to model agricultural output and input markets with their interconnections to rural societies and environment were recently reviewed by Millington et al.[41] and Rizojeva-Sileva et al. [42]. Millington et al.,[41] introduced the concept of "telecoupling" to refer to art of integrating agricultural markets to the environment and rural economies both in local and global contexts. They classify those empirical methodologies under partial equilibrium economic models, system dynamics modeling, and agent-based modeling. What they came up with is the use of "hybrid models" tailored with respect to the empirical requirements of research questions. Rizojeva-Sileva et al.,[42] approach the issue from the perspective of "simulation" and they classify those empirical methodologies under system dynamics (both partial and general equilibrium models), agent-based models, hybrid models, and discrete event simulation[3] [1]. In this review, our concern will not be the modeling of individual events and therefore discrete event simulation methods will not be elaborated. The use of hybrid models introduces new challenges such as extensive data requirement, theoretical consistency, and representation problems; besides, each hybrid model comes with its own distinguishing and structural features. Hence hybrid models are not reviewed here.

We use the concept "agricultural modeling platforms" and we classify the models into two groups based on how they approach the problem. The first group utilizes the "systems approach" which covers equilibrium type models (both general and partial) and sector models. The second group uses the "agent-based approach". For both approaches, first, general characteristics of partial and general equilibrium models and agricultural sector models are introduced by referring to the relevant literature. Under sector models specifics of normative and positive mathematical programing and econometric mathematical programing models are explained. For the agent-based approach, characteristic elements of the models and decision making process are elaborated. Then, some selected well-known models under each type are reviewed by highlighting their distinguishing features.

In the systems approach, a deeper understanding regarding the causes of behavior is required and searched. This behavior is about the agricultural sector's (or particular agricultural production activity's) response to various endogenous and exogenous changes in the system and might be about identification of linkages between the agricultural sector and other components of the economy. By using feedback relations, in more technical terms by using cause-effect loops, the systems approach models the interactions in one component and among various components in a top-down fashion. Specific behavior of individual agents is not modeled but, rather, the overall response of the sector/component.

The agent-based approach is relatively new in the literature. It employs a bottom-up strategy to model the behavior of agents (individual elements of the system) with respect to endogenous and exogenous changes in the system and to model the interactions among agents. The agents are farms and hence farm-based data is used to reveal the behavior and revealing the macro response/behavior is not the main concern here and therefore is out of the scope of this review.

[3] Integrated Assessment platforms (such as SEAMLESS) will not be included in this review as they bring various models with various capacities for modeling exercises for modeling multi-functionality of the agricultural sector

Computable general equilibrium (CGE) and partial equilibrium (PE) models are called market/price equilibrium type models. Probably one of the main distinguishing features is the scope these models focus on. While PE models focus on one particular sector of the economy (agricultural sector in this review) and hence they allow for in-depth analyses, CGE models attempt to cover the whole economy where agriculture is a part of and they search for the mutual impacts across sectors and allow for feedback relations among markets/industries. PE models that focus on agriculture can be classified into two as PE agricultural trade models[4] [2] and PE agricultural sector models. The former's main emphasis is on the quantification of international trade either on a net trade basis or on a bilateral trade basis. These groups are out of the scope of this review as the majority of these models ignore input markets and the input-output relations in the agricultural sector. Hence, in this review, our attention is on the PE agricultural sector models.

In general, CGE models focus more on commodity groups and/or sub-sectors of agriculture. For this reason, agriculture-focused CGE models will not be elaborated in this review, but rather general information will be provided. CGE models are based on general equilibrium theory and to maintain analytical tractability some strict assumptions like perfectly competitive markets and market clearing, zero transaction costs, homogeneous products are made. However, in some models, those strict assumptions are replaced with non-market clearing, imperfect competition, heterogeneous products, etc. as well. Nevertheless, in all CGE models the core dynamic process is that prices adjust until supply equals demand [41]. Some CGE models that explicitly represent the agricultural sector allow farm problems to be better addressed since primary factors of production (the value added) such as land, labor and capital are explicitly modeled. The CGE modeling platforms allow the direct and indirect linkages between primary and processed products (like grains-food industry) and between agricultural inputs and outputs (like chemicals-grains). Sub-sectors are also linked through their competition for components of value added in the relevant land, capital, and labor markets.

A significant distinction is that PE models assume demand to be independent form production whereas in CGE models production decision affects demand through a change in income. CGE models' coverage is much wider than the one in PE models; however, the level of aggregation does not allow to model impacts of new policy instruments and also in most cases to model individual products. Both PE and CGE models assume the entire economy consists of collectively represented production and consumption sectors and the "whole" economy is modeled simultaneously for the relevant aggregation of economic actors. Depending on the level of country, region, and commodity aggregation, theoretical underpinnings (homogeneous or heterogeneous products, bilateral or pooled markets) empirical data requirements of a CGE model could be enormous. The disaggregation in the agricultural input markets and specifics of value added components may increase the data requirements. Depending on the type of exercise, additional exogenous policy data, macro data etc. might be needed as well.

PE agricultural sector models allow for much more deeper analyses when compared to CGE models. The depth of this modeling platform is based on the possibility of explicit modeling of a large number of products at disaggregated levels while linking those with endogenous behavioral input markets. Land as the main input for agricultural production is also incorporated to these models. Data requirements, in general, are restricted with agricultural products based output, input use, land, capital, and labor data in addition to policy data. Apparently, ignoring the inter-linkages with non-agricultural industries and with macro balances (as opposed to CGE models) become the advantage of PE modeling platforms in the level of disaggregation in the agricultural sector. The disaggregation level in PE models is also supported by the use of mathematical programming and increasing computational power. The use of optimization techniques is a perfect combination with the neoclassical economic theory that introduces and supports the

[4] e.g., MTM, SPELL, AGLINK, ATPSM, VORSIM

maximization behavior of farmers which allows for agricultural policy analyses on the socio-economic and environmental systems linked to the farming sector [43].

Another strong argument for using mathematical programming in the agricultural sector modeling, hence making PE modeling platforms more convenient tools for agricultural policy analyses, is to model the link between economic elements and biophysical and ecological elements of the farm. As Hazell and Norton[44] argued, "mathematical programming models offer unique advantages over other methods because they allow the analysis of the multi-variant and highly interlinked nature of agriculture". More recently, Heckelei and Britz [45] distinguished three developments which evolved in programming models.

Overall, PE models have the capacity to model the effects of not only price support but other policy instruments such as farm-specific ceilings, the dairy quota, set-aside obligations, and stock density restrictions. Additionally, multi-functionality of the agricultural sector now can be better endogenized in PE platforms. Lastly, the increased capacity to model impacts of inevitable constraints (real life constraints) in livestock industry such as the land balance and animal feeding requirements definitely increased the credibility of optimization exercises. The theoretical evolution of mathematical programming and the calibration of it from linear and quadratic programming to positive mathematical programming and new techniques that combines econometrics with mathematical programming[5] [3] also enabled explicit analyses of the effects of agricultural policies at regional or sector levels using information sets that were considered insufficient for earlier methodologies [46].

Millington et al., [41] describes agent-based model (ABM) as a computer simulation approach in which attributes, behaviors and interactions of disaggregated, individuated, and often autonomous, elements are represented. These models are used to represent and reflect how agents' differentiated characteristics affect their decision-making process. The flexibility introduced with the ABM in reflecting the attributes of the individual subjects, made this approach to be used in a variety of analyses regarding human–environment interactions and land use and landscape change. With regard to the agricultural sector, ABMs are used to investigate how farmers adapt to climate change, to organic farming, to the dynamics of structural changes, to transmission of innovations as well as simulation of water use management, environmental modeling, and also how their decision making is affected by social networks.

Mainly, the ABM approach overcomes two simplifying assumptions of the traditional models: agent homogeneity and the difficulty in modeling interactions among agents and the environment. Therefore, with an ABM approach, the systems will have two decisive features. The agents in the system interact, which introduces the bottom-up modeling strategy and it would display local and global properties [47]. If ABMs focus on individual actions and interactions, usually a local level of agents is represented. Nevertheless, multiple levels of hierarchical organization can be represented as well such as households and villages [48].

A few advantages of the ABM approach are summarized by Billari Fert et al., [49]. First, feedback relations are relatively easy to include; second, it is relatively easy to model heterogeneous and not fully rational agents compared to conventional mathematical models; and finally, it is possible to construct and solve problems that are non-tractable by usual analytical models (non-linear systems or systems with a large number of interacting agents). Axtell [50] also adds with ABMs systems far from any type of equilibrium; time, space and social networks can be modeled. However some disadvantages are also mentioned. ABM fails in terms of robustness compared to conventional mathematical models as the solutions of the former are dependent on the initial conditions of the simulation. There is this "black box" criticism which refers to the difficulty in

[5] Combination with maximum entropy estimators [52]; symmetric positive equilibrium problem (SPEP) (Paris, 2001) or the estimation of constrained optimization models [46].

representing the assumptions and algorithms related to the modeling in a standardized and comprehensible manner.

6.4.1 A brief comparison of PE and ABM approaches

We believe there is no correct answer to the question of "which approach should be used to model the agricultural sector (or to represent the multi-functionality of agriculture)". As it has been seen in the last decade's modeling efforts, hybrid and modular approaches that combine various modeling methodologies have become more common. Nevertheless a brief comparison among PE platforms and ABM approach can be done based on their "economic issue" focus, main model components, data dependency, agent inclusion, and policy coverage.

With the level of disaggregation used, ABMs are naturally strong at local representation; whereas PE models are more devoted to global representations. Obviously neither is restricted with the given definition; however, applications in the other extreme would require probably unfeasible data and assumptions. For instance, PE models which inherently depend on heavy data load, can work only at levels where this data are consistent and regularly collected. In addition, to represent individuals' behavior in the global scale with an ABM would demand strong assumptions about agents.

In general, ABMs are used in the agricultural sector to investigate on which rules agents expand their land, how land is distributed, and how land use is changed at local or regional scales. In PE platforms, the main interest is on how output is produced and traded regionally and/or globally. In the latter case, land is generally only a constraint and other factors of production are sometimes exogenous to the system or modeled in a more "coarse" sense. In the former, production decision is modeled as well; however, international trade requires a hybrid approach.

In PE models, agents are represented implicitly and with some strict assumptions such as perfect rationality, homogeneity, profit maximization, and market clearing. The key to PE models is the assumption that actors are price-takers in the markets. However, in ABMs agents are explicit, heterogenous, and they interact with each other. Feedback loops are not represented as explicitly in ABMs as they are in PE models. However, in ABMs, interactions among agents actually bring the dynamics and the information created by feedback loops. In PE models, resource flows are not represented explicitly but instead these are determined through supply and demand. Information on prices of products is the feedback between producers and consumers. In ABMs, resource flows are implicit in agent behavioral equations and in interactions among agents.

As stated by [41], in modeling projects, time for development, data for parameterizing, and calibrating are the primary constraints. Developing computational models from scratch can be very demanding; however, using existing modeling platforms may not facilitate representation as accurately as planned. Probably, the main trade-off is between time spent and obtained accuracy.

Further and in depth comparison of PE platforms and ABMs is provided in the following section by using selected empirical models of each approach from the literature.

6.4.2 Main characteristics of selected PE and ABM platforms used in agricultural modeling

In this comparison we will focus on how production, input demand, and foreign trade are modeled; how output price is determined; and how farm/activity/agent based findings are aggregated at market level. The main assumptions used (determinants of), policy instruments and distinguishing features of each model will also be summarized. Some specifics, such as modeling level, geographical scope, temporal properties, empirical methodology, and data sources will be presented in a comparative way in Table 2 at the end of the section. The reviewed

PE platforms are CAPSIM, AGMEMOD, CAPRI, AROPAJ, IFM-CAP, and PEM whereas the reviewed ABMs are AGRIPOLIS, REG-MAS, LARMA, SWISSLAND, and GLOBIOM.

6.4.2.1 Common Agricultural Policy Simulation Model (CAPSIM)

CAPSIM uses a partial equilibrium framework and it is developed particularly for policy relevant analysis of the CAP.

6.4.2.1.1 Main components

Supply side: the output level and input demand are outcomes of producers' profit maximization behavior at each activity level in which yields are exogenous and land and nutrients (energy and protein) act explicitly as constraints (primal technology description). With this setting technological constraints can be imposed without specifying the primal technology in full detail (which is the case in standard programming models). An additional technology constraint is also used which summarizes the effects of other nutrients and scarce labor and capital, which are not explicitly represented. Feed allocation is not modeled; however, controlling aggregate balances on energy and protein are used to check the consistency of simulation results for animal production and feed demand. A normalized quadratic equation form is used and homogeneity, symmetry, and consistency conditions are kept. Additionally, parameters are calibrated for the base year and applied land prices for activity types and for qualities are different but their prices move together.

Demand side: consumers act with standard utility maximization behavior and food demand reflects Engel's law which is achieved with quadratic or linear Engel curves. A generalized Leontief functional form is used which considers only substitutes. Parameters are calibrated to the base year and the margin between producer prices for raw materials and user prices is the processing cost. Lastly, the difference between EU producer prices and consumer prices are kept constant.

Market clearing: the market is cleared through an identity equation which equalizes excess supply to sum net trade, intervention sales, and violation of WTO limits.

6.4.2.1.2 Policy instruments and variables

- Premium policy (per ha or head specific for activity, official premium per ton for group premiums, ceiling on levels for premiums)
- Endogenous set aside
- Milk quota
- Price transmission equation (that incorporates subsidies and taxes, levies, tariffs) is used to link international prices to EU prices
- Price transmission in the EU is based on quality differences
- WTO limits are implemented
- Sugar levies are taken into account
- Quota on sales
- Administrative price
- Specific tariff, ad valorem tariff
- Producer payment per ton (only used for dairy premium)
- Export quota, import quota (for exogenous change in import quantities)
- Base year border prices are exogenous

6.4.2.1.3 Main assumptions and distinguishing features

Technological change is assumed to compensate for the cost of inflation. On the supply side, yields are exogenous and land and nutrients supply are fixed. Scarcity of any of them would increase shadow prices and decrease revenues and hence activity levels. As a result factor balance is reached by changing demand against fixed factor supply. Parameter specification relies on calibration techniques. Standard aggregate Allen elasticities of substitution are used to derive starting values for Hicksian elasticities. Modeling platform allows for calculation of producer, consumer, and processing industry welfare through calculating equivalent variation. Depreciation of intervention stocks are estimated. A sector wide approach is used where the interdependencies between activities are recognized. EU border prices are endogenous in the system. The platform pays special attention to milk which is highly disaggregated and to sugar for which Common Market Organization is incorporated with some detail.

6.4.2.2 Agricultural Member State Modeling (AGMEMOD)

AGMEMOD is a partial equilibrium modeling capacity developed for the medium-term projection of the agri-food markets and to undertake model-based policy analysis on the agri-food sector in each EU Member States.

6.4.2.2.1 Main components

AGMEMOD utilizes a common country model template which describes: acreage, animal stocks, yield levels, production, commodity stock building, food and feed demand, processing demand, and imports and exports. These indicators are calculated as behavioral responses of economic agents to changes in prices and in policy instruments and to other exogenous variables in the agricultural market.

For each of the crops covered, projections are made for area and yield (implicitly on production), use, trade, stocks, and domestic prices. In the case of oils and meals, projections cover crushing of oilseeds and processing into oils and meals, as well as relevant trade, stocks, and prices.

Animal products cover projections on stocks of live animals, slaughter, and trade in live animals. The model determines the ending numbers of breeding animals and the number of animals produced by breeding under consideration of productivity. Within each livestock group, there is a category of animals to be slaughtered and the simulated average slaughter weight allows meat production per category to be determined. In the livestock sector, other projected figures are domestic use, per capita use, trade in meat, and domestic prices.

The dairy sector is modeled at two levels. On the first level, milk production, milk imports, exports, on-farm use and deliverables to dairies are determined. At the second level, the model allocates fat and protein to different dairy products based on prices of dairy commodities, on assumptions or estimates concerning the fat and protein content of raw milk and other dairy commodities.

*Market clearing: c*ommodity prices adjust to clear all commodity markets considered on the world market and for each commodity sub-module; production, domestic utilization, beginning and ending stocks, and imports and exports have to sum up to zero which means one of these indicators should be a residual. In general, either exports or imports (the one with greater value becomes the residual-closing variable).

6.4.2.2.2 Policy instruments and variables

- Agenda 2000 agricultural policy
- Decoupled payments to arable crops and livestock
- Single farm payment scheme
- National policies with a potential impact on the national agricultural sector beyond the CAP

- Price transmission equations link domestic prices with EU prices

6.4.2.2.3 Main assumptions and distinguishing features

The cost index for the crops is assumed to follow the GDP deflator. For each animal product, a cost index is defined which depends on the prices of various grains and protein crops and the GDP deflator. Feed costs depend on the grain prices. Other input prices depend on the factors outside the agriculture. Individual crop sector models are linked through the allocation of land and different commodities are linked together through cross-price effects in supply and demand equations. Crop and livestock sectors are linked through the use of feeds. AGMEMOD can be linked to CAPRI and AGLINK.

6.4.2.3 Common Agricultural Policy Regional Impact (CAPRI)

The CAPRI model is a regionalized agricultural sector model built for policy analyses with a focus on the EU.

6.4.2.3.1 Main components

*Supply side: p*roducers of both crops and livestock products maximize profit subject to land supply, policy restrictions (sales quota and set aside obligations), and feeding restrictions based on requirement functions. The maximization procedure imposes the two stage decision process. First, producers determine optimal variable input coefficients, then in the second stage the profit maximizing mix of crop and animal activities is determined simultaneously with cost minimizing feed and fertilizer in the supply models. Grass and arable land availability and the presence of quota impose a restriction on acreage or production possibilities. Crop production is also constrained by set aside obligations. Animal requirements are found as the solution of cost minimizing and feeding combination. Fertilizer requirements have to be met by either organic nutrients found in manure or in purchased fertilizer.

A nonlinear cost function covering the effect of all factors, not explicitly handled by restrictions or the accounting costs, ensures calibration of activity levels and feeding habits in the base year and plausible reactions of the system. All other outputs and inputs can be sold and purchased at fixed prices. Selling of milk cannot exceed the related quota and the sugar beet quota regime is modeled by a specific risk component.

On the supply side, independent aggregate non-linear programming models that represent activities of all farmers at regional or farm type level are used. They employ a hybrid approach that combines a Leontief-technology function for variable costs, covering a low and high yield variant for the different production activities, with a non-linear cost function which captures the effects of labor and capital on farmers' decisions. Prices are exogenous in the supply module and provided by the market module. Grass, silage and manure are assumed to be non-tradable and receive internal prices based on their substitution value and opportunity costs. A land supply curve lets the total area use shrink and expand depending on returns. The supply models are solved independently at fixed prices and market clearing conditions provide new prices. The behavioral functions for supply, feed, processing and human consumption apply flexible functional forms where calibration algorithms ensure full compliance with micro-economic theory.

Market module: The market module consists of two sub-modules. The sub-module for marketable agricultural outputs is a spatial, non-stochastic global multi-commodity model for about 50 primary and processed agricultural products, covering about 70 countries or country groups in 40 trading country groups. Bilateral trade flows and attached prices are modeled based on the Armington assumptions. A second sub-module deals with prices for young animals.

6.4.2.3.2 Policy instruments and variables

- Detailed coverage of CAP

- Sales quota
- Set aside obligations
- Bilateral tariffs and export subsidies (tariff rate quota, MFN tariffs, preferential agreements)
- Intervention purchases
- Sugar quota regime

6.4.2.3.3 Main assumptions and distinguishing features

The platform allows for market analysis at global, EU and national scale; and the demand system allows for the calculation of welfare changes for consumers, processing industry, and the public sector. The parameters of these functions are derived from elasticities borrowed from other studies and are calibrated to projected quatities and prices in the simulation year. The model includes nitrogen, phosphorus, potassium (NPK) balances and a module with feeding activities covering nutrient requirements of animals. Main constraints outside the feed block are arable and grassland - which are treated as imperfect substitutes -, set-aside obligations, and milk quota. The European agricultural land use is represented completely (including fruits, vegetables, wine, etc.), but some globally relevant crops (e.g. peanuts) and forestry are not modeled. In the market module, special attention is given to the processing of dairy products in the EU. First, balancing equations for milk fat and protein ensure that these exactly exhaust the amount of fat and protein contained in the raw milk. The production of processed dairy products is based on a normalized quadratic function driven by the regional differences between the market price and the value of its fat and protein content. Prices of raw milk are derived from their fat and protein content valued with fat and protein prices. Yields are determined exogenously by trend analysis. The cost function terms are estimated from ex-post data or calibrated to exogenous elasticities. Fodder (grass, straw, fodder maize, root crops, silage, milk from suckler cows or mother goat and sheep) is assumed to be non-tradable, and hence animal processes are linked to crops and regional land availability. CAPRI can be linked to CGE models.

6.4.2.4 The European Agroeconomic Model (AROPAj)

The AROPAj model is actually a flexible supply modeling platform which aims at incorporating any geographical extension of the EU as well as the continuously changing Common Agricultural Policy in the analysis.

6.4.2.4.1 Main components

AROPAJ has a short-term focus. The supply side is defined as a production set based on the relations between crops and livestock activities. The relations are grouped under three categories: (i) agronomic and crop rotation constraints; (ii) nutriment requirements for animals; (iii) balances between bovine numbers taking into account the gender, the final product (milk or meat), and the age. Farm-groups have a given amount of area (a quasi-fix factor) and utilized areas for agriculture (with the required resources) in each farm that are parameters of the model. Shadow prices of land are calculated by the dual structure. Yields and variable costs are estimated at the regional scale for any set of crop and farm group. On the input side, there is special attention on nitrogen inputs and on the relation between nitrogen fertilizing and the yield. The entire price system is included like parameters meaning prices need to be obtained from other models.

6.4.2.4.2 Policy instruments and variables

- All pricing tools
- All policy tools calling for thresholds on input (i.e. land) or output (i.e. quota)
- Luxembourg agreement

6.4.2.4.3 Main assumptions and distinguishing features

This is a generic and flexible system designed to be adaptable to different European farm types. Area is assumed as a quasi-fix factor for each farm-group. On the input side, there is special attention on nitrogen inputs and on the relation between nitrogen fertilizing and the yield. There is special focus on on-farm use of farming products. Beside the on-farm consumption of cereals for feed, the potential use of nitrogen brought by manure is also encountered.

6.4.2.5 Individual farm model for common agricultural policy (IFM-CAP)

IFM-CAP is developed for the *ex-ante* assessment of the medium-term adaptation of individual farmers to policy and market changes with the aim of answering the question of: how policy reform affects farm income, jobs, typologies of looser/gainer farms, scale, location and specialization of looser farms.

6.4.2.5.1 Main components

IFM-CAP simply solves a maximization problem in terms of input choice and land decisions subject to a set of constraints representing production technology and policy restrictions at given prices and subsidies. On the supply side, in the maximization problem of farm income, operating costs per unit of production activity are taken into account. Land is a constraint (arable and grassland) for which the supply (land endowment) is fixed. Labor and capital captured through positive mathematical programming (PMP) parameters. Animal demography and livestock constraints are balanced with feed demand and feed supply. Farmers maximize their income at given yields, product prices, and production subsidies subject to resource (arable and grassland and feed requirements) and policy constraints such as sales, quota, and set-aside obligations. Land constraints are used to match the available land. Constraints relating feed availability to feed requirements are used to ensure that the total energy, protein, and fibre requirements are met by farm-grown and/or purchased feed. Farm income is defined as the sum of gross margins minus a non-linear (quadratic) activity-specific function where the gross margin is the difference between total revenue including sales from agricultural products and compensation payments (coupled and decoupled payments) and the accounting variable costs of production activities. The accounting costs include costs of seeds, fertilizers, crop protection, feeding and other specific costs. The quadratic activity-specific function is a behavioral function introduced to calibrate the farm model to an observed base year situation (as is the usual case in PMPs) and it captures the effects of implicit factors (price expectation, risk aversion, labor requirement and capital constraints).

6.4.2.5.2 Policy instruments and variables

- Single farm payment
- Set-aside premiums
- Other crop payments
- Art. 68 subsidies
- Additional aid
- Subsidies dairying and others
- Direct payments
- Special premiums
- Slaughter premium
- Payments (extensification, bull fattening, suckler cow, heifers raising)
- Compensatory payment set-aside

6.4.2.5.3 Main assumptions and distinguishing features

A flexible platform to model a wide range of farm-specific policies, to be applied on a EU-wide scale, that reflects farm heterogeneity, covers all main agricultural production activities, permits a detailed analysis of different farming systems, and estimates the distributional impacts of policies across the farm population. All the individual farm models have an identical structure (same equations and variables, but the model parameters are farm-specific) and no cross-farm constraints or relationships are assumed, except in the calibration phase in which all individual farms in each region are pooled together to estimate the behavioral function parameters. Land endowment is fixed and labor, energy, water, and capital resources are captured through PMP parameters. Data on accounting unit costs for crops (i.e. specific costs related to seeds, fertilizers, crop protection and other crop-specific costs) and feeding costs are estimated using a Bayesian approach. Sugar beet quota are estimated using the national share of quota. Technological progress is integrated through exogenous yield trends.

6.4.2.6 Policy Evaluation Model (PEM)

PEM is an agricultural sector model built to assess agricultural producer support policies by incorporating Producer Support Estimates (PSE) database.

6.4.2.6.1 Main components

PEM is a global comparative-static, partial equilibrium, net-trade model. The behavioural functions of the model are derived from cost minimisation under an explicit constant elasticity of substitution (CES) production function and regional input markets for intermediate and primary factors. Under different endowments, technology, market and policy environments the model solves for optimal decision of the farmer. PEM has four crop sectors and two cattle sectors and each farmer manages three fixed production factors: grasslands, arable lands and family labor. Labor can be used both on- and off-farm. Farmers are grouped under four represantative farms combining dairy and crop production: a high milk and low crop yields situation; both low milk and crop yields; a low milk and high crop yields situation; both high milk and crop yields. Basing on these farm structures, PEM illustrates how productivity and profitability differences affect the environmental effects of agricultural policies. Environmental indicator coefficients are used to convert changes in the inputs (fertilizer use, cattle stocks and land use differentiated by sector) and commodity production levels into GHG emissions, N balance and P balance impacts. CAPRI database are used to calibrate these four representative farms (various yields and costs). The decision of the representative farms between livestock and crop choices is associated with on-farm fodder production; manure use as a source of nutrients; competition for quasi-fixed resources such as land and labor between crop and dairy production and under different agricultural policy instruments, the farmer adjusts decision variables to reach new profit-maximising levels.

6.4.2.6.2 Policy instruments and variables

- Market price support
- Payments based on variable input use
- Payments based on current area of all crops
- Payments based on animal numbers
- Payments based on non-current crop area

6.4.2.6.3 Main assumptions and distinguishing features

The market elasticity parameters represent medium-term adjustments of approximately five years. Investment costs have a key role in farms' adjustment and production response to different agricultural support policy instruments. To allow for better tractability policy support are simulated and reported independently for each country which means impacts of policy changes in one country do not influence the results of other countries. Mineral fertiliser and manure are assumed to be perfect substitutes and fodder and other crops compete for arable land. In addition all activities compete for farm labor, which otherwise can be employed off-farm at the given reservation wage. Grass silage is not marketed, hence costs of grass silage reflect the opportunity costs of labor and land; the substitution value against feed concentrates, as well as production costs. The costs of mineral fertiliser and concentrates are explicitly considered and besides grassland and grass silage, the model considers the arable crops wheat, barley and rape. Input and output prices are exogenous. The differences in application costs relative to mineral fertiliser and the content of plant-available nutrients reflects the value of manure.

6.4.2.7 Agricultural Policy Simulator (AGRIPOLIS)

The AGRIPOLIS model is an attempt to facilitate capturing heterogeneity between farms with parts of their environment and to take into account the interactions between farms.

6.4.2.7.1 Main components

Supply side: the farm (agent) aims at maximizing household income accordingly with neoclassical production theory. Its behavioral problem is deciding on the income maximizing combination of production activities and investment choices with respect to resource constraints. Price and policy expectations also enter into the decision problem. However, behavior and actions of other farms are not included.

Each farm's activities are distinguished between standard production activities, auxiliary activities, investment activities, and the decision to continue farming. For production, the farm uses various production factors such as land, buildings, machinery, liquid capital, and labor of different types and capacities. The auxiliary activities are land rental activities, production quota, and manure disposal rights. Rental activities include labor-hiring on a fixed/per-hour basis and off-farm employment opportunities as well. Farms are able to get long/short-term loans and to invest. Loans are either to finance farm activities and/or to balance short-term liquidity shortages; unused liquid assets are invested at the assumed savings rate. Over their useful life, these investments increase the agricultural production capacity but they are depreciated as well. Farmers’ decision to exit or stay in the sector are dependent on expected returns for the next year. If farms' equity capital is zero, the farm is illiquid and if farm-owned production factors would earn a higher off-farm income then the agent continues exiting. Another reason to cease to exit is in case there are no successors to take place after an agent reaches a certain age (a generational change). For a successor to take over, generated farm income should be at least as much as off-farm income.

Landscape is the key factor of production in AGRIPOLIS which is represented by a set of equally sized plots. These plots may have several distinguishing attributes: soil type, ownership type, idle land, rent paid, size, transportation costs, etc. At the macro level, land is of three types: arable land, grassland, and non-agricultural land (natural borders such as forest, roads, etc.).

Land provides the basis for fodder production or manure disposal and farms extend their hectare base exclusively via renting land. Lands are rented either from farm agent landowners or from external, non-farming landowners (not modeled explicitly). Rental land in the market stems from two sources: from farms that have ceased from production and from terminated rental contracts. Through a sequential auction, the land is reallocated in the AGRIPOLIS.

Market module: AGRIPOLIS agents interact indirectly (no direct negotiation is allowed) by competing on factor and product markets. Interaction on markets is organized by market agents that explicitly coordinate the allocation of scarce resources (land) and markets for products, capital, and labor are coordinated via a price function with an exogenously given price elasticity and a price trend associated with each product.

6.4.2.7.2 Policy instruments and variables

A switch from payment coupled to production (Agenda 2000) to single farm payment (decoupled payments)

6.4.2.7.3 Main assumptions and distinguishing features

AGRIPOLIS not only comprises a large number of individually acting farms that operate in a region but farms' interactions with each other and with parts of their environment as well. In other words, the model approaches regional agriculture with three main elements: the farms in a region, the landscape the farms are situated in, and the markets for inputs and outputs. The land is fully endogenous and because it is immobile, land markets are localized. As opposed to other input and output markets, land prices are determined in the market by interactions of landowners and farmers. In the simulation model, each farm/agent in the region acts individually, senses parts of its environment, and acts upon it. This behavior is described by attributes of the agents. The agent evolves subject to their actual state and to changes in their environment (the role of th environment is threefold: the direct environment of a farm consisting of other farms located in the same region; the spatial context in which the farms are located; and the land input to agricultural production). Expectations are adaptive. Regarding investments in fixed production factors, the fixed costs per unit decline as the size of the investment grows. Larger investments are associated with a lower labor input per unit produced. As for investments in fixed assets, the opportunity costs of such assets are zero (as they cannot be used for other agricultural or non-agricultural purposes). All investment costs are sunk. The opportunity costs of labor are as high as the earnings from off-farm labor (farms can benefit from technological progress by realizing additional cost savings when adopting new technologies). The general economic framework conditions enter the model via interest rate assumptions.

6.4.2.8 Information System of Structural Change in Switzerland (SWISSLAND)

SWISSLAND is a model for analyzing effects of agricultural policy changes, of structural changes in the agricultural sector, and for creating options for decisions of individual farms.

6.4.2.8.1 Main components

Supply side: the SWISSLAND market model is a reduced-form model that captures the economic behavior of producers, consumers, and trade. In the supply side, an extrapolation algorithm is used to calculate product quantities and various key structural and income figures (land-use and workforce trends, the number of farms, farm sizes and types, and income development according to the economic accounts for agriculture). Farm managers maximize their expected household income, which is the sum of agricultural and non-agricultural income. The agents in the model can alter their production program and accordingly, their resource use (land, labor, capital, and animals), bearing in mind natural growth in earnings, price changes on the product and factor markets, and agricultural policy transfer payments. Neighborhood interactions have priority and are determined endogenously. Factor endowment with available land is the main constraint for each farm. Balances for nitrogen, land, labor, and fodder are kept and investments are allowed.

Demand side: wherever possible, behavioral demand functions are used for food consumption, feed, and processing demand. Domestic prices for all traded commodities depend on world prices, exchange rates, transport costs, and country-specific policies that affect prices. Domestic prices are specified as a function of import prices adjusted for an ad valorem tariff and transport costs. Producer prices are specified as a function of domestic prices adjusted by an exogenous marketing margin.

Market clearing: the model projects supply-and-demand quantities at the agricultural-sector level whilst taking into account external trade in agricultural goods on the global market. The interaction of demand and supply as well as foreign trade effects determine the domestic market prices in an iterative procedure. In the market's clearing identity equation there are production, imports, food, feed and processing demand, stocks, imports, and exports. Import quantities are determined as a function of the import price and exports float to clear the market. Owing to various cross-price relationships on both demand and supply sides, a change in the net trade position of any product may cause a change in the net trade position of any other product.

6.4.2.8.2 Policy instruments and variables

- Specific import and export taxes/subsidies
- Tariff-rate quota
- Producer and consumer subsidies

6.4.2.8.3 Main assumptions and distinguishing features

All commodities are treated as tradable and homogeneous, except for raw and liquid milk which are non-tradable. The model is a reduced-form model with production, consumption, and other behavioral equations specified by constant-elasticity functions. Interactions between the agents (exchange of resources) and the adoption of innovative technologies take place at individual-farm level. The agents act autonomously. The attributes of the farm manager have individual-farm relevance. The farm level depicts behavioral heterogeneity (factor endowment, soil quality, topographic and climatic conditions, opportunities for off-farm activity, opportunities for cooperation, market access, etc.). Also, farms exits are allowed and land-lease decisions, farm exits and succession, conversion to organic farming, and labor allocation are modeled endogenously.

6.4.2.9 Regional Multi-Agent Simulator (REGMAS)

REGMAS is used to spatially model long-term simulations of the effects of policies on agricultural systems.

6.4.2.9.1 Main components

Supply side: on the supply side, producers (agents) aim at maximizing profits while they are competing in the land market to use the new rented land together with investments and other inputs to increase their competitiveness. The agents also have the option to release agricultural plots as well. Space (location of the farm) is important for two reasons: first, it influences transport costs and, second, it makes farmers interact each other by competing for the same bordering land plots. For investing in machinery and hiring labor, a simple linear profit maximization problem is adopted. Mixed integer programming scale effects (physical and economic size of farms) are also reflected through the use of integer parameters. Farmers maximize their profit any time they bid to rent a new land plot in order to calculate the respective shadow price, any time they plan a new investment or when they decide the production levels using available resources and assets. Hence, farmers' activities are of two types: annual activities that generates costs and revenues in one year and activities that generate results over multiple years (investments). This structure of REGMAS allows assessing how farmers adapt to changes in their environment (changes in resource endowment, activity gross margins, market prices or policy support). Agents' performance can evolve over a simulation period on the basis of investments as well. To invest, agents can borrow money in the credit market up to a certain share of its total capital value. The modeling framework considers the spatial heterogeneity by associating different rental prices to each plot and, thus, can investigate possible land abandonment even when land cultivation is on average profitable. The model must fix the environment where the simulation will be generated. This environment includes the legislative (subsidies, legal constraints, etc.), the biophysical (agronomic and technical coefficients), and the economic dimensions (factor and product prices). Then, individual farmers can be created, positioned in the modeled space, and granted with the tools and resources they need to operate.

6.4.2.9.2 Policy instruments and variables

- The Fischer 2003 CAP Reform: the Single Farm Payment (linked to historical payments)

- Health Check of the CAP in 2008

6.4.2.9.3 Main assumptions and distinguishing features

The original feature of the model is that the spatial dimension is initialized from real land-use data and plots are explicitly modeled accordingly with agents' individual resources (land typology, altimetry, environmental constraints, etc.). Area plots are explicitly modeled in the decision matrix as individual resources without the need of aggregating them in soil classes. Through the impact of distance on costs and land renting, the model allows very detailed analysis as farmers' decisions can be based on individual plot properties and farmers' activity can admit spatial interaction. The model uses sample farms for which detailed data are available from the FADN. Then, a scaling coefficient is used to minimize the differences between the aggregate figures of the simulated region and of the real region.

6.4.2.10 Land Rental Market (LARMA)

LARMA is built to address drawbacks of neoclassical economic approaches by integrating the market model into an ABM framework.

6.4.2.10.1 Main components

The model relaxes the assumption of a representative agent in order to reveal the effects of heterogeneous agents' characteristics on the prices that they are willing to pay or accept for land rental. Agents' interactions are not bilateral, but still each agent interacts with others in the land market. Farmland supply and demand and agents' willingness to pay for rent or accept leasing are endogenously determined depending on agents' working capital (WC) and personal characteristics. There is one main type of agent (farmers) and they either operate on owned and/or leased farms or rent out their land. These agents may have different land allocation strategies, risk aversion behavior and working capital characteristics. On each cropping cycle, each agent goes through three model steps. First, the area to be cropped should be updated by the farmer (whether it is maintained, expanded or released). Second, farmers adopt their expectations for the current cycle based on the expected status of climate conditions, output prices, and input costs. Third, farmers allocate land among a set of viable activities and agronomic management decisions. Then economic returns are calculated from simulated yields, crop prices, and input costs.

Following the neoclassical economics approach, equilibrium between demand and supply will provide land rental prices. Formation of land rental price involves three steps. The identification of potential supply and demand; the formation of "Willing to Accept Price" and "Willing to Pay Price"; the calculation of a Market Clearance Price. The model accounts for the value of working capital and progress rate in the calculation of "Willing to Accept Price" and "Willing to Pay Price".

6.4.2.10.2 Main assumptions and distinguishing features

Land sales are not accounted and land release occurs only through land rental. At the start of a production cycle, the model assesses whether each farmer can: (a) return to active farming (for landlords), (b) maintain previously cropped area or, (c) expand production by renting additional land, or instead (d) must release some or all previously farmed land. This assessment is based on a farmer's ability to cover: (a) implantation costs (labors, seed, and agrochemicals), and (b) rental costs (for rented farms).

6.4.2.11 The Global Biosphere Management Model (GLOBIOM)

The Global Biosphere Management Model (GLOBIOM) is a partial equilibrium model particularly built to analyze the competition for land use between the agriculture, forestry, and bioenergy sectors. Since the development of the model, GLOBIOM is used for impact analysis of climate change and adaptation, a wide range of sustainable development goals, and - specifically - for impacts on land use change.

6.4.2.11.1 Main components

Supply side: the model maximizes the sum of producer and consumer surpluses with respect to certain constraints (related to technologies available, biophysical resources availability (land, water), capacity constraints, etc.). Producer surplus is determined at a regional level by the difference between market prices and the supply curve (which represents the value of primary factors of production (labor, land, capital), cost of secondary inputs, and international transportation costs). The model allows new technologies and transformation pathways for different sectors.

The yields are distinguished by crop management system, land characteristics, and by spatial units which allows for endogenous marginal yield modeling. The crop management system integrates four technologies (subsistence, low input rainfed, high input rainfed, and high input irrigation) for all regions and, in addition, combinations of different rotation systems for all NUTS2 regions in the EU are also possible. Requirements for each system and location are retrieved from the biophysical model EPIC.

The supply side is modeled at a very fine resolution allowing for more than 10.000 supply units (differentiated w.r.t. topographic, climatic, and soil conditions). Depending on the yield and cost in each unit, the model determines crop allocation and production. Land quality is crop specific in the supply side.

The model uses a bottom-up strategy in a spatial fashion and landscape is characterized among 5 altitude classes, 7 slope classes, and 5 soil classes. At the bottom level, there are detailed grid-cell information which covers climate, topography, soil, and crop management data which at the same time provides the biophysical and technical cost information. Productivity of land for each type of crop is specific to the grid cell level and the modeling framework allows for conversion of other land to croplands (based on expected profitability linked to productivity and input costs). The same approach is used to model grasslands as well. Therefore, to account for these conversions, the model allows for direct calculation of the value of the marginal productivity of land. While land expansion is possible at the level of each spatial unit, land use change is considered at the local level. Lastly, land use changes are modeled on the basis of land use conversion possibilities matrices between land use types and associated conversion costs.

Demand side: the demand is determined by maximizing the difference between demand curves and market prices, which is consumer surplus. Demand is represented through separated demand functions for food which are specified to be functions of the population size, gross domestic product (GDP) and product prices.

Market clearing: for each product and region, markets are cleared through endogenously adjusted market prices and supply and demand quantities are found as a result of the maximization of the sum of the consumers and of the producers' surplus. Market balance is solved for 37 economic regions. Trade in GLOBIOM is expressed in physical units and products are assumed to be homogeneous goods. Therefore, regions with the least cost (adjusted with tariffs and transportation costs) source the trade. The model endogenously computes bilateral trade flows and trade patterns are determined by initial trade flows, the evolution of relative costs of production between regions, and the trading costs.

6.4.2.11.2 Policy instruments and variables

Various tariff policies

6.4.2.11.3 Main assumptions and distinguishing features

Explicit representation of production technologies and geographically explicit allocation of land cover and land use are GLOBIOM's distinguishing features. This model can also be linked to the MESSAGE model to represent energy markets as well. The allocation of land takes into account abandoned land, idle land, and temporary meadows, i.e., land which is not harvested. Yields are endogenously determined for all locations and crops. The modeling framework allows for the use of residues for the livestock sector and the industrial and energy uses. Cross-price effects for usual food products are not represented except for vegetable oils. Trade creation is possible.

Model	Modeling Level	Geographical Scope	Temporal Properties	Empirical Methodology	Data Sources
CAPSIM[52]	-Activity based	-EU 15	-Comparative static	-Normalized quadratic equation form -Generalized Leontief functional form	-Economic Accounts on Agriculture
AGMEMOD[53]	-Activity based	-EU	-Recursive dynamic	-Econometric	-USDA -FAOSTAT -EUROSTAT
CAPRI[54]	-Region-based -Farm-type based	-280 NUTs2 regions -EU27, Norway, Turkey, Western Balkans	-Comparative static	-Non-linear programming -Leontief functional form	-EUROSTAT -FAOSTAT -FADN -OECD
AROPAj[55]	-Farm-group based	EU	-Comparative static	-Linear programming -Non-linear programming	-FADN
IFM-CAP[56]	-Farm-based -Aggregation by --Farm typology --Farm size	-FADN (except farms with less than three years' observation during the base year period) regions -NUTS -Member states -EU	-Comparative static	-Non-linear programming -Positive mathematical programming	-FADN -EUROSTAT -FSS -CAPRI database
PEM	-Farm-type based	-23 European countries	-Comparative static	-Non-linear programming	-CAPRI database
AGRIPOLIS [57]	-Agent based	-EU	-Dynamic	-Design of Experiments -Meta-Modeling -Mixed-integer programming -Linear programming	-FADN
SWISSLAND[58]	-Agent based	-Switzerland	-Rec. dyn.	-Positive mathematical programming	-FADN
REGMAS[59]	-Agent based	-EU	-Comparative static	-Mixed-integer linear programming	-FADN
LARMA[1]	-Agent based	-Argentina	-Dynamic		
GLOBIOM[60]	-Agent based	-Global: 37 regions	-Rec. dyn.	-Linear programming	-FAOSTAT -EUROSTAT

Table 25 Comparison of Main Features of Modeling Platforms

Source: authors' elaboration.

6.5 Existing models that can be used in ABM; suggestions for the development of AGRICORE ABM

Building a modeling platform that approaches the agricultural sector from various angles and that accounts for the multi-functional structure of the sector is a real challenge. Different methodologies used for modeling the agricultural sector have their own strengths but at the same time weaknesses. To overcome the weaknesses and to find solutions for various problems at different levels, recently hybrid approaches are commonly used which combine different methodologies to model the agricultural sector. These hybrid models are mostly built and tailored accordingly with the specific aims of the modeling exercise.

In the previous sections, general and specific features of mainly partial equilibrium and agent based models were reviewed and also a brief comparison among these approaches was provided. An innovative approach in building a modeling platform for agricultural policy analyses might focus on the neglected issues in the existing empirical models.

From the above perspective, and according to the stated purposes of the AGRICORE project, the agent based approach that considers farms as decision-making agents and that puts farms to the core of the modeling platform is more appropriate rather than using a representative group. In this way, attributes of the individual farmer and farm can become a factor and can be taken into account in affecting farmers' decision regarding their agricultural practices. In other words, heterogeneity among farmers/farms, which is sourced by the surrounding economic, social, and environmental conditions, could become a determining factor in farmers' decision process. From an agricultural/rural policy point of view, the agent based approach might also be more suitable to analyze the impacts of second pillar policies under the CAP, which focus on rural development and that are more farm oriented rather than market based. Similarly, the effects of expected policies in the post 2020 reform of the CAP, which will have a focus on rural value chains, cleaner energy and technology, and sustainable environment might be better modeled with the agent based approach.

In the above setting, the first decision level for the agent should be the decision regarding land use: whether it will be used for agricultural purposes or not. Another way to put this problem is determining the criteria for the agent in the model to continue farming or not. At the second level, the model should calculate expected profitability for various agricultural activities on the farm so that the agent decides to change land cover or not. However, at this second level, the decision is not only related to the short-term; in other words, continuing to produce should not be the only option for the farmer given by the modeling platform. The agent should be given the opportunity to invest in agriculture or not. Therefore, at this level, the short and long-term behavior of the agents should be determined with some criteria. The criteria in most cases is the expected profit which has two components: revenues and costs.

Calculation of revenues and costs introduces other challenges to the modeling platform such as how the effect of production technology will be encountered and if the platform will allow for change in the technology. The other question to answer is about the price determination procedure in input and output markets. These prices can be the outcome of an equilibrium condition in the national or global market or they can be exogenous to the system. In both cases, the modeling platform should allow accounting for the impact of existing agricultural policies on input and output prices.

Input markets are quite important in formulating the problem of the agent. Inputs cover both primary factors of production (land, labor, and capital) and intermediate inputs (fertilisers, pesticides, feed, seed, irrigation, etc.) The availability of these becomes the constraint on production; however, in most cases, their supply level is fixed. The demand and supply conditions in input markets not only determine the prices but also those conditions are mostly related to the location of the farm. Type of soil, rainfall, altitude, slope, etc. are all important in determining the initial demand and supply conditions. Therefore, the source of data for individual plots should be definitely better than using activities or sub-sectors at an aggregated level.

Based on the characteristics of plots, input demand modules should allow for input substitution which we do not see for most of the models. This substitution could be an outcome of endogenously changing input prices as well. Similarly, in some models, the substitution possibility for output production is not modeled either. In some modelin platforms, as output prices are taken exogenous zero substitution is an expected output. However, modelin prices endogenously should allow for output substitution in the profit function.

6.6 References

1. ^ 1 2 F. Bert et al., "Agent-based modeling of a rental market for agricultural land in the Argentine Pampas," 2010.
2. ^ 1 2 3 4 E. Commission, "Farm structures," DG Agriculture and Rural Development, Unit Farm Economics, 2018.
3. ^ 1 2 E. Commission, "Production, yields and productivity," DG Agriculture and Rural Development, Unit Farm Economics, 2018.
4. ^ 1 2 E. Commission, "EU Farms and Farmers in 2013: An Update," EU Agricultural and Farm Economics Briefs No: 9, 2015.
5. ^ 1 2 3 E. Commission, "Young farmers in the EU–structural and economic characteristics," EU Agricultural and Farm Economics Briefs, 2017.
6. ^ 1 2 3 4 E. Commission, "EU Agricultural Outlook for Markets and Income 2019 – 2030," DG Agriculture and Rural Development, Unit Farm Economics, 2019.
7. ^ AEIAR, "Status of Agricultural Land Market Regulation in Europe," 2016, [Online]. Available: http://www.aeiar.eu/wp-content/uploads/2016/04/Land-market-regulation_policies-and-instruments-v-def2.pdf.
8. ^ J. Loughrey, T. Donnellan, K. Hanrahan, and T. Hennessy, "Agricultural Labour Market Flexibility in the EU and Candidate Countries," 2013.
9. ^ 1 2 3 4 J. Loughrey et al., "The impact of decoupled payments on off-farm labour supply: evidence from Ireland and Italy," 2013.
10. ^ L. Shutes, "13. Labour supply curves for EU Member States and candidate countries: an applied general equilibrium analysis," Land, Labour and Capital Markets in European Agriculture, p. 139, 2013.
11. ^ B. Tocco, A. Bailey, and S. Davidova, "Determinants to leave agriculture and change occupational sector: Evidence from an enlarged EU," 2013.
12. ^ A. Olper, V. Raimondi, D. Cavicchioli, and M. Vigani, "Agricultural labour and farm subsidies: new evidence from the EU," 2013.
13. ^ E. A. Kaditi, "16. The impact of CAP reforms on farm labour structure: evidence from Greece," Land, Labour and Capital Markets in European Agriculture, p. 186, 2013.
14. ^ M. Petric and M. Kloss, "27. Factor market imperfections and productivity in EU agriculture," Land, Labour and Capital Markets in European Agriculture, p. 316, 2013.
15. ^ D. Viaggi, M. Raggi, V. Gallerani, and S. G. y Paloma, "The impact of EU common agricultural policy decoupling on farm households: Income vs. investment effects," Intereconomics, vol. 45, no. 3, pp. 188–192, 2010.
16. ^ 1 2 H. Dudu and Z. Smeets Kristkova, "Impact of CAP Pillar II payments on agricultural productivity," 2017.
17. ^ 1 2 3 E. Commission, "Fertilizers in the EU: Prices, trade and use," EU Agricultural Markets Briefs: No 15, 2019.
18. ^ E. Commission, "EU Cereal Farms Report - 2017," Directorate-General for Agriculture and Rural Development, 2017.

19. ^ E. Kress-Rogers and C. J. Brimelow, Instrumentation and sensors for the food industry, vol. 65. Woodhead Publishing, 2001.
20. ^ 1 2 S. McCorriston, "Why should imperfect competition matter to agricultural economists?," European Review of Agricultural Economics, vol. 29, no. 3, pp. 349–371, 2002.
21. ^ T. Reardon, C. P. Timmer, C. B. Barrett, and J. Berdegue, "The rise of supermarkets in Africa, Asia, and Latin America," American journal of agricultural economics, vol. 85, no. 5, pp. 1140–1146, 2003.
22. ^ R. J. Sexton, "Market power, misconceptions, and modern agricultural markets," American Journal of Agricultural Economics, vol. 95, no. 2, pp. 209–219, 2013.
23. ^ 1 2 A. Sorrentino, C. Russo, and L. Cacchiarelli, "Market power and bargaining power in the EU food supply chain: the role of producer organizations," New medit, vol. 17, no. 4, p. NA-NA, 2018.
24. ^ 1 2 C. Russo, R. E. Goodhue, and R. J. Sexton, "Agricultural support policies in imperfectly competitive markets: Why market power matters in policy design," American Journal of Agricultural Economics, vol. 93, no. 5, pp. 1328–1340, 2011.
25. ^ J. B. Kirkwood, "Buyer power and exlusionary conduct: Should brooke group set the standards for buyer-induced price discrimination and predatory bidding," Antitrust LJ, vol. 72, p. 625, 2004.
26. ^ 1 2 J. Meyer and S. Von Cramon-Taubadel, "Asymmetric price transmission: a survey," Journal of agricultural economics, vol. 55, no. 3, pp. 581–611, 2004.
27. ^ P. Vavra and B. K. Goodwin, "Analysis of price transmission along the food chain," 2005.
28. ^ O. Fernandez-Amador and J. Crespo-Cuaresma, "The role of asymmetries in the price transmission mechanism for milk products in Austria, University of Innsbruck," 2010.
29. ^ R. N. Acharya, H. W. Kinnucan, and S. B. Caudill, "Asymmetric farm–retail price transmission and market power: A new test," Applied Economics, vol. 43, no. 30, pp. 4759–4768, 2011.
30. ^ B. Velázquez, B. Buffaria, and others, "About farmers' bargaining power within the new CAP," Agricultural and Food Economics, vol. 5, no. 1, p. 16, 2017.
31. ^ S. Ciliberti and A. Frascarelli, "Mandatory rules in contracts of sale of food and agricultural products in Italy: an assessment of Article 62 of Law 27/2012," 2013.
32. ^ A. Matthews, L. Salvatici, and M. Scoppola, "Trade impacts of agricultural support in the EU," 2017.
33. ^ R. Prosterman and L. Rolfes, "Review of the legal basis for agricultural land markets in Lithuania, Poland, and Romania," World Bank Technical Paper, pp. 110–139, 2000.
34. ^ J. Swinnen and L. Vranken, "Review of the transitional restrictions maintained by Bulgaria and Romania with regard to the acquisition of agricultural real estate," Report to the EC DG Internal Market, pp. 1–85, 2010.
35. ^ N. Swain, "Agricultural restitution and co-operative transformation in the Czech Republic, Hungary and Slovakia," Europe-Asia Studies, vol. 51, no. 7, pp. 1199–1219, 1999.
36. ^ P. Ciaian and J. F. Swinnen, "Land market imperfections and agricultural policy impacts in the new EU member states: a partial equilibrium analysis," American journal of agricultural economics, vol. 88, no. 4, pp. 799–815, 2006.
37. ^ P. Ciaian, d'Artis Kancs, J. F. Swinnen, K. Van Herck, and L. Vranken, "Institutional factors affecting agricultural land markets," 2012.
38. ^ M. Cipollina and L. Salvatici, "Measuring protection: mission impossible?," Journal of Economic Surveys, vol. 22, no. 3, pp. 577–616, 2008.
39. ^ H. Boumellassa, D. Laborde, and C. Mitaritonna, A picture of tariff protection across the world in 2004: MAcMap-HS6, version 2, vol. 903. Intl Food Policy Res Inst, 2009.
40. ^ V. Raimondi, M. Scoppola, and A. Olper, "Trade Preference Through Tariff Rate Quotas and the Gravity Equation: Does the Tariff Equivalent Matter?," in The Trade Impact of European Union Preferential Policies, Springer, 2011, pp. 175–195.

41. ^ 1 2 3 4 5 J. D. Millington, H. Xiong, S. Peterson, and J. Woods, “Integrating modelling approaches for understanding telecoupling: Global food trade and local land use,” Land, vol. 6, no. 3, p. 56, 2017.
42. ^ 1 2 A. Rizojewa-Silava, I. Pilvere, and S. Zeverte-Rivza, “AGriculture modelling in the European Union,” in Proceedings of the International Scientific Conference" Economic Sciences for Agribusiness and Rural Economy", 2018, no. 2.
43. ^ L. Salvatici et al., “olitiche Agricole dell’UE,” 2000.
44. ^ R. D. Norton and P. B. Hazell, Mathematical programming for economic analysis in agriculture. Macmillan, 1986.
45. ^ 1 2 T. Heckelei and W. Britz, “Models based on positive mathematical programming: state of the art and further extensions,” 2005.
46. ^ F. Arfini, “Mathematical programming models employed in the analysis of the common agriculture policy,” 2001.
47. ^ R. Axelrod and L. Tesfatsion, “On-line guide for newcomers to agent-based modeling in the social sciences,” Handbook of Computational Economics, vol. 2, 2012.
48. ^ D. Kremmydas, “Agent based modeling for agricultural policy evaluation: A,” 2012.
49. ^ F. C. Billari, T. Fent, A. Prskawetz, and J. Scheffran, “Agent-based computational modelling: an introduction,” in Agent-Based Computational Modelling, Springer, 2006, pp. 1–16.
50. ^ R. Axtell, “Why agents?: on the varied motivations for agent computing in the social sciences,” 2000.
51. ^ Q. Paris and R. E. Howitt, “An analysis of ill-posed production problems using maximum entropy,” American journal of agricultural economics, vol. 80, no. 1, pp. 124–138, 1998.
52. ^ H. Witzke and A. Zintl, “CAPSIM-Documentation of model structure and implementation,” Agriculture and fisheries-Working papers and studies, 2005.
53. ^ P. Salamon et al., “AGMEMOD outlook for agricultural and food markets in EU member states 2018-2030,” 2019.
54. ^ W. Britz, “Overview of CAPRI in CAPRI model documentation 2011,” CAPRI model documentation, 2011.
55. ^ E. Baranger, M. Clodic, E. Galko, P.-A. Jayet, and P. Zakharov, “Improvement of the AROPAj model covering a large range of agricultural activities at wide (UE) and high resolution (mapping of farm types) scales,” 2008.
56. ^ K. Louhichi, P. Ciaian, M. Espinosa, L. Colen, A. Perni, and S. Gomez y Paloma, “EU-wide individual Farm Model for CAP Analysis (IFM-CAP): Application to Crop Diversification Policy,” 2015.
57. ^ K. Happe, K. Kellermann, and A. Balmann, “Agent-based analysis of agricultural policies: an illustration of the agricultural policy simulator AgriPoliS, its adaptation and behavior,” Ecology and Society, vol. 11, no. 1, 2006.
58. ^ A. Möhring, G. Mack, A. Zimmermann, A. Ferjani, A. Schmidt, and S. Mann, “Agent-Based Modeling on a National Scale–Experience from SWISSland,” Agroscope Science, vol. 30, no. 2016, pp. 1–56, 2016.
59. ^ A. Lobianco and R. Esposti, “Assessing the Impact of the ‘Health Check’in an Italian Region: An Application of the RegMAS Model,” The Common Agricultural Policy After the Fischler Reform: National Implementations, Impact Assessment and the Agenda for Future Reforms, p. 137, 2011.
60. ^ V. Krey et al., “Message-globiom 1.0 documentation,” International Institute for Applied Systems Analysis: Laxenburg, Austria, 2016.

7 Agricultural Land Markets[6]

7.1 Characterizing Land as a Farm Asset

Land is an important factor in agricultural production and constitutes the very largest share of farm assets. Its amount is constant, in a given spatial location due to its immobile attribute. Other uses are competing with agricultural use in many places, particularly urban sprawl. However, the JRC estimates on land-use change in the EU indicate that land take for urban, infrastructure, and industrial purposes exceeds 1,000 km^2 per year[1]. On the demand side of agricultural lands, different expectations of the role of agricultural land have emerged from society, including the expectations of land to control and purify water, to sequester carbon to contribute to climate change mitigation, to provide a habitat for biodiversity, to enable sustainable nutrient cycling of animal and human waste streams[2].

Land use and cover change (LUCC) have been extensively studied to assessing impacts of policies, regulations, and climate change on landscape and ecosystem service provision[3]. Recently, causes of the agricultural land abandonment has also taken the interest of researchers[4]. Agricultural land market has been one of the neglected factor market and not studied at a viewpoint of holistic perspective. Majority of existing studies are interested in only one aspect of the market such as land price and rent determinants, capitalization impact of policies, drivers of intensification. On the other hand, LUCC literature used agent-based models (ABMs) has not treaded land market exclusively.

Farm holdings can operate on their own-land (majority of family farm), rented land (tenant), common land (i.e. pasture and meadow), and various mix of these land titles. The price of farmland is affected by both internal and external forces to agriculture. The income generating potential is a basic land value determinant internal to agriculture. The principal external forces consist of inflation, farm expansion, urbanization, rural parcelization, foreign investment, conglomerate corporation entering agriculture, and vertical integration in the food system[5]. Historically higher farmland rental price has been associated with higher return from agriculture depending on yield, favorable market prices of output and inputs and also external forces such as government support payment, real interest rate, and high inflation rate, low investment risk perception in land, tax policies, and urban expansion pressure. However, farm value survey conducted in 2019 by Iowa State University, indicated that the participant listed three most important positive factors affecting land prices are favorable interest rate, limited land supply, and strong yield. Government payment is also listed among other positive factors. The respondent listed the most important three negative factors which are commodity prices, weather, and import tariff[6].

The overwhelming majority (96% in 2016) of the EU's farms are classified as being family farms. By definition, the family farm is managed by the family and at least 50% of the regular labor force is provided by family members. Indeed, more than nine in every ten farms (93%) in the EU only have family workers. Family farms were the dominant type in all member states. However, France had a relatively sizeable minority of non-family farms (27.3 % of its close to 0.5 million farms) along with Estonia (21%). Two-thirds of the EU's farm was less than 5 hectares (ha) in size in 2016. These small farms were typical in Malta (96.5%) and Cyprus (89.6%). At the other end of the production scale, 6.9% of the EU's farms were of 50 ha or more in size and worked two-thirds (68%) of the EU's utilized agricultural area (UAA). Although the average mean size of an agricultural holding in the EU was 16.6 ha in 2016, only about 15% of farms were this size or larger[7]. Therefore, small and medium-size family farms are the main farm types in the EU

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countries and impact of policies and regulations on their sustainability and profitability are important at a viewpoint of political economy and societal demand.

As of 2013, based on Eurostat FSS data, the total size of common land in the countries (used method B for definition) was recorded as 8.85 million ha[8]. In terms of percentage of total utilized agricultural area, the common land is highly important in Greece (30%), Croatia (28%), Bulgaria (18%), Romania (12%), Ireland (9%), Austria (7%) and United Kingdom (7%).

More than 43% of the land in the EU-28 is farmed under tenancy arrangements[9]. The farmland rental market is an essential part of land assets in agricultural production in many parts of the world, particularly where commercial farming is dominant such as Argentina Pampas[10] and in several EU countries (regions). According to FADN data from 2015, an average, share of the rented farmland in EU was 54 percent (52 in New Member States (NMS) vs 54 in Old Member States (OMS)) and ranged from 91 % in Slovakia to 19% in Ireland[11]. Rented farmland shares are very high in France (82), Bulgaria (84), Malta (82), Czech Republic (77), Belgium (72), and Germany (66). Farmland represents a large share of the total assets in production and the volatility in land prices is generally relatively low[12]. The farmland rents make up roughly 5% of total costs in the EU agricultural production[13].

The share of rented land data confirm that one of the most important land market types in many EU member states is rental land market. Therefore, farmland rent and factors affecting to its level are important considerations from the viewpoint of political economy (i.e. common agricultural policy distributional impact) and competitiveness of agriculture sector in world market.

Regarding spatial characteristic of land market, because of its immobility and heterogeneity (size, soil quality, amenities etc.), demand of the agricultural land, policy measures and regulations are important factors affecting land value and rent. Although there are literature reviews on LUCC and the impacts of LUCC on environment and ecosystem services provision, and local-global and global-local linkage[14][15][3], relied upon literature searches, a comprehensive literature review on agricultural land market has not been accessed yet. Given the importance of land in agricultural production and increasing pressure for alternative and use, an assessment tools are necessary to design appropriate policies for supporting sustainable agriculture production and responsible use of the agricultural land. These necessities entails a comprehensive literature review on land market in the agriculture and clarify gap in the existing models and provide vision for development of more appropriate agricultural and environmental policy tools.

The second part of this review focus on institutional (policy measures and regulations) and external factors affecting the land markets. Part third provides a detailed overview of the current state-of-the-art theoretical methods to assess or model the value/price of owned/rented land. Fourth provides information about the geographical areas, determinants and datasets for land market analysis, particularly determinant of land value and rent, drawn from the existing literature. Part five discusses the existing ABM models to determining the transactions in the land market. The neglected determinants/factors of the markets for agricultural land are discussed in part 6. The final part discusses the gap in existing ABM model at the viewpoint of land market and makes suggestions for ABM based AGRICORE project.

7.2 Institutional and External Factors Affecting the Land Markets

7.2.1 Land Market Measures

Land market institutions in EU countries include measures to protect tenants, measures to protect (local) owner-cultivators, measures to protect land owners, and measures prevent fragmentation[16]. According to these measures classification, Swinnen et al.,[17] documented the situation in EU countries as below.

Measures to protect tenants in the EU impose a minimum rental contract duration, maximum rental prices, automatic rental contract renewal, conditions for rental contract termination and pre-emptive buying right of tenants. Belgium, France and the Netherlands apply maximum rental prices for agricultural land which depends on the expected marginal productivity of a plot. In Austria, "Grundverkehrsbehörde" approves rental contracts. This authority can disapprove the contract if the rent is 50% higher than the average price in the region. The national legislation in Austria, Belgium, France, Italy, the Netherlands, Portugal, Spain, Slovakia and Slovenia stipulates a minimum duration for a rental contract. Rental contracts are automatically renewed in many EU countries. The owner can prevent the automatic extension of a rental contract if the owner or a close relative wants to use the land him/herself in Belgium, France and the Netherlands. Otherwise the rental contract is automatically renewed with the previous tenant. The national legislation in Belgium, France, Italy, Portugal, Sweden, Hungary, Latvia, Lithuania, Romania and Slovenia gives a pre-emptive right to tenants to buy the land.

Measures protecting the owner-cultivator include restrictive conditions on the owner (such as nationality), maximum sales prices, and pre-emptive buying rights for neighboring farmers and maxima on the transacted area. Restrictions were introduced on foreigners to buy (or rent) land during the accession of new member states since the land prices are low due to the large income differences and poor-functioning rural credit markets in these countries. There are other restrictions in Austria, Denmark, Spain, Hungary and Poland other than nationality. In Austria, new owners should live closer to the plot and have to prove their competency in the agricultural sector through experience or education. Also in Poland, farmers should have a proof of competence in the agricultural sector. In Hungary, the new owner is legally obligated to cultivate the land. Neighboring farmers have a pre-emptive right to buy the plot in France, Italy, Portugal, Hungary, Latvia and Slovenia.

A well-defined maximum sales price does not exist. However, the government can interfere in the market if the sales price of agricultural land is considered too high in Austria, France and Poland. In France, Hungary and Lithuania, there are size limitations on the amount owned or transacted land. The SAFER in France can refuse a transaction if the amount of land sold is too high[7] [1]. In Hungary, an individual farmer can own and cultivate up to 300 ha; and farming companies can not own any agricultural land and can only lease up to 2500 ha. In Lithuania, the owned land upper limit for a natural person or a legal entity is 500 ha. Table 1 summarizes the most relevant land market regulations in the EU.

There are also measures to protect the landowner and prevent fragmentation in some MSs. Finland, Sweden, Hungary, and Poland use a maximum duration of rental contracts. Austria, Czech Republic, and France also regulate the minimum rental price. Italy, Portugal, Czech Republic, Hungary, Lithuania, Poland, Slovakia, and Slovenia have pre-emptive rights for the co-owner to buy land to prevent land fragmentation. There exists a legal minimal plot size in Germany, Bulgaria, Estonia, Lithuania, and Slovakia.

[7] It was created in 1960, SAFER ("Sociétés d'Aménagement Foncier et d'Etablissement Rural") is a private body but have public service mission, and are controlled by the State. Generally, there is one each NUTS3 level and its general authority located in Paris. Their main mission is to regulate the transfer of agricultural land, and their specific mission are to support the settlements of farmers, especially young farmers, to support land and farm consolidation, to favor transparency and functioning of rural land markets, and to support rural development and environmental protection[18].

Types of Measures to	Instruments	Countries applied in the EU	Conditions
Protect Tenants	Minimum rental contract duration	Austria, Belgium, France, Italy, the Netherlands, Portugal, Spain, Slovakia, and Slovenia	In France, beneficiaries must be under retirement age and provide proof indicating their professional capability or experience. They have to farm the land for a minimum of 9 years and participate fully in the farming of the property. They must have the necessary livestock and equipment.
	Maximum rental prices	Belgium, France, the Netherlands, and Austria	Depend on the agronomic quality of plots (expected marginal yield). In Austria, the contract needs to be approved by the local public authority, it is disapproved if the rent determined in the contract is 50% higher than the regional average.
	Automatic rental contract renewal	In many EU countries	Normally, the contract is automatically renewed with the previous tenant.
	Condition for rental contract termination	Belgium, France, and the Netherlands	The (automatic) extension of a rental contract can only be prevented by the owner under certain specific conditions (e.g. when the owner or a close relative wants to use the land for themselves).
	Pre-emptive buying right of tenants	Belgium, France, Italy, Portugal, Sweden, Hungary, Latvia, Lithuania, Romania, and Slovenia	Tenants have a pre-emptive right to buy the land.
Protect the (local) owner-cultivator	Owner restriction (such as nationality)	Almost all NMS have some restrictions but the precise nature differs among countries. There exist other restrictions than nationality for land owners in Austria, Denmark, Spain, Hungary, and Poland.	In Hungary, Poland, and Latvia, no company with majority foreign ownership can buy land. In Estonia, Hungary, Latvia, Poland and Slovakia, foreign individuals ("natural persons") are only allowed to buy a plot after renting and farming the plot for at least three years. In Lithuania, foreign natural persons are allowed to buy agricultural land in case they have been staying and farming in the country for at least three years or when they are married to national citizen. Greece and Finland restrict foreigners' renting or buying agricultural land in specific regions. In Austria, new owners of agricultural land should have their residence relatively close to the plot and have a proof of competence in the agricultural sector (through experience or education). Exactly, the same proof of competence also exists in Poland. In Hungary, there is a legal obligation for new owners to cultivate land.
	Maximum sales prices	In none of the countries, there exists a well-defined maximum sales price	In Austria, France and Poland, the government can interfere in the sales market of agricultural land in case the sales price of the agricultural land is considered too high. In France, the SAFER can disapprove a transaction when there is suspicion of "speculation". In Poland, sales prices of agricultural land are in principle free, but when the sales price of an agricultural land is "extremely high", a party with a pre-emptive right mayask the local authorities for downward correction of the sales price.

	Pre-emptive buying rights for neighbouring farmers	France, Italy, Portugal, Hungary, Latvia, and Slovenia	Neighboring farmers have a pre-emptive right to buy in the case an agricultural plot is sold.
	Maxima on the transacted area	France, Hungary, and Lithuania	In France, the SAFER can refuse a transaction if it considers the amount of land sold is too high. In Hungary, an individual farmer can own and cultivate up to 300 ha while a legal entity (farming company) is not allowed to own any agricultural land and can only cultivate up to 2,500 ha (leased) land. In Lithuania, there is an upper limit on the amount of land that can be owned by natural person or legal entity (up to 500 ha).
Protect the land owner and prevent fragmentation	Minimum rental prices	Austria, Czech Republic, and France	In France, there is a legal minimum rental price for all land transactions, which depends on soil quality and location of the plot. In the Czech republic, there is no legal minimum price of agricultural land, but in case of disputes between the owners and the tenants, the government can decide to set the rent at 1% of the "administrative price" of the plot.
	Maximum duration of the contract	Finland, Sweden, Hungary, and Poland	In some countries, there are restrictions on the maximum duration of very long rental contracts, but these measures cannot be considered to protect the owner. For example, in Bulgaria, there exist "Arenda" contracts with a maximum duration of up to 50 years and in Belgium, there exist "erfpacht" contracts which can have a maximum duration of 99 years.
	Minimum plot size	Germany, Bulgaria, Estonia, Lithuania and Slovakia	In Germany, when a landowner wants to split a plot of one ha, they will need to have permission from the local authority. In Bulgaria, the minimum plot size for agriculture land, pasture land and vineyards is 0.3, 0.2 and 0.1 ha respectively. In Lithuania, the legal minimum plot size is 0.01 ha.
	Pre-emptive buying right of co-owner	Italy, Portugal, Czech Republic, Hungary, Lithuania, Poland, Slovakia and Slovenia	Co-owner of land has priority to buy land in order to prevent land fragmentation when a landowner want to split a plot.

Table 26 Land market measures in the EU countries

Source: Swinnen et al. (2013) [16, p.69-70].

7.2.2 Land Market Regulations

The European Association of Rural Development-AEIAR[19] analyses and discusses the existing land market (free and rented) regulatory provisions in member states. Land market regulations in the EU Member States differ from each other depending on the structure of agricultural land in the States. Regulations delineate the conditions for the land market. Some have laws on land market while others have institutional arrangements. Regulations include the authorization, pre-emption rights, maximum acreage, land abandonment, price review, and required qualifications for the farmers to own agricultural land. There is a dual land market structure in Poland: private and public land market; while this is not the case in other countries. Land lease is also regulated in the member states, except for Hungary and Lithuania. Conditions are set in the land market laws and land lease also needs to be approved. Among conditions are the age of the tenants, the terms of the rental agreements, career of the tenant, size of the land leased, residential building, necessary farm equipment, limits on land leased (the length of the contract, the status of parties), pre-emption rights and price control. The transfer of shares in farming companies or agricultural land companies are not regulated in the Member States except for Germany and Poland. In some EU countries, there is not a regulation on having agricultural land by foreigners in and outside the EU while some do have them. Additionally, in some cases, sales of agricultural land to foreigners need to be approved by the authorities.

Countries	Regulation of the land market	Regulation of land leases	Regulation of the transfer of shares in farming companies or agricultural land companies	Regulation of access to the agricultural profession
Germany	The Federal Länder administrative authorities must approve the sales of agricultural land ranging between 0.25 and 2 ha. The authority can refuse the approval in the following cases: If the sale will lead to poor distribution of the land and If the agricultural structure worsens; The sale price is disproportionate, exceeding the market rate by over 50%. The limit in Baden-Württemberg is 20%.	The Federal "Law on land lease" controls the lease of land. Land Government Authorities approve new agreements and significant changes.	The sale of shares and securities in agricultural companies does not require any approval.	No regulation.
Belgium	The Flemish Land Agency (VLM) has a pre-emption right in integrated territorial development projects. Land prices can be negotiated, and the transactions do not need to be approved.	In addition to pre-emption, term of rental agreements have to be a minimum of 9 years. But, it may be 18 years or more, a 'career agreement' of minimum 27 years, also very long-term agreements with construction rights. Rental price for a 9 year rental agreement is regulated. No quantity restrictions.	No regulation.	No regulation.
France	SAFERs are responsible for observing land transactions, setting-up and restructuring agricultural and forestry structures. There is a pre-emption right that must be justified and approved. SAFERs are entitled to a price review.	The rental market is not regulated directly. The rental price is controlled. It must fall between fixed price brackets. Conditions: a) Beneficiaries must not be over retirement age, b) Provide evidence of professional capability or experience, c) Farm the repossessed land for a minimum of 9 years and participate fully in the farming of the property, d) Occupy the residential buildings on the repossessed property or a local residence, e) Have the necessary livestock and equipment.	No regulation.	There is no farming-specific system of intervention or monitoring relating to the influx of foreign capital in farming.
Hungary	Questionnaire Law CCXII (112): Law limits the amount of land acquired and used.	No regulation.	No regulation.	Legal entities are not able to acquire land.

	Purchase land shall be incorporated in a contract. A pre-emption right exits. Resident individuals and citizens of MS that are farmers can own land. Investors not engaged in agricultural production cannot own land. Only individuals cultivating land can own. The maximum size can be 300 ha. The maximum permitted size of land held in possession is 1,200 ha. Feed producer can have 1,800 ha for seed production in an isolated area.			
Italy	The Institute of Studies, Research and Information on the Agricultural and Food Market encourages farm transactions. The public assets are reallocated by privatizing and eliminating the large farms through an action. Assistance for setting up young farmers. There is a pre-emption right to the owner cultivating and/or by any tenant who has been farming there for at least 2 years. Pre-emption rights have been extended to farming companies of which at least half of members are farmers with professional skills and capabilities	Rent control is fixed by law. Tools are regarded as being too restrictive. The term of the lease is fixed at 15 years. They provide full protection for all tenants.	No regulation.	No regulation.
Lithuania	The rule is the pre-emption right without price revision for farmers and agricultural companies. To invest in farms one has to reside for more than 3 years in Lithuania. These restrictions do not apply to rentals. Land abandonment was avoided. Speculations are restricted.	No regulation.	A seller must offer his share to the co-owners first. The transfer of company shares is not under control.	No regulation.

Poland	There are two different agricultural land markets: The private agricultural land market including all transactions (lease and sale) whether owned by individuals or legal entities. The public agricultural land market (land belonging to the Treasury) where transactions can be done between the Agricultural Property Agency (ANR) and the buyers. Family farms can be up to 300 ha in size.	There is no specific limit for the leased land, the length of the contract, the status of parties to the transaction and for Polish citizens or foreigners. Exceptions in leasing public land: Tenants leasing public land have a pre-emption right to buy if on sale. Lease land over 500 ha needs approval by the ANR. Short-term lease agreements on public land are also possible.	The transfer of shares in agricultural production companies requires the authorization of the Council of Ministers.	The purchase of agricultural or forestry property by foreigners needs approval.

Table 27 Land market regulation in the EU countries

Source: AEIAR (2016) [19].

The nature of land markets in Europe differs both over time and across countries and in terms of regulations of land exchanges. _Data on land measures based on 15 variables was collected and grouped in four sub-indicators: (1) Tenant Protection Index (TPI); (2) measures to protect the owner-cultivator—Owner Protection Index (OPI); (3) measures to protect the owner; and (4) measures to prevent fragmentation. In addition, aggregate Land Regulation Index (LRI) was also taken into account[16]. The indicators reflect the large differences among the EU countries in land market regulations, and again the variation in interventions is not a simple East-West divide. That is, there is enormous heterogeneity in land markets and regulations in Europe. For the 24 EU countries, the most regulated land "markets" are in France (TRI = 9) and Hungary (TRI = 8). The most liberal regulations exist in Ireland (TRI = 0), Greece (TRI = 0.25), the UK (TRI = 0.5), Romania (TRI = 1.5) and Czech Republic (TRI = 2.5). France has a high regulatory index for both rental and sales markets. Belgium and the Netherlands have a high regulation index for rental markets but not sales markets. Poland and Hungary that have high regulation index for sales markets but not for rental markets. Correlation between the share of land renting and the TPI is positive but weak for the EU as a whole. Relationship is much stronger in the Western countries than in the Eastern countries. Extensive regulation of land rental contracts in West European countries constrained re-allocation of land. This led to so-called perverse effects and encouraged landowners to sell. The first strategy was to improve the rental conditions for the tenants through regulations, including better conditions in case of contract termination, such as compensation for land improvements and automatic rights for rent renewal and pre-emptive rights. The second strategy was to help the tenant become the owner of the land through government subsidies to buy the land, stimulating the demand for land or through increased land and inheritance taxes, stimulating the supply of land. In both strategies, market prices for non-regulated land increased much stronger than regulated land prices. The strong price distortions are due to the regulations. In response to these developments, countries relaxed some of their regulations.

7.2.3 Rules/restrictions on purchasing/selling/renting land

As in the case in all factor and commodity markets, there are some institutional regulations in the EU agricultural land markets as price regulations, tax regulations, and quantitative limitations on the sale, purchase and use of agricultural land. The two main agricultural land sales price regulations are minimum and maximum sales prices. They have quite different implications for seller and buyer behavior. A minimum price lowers land demand if the market price "unregulated" is below the price regulated. On the other hand, if the unregulated market price exceeds the price ceiling imposed, the maximum price reduces land supply. In both cases a black market can arise for agricultural land sales, where the difference between the equilibrium price and the regulated sales price is paid under the table, in addition to the regulated sales price[20]. Since different land sales markets are spatially divided, the market power and negotiation power between the seller and the buyer are always asymmetrical. Market power and thus negotiation strength is usually on the side of landowners, especially for agricultural land markets with family farms[21]. Furthermore, the relative negotiating strength of the seller and buyer is heavily affected by rather high transport costs which spatially divide the land markets[20]. Land taxes also play an important role in the decision of seller/buyer for selling and purchasing agricultural land. Land sales taxes are usually meant to deter land price inflation by absorbing profits from land sales. In comparison, purchasing and usage taxes influence farmland buyers' behavior. According to the results of the project entitled "Study on the Functioning of Land Markets in the EU Member States under the Influence of Measures applied under the Common Agricultural Policy"[17], which was undertaken for the European Commission, low sales taxes on agricultural land and SPS entitlements promote structural changes in agriculture by reallocating agricultural land and entitlements from less productive to more productive farms (e.g. Germany). Farmland markets in low-tax countries are more open to non-agricultural investors' speculative purchasing/selling (e.g. Finland). Differentiated ownership taxes on agricultural land for farmers and non-farmers decrease the incentive to speculative long-term farmland purchases (and sales) by non-agricultural investors and hinder systemic change (e.g. Greece). Drivers for sales prices of agricultural lands indicated in the report of the project can be listed as agricultural commodity prices, agricultural productivity, both coupled and decoupled agricultural policies, less favored area and environmental payments coupled to the land, requirements for manure spreading area, and investment subsidies. According to EEA[22], the institutional framework with regard to agricultural land market is composed of "legal framework", "cadastral systems, land registers and tenure security", "transferability of properties, transaction costs", "land taxation systems" and "financial markets; especially access to credits, such as options for mortgaging land and real property".

Rules regulating the transaction (purchasing/selling/renting) of land are approached from the perspective of tenants and owners. In the EU, as mentioned before, tenants are protected through impositions of minimum rental contract duration, maximum rental prices, automatic rental contract renewal, conditions for rental contract termination and pre-emptive buying right of the owners/cultivators are also protected by similar land market regulations such as restrictive conditions on the owner (for. ex. nationality), maximum sales prices, pre-emptive buying rights for neighboring farmers and an upper limit for area transaction by the tenant[16] .

Transactions of foreign investors to buy or rent land are restricted particularly in the new member states of the EU. Low land prices can become attractive for big foreign investors however this may create an unequal right in those countries in which average level of income is low and rural credit markets are poor-functioning. Restrictions on foreigners may show differences among countries[16][8].

Kay [23] provided a brief report on land grabbing in the EU countries. According to this report, land grabbing is a contested term and it does not necessarily imply illegal land transactions or it is not just an issue about legal status of the land. From a social justice point of view, land grabbing deals with illegitimate capturing of the decision making power over how land is used, by whom, for how long, and for what purposes. Today in Europe, the process of land concentration and land inequality particularly affect small farms and land grabbing has become an active factor in the weakening of the socioeconomic and environmental vitality of the rural sector through control, privatization of farmland and/or dispossession of natural resources. This process of land concentration and land inequality has particularly affected Europe's small farms[9] [5] (average size less than 10 ha agricultural land) and the natural outcome of small, family farms exiting form agriculture became a barrier to entry into agriculture for young farmers. Furthermore, land grabbing also acts as an additional factor to land concentration, market forces and other structural and institutional barriers against entry to farm business for young and aspiring farmers. Today the CAP (system of direct payments) in the EU favors the expansion of large, industrial farms and the share of small farms benefiting from policy regime is quite small. This situation yields the conversion of land from agricultural to non-agricultural uses and transfers of prime agricultural land to urban sprawl, real estate interest, tourism enclaves, and other commercial undertakings[10] [6]. To conclude, the processes of land concentration, land artificialization, and land grabbing cause small farmers to lose control over land which leads to land transfer to fewer hands. Hence, democratic decision-making power is worsened. The exact measurement of the scale of land grabbing in the EU is quite difficult. While official statistics lack information on land grabbing due to their focus on large scale agricultural land and to the belief that land grabbing is in small rates, there is supplementary evidence collected from field trips,

[8] See Appendix Section A for various country-specific applications in the EU; Appendix Section B for various country examples in the Eastern and Western Europe; Appendix Section C for various other land regulation practices in various European countries.

[9] Between 2003 and 2013, the number of holdings of less than 10 hectares dropped by a third. Small farmers owning less than 10 hectares lost control over a quarter of their land. In contrast, the utilized agricultural areas occupied by large farms in the EU grew by 15% over the same period of time."[23]

[10] Land artificialization: conversion of land from agricultural to non-agricultural uses.

local research etc. suggesting that much of the information regarding land is not captured. The geographical distribution of land grabbing in the EU is uneven and the information on it indicates that farmland grabbing is concentrated in Eastern European Member States. One of the main reasons for this fact is that land prices in Eastern Europe are cheaper compared to Western Europe. Therefore it becomes attractive for investors to acquire farmland in these countries. Secondly, in some cases, the outcome of post-Communist land privatization, restitution and consolidation programs have been the emergence of dualistic agrarian structures in which land use is both highly concentrated and highly fragmented, facilitating farmland grabbing. Thirdly, lax enforcement of regulations and corruption can contribute to various controversial land deals and land grabbing in Eastern Europe. There are a number of features that are associated with land grabbing in Europe. In the European model, farming is still based on small, family farming; however, landholdings acquired through grabbing can amount to thousands of ha thus representing a deviation from the system in Europe. Sometimes, land is acquired by foreign capital owners and they become a member of the newly emerged asset class, made up of banks, investment, pension funds, and other financial actors controlling an ever-increasing share of European farmland. The lack of transparency in land deals in a number of EU countries is another fact and issue. The discrepancies between official records and local realities imply that land markets do not operate alone but there is also an extra-economic force.

Land grabbing, because of interest in the complexities of the phenomenon and negative effects on sustainable development of rural agriculture, has become a priority subject in academic research and political concern. This phenomenon leads to changes in agricultural production systems with unfavorable environmental consequences. It adversely affects socio-economic and cultural conditions and leads to a decrease in agriculture overall[24]. The Tirana Declaration[25] defines land grabbing as one or more acquisitions or concessions, including: a) violation of human rights, especially women's equal rights; b) the failure of the land users' concerns regarding their free, prior and informed consent, c) the lack of a thorough assessment or a lack of regard for, including gender-based, social, economic , and environmental impacts; d) the absence of transparent contracts that specify clear and binding commitments on activity, employment and benefit sharing; and (v) the absence of effective democratic planning. The debate on large land acquisitions (LSLAs) is complex and reflects the views of two main actor categories. The first point of view argues in favor of large companies which mobilize capital and control large areas of land and promotes the need for farming restructuring by concentrating sufficient size areas to encourage the modernization of agricultural systems. They concentrate on intensive technology and global market penetration through foreign investment and export growth. The other view represents the concern of those who historically use land (farmers, pastoralists and indigenous people) and have small-scale farms who say that LSLAs are threatening human rights, food security, employment, environmental quality and sustainable rural development. The effect of the LSLAs is not easy to quantify and needs monitoring in the sense of the international community's Sustainable Development Goals[24]. Key findings of the study[26] for European Parliament's Committee on Agriculture and Rural Development about the extent of farmland grabbing in Europe can be listed as follows.

- A heterogeneous set of actors, including foreign and domestic, state and non-state, natural and legal individuals, is involved in farm land grabbing in EU.
- Besides the establishment of large, corporate agricultural companies in Europe involving capital from all over the world, a new class of financial investors has been founded who are not involved traditionally in the agricultural sector, consisting of banking groups, investment funds, traders, and private equity companies engaged in EU acquisition of farmland. The acquisition of farms in Europe also involves a new set of "land deal brokers" which includes speculators and scammers mediating company and state interests in land.

- Compared to the older EU Member States, the relatively low prices of land in new countries of Eastern Europe have been a major incentive for investors to acquire farmland in these countries, and have fostered land speculation and artificialization processes.
- Land reform processes led to the emergence of highly dualistic agricultural structures in the former Socialist Member States that paved the way for farmland grabbing.
- Dramatic land processes within the EU coincided with the concentration of CAP subsidy benefits in the hands of less and more large land holdings.
- High and increasing rates of food market concentration in the EU allow for the excess of buyer power, undermines farmers' incomes, and makes them more vulnerable to agricultural land grabbing and land concentration processes.
- EU Bio-energy policy has been encouraging new investors involved in the increase in energy crops to acquire agricultural land and to increase land prices, especially the 2009 Renewable Energy Directive.
- Together with high capital costs of EU agriculture, agricultural land grabbing contributes to the exit of small-scale farms across Europe and prevents the entry of young and aspiring farmers. Farmland grabbing is replacing the European family farm model with large scale farmers, with negative consequences for Europe's food and local food culture and potentially European food security over the long term. Against long-term processes of rural decline, large-scale land deals, through owning, privatizing and/or disposing of natural resources have been an important factor in further weakening the rural sector's socioeconomic
- The grabbing of farmland causes land and environmental degradation by replacing a model of family farming based on healthy agricultural practices with an industrial farming system that is highly dependent on the production of monoculture and the intensive use of agrochemicals.

7.2.4 Different contractual arrangements in the market for rented land

Just like in sales markets, minimum rental prices can reduce land demand while maximum rental prices can reduce land supply. Generally, agricultural land rental prices are more regulated than land selling prices. Black market for agricultural land tend to exist in countries with regulated rental prices. SPS tends to increase rental prices for agricultural land in the black market (e.g. Belgium) and black market sizes (e.g. Belgium and the Netherlands). In order to circumvent the strict rental regulations, market participants developed a so-called "gray" rental sector in which farmers' contract outside the official system. Today, gray rents are not reported to the authorities and they are 50% higher on average than the land rented and officially registered. To stop the ongoing deterioration of the formal rental sector, there have been more liberal forms of rental contracts. Since 1 September 2007, rental deals for less than 6 years are not subject to any of the regulations. However, contracts of more than 6 years remain subject to restrictions[20].

7.2.5 Fixed/controlled rental/purchasing prices

Rental contracts for farmland are often regulated and have a long duration. In some cases, clauses apply preventing rents from rising quickly when renewing contracts[11]. Rentals being regulated, their evolution depends on regulations setting the minimum and maximum prices. The latter are based on gross farm incomes. Thus, gross farm incomes and their drivers indirectly affect rentals[18]. The agricultural land prices in France had continuously increased for 15 years until 2008. Although not a major factor, the capitalization of subsidies in sale and rental prices of land is one of the reasons for farmland price goes up. Competition with non-agricultural uses of land is the main up-driver of agricultural land prices. It is expected to continue for the next years. Farmers' anticipations regarding uncertainty of the policies such as direct payments or single farm payments (SFP) also may reduce the land market activity in the next five years. However, other factors may contribute to an increase of the transactions, such as agricultural prices and bio-fuels. In addition, the socioeconomic, agricultural and legal conditions also influence land markets[18]. The drivers for rental prices for agricultural lands are listed to be agricultural commodity prices, agricultural productivity, both coupled and decoupled agricultural policies, usage for bio-energy and farm size[18].

7.2.6 The role of "environmental/green factors"

EEA [1] reports the JRC estimates on land-use change the EU. Land take for urban, infrastructure and industrial purposes exceeds 1,000 km^2 per year. About 16% of land in EU is subject to water erosion and 6% is affected by wind erosion. In addition, 45% of Europe's soils have a low organic content and soil contamination is widespread, affecting three million sites. In addition, Intensive agricultural production due to the CAP has an impacts on soil erosion. The Natura 2000 network was developed under the Birds and Habitats Directives. It protects for almost 20 % of EU territory. Almost half of which was not previously protected under national legislation. In these areas, it is believed that land take has been reduced sharply and land degradation has potentially reversed[1]. The 7EAP and EU biodiversity strategy for 2020 put an emphasis on the 'greening' measures in the CAP, through crop diversification, protection of permanent grassland and the maintenance of ecologically valuable farmland and forest areas. Territorial agenda of the European Union 2020: Towards a more competitive and sustainable Europe of diverse regions addresses land issues, an informal strategic policy paper. In summary, several EU policy documents draw attention to approaches and measures that address land take and land degradation[1].

Renewable energy sources include wind, solar, hydroelectric power, tidal power, geothermal energy and biomass. The 2030 climate and energy policy framework for the EU in 2014 sets out the targets Member States have to meet collectively: to increase the share of renewable energy and increase energy savings by at least 27% by 2030. The Renewable Energy Directive (2009), the Fuel Quality Directive (2009) and Directive 2003/30/EC all address the importance and the role of renewable energy [1]. The JRC-IPTS published a report in 2010 which assessed the impact of The Renewable Energy Directive on land used with AGLINK, ESIM and CAPRI for year 2020. According to the study results of AGLINK, arable land increase 1.44 mn ha and pasture land decline 1.12 mn ha as result of the directive. According to the report, ESIM indicated that total amount of agricultural land will increase 0.700 mn ha. Finally CAPRI confirms that amount of arable land will increases while pasture and follow land decline[27].

Promotion of biofuels has important impact on land and agriculture, therefore, environment, as well as GHG emissions. The Renewable Energy and Fuel Quality Directives aims to limit the potential side-effects of biofuel policy target: 'biofuels and bioliquids. These provisions focus mainly on climate issues related to biofuels. European Commission proposed to limit the share of 'energy from biofuels produced from cereal and other starch rich crops, sugars and oil crops' to 5 % of the total energy consumption of transport by 2020[1].

Two EU Energy Policy: Trans-European energy network (TEN-E) and renewable energy (biofuels and biomass), affect the land. TEN-E investments lead to direct land take and land fragmentation, with a low impacts while biofuels promotions put a pressure on land, change land-use, and intensive agriculture[1].

Agricultural land covers 47 % of the EU territory while forests covers approximately 37 %. As a result, the EU's CAP has a key role addressing climate change, through mainly sustainable land management. The CAP changed over time from production support and market stabilization to more market oriented policy. Environment-related considerations took a large space in the CAP progressively. Currently the main source of support for farmers is direct payments largely decoupled from production[1].

Soil and carbon stock are put under good agricultural and environmental conditions (GAEC) requirements in the legislation for the 2014–2020 with three specific requirements: minimum soil cover, land management to limit erosion and maintenance of soil organic matter. Second pillar program requires at least 30% of the resources allocated to each rural development program (RDP) such as Natura 2000 areas, agri-environmental climate measures, organic farming, and forestry measures to improve the sustainability. Most of the rural development programs are also subject to cross compliance requirements like direct payments. Direct payments have been a main driver for the intensification of agriculture. It therefor affects the soil degradation. However, the decoupling of direct payments mitigated these direct impacts of the CAP on land resources. Decoupling can result land abandonment for extensive farming in particular. This can negatively affect land, including erosion. Cross-compliance and rural development payments have addressed land use, management and degradation. Through the agri-environmental measures spending for rural development can also have positive impacts. Greening measures could reduce land degradation. Results of these measures depend on the implementation of the MSs [1].

The new investors involved in energy crops production has been encouraged by the EU bio-energy policies, particularly the 2009 Renewable Energy Directive, to acquire agricultural land and to increase land prices[26]. Similarly, the recent introduction of a phosphate scheme has placed upward pressure on land rental prices in the Netherlands[28]. Gutzler[29] assessed the impact of the renewable energy law (EEG 2000) and expansion of irrigation use on agricultural intensification in the federal state of Brandenburg, Germany. They used the DSPIR (driving forces, state, pressures, impacts and responses) analysis framework purposed by European Environmental Agency (EEA) together with a mathematical programming model for the evaluation. The results of assessment indicated that considerable potential for agricultural intensification is exist. The assessment also found that intensification has been accompanied by adverse environmental and socioeconomic impact.

7.2.7 The role of policy (support to) on agriculture in determining dynamics in the land markets

Recently, the discussion on the capitalization of government support into land prices gained importance through the increasing share of rented agricultural area in most part of developed world. Empirical investigations of the capitalization rate have been applied since Hedrick's work in 1962[30]. The agricultural subsidies and their capitalization in land values have been widely studied. Until the decoupling of policy support in the late 1990s in the US, and in the EU in 2003, the studies mostly focused on the amount of capitalization of agricultural subsidies which were coupled to production decisions such as production quotas or policy interventions[31][32]. The reform of the CAP 2003 introduced single payments that are quite decoupled from the decisions taken by farmers on production[33]. Especially after the CAP Reform in 2003, studies about the impact of decoupled subsidies emerged. The studies about the impact of CAP Reforms on land values show that the SPS capitalization entirely depends on the ratio of eligible area to the total number of entitlements. If there is a deficit of the allocated entitlements when compared to the eligible land area, then the farmers benefit from SPS and it is not capitalized on land values. However, if there are surplus allocations, then the SPS is capitalized on land values so that landowners benefit instead of farmers[34]. According to Swinnen and Knops[16], it is necessary to incorporate both first and second-order (direct and indirect) effects for policy impacts on land markets to be properly modeled. A large number of theoretical and empirical studies have examined and contrasted the effects on farmers' decisions and incomes in developing countries of various income support instruments (market price support, production subsidies, factor subsidies, coupled and decoupled payment, etc.). Many of these studies only take into account the direct first-order effects of policy instruments, as they presume that farmers' prices of input/factor are exogenous and are not influenced by policies. Besides these direct first-order effects, most of the agricultural policies implemented also lead to further adjustments in the second-order. In fact, farm subsidies do not only influence the factor reward but also the factor demand, prices of factors, inter-sectorial factor allocation, factor ownership etc. through altered farmer incentives. Latruffe and Le Mouël[35] reviewed theoretical and empirical literature and drew some conclusions with respect to how agricultural subsidies are translated into higher land values and rents. In other words, how the subsidies increased landowners' benefit instead of agricultural producers are clarified. The review based on agricultural production theory showed that agricultural support policy instruments contribute to increase the rental price of farmland. Moreover, the extend of which, the rental price of farm land increase closely depends on the level of the supply price elasticity of farmland relative to those of other factors/inputs. On the other hand, it vary according to the factor/input substitution possibility in agricultural production. The total of 18 empirical literatures using the present value model (13), the hedonic price model (2), producers' profit maximization (2), and ad-hoc regression (1) published over the period of 1989-2006 showed that land price and rents have a significant positive response to government support, consistently less than unitary "elasticity of supply" (Es), or inelastic supply elasticity (Es<1). Regardless of the policy instrument, the lower the elasticity of farm land, the higher the increase in the rental price of farm land. Generally, studies indicated that land prices are more responsive to government support-based return than to market-based returns. Killian et al.[34] discussed the effect of the Fischler Reform in CAP whose main modification was the implementation of SPS that replaces the payments paid per ha or animal by single farm payments by making a comparison between the periods before and after the reform. Authors also empirically tested the effect of single payments on the rental prices of lands, whether or not the payments are capitalized in the prices, and, if so, what the capitalization ratio is in Bavaria, Germany. The data set included observations at municipality level in Bavaria in 2005 when the SPS started to be implemented. According to the results of their empirical analysis, decoupled payments were found to be more capitalized into rental prices than coupled (with production) direct payments between 1992 and 2004. One additional euro of direct payments would increase rental prices ranging from 28 to 78 cents and the capitalization ratio was found to be higher after the Fischler Reform (15 to 19 cents increase in the capitalization into rental prices). The study also showed that the land price and the capitalization ratio did not (and will not) decrease due to the Fischler Reform, the authors suggest to decrease the number of single farm payments or the implementation of Bond scheme, proposed by Swinbank and Tangermann[36] which includes a transition of payments in completely decoupled and tradable bonds, to overcome the possible competitive disadvantages that EU countries may have. Feichtinger and Salhofer[30] provided an overview of the theoretical foundation, empirical procedures, and derived results of the literature identifying determinants of land prices. The authors also estimated a regression model both for the net present value (NPV) and the hedonic price framework using empirical findings/inputs from 26 published articles used theoretical bases, either econometric form of NPV or the hedonic price model, measuring the effects of different government support polices on land prices. In the light of reviewed literature, the variables explaining to land value are classified into two major and six sub-groups; internal/agricultural variables (agricultural production and government payments) and external variables (market, macroeconomic and urban pressure).

According to the meta-regression results, total government payments capitalize into land values with an elasticity of 0.388, with a 95% confidence interval between 0.293 and 0.483. There are no significant differences in the capitalization elasticity for market price support and direct payments compared to aggregated payments. Compared to total payment, capitalization elasticity is higher (+0.143) for decoupled payments and significantly lower (-0.184) for agri-environmental payments. Neglecting non-agricultural variables in the regression results in a 14.8% point higher capitalization rate. It was verified that the land type, the data type, and estimation techniques have a significant influence on the capitalization rate. Swinnen et al.[17] in their literature review on the empirical attempts to estimate the impact of agricultural support policies on land value were classified into two broad categories as land price and land rent studies. While the theoretical explanations, and hence the empirical specification between the two approaches, may differ considerably, usually the choice between two alternatives is determined by data availability: the availability of either land price (typical from regional datasets) or rental data (typically from farm-level survey).

The large majority of early studies have estimated the net present value of land as a function of government payments and other explanatory variables. More recent studies, however, tend to use farm level data and estimate the capitalization of subsidies in rental prices. The empirical findings from the studies on land capitalization of agricultural subsidies can be summarized as follows. (i) Landowners benefit from decoupled subsidies. (ii) Land capitalization of decoupled subsidies varies between 6% and more than 100%. (iii) Large variations in the estimated capitalization rate between different studies does not allow to reject the theoretical hypothesis of subsidy capitalization. Theoretical studies on EU direct payments found that the impact of direct payment on land prices depends on (among others): the ratio of land entitlements to eligible land (for SPS), the implementation of the SPS model (historical vs regional), the tradability of entitlements (for the SPS), the elasticity of land supply, cross-compliance requirements, land market regulation, credit market constraints, the length of the rental contracts, and bargaining power in the land markets. The studies found that between €0.06 and €0.94 per additional the SPS payment is "capitalized in land prices" in the EU-15. In other words, each additional euro of the SPS leads to an increase of land rents between €0.06 and €0.94. In the NMS, land sales and rental prices have increased strongly with the increases in single area payment system (SAPS) since accession in 2004. Correlation between the direct payments and land prices is very strong in those countries. Studies found that rental price increases in the NMS. There is stronger capitalization of SAPS in more credit constrained markets, and lower capitalization in countries where more land is used by corporate farms, reflecting a strong bargaining position of the farms in the land market. Swinnen et al.[16] examined the effect of the SPS with and without structural changes in farms and concentrated on the impact of the SPS on income distribution and farm restructuring through alternative entitlement tradability, cross-compliance, and greening requirements of the CAP, various models for SPS implementation, entitlement stock, market imperfections, and regulations on institutions. The authors stated that the details of the SPS implications are very important for the distributional effects as farmers benefit from 100% of the SPS value to a negative policy effect and SPS implication can have disruptive effects on farm structural changes.

Ciaian et al.[37] assessed the impact of the 2013 CAP Reform on the decoupled payments' capitalization into land values. The authors used a stylized land market model with an upward sloping land supply with respect to the land rental price, a downward sloping land demand with respect to the land rental price, and exogenous output and input prices. The change in rental price given a change in the value of the marginal decoupled payment was calculated as land demand elasticity is divided by differences between land supply and demand elasticity. According to the formula, in an extreme situation with a fully inelastic land supply, the marginal decoupled payment is fully capitalized in land rents. The average capitalization rate decreases (increases) with the land supply elasticity (demand elasticity). The average capitalization rate for the 2013 CAP Reform further decomposed into four different reform element; budget change and external convergence of payments; internal convergence payments; differentiation; entitlement allocation method, if entitlements are in surplus. The authors found that, on average in the EU, the 2013 CAP Reform caused the increased capitalization rate of decoupled payments into land rent from 34% in the pre-reform period to 51%. This result imply that the reform caused land rental price to increase by an additional 18 cents for each euro of decoupled payment relative to the pre-reform situation. The capitalization rate slightly reduced in NMS (from 83% to 79%) whereas it increased in OMS (from 21% to 43%). These results also suggest that the main source of capitalization in the EU is the pre-reform capitalization (69%), entitlement stock change (19%), internal convergence (18%), budget change (1%) and the differentiation of payment (-7%). Based on the estimated capitalization rate and the FADN data on the share of rented land, the non-farming landowners' gains from decoupled payment, on average, increased from 18% in the pre-reform period to 27% in the post-reform period (from 44% to 42% in NMS and from 12% to 23% in OMS). Given the amount of decoupled payments in the EU CAP budget (€37 billion), non-farming landowners' gain a relatively small to moderate part of decoupled payment.

7.2.8 External factors affecting land market

Smith et al.[38] reviewed drivers and pressures that influence competition for land and they examined land use changes, both in retrospect and in future prospect. The drivers (underlying causes) and pressures (direct causes) of land competition are each classified into three sub-group of factors. The first group of drivers was named as socio-economic and technological factors which consist of technology, trade, macroeconomics, infrastructure investments, commodity prices, and demand changes, and market failures. The second group of drivers, named societal trends, include population growth, agricultural intensification, dietary changes, non-food goods and services, urbanization, economic development, migration pattern, and cultural factors. The third group of drivers entitled as institutional factors include land distribution, land-tenure security, land use policies, regulation and degree of illegality, institutional capacities, and governance. The first pressure group, named natural causes, includes hurricanes, natural fires, pests, floods, water availability and global warming. The second group of pressures, named land transition, include crops and pasture, urban sprawl, road building, forest clear-cutting (i.e. pulp, paper), and oil-mining. The last pressure group, named land degradation, includes of logging, induced fires, over-grazing, firewood-over harvesting, and defaunation.

Latruffe et al.[39] estimated the determinants of agricultural land prices in Brittany (a French region) with individual transaction data for the period of 1994-2010. They found all variables used as proxy for the revenue from non-agricultural use of land are positive sign (i.e. the price of the land increases under increasing urbanization pressure). The environmental regulation variable has a positive effect on land prices, which indicates, as predicted, land prices rise because of the competition among non-agricultural uses.

Farmland values are driven by a complex set of factors, including variables that affect expectation about future agricultural returns, alternative investment options, and macroeconomic conditions. Farmland prices also vary across location due to the urban influence, differences in agricultural production practices, crops suitability, and local policies. In addition, several structural characteristics of farm real estate markets—including idiosyncratic property features—ownership concentration, unique rental market features, and very thin transaction markets –may make farmland price dynamics appear to be more complex than those of traditional financial assets. Farmland markets may also be impacted by broader trends that affect other assets. With the stock market at high records and bond yields near historically low levels, investors accept a higher discount factor for future anticipated income; essentially, price-to-earnings ratios have risen or, alternatively, capitalization rates have declined. Because farmland generates income well out into the future, a similar effect could occur in farmland valuation if farmland markets behave similarly[40].

On the demand side of agricultural lands, different expectations of the role of agricultural land have emerged from society, including the expectations of land to control and purify water, to sequester carbon to contribute to climate change mitigation, to provide a habitat for biodiversity, and to enable sustainable nutrient cycling of animal and human waste streams. Over a series of CAP reforms, such expectations or "social demands" have transformed into a multitude of EU and national policies that seek to safeguard the sustainability and the multi-functionality of European agriculture, leading to a highly complex land management regulation environment. The latest CAP reform aims simultaneously to simplify and improve environmental and climate change policies, creating strategic regional strategies that make it possible for more focused and context-specific policies. In this context, Schulte et al.[2] aimed to make a contribution to the information base behind the implementation of these strategic plans by mapping the changes through society's demands on land functions through EU Member States. The study drew conclusion on the basis of a comprehensive analysis of the current policy framework on sustainable and multi-functional land management. Their study is based on the findings of a workshop at EU level that is organized by the EU funded project, LANDMARK[11] (LAND Management: Assessment, Research, Knowledge) consortium in Brussels in 2018 where a number of European stakeholders identified key potential climate and socio-economic trends in European agriculture, along with the related demand for land and soil resources. LANDMARK has developed a framework for the quantification to which each soil feature can (for six major agri-environmental zones in Europe) be supplied with combinations of soil types, land use types, and land management practices. Authors identified social demand for different soil functions using a variety of datasets that are publicly available such as Eurostat, EEA, and data collected by the JRC for certain projects. Data were consolidated at NUTS levels and presented as a demand per unit of UAA and the maps were created by using ArcGIS 10.2. Eventually, to consider the relative societal demands of all soil functions regarding individual member states, the values for each soil function were converted to z-scores similarly to Schulte[2]'s methodology. According to the results of the study, the societal demands for five soil functions which are *primary production, regulation and purification of water, carbon sequestration, biodiversity and nutrient cycling.* These soil functions are determined by population, farming and livestock densities, and geo-environment and landscaping conditions that are differ significantly between Member States. Furthermore, overall societal multi-functionality demands differ among Member States, with the lowest demand identified for higher EU CAP funding for 'Environmental Security' and regional development expenditure in Member States.

7.2.9 Other relevant institutional or external factors

The economic factors that drive land prices can be categorized as demand, competitive land usage, agricultural productivity, hedging against inflation, and amenities. The quantity of land placed on the market (supply) compared to demand also plays a role. Land values are particularly sensitive to spatial characteristics since market access is as important for farmers as the access for consumers to urban goods and services. The spatial characteristics affecting land prices include the presence or absence of constructions, access to roads, land features (arable land, meadow, irrigated or unirrigated land, suitability for machinery use), and whether the immediate ownership is known. Small areas were often found to be more expensive per ha than large areas, in particular where farm buildings and housing are sold. The statistics do not usually show whether an area sold has a milk quota. The impact of a quota on land prices is incomplete. Land is highly diverse and it is difficult to interpret an average series of land prices that reflect the different proportions of various land types through time[20].

7.3 The current state-of-the-art theoretical methods to assess or model the value/price of owned/rented land

The foundation of the economic theories of land dates back to early 1800s and mid-1900s, but they are still used in current research. Ricardo[41] introduced land rent stemming from differences of land fertility (reflects land quality). According to the land rent theory of Ricardo,

[11] LANDMARK is a multi-actor network composed of 22 information institutes from the 14 EU countries, Switzerland, China and Brazil, which comprises universities, research institutes and extension service. It applies Functional Land Management (FLM) framework developed by Schulte et al. [2] which is a methodology that optimizes the delivery of land based ecosystem services to fulfil societal expectations rather than maximizing it.

land with higher quality generate surpluses over land with lower quality and these surpluses are paid as rent to landlords. Von Thünen[42] model focused on location and transportation costs, which as well as land quality, are characteristics of parcels[43]. According to this theory, rental price of farmland is determined by the demand of farm products in the urban markets and the distance of each parcel of land from that market[44]. Therefore, economic rent per ha of land is equal to the unit profit minus transportation costs per unit market product. Economic rent per ha of farm land decreases linearly with increasing distance from the market and it is determined by yield per ha multiplied by the market price minus the production and transport cots of each crop. Another well-known microeconomic theory of land is called bid rent theory[45] which is used in the context of urban land use and land values. Bid-rent theory relies on correlation between urban land use and land values. Household and companies make a trade-off between the land price, transportation cost, and the amount of land they use which results in a convex land price curve with the highest land price near the city centre[43]. Alonso[45] and others assume that land moves towards the use that generates highest potential income, reflected in bid-prices[46]. From the consumer utility maximization side, according to bid-rent theory[45], households choose locations at a certain distance from the central business district by means of maximizing the utility they get from the joint consumption of a spatial good (land lot or house) and composed good (all other good) under their budget constraint such as income minus transportation cost[47]. The derivation of agricultural and rural land values in the bid-rent theory owes more to Von Thünen's theory than the work of Alonso. The crops that produce the highest revenue at a certain location will be able to make the highest bid and thus will be cultivated on that parcel. The land is sold to household or firm if their bid is higher than the return from agriculture, consequently this situation determines the boundary of the city too[43]. Bert et al., [10] modeled the agricultural land rental market in the Pampas region of Argentina. The major part of the land in the Pampas region is cropped by tenant. The land rental market (in the real world) is named LARMA has endogenously set up land rental price based on Willingness to pay (WTP) of tenants and Willingness to accept (WTA) of landowners. The model is referred to as a hybrid model since it partly relies on neoclassical economic theory, but addresses the drawback of the microeconomic approach by being integrated into an agent-based model that involves heterogeneous agents interacting in a dynamic environment. The shadow prices of land was obtained in AOROPAj[48] aimed to compare land use models based on three different agricultural land rent proxies: farmers' incomes; the price of land and shadow prices of land derived from the model of mathematical programming (AROPAj). This was the first study used land shadow price as a proxy for land rent from agriculture.

Land has special characteristics compared to other production factors such as fixed supply (except land reclamation), fixed parcel location, and the use of a land parcel affects the use and value of surrounding parcels. This last property, called an externality of land use, gives rise to government intervention. The special characteristics of land, externalities and government interventions make complicated the analysis of land market[43]. The lack of reliable land transaction data (i.e. price) and other government regulations makes it rather complicated to analyses land market. In practice, land value and land price is approximated by various valuation methods. Most studies analyzing the determinant of land sales prices either refer to the NPV or to the hedonic pricing approach as basis of their work[30].

The farmland market is much less liquid than the agricultural products markets. The return to agricultural production is one of the key driving factors of the farmland market. Some farmland market can also be influenced by a number of factors, such as the potential conversion to urban development and tax policies including capital gain. As with any product or resource, farmland's price depends upon the supply offered to the market in particular time. The amount of land offered to the market depends significantly on the demographic and investment behavior of landowners. Much of the farmland is owned by older individuals, and as they retire or die, their property is likely to be sold or transferred as a gift or bequest. These types of transfers typically do not have major impacts on land prices because they are in essence non-market transaction.

However, the recipient of the gift or bequest needs to decide whether to sell or keep the land[49]. The decision is clearly affected by the current financial position of the recipient, as well as the returns on an alternative investment that might be made with the proceeds of the sale of the gifted/inherited land. If it generates a higher return than the alternative investments, it is less likely to be offered to the market, whereas a lower return of the farmland compared to the alternative investments would likely result in more property offered to the market by both the retired farmers and their family members. The investment behavior of farmland owners together with agricultural return is significantly affected if retiring farmers and their families sell farmland or rent to other farm operators.

According to a traditional economic theory, called Returns Discount Model (RDM), economic value of farmland can be estimated using the expected annual return to land divided by the capitalization rate (the minimum is the interest rate on savings and the maximum is the interest rate on borrowing from the bank) minus capital gain of land[50][51]. The economic return (discounted stream of excepted return) on farmlands are not sufficient for explaining the behavior of market prices and additional factors should be considered in the valuation model such as investors' risk aversion, capital gain expectation and transaction cost[50]. Many empirical studies indicated that agricultural land values are actually driven by a complex set of factors and farmland values are only partially explained by agricultural returns; multiple non-agricultural attributes of farmland also contribute to the market value[51]; such as development potential of location, proximity to some infrastructures (golf courses and college campus), and median household income. Agricultural land is taxed according to its income potential from agricultural production, typically referred to as the agricultural use value. Borchers et al.[51] found that a divergence exists between agricultural use value and market value. However, without high natural amenity value or urban pressure, the value of agricultural land in excess of its use in agricultural production is also used as a measure of assets price bubbles. Although, RDM has been found to be inadequate to determine land value, a modified version remains applicable to the valuation of farmland. As a matter of fact, it was found to be well performed as a tool to assess change in land prices in Poland[52]. A number of factors should be taken into consideration in agricultural land pricing, of which the most important are the land rent and legislative regulations related to agricultural land[53]. The farmland price can be derived from land rent using universally recognized formula (land price equals to land rent divided by interest rate). Taxes, tax relief, and urban pressure appear to be the main drivers influencing land prices[51][22]. According to EEA[22], institutional framework having impact on land prices are; i) legal framework; ii) cadastral systems, land registers and tenure security; iii) transferability of properties and transaction costs; iv) land taxation systems; v) financial markets; especially access to credits such as options for mortgaging and real property. Swinnen et al.[17] analyzed the farmland prices in the EU countries based on theoretical literature reviews and expert opinions and they concluded that the factor underpinning farmland sales prices are highly heterogeneous across countries. The most common ones are agricultural commodity prices, urban pressures, infrastructural expansion, agricultural subsidies, farm size, and coupled subsidies. Particularly in NMS, direct payment are considered a driver for the increase in land prices. During 2008-2012, rural development payment became a more important driver of land prices than in the 2003-2007 period. In the analysis of the drivers of land prices, the following factors are commonly mentioned: taxes, inflation, buyer characteristics, seller characteristics, land size, subsidies, sales regulations, agricultural commodity prices, agricultural productivity, the distance to urban centers, urban pressure, existence of infrastructures, option values of future land development, and the existence of recreational amenities[22]. It was found that the main determinant of Italian farmland prices are population density, GDP per capita, land productivity, agricultural prices, and farm subsidies[54]. Empirical studies confirm that intensification of agriculture is driving up land rental prices. However, a spatial lag model was applied to the agricultural sector in West Germany using county-level price and cost data of the FADN rejected the null hypothesis of no impact of labor and livestock intensity on land rental prices. The results are not surprising and they are also in line with traditional concepts of production and location theory in agriculture: heterogeneity of land quality or distance to market lead to higher production intensity, larger land rents and, in turn, to a higher willingness to pay for rent[55].

A search in the web of science and scopus (with several key words such as agricultural land market analysis, and agricultural land price/rent/value, etc.) provided several hundreds of articles on land use and land cover change in different disciplines instead of in the agricultural land market. Only a few studies are found related to the agricultural land market. Thus, we searched articles with many different key words related to components of land markets in Google Scholar and found the literature listed in Table 3. Therefore, a systematic literature review using only a few key words was not possible. The articles are given in Table 3 are a non-exhaustive list of land market studies employed non-ABMs tools. As seen in the table, studies, can be grouped as land property price, land supply, policy impact on land rental price and policy impact on land prices. Net present value, hedonic price, logistic regression with land use scanner data, and ad-hoc regression analysis are common methodologies used in the studies.

There are also a few studies used ABM based land use change analysis in agricultural and environmental policy assessment and climate change impact domain which are below. Generally, ABM based studies related to farm land have been focused on LUCC instead of land supply, demand, and prices/rent. In these studies, farm number, farm size, farm intensification were a primary focus and land was treated as an endogenous variable depending of farm profitability and some other conditionality (farmer demographics and social attributes such as age, presence of successors). In many studies, land prices are not considered either or they are treated as an exogenous variable obtained directly from market realization. In the models, the rental price of parcels are obtained from market data (from FADN). Nonetheless, recent ABM based land models treated farm exit/investment decisions in terms of profitability indicators (from FADN) and the demographic situation of farmers (retirement age, having successors). Among these classes of ABM based model, one can mention the Agricultural Policy Simulator (AgriPolis), Land Rental Market Model (LARMA), the evolutionary ABM of Belgium Agriculture, SwissLand Model, and Agricultural Dynamics through Agent-based Modelling (ADAM).

AgriPolis combines agent-based modeling of structural changes with agricultural policy analysis. It was used to investigate the impact of a policy regime switch in agricultural policy on structural change under various framework conditions. The model constructs a virtual world of an agricultural region and comprises a large number of individually acting farms that operate in a region, as well as farms' interactions with each other and with part of their environment. The modeler can completely control the rules of the model. The model was a further advance in the model originally developed by Balmann (1977) to study path dependencies in structural change in the abstract agricultural region. AgriPolis provides an interface to initialize the model with empirical data on individual farms and existing regional agricultural structures. Landscape is the key factor of production in AgriPolis which is represented by a set of equally sized plots. These plots may have several distinguishing attributes: soil type, ownership type, idle land, rent paid, size, and transportation costs, etc. At the macro level, land is of three types: arable land, grassland, and non-agricultural land (forest, roads, etc.). Land also provides the basis for fodder production or manure disposal. In the model, farmers' decisions to exit or stay in the sector are dependent on expected returns for the coming year. If farm's equity capital is zero, the farm is illiquid, or if farm-owned production factors would earn a higher off-farm income than farm income it is rational for the agent to exit. Another reason to exit is in case there are no successors to take place after an agent reaches a certain age (a generational change). For a successor to take over, generated farm income should be at least as much as off-farm income. In the model, farms can extend their ha base exclusively via renting land. Lands are rented either from farm agent landowners or from external, non-farming landowners (not modeled explicitly). Rental land in the market stems from two sources: from farms that have ceased from production and from ended rental contracts. Through a sequential auction the land is reallocated in the AgriPolis[56].

The LARMA model (Land Rental Market) was developed to endogenously determine land rental price (LRP) in the Argentina Pampas region due to the importance of rented land (more than half). The model was introduced as a hybrid model by authors in which it relies partly on neoclassical economic theory, but it addressed drawbacks of the neoclassical approach by being integrated into an agent-based model. The LRP formation assumes economic equilibrium where price established supply of rental land area equals land demand. The LRP depends on: (a) the "willingness to accept" price (WTAP) of owners renting out land due to lack of capital or dissatisfaction with recent economic progress (a Minimum Progress Rate, MPR, is targeted), and (b) the "willingness to pay" prices (WTPP) based on economic gross margin and working capital (WC) of potential tenants. Land owners base WTAP on the estimated profit they could achieve from operating their farms. Potential tenants base WTPP on their target gross margin from the upcoming production cycle. In the model, an economic Progress Rate (PR), defined as the relative increase in farmer's WC over most recent cropping cycles-is calculated and compared to the MPR (defined arbitrarily for each farmers at initialization). If the farmer's PR ≥ MPR, they are satisfied and they will continue farming. Conversely, if the farmer's PR < MPR, they will consider renting out their farm (despite having the WC to operate it) and, therefore, they need to form WTAP. This farmer will actually rent out their farm only if the formed LRP is larger than their WTAP. The second step in the LARMA model involves the formation of WTAP and WTPP. The WTAP is the minimum prices that an owner is willing to accept to rent out their farm.

The authors of the model, assumed that an owner's WTAP is based on an estimation of the profit that could achieve from efficiently operating their farm. In the model, the inherent risk in agricultural production was also considered and it computed the Expected Utility of a range of production income (expressed as a certainty equivalent (CE) income, differentiated by the risk aversion of the owner). It was further assumed that the WTAP equals the CE. An initial experiment with a simplified economic context (input and output prices) did not show significant differences in regional land tenure from LARMA vs. use of an exogenous, fixed LRP. Nevertheless, simulated LRP trajectories reproduced the observed dynamics: prices followed the trajectories of conditions driving crop yields and profits[10].

Maes and Passel[57] built the evolutionary economics based ABM of the Belgian agricultural sector in order to contribute to the effective design of agricultural policies. According to the authors, the effective policy design requires understanding of drivers behind the evolution of the agricultural sector. In this context, evolutionary economics offers a more appropriate starting point to analyze economic transitions and to design policies. The model was calibrated to historical data of production and farm diversity for the period 2003-2013 and it used to compare two types of modeled behavior with the evaluation of sector during the period 2003-2011. The results of the model indicate that rational profit optimizing behavior cannot always explain the past evolutions. The main orientation of the research was to look at the evolution of the agricultural sector in Belgium and the influence of new manure-treatment methods on this evolution. More specifically, the focus was the investigation of structural change in agriculture measured as shifts between different types of producers. In the model, farmland was divided as forage for animal nutrition, pasture and grassland, horticulture, and crops (all other types). The livestock sector is grouped into three broad categories are: pig product (live pig), dairy products (raw milk and cow for sale), and cattle products (including all other live cattle). The land market and the manure and feedstock markets in the ABM were treated as double auctions (react to the quantities and prices requested by farmers) while other markets (capital, fertilizers, investments, and different outputs) were assumed to be exogenous. The prices of these exogenous factors are either assumed fixed or given by external data, but live animal price is econometrically estimated assuming market power in the slaughterhouse market. In the double action markets, any party has the possibility to enter bids for purchase and sale of a good. The double auction mechanism relates sale bids with purchase bids and forms a negotiated price for the transaction. In the evolutionary ABM model, the maximization objective of the farm agent is constrained by the availability of loans and by the level of financial risk the farm agent is willing to take. It was assumed that the loan requirements for investment in land, animals or installations is borrowed from banks, and that the value of the land of the farm is used as a guarantee rather than as a future business plan of the farm agent. The financial risk of the farm agent is defined as the ratio of liabilities over owned assets. Each farmer is willing to take a unique maximum level of risk and the risk preference of farmers decreases with aging and falls to zero at the age of 65.

The model includes two different behavior sub-models, one of them with behavioral diversity, and three different objective functions (profit maximization, expand farm value, and ideal farm structure) with them. The profit maximization objective is constrained by limited choices and loan availability and the farm agent decides on optimal quantity of land, animals, and types for a maximum profit next year. The farm value in the long-run is measured with the entire value of the farm which includes liquid and fixed assets and agricultural land. The ideal farm structure contains certain land surface and animal stocks. This ideal also consist of a full ownership of all land under cultivation and every affordable step that can bring the farm closer to the ideal, is implemented. When achieved, the farmers stops the farm growth and invests only in efficiency. The behavioral diversity consist of growing family farm, stable family farm, innovator farm, elderly farmers, and industrial farm. At the end of the lifetime of the farmer, the farm has to find a successor, or let it evolve into an elderly farm. Succession is a crucial steps in the history of family farms. In the evolutionary economics based ABM of the Belgian agricultural sector, a succession rate of 41% was implemented. Elderly farmers stay active after their pension age and continue farming without further adapting their farm structure. The typology of elderly farms consist of farmers that gradually retire and do not find a successor. They live up farm's assets, maintain the land ownership position and do not invest to achieve higher efficiency and new innovations. The activity only stops when the owner passes away.

ABM based SWISSland is a dynamic recursive system consisting of the modeling of both sectoral supply and sectoral demand for raw products. The interaction of demand and supply as well as foreign trade effects determine the domestic market prices in several iterations. The SWISSland supply module uses an extrapolation algorithm to calculate sectoral parameters. These are primary product quantities and various key structural and income figures, such as land-use and workforce trends, the number of farm sizes and types, and income development according to the economics accounts for agriculture. In the SWISSland model, farm exit is shaped primarily by the farm manager's life cycle. Normally, once the farm manager turns 65 and starts receiving his state pension- which coincides with the lapse of entitlement to direct payment-the farmer either closes down and the land is put up for lease or the farmers production resources (i.e. land and capital resources) are transferred in their entirety to a family successor. The SWISSland model also considers that the farm "exit and entry decision" are significantly influenced by location, size and types of the farm, receipt of direct payments, and form income. The farmers' age, availability of successor, farm characteristics (location, size, types), receipt of direct payment, and farm income are used to establish principal rules which drive agents' farm-exit and farm-takeover in the SWISSland model[58].

Letort et al.,[59] analyzed the impact of environmental regulations on the farmland market and farm structure in Brittany (region in France) using a ABM which is a simplified version (favours simplicity at the expense of realism) of AgriPolis[12] [8]. The model was calibrated to reproduce the

[12] The AgriPolis model, initially built by Balmann (1977) and further advanced by Happe (2004) and Happe et al., 2016 is one of the first highly detailed ABMs creates to assess the impact of different agricultural policy schemes. The AgriPoliS models all production and investment decisions (labour, capital, and land) and farms are assumed to adjust their production and investment decisions accordingly with changing market conditions and policies. Farms interact with each other in markets, including land. Supply of land may increase either through the end of a rental contract or the exit of a farm from agriculture. Land (plot) allocation is realized through auctions (bidding system). A farm values a plot, thus bids for that plot, with the assumption that it minimizes the sum of transportation costs and additional costs. In the auction the

agricultural structures observed in the region and to model the land market in order to analyze structural changes in various economic and political settings. The Brittany region is specialized in intensive livestock production (dairy, pig, and poultry) with various farming practices. The region has been classified as a nitrates vulnerable area since 1994 and has only a small amount of land where manure is spread. The Nitrate Directives stipulates that farmers cannot exceed the application of 170 kg of organic nitrogen per hectare; in 2010, 20 % of framers in the region exceeded this limit. Therefore, these farmers must either treat the excess manure they produce or export it to be spread in neighboring farms and/or areas, including fierce competition in the land market. On the other hand, modifying production practices or production system as a whole lead to changing farm's structures. The ABM assumes that farmers have two non-joint production activities. They raise animals using one specific variable input that includes all expenditures required for their animals (feed, veterinary care, etc.) and at the same time they produce cash crops using one specific variable input that includes all expenditures required for crops (fertilizers, pesticides, etc.). The simplification followed in the model has some implications. First of all, production choice is not modeled, instead all effort is given on economic mechanisms occurring in the land market and land allocation. Second of all, a stylized approach to model the land market is used in which only the economic behavior of farmers is considered but market imperfections are not. Lastly, sales and rental markets for land are not differentiated. Based on the structure above, the model was developed to assess the impacts of changes in various economic or political settings on the land market. The model assumed that labor and capital are fixed in the short run and technologies are variable in terms of stocking density. Therefore, diminishing marginal productivity (decreasing returns to scale) with respect to variable factors (feed and fertilizers, etc.) is the key in production as other inputs (labor and capital) are fixed. Farmers' production choices are not modeled; instead, farmers apply their specific technology to every plot that they own or acquire and with the increase in the number of plots, with constant technology, production increases as well. Therefore, the competition for land among farmers with fixed but different technologies introduces the structural change. When purchasing/renting (does not differ) new land, dairy farmers increase their cattle proportionally to the additional fodder area they obtain; while pig and poultry farmers increase their livestock proportionally to the additional cash crop area they acquire. The model was calibrated such that the simulated land prices are similar to the land prices observed in the sales market of the studied area. Land market interactions consist of four steps in the ABM: farmer bid[13] [9] (their willingness to pay is defined according to the net present value model) are calculated for every plot in a given period and each plot is then assigned to a farmer who offers the highest bid at a prices corresponding to this offer; after the sales are made, each farmer updates the characteristics of his farm: they computes their new total area and the value assigned to each of their plots and deduces the total value of their farm; during an iteration period, land values are calculated by farmers one by one in random order. The model allows to entry and exit of farmers such that for any period, farmers who have not been assigned any plots are removed from the model and do not participate in the next period; on the entry side, the model provides an opportunity for new farmers to enter the market. Potential new farmers are characterized by randomly chosen production technologies and individual characteristics, but they have no predetermined plots. The first step therefore aims at locating each potential new farmers on the plot i) for which they offer a bid hat exceeds any other active farmer's offer and ii) maximizes their own profit. Then, potential new farmers participate in land transfers among all farmers and may become the new owners of several additional plots. The model is calibrated using FADN data from 2010. The input dataset contains information on

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maximum amount a farm is willing to pay for a plot is determined by the shadow price (the difference between the marginal utilization of the plot and sum of the transportation costs and additional costs). The rental price on a plot is defined as the average rent paid in a region.[59]

[13] A "bid" is defined according to the net present value maximizing model.[59]

land plots, farm agents and additional information describing the economic and political context[14] [11]. The baseline scenario represents the reference situation in which all farmers are required to comply with the limit of 170 kg of organic nitrogen per hectare. Then, four different policies were simulated aiming at reducing the same environmental impact of livestock activities in terms of reduction in the spread of organic nitrogen level. Each scenario began with the same initial land market equilibrium. Then, each policy was implemented for one period. Simulation results are interpreted in terms of changes in the land market and agricultural structures from the baseline situation. All the results are defined as the average of the output variables obtained t through the 300 replications.

In order to reduce 2% of the spread of organic nitrogen, four different scenarios were simulated against the baseline. These was a rise in the cost of manure treatment (from 5.5 to 8.5 €/ kg N for all farms), a lowering of the organic nitrogen limit (from 170 to 163 kg N per ha for all farms), environmental zoning (from 170 to 125 kg N/ha in 45% of the area and 170 kg N/ha in the rest of the area), and grass payment (from 0 to 100 or 200 €/ha for farms complying with some conditions regarding the share of corn and grassland in rotation). Simulation confirmed that the agent-based approach is useful in studying complex economic processes that cannot be easily addressed by analytical means and in comparing public policy instruments. The results indicated that the same environmental benefit can be obtained in several ways[59].

The Agricultural Dynamics through Agent-based Modelling (ADAM) was developed to represent the main process driving agricultural land use change in Belgium. It simulates the number of farmers, the size of farms, and the corresponding land use at the parcel level trying to capture the main processes of farms' abandonment or growth[60]. The ADAM model assumes that a combination of internal (farm size and farm types) and external (market, policies, and physical environment) properties give the profitability of a farm (mixed farm ignored). The model is driven by the yearly decision made by individual farmers. The decisions are based on a combination of the characteristics of the farm and they define whether a new farm will be created and whether a farmer continues, stops its activities or takes over an individual parcel or an entire farm. The decisions are steered by external factors such as the availability of new agricultural land, employment alternatives, and the reference wages in the region. Furthermore, the survival threshold for a farm, the characteristics of the parcels, the farmers' age, and the availability of a successor also play a role in these decisions[60].

A major number of the empirical studies employed non-ABMs which aim to reveal the drivers of agricultural land values and the impacts of policies on the land values use either the net present value or the hedonic price methodology. Some of the studies are at regional or municipal level while some are at national. Usually the studies require surveys to betray the land transactions done between the agents, characteristics of the contracts and socioeconomic conditions of the farmers. Often the studies also aim to state the impacts of agricultural policies on land property or rental values, especially whether the recent CAP subsidies are capitalized in land values or not. There are also some studies in the literature which include environmental policy simulations in order to take nitrogen pollutants emissions into consideration. A brief results based on synoptic and selective literature review is given below including the said aspects. The detailed review of these studies are presented in Table 3. The data sets used in the studies covered by this review are given with details in Appendix Section D (Table 4).

In order to better discover geographic areas (scale), determinants and data set (survey, GIS etc.) of land market analysis, some of recent non-ABM employed quantitative empirical studies

[14] The economic environment reflects the input and output prices. The environmental regulation imposes the constraint of fixed level of organic manure per hectare that farmers cannot exceed; therefore surplus manure is an additional cost (either has to be treated or exported) that reduces profits. Manure exports are not allowed in the analyses.

generally focused on land value, price and rent estimation are examined and very briefly introduced below. The detail of these literature are presented in Table 3.

Wasson et al.[61] estimated a hedonic price model with parcel specific data related to amenities and agricultural attributes to provide a more precise representation of the value of amenities and their potential contribution to agricultural lands in Wyoming. According to the results of the study, it is seen that amenities have positive impact on land prices per acre. The study of Eisenhauer and Mitchell[62] can be given as an example of studies that use income capitalization model in their analysis The authors examined Canadian farmland as a class of investment assets with respect to its core value and the growth of its historical value. The model indicates that the value of an asset that produces income is that it will generate in the future so the farmland value is the ratio of rent income to the discount rate. According to the results of the study, rising farm income has been the main driver of Canadian agricultural value over the past 30 years. As agricultural policies and regulations are expected to have potential effects on agricultural land prices, there are a number of studies in the literature aiming to evaluate whether they have significant effect on the prices or not. For example, Latruffe et al.[39] analyzed the determinants of agricultural land prices in Brittany (a French region) to evaluate the role of regulations (environmental regulations and SAFER intervention) that could influence the price of agricultural transactions and focused on the role of the regulations on the environment and land transactions in agricultural land prices. The environmental regulation variable has a positive effect on land prices, which indicates that land prices rise because of the competition between them. As far as the land transaction variables are concerned, there is no significant impact of the SAFER intervention on the sales prices. Another study that evaluates the environmental regulations' effects on agricultural land prices is the study of Nilsson and Johansson[63]. The authors constructed a cross-regional regression model based upon municipal data to identify the underlying factors that explain agricultural land prices. The results indicate that agri-environmental payments do not appear to have the size or kind of design needed to generate inflated land prices. Other possible impact on agricultural land values can be from land tenure structures and different agricultural practices. Choumert and Phelinas[64] assessed the effect of (specifically the practice of cultivating genetically modified soybeans) on agricultural land values in Argentina. The authors indicate that good land quality has a positive effect on its value in comparison to average quality and the tenure is also an important variable in the value of farms. Also Reydon et al.[65] discussed the price determination drivers of land prices and aimed to forecast the land prices in specific markets in the state of Maranhao in Brazil in their study and they revealed that improvements in the farm and the non- presence of rock fragments in the soil were found to be most effective on land price. Their model has been used by the Agrarian Development Ministry of Brazil to set limits for purchasing of land throughout the different land credit programs in the country. In some of the studies in the domain, if there is lack of land purchase or rental price data, shadow prices are used as proxy. For instance, Chakir and Lungarskay[48] use shadow prices of land derived from the model of mathematical programming (AROPAj). The importance of this study is that it is the first study to use land shadow price as a proxy for land rent from agriculture. The research to evaluate agricultural land prices often use survey data or secondary institutional data in the analysis. However in some studies, orthophoto maps and Geographical Information Systems (GIS) data are also used. For example, Kocur-Bera[66] aimed to identify factors driving agricultural property prices after Poland's accession to the EU in regions where agriculture had been the dominant mode of production before the accession by using a set of data obtained from different sources. Some of the studies use a larger data set including macroeconomic data and climatic factors and meteorological data. In their study, Mela et al.[54] evaluated the role of agricultural factors such as agricultural prices, productivity and non-agricultural factors such as economic growth, changes in land utilization and urban real estate trends as determinants of farmland values in Italy. They constructed a bioclimatic aridity index (AI) to include the climate impact in the study. The index is computed by dividing the annual cumulative precipitation value to the annual cumulative evapotranspiration values of each region. Price volatility is also seen in agricultural land markets just like in all other markets. However, there are few studies to understand the reasons lying behind. The study of Borawski et al.[67] is one of these few studies and it aimed to identify the price volatility in agricultural land markets in Poland for the period of 1992-2016. Spatial approach is also used in some of the studies concerning the agricultural land values. In order to provide more insight into the German agricultural land market, Lehn and Bahrs[68] estimated a general spatial model of standard farmlands prices for arable land in the state of North Rhine-Westphalia using cross-sectional data at municipal level. Some studies give attention to the relationship between economic growth (hence the increase in GDP) and the agricultural land values. The study of Rutkauskas and Gudauskaite[69] is one of these studies and it aims to explain empirically major factors behind the latest changes in Lithuania's agricultural land prices. The results indicate that gross domestic product has a large effect on agricultural land prices in Lithuania. Technologic investments would also contribute to major land price increases as helps to improve productivity, rising farm workforce and produce greater income. The study of Grau et al.[55] was intended to address the gap in the literature of empirical applications based on New Economic Geography (NEG) theories which enable to analyze the spatial heterogeneity of land price dynamics and aimed to examine whether NEG models are helpful to understand the relation between land prices, production intensity and agricultural agglomeration. In this respect, the NEG model proposed by Pflüger and Tabuchi[70] was adopted and interpreted in terms of agricultural production. As an example to the studies evaluating EU Water Framework Directive’s effects on land prices, Olsen et al.[71] discussed the effects of the implementation of mandatory riparian buffer zones (zones that are adjacent to streams and lakes) as part of the implementation of the EU Water Framework Directive on agricultural land prices in Denmark. There are many studies that aim to evaluate if CAP payments are capitalized in land purchase or rental values or not. For instance, the study of Takac et al.[72] analyzes rental land markets in Slovakia, along with the legal rental regulations, and describes the effect on land rental prices of some factors such as the CAP. Results from econometric models found that all CAP payments had an impact on rental prices, namely the Single Area Payment System (SAPS), agri-environmental climate schemes (AECS) and animal welfare payments, which had positive effects.

Authors	Research Issues/Aims	Policies / Scenarios	Scope	Data	Model / Tools	Results
Land Property Prices						
Choumert and Phelinas (2014) [64]	Assessing the effect of land tenure and agricultural practices (Genetically Modified Organism-GMOs soybeans) on land values	No policy is evaluated	Pampas (Buenos Aires and San Justo) in Argentina	Survey data: 186 farmers owning and/or cultivating 338 plots	Hedonic Price	The parcels in Buenos Aires province are more valuable than the parcels in Santa Fé. The larger the surface plots, the lower the hectare value would be. Good land quality has a positive effect on its value in comparison to average quality. In case of rain, low access to parcels reduces the value of the parcel. If a plot is closer to the market, its value is higher. The plots nearer to roads are less valued than others, ceteris paribus as being near the roads increases the dirt possibility. The tenure is an important variable in the value of farms. In addition, the plots rented (including the sharing) by individuals or by companies are adversely appreciated in comparison to plots owned.
Reydon et al. (2014)[65]	Analyzing the price determination drivers of land prices and to forecast the land prices in specific markets	No policy is evaluated	The state of Maranhao in Brazil.	Survey conducted in 8 municipalities	1) Cluster analysis to determine the homogeneous zones and 2) Hedonic price	Improvements in the farm and the non-presence of rock fragments in the soil were found to be most effective on land price. The model was used by the Agrarian Development Ministry of Brazil to set limits for purchasing of land throughout the different land credit programs in the country.
Koomen and Buurman (2002)[43]	Comparing the land prices of the Land Use Scanner with actual land prices obtained from a land price model	None	Provincial: Dutch (Noord Brabant)	GIS data, price, infrastructure, land use, soil type and land use plans	Land use scanner model based on GIS and balances the demand for various land use functions with supply of suitable land using double constrained logit mode	The link between theories of land use and land price could prove to be difficult to establish from both an operational and theoretical point of view.
Filatova et al. (2009)[47]	Analyses land markets, discussing	None	Regional: Coastal zone	Experimental artificial data	An Agent-based Land Market Model (ALMA)	The basic model of buyers and sellers trading land in the urban area produces results identical to the monocentric urban model.

	interactions between traders.		of the Netherlands			
Rahman (2010)[73]	Identification of socioeconomic factors affecting farmers' decision to rent farmland	No policy is evaluated	National scale: Bangladesh	Survey data covering 406 farms from 21 villages.	Bivariate tobit model	Farmers who are poor in land area but rich in resources tend to rent land. Also, the farmers who are rich in land ownership but poor in resources tend to lease their land. Trained farmers tend to lease their land. The demand for land rental is high among less educated farmers.
Cynernab and Cymerman (2019)[74]	The research is based on the hypothesis that there is a correlation between the economic development level of Poland's 16 voivodes and the development of agricultural real estate markets.	No Policy is evaluated	National Poland	The study examines the 16 voivodes of Poland, covers the years 2005-2015.	In the study, the data between 2005 and 2015 were compared with economic data. Comparison ranking method and Searman correlation coefficient were used.	It was proved that agricultural real estate markets, which are seen in the most economically developed voivodeships, are developing faster than economically underdeveloped voivodeships.
Grau et al. (2019)[55]	To address the gap in the empirical literature based on New Economic Geography (NEG) theories which enable to analyses the spatial heterogeneity of land price dynamics and aimed to examine whether NEG models are helpful to	No policy is evaluated	Regional: West Germany	Data of 261 Western Germany counties from FADN.	NEG spatial lag model proposed by Pflüger and Tabuchi (2010) that is based on the Helpman (1998) model	Authors indicate that the short run effects' confirmation may be considered as a fundamental condition for NEG validity in agricultural context although the empirical results of the study cannot be interpreted as direct satisfaction of the long-run predictions of the theoretical model. According to the study, high land prices trigger centrifugal forces, which prevent further concentration of intensive agricultural production and can cause negative environmental effects such as groundwater pollution as a negative external effect of intensive pig and poultry production.

	understand the relation between land prices, production intensity and agricultural agglomeration.					
Wasson et al. (2010)[61]	The study aims to estimate a model with parcel specific data related to amenities and agricultural attributes to provide a more precise representation of the value of amenities and their potential contribution to agricultural lands.	No policy is evaluated	Regional: 22 counties of Wyoming (USA)	Parcel specific data collection on arm length sales of Farm Credit Service for the period of 1989-1995 and GIS data	Hedonic price model	According to the results, the measures of amenities such as the value of fishing quality across the state, the value of fishing quality in the western region, the value of alpine view in the western region and the value of roughness of view in the western region (WSTD10) positively and significantly increased price per acre. Productive lands with on-site fishing and scenic views have a higher price.
Rutkauskas and Gudauskaite (2018)[69]	Aims to explain empirically major factors behind the latest changes in Lithuania's agricultural land prices by using quantitative methods of analysis and presenting an original model that can explain the price movement of agricultural land prices over almost two decades.	No policy is evaluated	National: Lithuania	The primary data source for the dependent variable is the Center of Registers database with prices of Lithuanian agricultural land transactions reported for the period between 2004 and 2018.	The analysis in the study is based on time-series data by adopting Engle and Granger co-integration test to estimate an error correction model (ECM).	The results of the study indicate that it is possible to forecast the agricultural land prices from the changes of exogenous variables. Gross domestic product is found to have a large effect on agricultural land prices in Lithuania. Technologic investments would also contribute to major land price increases as helps to improve productivity, rising farm workforce and produce greater income. Furthermore, if the regulated agricultural products buying prices are higher, the agricultural activity is more attractive. The EU and the national government's support also plays a major role in understanding agricultural price increases in Lithuania's land prices.

Eisenhauer and Mitchell (2011)[62]	Aims to examine Canadian farmland as a class of investment assets with respect to its core value and the growth of its historical value.	No policy is evaluated	National: Canada	Statistics Canada. Table 002-0003 - Value per acre of farm land and buildings.	The study takes income capitalization model as the framework of the analysis	Rising farm income has been the main driver of Canadian agricultural value over the past 30 years The results also indicate that the components of farm income, farm productivity, and commodity prices display somewhat different attributes: general farm productivity has increased relatively steadily, while farm commodity prices have shown strong connections with absolute farmland value and tend to support long-term farmland value levels. Commodity prices have not followed the values of agricultural just as farm productivity, agricultural scale, or total profits did. Agricultural profits had not shown a clear correlation with agricultural values. Interest rates had greatly affected agricultural values. Furthermore according to the authors, the fundamental driver of agricultural land value growth was found to be farm income and productivity growth.
Lehn and Bahrs (2018)[68]	Aims to provide more insight into the German agricultural land market particularly in farmlands prices for arable land	No policy is evaluated	Regional: North Rhine-Westphalia (Germany)	cross-sectional data on municipal level	a general spatial model	The findings of the study show that arable land is highly competitive. The key drivers of prices are urban sprawl and livestock production. There are a number of legal regulations in Germany to reinforce these price rises and have counter-productive effects to reduce price increases. It should therefore be more efficient and effective to change current regulations that exacerbate price-creasing impacts rather than establishing new regulations.
Land Price Volatility						
Borawski et al. (2019)[67]	The causes of price volatility in Poland over the period of	No policy is evaluated	National coverage: Poland	Quarterly data from 1992 to 2016 from the	In this study, variance analysis (ADF and GRACH) models	It was observed that the prices of both private and agricultural property agencies increased over the period of 2003-2016. Agricultural land prices increased after Poland became a

	1992-2016 were investigated.			main statistics office in Warsaw.		member of the EU. As a result of legal regulations made in Poland, agricultural land price volatility remained low.
Land Supply						
Kobe et al. (2018)[75]	To determine the land market model and identify the driving forces in the rural areas of Oyo state in Nigeria.	No policy is evaluated	State level (Oyo) in Nigeria	48 farmers operating in the Oyo State of Nigeria.	Descriptive statistics, chi-square test, and regression analysis.	Land price, family size and farm income contributed positively to land demand. Moreover, land price, age, non-agricultural income and land ownership are variables that increase land supply.
Agricultural Land Demand						
Schulte et al. (2019)[2]	Aims to make a contribution to the information base behind the implementation of the strategic plans by mapping the changes through society's demands on land functions through EU Member States	CAP reforms	EU Member States	A variety of data sets that can be reached by public such as Eurostat, EEA and JRC.	Data were consolidated at NUTS levels and presented as a demand per unit of UAA. Eventually, to consider the relative societal demands of five soil functions regarding individual member states, the values for each soil function were converted to z-scores similar to Schulte (2015)'s methodology.	The societal demands for five soil functions which are primary production, regulation and purification of water, carbon sequestration, biodiversity and nutrient cycling, as determined by population, farming and livestock densities, and geo-environment and landscaping conditions differ significantly between Member States. Furthermore, overall societal multi-functionality demands differ among Member States, with the lowest demand identified for higher EU CAP funding for 'Environmental Security' and regional development expenditure in Member States. The results also indicate that the insights that can be taken from the observations in the sense of the 2021-2027 proposals for the new CAP which include an improved conditionality of direct income support for farmers and the instigation of eco-systems in Pillar I apart from Pillar II agri-environmental and climate initiatives. Also, the transition to national strategic planning provides an opportunity to make sustainable land management more efficient and focused if the plans take account of the

						changes in the social demand for soil functions and the capacity of contrasting soils to perform such multi-functions.
Policy Impact on Rental Prices						
Killian et al. (2008)[34]	Empirically testing the effect of single payments on rental prices of lands and whether the payments are capitalized in the prices	Fischler Reform in CAP	Bavaria in Germany	Municipality data of 2005 (among the 2056 municipalities in Bavaria, only municipalities with a minimum of seven observations for the dependent variables are included)	Two stage regression analysis was done with OLS estimator	Decoupled payments are more capitalized into rental prices than coupled direct payments between 1992 and 2004. One additional Euro of direct payments would increase rental prices by 28 to 78 cents. The capitalization ratio is found to be higher after the Fischler Reform (15 to 19 cents increase in the capitalization into rental prices). As land price and capitalization ratio will not decrease due to the Fischler Reform, the EU countries may have competitive disadvantage in international markets. The suggested solutions for the possible disadvantage are decreasing the number of single farm payments or the implementation of Bond scheme proposed by Swinbank and Tangermann (2004) which includes a transition of payments in completely decoupled, tradable bonds.
Mela et al. (2016)[54]	Evaluating the role of agricultural factors such as agricultural prices, productivity and non-agricultural factors in land utilization and urban real estate trends as determinants of farmland values	CAP farm subsidies	National: Italy (All 20 regions)	Balanced panel, with an average annual level of 440 observations for 20 Italian regions from 1992 to 2013 (22 periods)	Net present value approach with the Correlated Random Effects (CRE) Model	Italy's land values are mainly determined by potential alternative land uses. Farmers' demand for land is only important where the agricultural sector is well-structured and able to produce stable and strong cash flows (in terms of infrastructure). House prices are effective on crop land values. Despite the CAP's progressive elimination, farm subsidies continue to capitalize on farmland values.

Patton et al. (2008)[76]	This study investigated the effect of EU direct payments (combined and disaggregated) on rental prices in Northern Ireland.	EU Direct Payments	Regional coverage: Northern Ireland	Panel data for the farm business survey conducted in less preferred areas for the farms covering 1994-2002 period. A total of 1264 observations from 212 farms were used.	A land lease function was estimated by using data collected from farms. Sargan and Ar test were used in the analysis phase.	The effect of direct payments on rental prices varies considering the types of payments. Combined direct payments to sheep farmers were capitalized into rental value, but were not seen in farmers engaged in cattle breeding. The separation of direct payments can be important for farmers who own their land. Thus, these payments increase the dispersing effect.
Takáč et al. (2020)[72]	In this study, the effects of the EU Common Agricultural Policy Payments (CAP), geographical and economic factors on land rental prices were investigated.	CAP Payments	National coverage: Slovakia	Agricultural enterprise survey consisting of 450 enterprises representing 21% of Slovakia's arable land were used.	Data were analyzed using descriptive statistics and multiple linear regression models.	The most important factor affecting land rental prices is the economic performance of farms. CAP payments do not have a strong impact on rental prices. The most important reason for this situation is the long-term lease contracts with fixed prices and CAP payments applied for 15 years. Although land consolidation is an important factor, the regression coefficient is calculated as zero due to the small land remaining after land consolidation.
Loughrey and Hennessy (2019)[28]	In this study, the agricultural land lease market was analyzed by an agent-based micro-simulation.	Reforms in the taxation system and the EU CAP	National coverage: Ireland	Teagasc National Farm survey data (2015-2017).	Agent-based micro-simulation model	It was concluded that farmers tend to rent land on the basis of profit maximization and inequalities in terms of agricultural size occur.
Chakir and Lungarskay (2015)[48]	Comparing land use models based on three different agricultural land rent proxies: farmers' incomes; the price of land;	1) Effect of an input based tax on fertilizers, 2) Usage of land under different climate change scenarios	National: France	Land use, shadow price, agri revenues, land price, forestry revenues, population, slope, and soil texture data	1) Land use share model (Spatial Autoregressive Model- SAR and Spatial Error Model:SEM) in regression analysis 2) Environmental policy simulations by mathematical	Including spatial autocorrelation to the land use models gives better prediction. Increase in nitrogen prices will decrease the agricultural use of lands by 0.77 million ha and 1.4 million ha for 50% and 100% increase in the rice of nitrogen respectively. Also price increases in nitrogen increases the area used for pasture by 0.42 million ha and 0.77 million ha for 50%

	and shadow prices of land	(optimistic and pessimistic).			programming (AROPAj Model)	and 100% increase in the rice of nitrogen respectively. The most effected land class is the cropland area which is seem to increase in both two different IPCC climate change scenarios. Land area used for pasture decreases in both scenarios by 3.4 million ha. Forest areas decrease more under the pessimistic scenario.
Policy Impact on Land Property Prices						
Nilsson and Johansson (2013)[63]	Analysing the determinants of Swedish agricultural land prices by decomposing the prices of lands into the expected returns of agricultural and non-agricultural land use.	Direct income support to farmers	Municipality Level: Sweden	Data at municipality level including a sample of 11 000 farm transactions (269 municipalities among 290 Swedish municipalities)	Cross-regional regression model	Prices of agricultural land are closely related to local factors such as regional variations in the quality and structure of the local agricultural sector, agricultural support payments and the scale and structure of other local economic activities. The anticipated revenues from both agricultural and potential land use are proving to be an influence on agricultural land prices. Direct income support to farmers in the form of a single farm payment has a positive effect on agricultural land prices at all points. Agri-environmental payments do not appear to have the size or kind of design needed to generate inflated land prices. Access to the population expected to represent urbanity is the strongest explanatory factor, regardless of land's location
Kocur-Bera (2016)[66]	Identifying factors driving agricultural property prices after Poland's accession to the EU in regions	CAP Implementation	Regional: Poland	Survey data from 504 farms (54% of transactions in less favored areas and 46% of transactions outside those areas)	Hedonic Price	Agricultural property market prices in the studied region were mostly effected by distance from compact settlements, soil quality, location, land fragmentation, and cover of forests. Location and quality of the soil were found to be the key drivers of price.
Zrobek-Rozanska and Zienlinska-	The effects of the law preventing the abuse of agricultural	The law applied to prevent abuse	National: Poland	The data used in the research is based on	Within the scope of the research, interviews were made with various	Both positive and negative consequences of the policy arrangement made to prevent abuse of agricultural lands has been determined. The

Szczepkowska (2019)[77]	lands enacted in 2016 were examined.	of agricultural land		numerical data obtained from public institutions and various institutions. In addition with the data obtained by the survey method.	institutions, the survey data were analyzed and the transactions in the real estate market between 2015 and 2018 were analyzed.	purchase and sale of agricultural land for speculative purposes has declined, but efforts to circumvent the current regulation have increased. Within the scope of the policy applied, those who are not individual farmers can get at least 1 ha (previously 0.3 ha). Thus, fragmentation of agricultural lands was prevented. This provides an opportunity for farmers to meet their financing needs. In addition to enforcement and bankruptcy procedures in agricultural lands, new regulations in inheritance law have been shown to make a positive contribution.
Olsen et al. (2019)[71]	The study discusses the effects of the implementation of mandatory riparian buffer zones (zones that are adjacent to streams and lakes) as part of the implementation of the EU Water Framework Directive on agricultural land prices in Denmark. It aims to isolate the impact of the legislation on land prices	EU Water Framework Directive	National: Denmark	The data cover all sold farm properties for the period of 2010-2015 and was based on the broad OIS database of the Danish property (OIS, 2017).	Hedonic Price Model	The results indicate that while the model explains a large proportion of variations in land prices, there is no substantial influence of the buffer zones. According to the authors the reason lying behind this result can be that the farmers do not anticipate that the presence of buffer zones on an agricultural estate would affect the anticipated future income which include compensations.
Latruffe et al. (2013)[39]	Aims to evaluate the role of regulations that could influence the price of agricultural	-EU Nitrate Directive Regulation	Regional Brittany (France)	The data were collected by notaries from the database of all individual	Present Value Model	With regard to agricultural revenue proxies, the gross margin per hectare and the number of family working units per hectare have a positive impact on land prices. The amount of rain and radiation from the atmosphere

	transactions and focuses on the role of the regulations on the environment and land transactions in agricultural land prices.	-SAFER intervention on land transactions		transactions of arable and pasture land in Brittany between 1994 and 2010.		decreases the price. The plot size though has a negative effect, while a positive effect had been expected. The environmental regulation variable has a positive effect on land prices, which indicates, as predicted, that land prices rise because of the competition between them. As far as the land transaction variables are concerned, there is no significant impact of the SAFER intervention on the sales prices. There is a negative effect on the variable indicating whether the land is currently held by the farmer buyer.

Table 28 Non-exhaustive list of land market literature review

Source: authors' elaboration.

The main features of the non-ABM based publications cited above in this review can be synthesized as follow. A major number of the empirical studies which aim to reveal the drivers of agricultural land property or rental prices and the impacts of policies on these prices use the net present value methodology[54][39], the hedonic price methodology[66][64][71][61]. Some studies use more specific econometric models as spatial auto-regressive model[48], general spatial model[68], New Economic Geography (NEG) spatial lag model[55], generalized auto-regressive conditional heteroscedasticity (GARCH) model[67], Engle-Granger co-integration and error correction model[69].

Some studies about land property prices are at regional level[64][65][43][47][55][61][75] or municipal level[68] while some are at national[69][74]. These studies do not aim to evaluate the impacts of agricultural policies on land prices. Generally they aim to analyze the prices by discussing the interactions between traders, by determining the drivers of farmland prices or by identifying the socioeconomic factors affecting farmers' decisions to rent or purchase farmlands. Also there are studies which take the effect of land tenure and agricultural practices on land values into consideration[64]. A few studies aim to reveal the potential contribution of amenities and agricultural attributes to land values[61]. There are few studies to understand the causes of agricultural land price volatility through time[67]. There are again few studies on land supply and land demand in the agricultural land literature which aim to determine land market models to identify the driving forces of farmland supply[75] and to map the changes through society's demands on land functions[2].

An important part of the studies examined, aim to state the impacts of agricultural policies on land property or rental values, especially whether the recent CAP subsidies are capitalized in land values or not[34][54][76][72][63]. Other implemented agricultural policies' impacts on agricultural land values are also investigated in some studies as the impact of EU Water Framework Directive[71] and EU Nitrate Directive Regulation[39]. The common result of these studies indicate that implementation of above said agricultural policies have positive impacts on land values and in general CAP subsidies are capitalized in farmland purchase or rental values. A few studies aim to reveal the impacts of some national laws about agricultural land transactions to prevent the abuse of land on land prices[77][39].

According to the datasets used in these studies, it is seen that primary data throughout surveys and secondary data from related institutions are used together for the analysis. In the studies aiming to reveal the drivers of agricultural land prices (either purchase or rental), land values per hectare (if not found shadow price for agricultural land is used), agricultural revenues, population density, characteristics of land such as slope and texture, total utilized agricultural area, number of transactions between farmers, production costs, location of the farmland (urban located or not), prices of the products produced, amount of governmental payments and amount of irrigation are used commonly as data. Some studies also use macroeconomic data as interest rate and inflation rate, property taxes and GDP in their analysis. The studies which aim to assess the impact of amenities on farmland values use number of seasonal houses in rural areas or their prices as proxy (Table 3). The data sets used in the studies in the review are given with details in Appendix Section D (Table 4).

7.4 Geographical areas, determinants, and datasets for land market analysis

Except a few assessment studies, ABMs in the agricultural domain have generally focused on LUCC (including landscape in some cases) in regional/municipality scales. The determinant of LUCC are generally common drivers including socioeconomic (population, income etc.), agricultural/environmental/energy policies and climate changes. Datasets used in the LUCC assessment are various including CORINE, FADN/FSS, and GIS data. The ABMs in agricultural land market assessment such as AgriPolis, LARMA, the evolutionary ABM of Belgium, SwissLand, and ADAM employed FADN/FSS data and farm survey data (LARMA). The Swissland model uses also market balance data of supply, demand and prices and covers entire country. In addition to the Swissland ABM, the evolutionary ABM of Belgium applies to the country level, the rest of the ABMs reviewed in agricultural and environmental policy analysis apply in regional scale.

Except a few models such as LARMA and AgriPolis, we have not encountered any ABM based modelling assessing policy impact on supply, demand, land value, land price, and land sales. Generally, ABM based LUCC/landscape change studies have assessed climate change impact and impacts of agricultural/environmental/energy policies on the environment (positive and negative externalities) and ecosystem service provisions at regional levels[14][78][79].

7.5 Existing ABM models to determine the transactions in the land market

Recent ABM based agricultural policy impact models such as Agripolis, LARMA[10], positive mathematical programming (PMP) based simulations[78], the evolutionary ABM of Belgium[57], the Swissland Model[58] and ADAM[60] demonstrated that ABMs are a powerful methodology to evaluate LUCC change, impact agricultural and environmental policies (regulations), and climate change impacts on land use and ecosystem service impacts. All of the mentioned models except partly AgriPolis and LARMA, do not directly focus on land market dynamics including value, price and rent of land, land supply, and land demand. Therefore, given the dynamics of the land market in the EU such as decline of farm numbers, increasing farm size, intensification (increasing yield with intensive input use), aging rural population (push factor for farm exit), land value and rental price changes due to several drivers including CAP, energy directives, water directive and environmental regulations, and also land market measures and regulations, the need of more land market focused ABM platforms is obvious in order to overcome the inherent spatial heterogeneity.

7.6 The determinants/factors neglected in the agricultural land market models and the GAP in existing ABMs

Villoria and Liu[80] stated that land supply elasticities determine the rate of land conversion in global policy models. However, they are only available in a few countries in the world. Therefore, analysts seeking to improve the spatial resolution of their models are forced to impose regionally homogeneous parameters over highly heterogeneous regions. The authors developed a framework and estimated spatially explicit land supply elasticities using gridded data for the American continent. The results suggest that the framework used in the study and estimates can be used to spatialize land supply elasticities observed at the national level, increasing the accuracy of spatially explicit economic models. Hertel [15] discussed economic perspective on land use change and leakage. The author state that land use change and leakage effects stemming from technological change, conservation programs and other policy interventions have received considerable attentions in the scientific literature in the past decade. Although economist have offered important insight about these leakages, yet much of the analysis undertaken by the land change science community does not fully avail itself of these insights. Similarly, many of the economics contribution to this field have ignored important findings from the land change science community. Perpina et al.,[4] assessed and spatially modeled agricultural land abandonment in Spain over the period of 2015-2020. The study used the outputs from the LUISIA territorial modelling (Joint Research Centre of the European Commission) and focused on regional and local projection of land abandonment between 2015 and 2030. Spain is taken as a representative of one of the countries highly affected by agricultural land abandonment in the

European Union. The most relevant factors driving land abandonment (biophysical, agroeconomics, farm structure and demographic) are described and mapped. The result of analysis reveal that in several regions of Spain (Galicia, the central Pyrenees/Ebro basin and northern, north-eastern and south-eastern Spain) are expected to undergone important abandonment process. The study also concludes that land abandonment in mountainous, high nature value farmlands and Natura 2000 areas are lower compared to outside area without conservation and protection measures.

Amenities of the parcel (comprehensive land quality indicators rather than soil quality), supply elasticities of land parcel and institutional regulations on land such as minimum and maximum transaction size and land rental price are the common ignored factors in the current ABMs in the agricultural and environmental policy impact assessment domain. There are a few ABMs assessed the impact of climate change impact on agricultural production decision[78] and environmental regulation production system adaptation[59]. Also, many ABMs do not include explicit land abandonment and did not evaluated impact of policies on land abandonment[4]. Time series and spatial panel data such the ABM model for Belgium agriculture can provide a more comprehensive picture of land market dynamics and impacts of policies and regulations on the agricultural land market. Currently, there is no ABM fully focused on land market dynamics (drivers, various policy measures impacts, etc.); instead, they generally focus on LUCC trajectories induced by a few common drivers and the impacts of the changes on ecosystem service provisions and environmental changes.

7.7 Which of the determinants/factors of the markets for agricultural land could be considered, and how could they be modeled, in the development of the AGIRCORE ABM model to fill in the gap in the existing literature?

The modeling platform to be built in the AGRICORE project should give special attention to the land module as agricultural land is the main factor of production for agricultural sector. We suggest a-three stage decision procedure to determine agricultural land to be used in various activities.

In the first stage, the modeling platform should decide whether the agent exits from agricultural sector or not basing on the attributes of the agent such as age, family members, family structure etc.; at this stage the other indicator that the model should look at is the change in the market sale price of the land which may trigger agents to shift to non-agricultural activities.

The specific attributes of the agent and land sale prices are not the only factors that affect agents' decision. The model should be able to decide the agents' staying in the farm business (using his/her land for agricultural production) basing on how they perceive market conditions (agricultural profitability and agricultural prices).

Likewise in this stage, the model should determine whether the agent continues agricultural production or rents his/her land basing on land rental prices. In the second stage, the platform should ignore the sold and rented land by each agent to others and should focus on the newly rented and bought lands by each agent and on the agents that use his/her own land for agricultural production. The main decision point at this stage is about the land cover; whether the agent is going to use the land for pasture, fallow, for perennial crops or else by looking at the alternative rate of returns. A simultaneous decision point here is whether the agents continue with some sort of agricultural production or are they going to invest for production in the long-run. This decision is about expected future profits and other related indicators. In other words, at this stage the agent is going to decide whether to use the financial resources for agricultural production in the short-run or for investment in the long-run.

The third stage is about land use. The platform should decide for each agent which crop and livestock products they are going to produce basing on the agents' attributes and on their physical conditions/constraints such as farm structure, climate, soil type, irrigation possibilities, and availability of other agricultural inputs, expected prices and profit.

7.8 APPENDIX

7.8.1 Section A

In Belgium, France and the Netherlands "imposition of maximum rental price" that depend on the agronomic quality is the main instrument used by the land legislation[15] [80]. In Austria, rental contracts are open to approval of the official authority which has the right to disapprove the rental transaction if the rent determined is 50% higher than the average price in the region. "Minimum duration for a rental contract" policy is used by many EU countries including Austria, Belgium, France, Italy, the Netherlands, Portugal, Spain, Slovakia, and Slovenia as an instrument to protect tenants. Again in many EU countries "automatic rental contract renewal" is in place and the renewal is done at least by the length of the initial contract period (in some countries it is done yearly). Some countries (Belgium, France and the Netherlands) give the right to prevent the "rental contract renewal" to the owner but only under special conditions such as if the land will be used by the owner or family. If the owner does not have an intention to use the land, rental contracts are automatically renewed with the same tenant. "Pre-emptive right to buy" the land by the tenant is an instrument commonly used in Belgium, France, Italy, Portugal, Sweden, Hungary, Latvia, Lithuania, Romania, and Slovenia[80].

7.8.2 Section B

Hungary, Poland, and Latvia do not allow foreign ownership more than 50% while in Estonia, Hungary, Latvia, Poland, and Slovakia, foreigners (individuals) are only allowed to buy a plot after renting and farming it at least for three years. Lithuania asks for three years residency and farming in the country before buying an agricultural land. In some specific regions, Greece and Finland also restrict foreigners' agricultural land transactions. There are also other restrictions than nationality in Austria, Denmark, Spain, Hungary, and Poland. While in Austria and Poland proof of competence in the agricultural sector and residence close to the agricultural land is asked, in Hungary the new owner is obliged to cultivate the land. In France, Italy, Portugal, Hungary, Latvia, and Slovenia, farmers have a pre-emptive right to buy the neighbor farmer's plot. A well-defined "maximum sales price" is not easy to determine but in some countries, governments interfere in the sale market if the sales price of agricultural and is considered to be too high (Austria, France, and Poland). Size limitations on transacted agricultural land is also used as an instrument in France, Hungary and Lithuania. For example, in Hungary an individual can own and cultivate up to 300 ha, while a legal entity (farming company) is not allowed to own any agricultural land and can only cultivate up to 2,500 ha of (leased) land. In Lithuania, a natural person or a legal entity can own up to 500 ha[16].

7.8.3 Section C

Some countries use "minimum rental prices" (Finland, Sweden, Hungary, France, and Poland) and "the maximum duration of a contract" (Austria, Czech Republic and France) regulations to protect

[15] In Belgium, rental prices are determined by multiplying the cadastral value of the plot and a regional 'tenancy coefficient'. These 'tenancy coefficients' are determined by a commission composed of members of the regional governments and the professional organizations based on the evolution of the agricultural profitability in the region in the past six years (Swinnen et al., 2010).

land owners. Land fragmentation (which is argued to constrain agricultural productivity) is prevented through the use of “minimum plot size restrictions/regulations/policies/laws” (Germany, Bulgaria, Estonia, Lithuania, and Slovakia) and “pre-emptive buying rights restrictions/regulations/policies/laws” (Italy, Portugal, Czech Republic, Hungary, Lithuania, Poland, Slovakia and Slovenia) of the co-owner[16].

7.8.4 Section D

Authors	Country	Methodology	Data	Variables	Main Results
Mela et al. (2016)[54]	Italy	Net Present Value	The data set is a balanced panel, with 440 annual observations for 20 Italian regions from 1992 to 2013	Farmland (dependent variable). Average annual land values per ha for total utilized agricultural area (UAA), arable land, permanent plants and vineyards. Population density, GDP at regional level. The share of the mountain area in the total area. The total agricultural output (excluding forest and fisheries) and in the case of arable crops, the value of the production of agricultural crops plus the value of animal farming (excluding ovine and caprine). Price statistics for agricultural production. The annual regional cumulative evapotranspiration values. Livestock units per hectare. House prices.	The more alternative land use potential there are, the higher the land values are . CAP's elimination is not enough to decrease the capitalization of agricultural farm subsidies on farmland values.
Chakir and Lungarskay (2015)[48]	France	1) Land use share model (spatial autoregressive model, SAR and spatial error model, SEM in regression analysis. 2) Environmental policy simulations by mathematical programming (AROPAj Model).	Land use, shadow price, agri revenues, land price, forestry revenues, population, slope and soil texture data.	Land Use (aggregated at 8 km x 8 km). Shadow Price (Scale: NUTS 2). Agri Revenue (FADN mean 1995-1999). Land Price (Agreste, mean 1995-2000). Forestry Revenue (Source: FFSM++, 2006). Population Revenue (Source: INSEE, 2000).	There is a negative correlation between nitrogen prices and the agricultural use of lands. The higher the nitrogen price is, the more the area used for pasture is. Both of the climate change scenarios (either optimistic or pessimistic) in the analysis increase the cropland values.

				Population Density (Source: INSEE, 2010) (Scale: 200 m x 200 m grid). Slope (Source: GTOPO 30) (Scale: 30 arc sec approximately 1 km). Texture (Source: JRC, Panagos et al. (2012)) (Scale: 1:1,000,000).	
Kocur-Bera (2016)[66]	Poland	Hedonic Price Methodology	Survey data from 504 farms (54% of transactions in less favored areas and 46% of transactions outside those areas.	Time (Month of transaction between 1 January 2008 and 31 December 2010). Area (Area of property (ha)). Land Plots (Number of land plots per transaction). Distance Location (distance in kilometers from compact settlements: close: up to 2 km, medium: 3–6 km, far: more than 6 km). Less Favored Areas (Location in and outside less-favored areas. Quality of Soil. Forest Cover (Percentage of forest cover in the respective municipality). Agricultural Land (Percentage of agricultural land in the respective municipality). Population (Population density (persons/km2) in the respective municipality). Slope Landform (flat terrain–the average slope of the land to 80, non-flat terrain).	Location (proximity or distance from compact settlements) and quality of the soil were found to be the key drivers of agricultural property prices.

Choumert and Phelinas (2014)[64]	Buenos Aires and San Justo in Argentina	Hedonic Price Methodology	Data of survey conducted in the consisting of 186 farmers owning and/or cultivating 338 plots.	Number of land transactions. The per-hectare value of each plot of land being cultivated. The soil quality of each plot of land. Plot-specific information on location and accessibility. The value in agricultural use as measured by percentage of the plot under soybean cultivation. Farmers' socio-demographic characteristics.	There is a negative relationship between the surface plots and ha value. Land quality, proximity to the market and land tenure are found to have significant effects on land values.
Bastiaan et al., (2014)[65]	Maranhao (Brazil)	1) Cluster analysis to determine the homogeneous zones. 2) Hedonic price methodology with a multiple regression model.	Data of survey conducted in 8 chosen municipalities out of 35 municipalities that are determined as homogeneous zones in Maranhao.	Electricity (access of farm to electricity as dummy variable). Improvements in farm such as barns (Dummy variable). Presence of rock fragments (Dummy variable). Soil index (varying from10 to 100) considering the physical properties of soil such as depth and texture. Subsistence (system of production is agriculture and husbandry related with subsistence with trade surplus or not as dummy variable).	Improvements in the farm and the non-presence of rock fragments in the soil were found to be most effective on land price.
Killian et. al., (2008)[33]	Bavaria (Germany)	Two stage regression analysis with OLS estimator.	Municipality data of 2005 (Among the 2056 municipalities in Bavaria, only municipalities with a minimum of seven observations for the dependent variable are included).	Dependent Variables: rental price of cropland (€/ha); rental price of utilized agricultural land (€/ha). Explanatory Variables: decoupled 1st pillar payments, DecP (€/ha), historic (farm specific) part of direct payments,	Decoupled payments are more capitalized into rental prices than coupled direct payments between 1992 and 2004. One additional Euro of direct payments would increase rental prices by 28 to 78 cents.

				agri-environmental payments (€/ha), payments for less favored areas, share of area of new rental contracts on all contracts, soil quality index (1-100), seize of a cultivated plot (ha), share of rental area, farms per 100 ha utilized agricultural area, share of utilized agricultural area on total land area, installed biogas power (kW/ha), dummy for agricultural regions (AG 1-12) with similar agricultural conditions.	The capitalization ratio is found to be higher after the Fischler Reform (15 to 19 cents increase in the capitalization into rental prices).
Nilsson and Johansson (2013)[63]	Sweden	Cross-regional regression model.	Data at municipality level including a sample of 11 000 farm transactions (269 municipalities among 290 Swedish municipalities).	Agricultural land price (log of the average municipal per ha price of agricultural land). Land fertility (log of average yields in kg of cereals and grains per hectare) Pasture (share of agricultural land that consists of pastures and meadows). Average farm size (in terms of hectares). Volume of activity (share of agricultural land that is sold during the period). Single farm payments (log of the amount of single farm payments received by farmers in a given municipality). Agri-environmental payments (log of the amount of agri-environmental payments	Direct income support to farmers in the form of a single farm payment increases agricultural land prices at all points. Agri-environmental payments do not capitalize in agricultural land prices. Accessibility to the population which is defined here as a proxy for urbanity has the highest impact on agricultural land prices.

				received by farmers in a given municipality). Accessibility to population (log). Rural amenities (log of the number of seasonal homes used as a proxy for amenities in the municipality's rural areas).	
Borawski et al. (2019)[67]	Poland	Generalized Autoregressive Conditional Heteroscedasticity (GARCH) models	Quarterly agricultural land price data	Private land prices data Agricultural Property Agency Land Prices data	Land prices in Poland were highly volatile for the analyzed period. Poland's EU membership increased the prices of agricultural land
Takac et al. (2020)[72]	Slovakia	Regression Model	The data collected in 2015 and 2016 by the Slovak Ministry of Agriculture and Rural Development on Agricultural Holdings	Single area payments. Greening Payments for sustainability and care for natural resources. ANC Area of Natural Constraints scheme payments. AECS Agri-environmental-climate schemes. ECO Payments for organic agriculture. WELFARE Payments for animal welfare. Investment subsidies Payments for investments. Distance from the district city. Distance of the agricultural holdings from the district city (LAU 1) km. Share of ANC land Share of Area of Natural Constraints in total land area. Total revenues share in total costs.	CAP payments capitalize in rental prices, namely the Single Area Payment System (SAPS), Agri-environmental climate schemes (AECS) and animal welfare payments, also have positive effects.

				Share of total revenues in total costs. Share of revenues from livestock production. Share of revenues from livestock production in total revenues from agricultural production. Share of revenues from agricultural production in total revenues. Share of revenues from agricultural (crops and animal) production in total revenues. Share of production costs in total costs. Share of production costs (material and energy) in total costs. Total number of employees. Total wages per agricultural holdings. Dummy variables for production areas: Maize production area–benchmark. Sugar beets production area. Potatoes production area. Potato–oat production area. Mountain production area. Dummy variables for land consolidation: Land consolidation–unrealized in the location of an agricultural holding - benchmark- Land consolidation–realized in the period 1990–2016.	

				Dummy variables for Region (NUTS III): The South-western regions of Slovakia (composed of the Bratislava region (BA), the Trnava region (TT) and the Nitra region)–benchmark. The Northern regions of Slovakia (the Trenˇcín region (TN). The Žilina region (ZA) and the Prešov region). The Southern regions of Slovakia (the BanskáBystrica region (BB) and the Košice region (KE).	
Olsen et al. (2019)[71]	Denmark	Hedonic Price Model	The data cover all sold farm properties for the period of 2010-2015 and was based on the broad OIS database of the Danish property (OIS, 2017).	Property size Sold land according to years 2011-2015 Dummy variables for primary husbandry type Forest area Wetland area Lake area Soil quality Farm building area Number of animals Buffer zone variables (streams, lakes etc.)	The results indicate that while the model explains a large proportion of variations in land prices, there is no substantial influence of the buffer zones. According to the authors the reason lying behind this result can be that the farmers do not anticipate that the presence of buffer zones on an agricultural estate would affect the anticipated future income which include compensations.
Latruffe et al. (2013)[39]	Brittany (France)	Present Value Model.	The data were collected by notaries from the database of all individual transactions of arable and pasture land in Bretagne between 1994 and 2010.	Dependent Variable: Land Price per ha. Interest rate. R Variables: Agricultural gross margin per ha of UAA. Sold plot's area. Number of family working units per ha of UAA. Rain quantity.	The gross margin per ha and the number of family working units per ha increase land prices while the amount of rain and radiation from the atmosphere decreases them. The environmental regulation variable has a positive effect on land prices, which indicates, as predicted, that land

				Atmospheric radiation. Soil cation exchange capacity. X variables: Population density. Number of second homes per ha. Urbanization growth rate. Attractiveness measured by employment concentration rate. Urban located or not. Environmental variable: nitrate surplus area or not. Land variables: buyer is a SAFER or not. Plot is farmed by buyer or not. Control variable: buyer is a farmer or not.	prices rise because of the competition between them. There is no significant impact of the SAFER intervention on the sales prices.
Grau et al. (2019)[55]	West Germany	New Economic Geography (NEG) spatial lag model proposed by Pflüger and Tabuchi (2010) that is based on the Helpman (1998) model.	Data of 261 Western Germany counties from Farm Accountancy Data Network (FADN).	Average land rental price (€/ha). Total labor costs (€/ha). Average wage level in the county (€/hour). Average labor intensity (hours/ha). Soil quality index. Total livestock costs (€/ha). Average costs per LSU (€/LSU).	High land prices can have negative impact on environment.
Wasson et al. (2010)[61]	22 counties of Wyoming (USA)	Hedonic price model	Parcel specific data collection on arm length sales of Farm Credit Service for the period of 1989-1995 and GIS data.	Nominal price per privately owned acre. Amenity related variables (value of fishing quality, roughness in view, lands with onsite fishing and scenic views, visible tree cover, alpine view).	Amenity related variables have significant effects on land values.
Zrobek-Rozanska and Zielinska-Szczepkowska (2019)[77]	Poland	Within the scope of the research, interviews were made with various institutions, the survey data were analyzed and the transactions in the real estate	The data used in the research is based on numerical data obtained from public institutions and various institutions.	Number of transactions per 1000 inhabitants. Average value of a single transaction.	The purchase and sale of agricultural land for speculative purposes has declined, but efforts to circumvent the current regulation have increased.

		market between 2015 and 2018 were analyzed.	In addition, it was used in the data obtained by the survey method.	Average area sold per 1000 inhabitants in ha. Price of 1 h. Price of 1 ha - private market.	Within the scope of the policy applied, those who are not individual farmers can get at least 1 ha (previously 0.3 ha). Thus, fragmentation of agricultural lands was prevented. This provides an opportunity for farmers to meet their financing needs. In addition to enforcement and bankruptcy procedures in agricultural lands, new regulations in inheritance law have been shown to make a positive contribution.
Cynernab and Cymerman (2019)[74]	Poland	Comparison ranking method and Searman correlation coefficient.	The data is based on information from the Central Database Office of Poland, the Local Database and the National Research Institute of the Agriculture and Food Institute.	Number of transactions per 1000 inhabitants. Mean value of a single transaction. Mean area of a sold property per 1000 inhabitants expressed in ha, Price of 1 ha sold by the Agricultural Property Agency, Price of 1 ha sold on a private market.	Higher the economic development level of voivodeships , faster the agricultural real estates are developing.
Rutkauskas and Gudauskaitė (2018)[69]	Lithuania	The analysis in the study is based on time-series data by adopting Engle and Granger co-integration test to estimate an error correction model (ECM).	The primary data source for the dependent variable is the Center of Registers database with prices of Lithuanian agricultural land transactions reported for the period between 2004 and 2018.	Market revenues. Returns to land. Net income. Producer price of wheat. Yield. Soil quality. Temperature and precipitation. Dummy for irrigation, presence of intensive crops, special crops, fraction of cropland and proximity of a port. Total government payments. One or multiple categories of government support.	Macroeconomic variables such as GDP and the amount of technological investments in a country have positive impact on land prices.

				Pig density. Manure density. Farm density. Average farm size. Size of the agricultural land market. Dummy for a specific region. Interest rate. Inflation rate. Property tax rate. Multifactor productivity growth. Debt to asset ratio. Credit availability. Unemployment rate. Total population. Population density per square kilometre. Population growth. Ratio of population to farm acres. Urbanisation categories. Rurality – fraction of the population living on farms. Dummy variables for metropolitan areas. Proportion of the labor employed in agriculture.	
Eisenhauer and Mitchell (2011).[62]	Canada	The study takes income capitalization model as the framework of the analysis.	Statistics Canada. Table 002-0003 - Value per acre of farm land and buildings.	Farm revenue. Farm efficiency/productivity. Commodity prices. Farm profits. Interest rates.	Farm income, productivity growth and interest rates are the most effective factors on agricultural land values in Canada in the last three decades. Neither the farm profits nor the commodity prices have significant effect on land values.

Lehn and Bahrs (2018)[68]	North Rhine-Westphalia (Germany)	General spatial model.	Cross-sectional data on municipal level.	Dependent variable: standard farmland value (SFV). Explanatory variables: Land use characteristics (e.g. share of arable land). Soil quality index. Average slope of the land. Farm characteristics.	Urban sprawl and availability of livestock production increase the agricultural land prices.
Schulte et al. (2019)[2]	EU Member States	Data were presented as a demand per unit of UAA. The values for each soil function were converted to z-scores similar to Schulte (2015)'s methodology.	Data were consolidated at NUTS levels for the member states in the study.	Drought frequency, severity and duration statistic. The qualitative likelihood of impact occurrence. The crop water deficit. The demand for land to produce food. The total feed demand, as calculated by using generic dietary need. The import of non-wood based products listed in the EUROSTAT trade database for demand for bio-based industrial production. Average yield of 3 tons of rapeseed per ha and an extractable oil fraction for biodiesel demand. The maximum amount of C-sequestration. Agri-environmental metric ‘population trends of farmland birds’. The sum product of livestock numbers and livestock-specific P excretions.	Population, farming and livestock densities are key drivers for societal demands for different soil functions, Societal multi-functionality demands differ among Member States.

Table 29 Recent Empirical Studies to Estimate Land Value/Price or Rent

Source: authors' elaboration.

7.9 References

1. ^ 1 2 3 4 5 6 7 8 9 European Environment Agency, The direct and indirect impacts of EU policies on land EEA, no. September. 2016, p. 122.
2. ^ 1 2 3 4 5 6 7 R. P. Schulte, L. O'Sullivan, D. Vrebos, F. Bampa, A. Jones, and J. Staes, "Demands on land: Mapping competing societal expectations for the functionality of agricultural soils in Europe," Environmental Science & Policy, vol. 100, pp. 113–125, 2019.
3. ^ 1 2 Y. Ren, Y. Lü, A. Comber, B. Fu, P. Harris, and L. Wu, "Spatially explicit simulation of land use/land cover changes: Current coverage and future prospects," Earth-Science Reviews, vol. 190, pp. 398–415, 2019.
4. ^ 1 2 3 J. C. Perpiña Castillo C. .. Coll Aliaga, E. .. Lavalle, C. .. & Martínez Llario, "An Assessment and Spatial Modelling of Agricultural Land Abandonment in Spain (2015–2030)," Sustainability, vol. 12, no. 2, p. 560, 2020.
5. ^ 1 2 B. Gardner, C. Nuckton, and others, "Factors affecting agricultural land prices," California agriculture, vol. 33, no. 1, pp. 4–6, 1979.
6. ^ 1 2 M. D. Duffy, "2019 Farmland Value Survey Iowa State University," no. December, 2015, [Online]. Available: http://www.extension.iastate.edu/agdm/wholefarm/html/c2-70.html.
7. ^ Eurostat, Agriculture, forestry and fishery statistics 2018 Edition. 2018, p. 200.
8. ^ 1 2 Eurostat, "Farm Structure Survey," no. December 2015, pp. 1–11, 2015, [Online]. Available: https://ec.europa.eu/eurostat/statisticsexplained/.
9. ^ 1 2 E. Commission, "Agricultural Farm Structures," 2018.
10. ^ 1 2 3 4 F. Bert et al., "Agent-based modeling of a rental market for agricultural land in the Argentine Pampas," 2010.
11. ^ 1 2 3 EU Commission, "Agricultural capital and land value," pp. 1–13, 2018, [Online]. Available: https://ec.europa.eu/info/food-farming-fisheries/farming/facts-and-figures/farms-farming-and-innovation/structures-and-economics_en.
12. ^ European Commission, "EU Farm Economics Overview," European Commission Development, Directorate-General for Agriculture and Rural Development, vol. 2015, no. and, p. 82, 2016, [Online]. Available: http://ec.europa.eu/agriculture/rica/pdf/EU_FEO_FADN_2013_final_web.pdf.
13. ^ E. Commission, "Young farmers in the EU–structural and economic characteristics," EU Agricultural and Farm Economics Briefs, 2017.
14. ^ 1 2 D. B. Van Berkel and P. H. Verburg, "Combining exploratory scenarios and participatory backcasting: using an agent-based model in participatory policy design for a multi-functional landscape," Landscape ecology, vol. 27, no. 5, pp. 641–658, 2012.
15. ^ 1 2 T. W. Hertel, "Economic perspectives on land use change and leakage," Environmental Research Letters, vol. 13, no. 7, p. 075012, 2018.
16. ^ 1 2 3 4 5 6 7 8 9 J. F. Swinnen and L. Knops, Land, Labour, and Capital Markets in European Agriculture: Diversity Under a Common Policy. Centre for European Policy Studies (CEPS), 2013.
17. ^ 1 2 3 4 J. Swinnen, P. Ciaian, d'Artis Kancs, K. Van Herck, and L. Vranken, "Possible effects on EU land markets of new CAP direct payments," 2013.
18. ^ 1 2 3 4 J. S. P. C. d'Artis Kancs, "Study on the Functioning of Land Markets in the EU member states under the Influence of Measures applied under the Common Agricultural Policy. Country Study for Italy," Journal of Economic Geography, vol. 10, no. 4, pp. 495–518, 2008.
19. ^ 1 2 AEIAR, "Status of Agricultural Land Market Regulation in Europe," 2016, [Online]. Available: http://www.aeiar.eu/wp-content/uploads/2016/04/Land-market-regulation_policies-and-instruments-v-def2.pdf.
20. ^ 1 2 3 4 P. Ciaian, d'Artis Kancs, and J. F. Swinnen, "EU land markets and the Common Agricultural Policy," 2010.

21. ^ D. A. King and J. A. Sinden, "Price formation in farm land markets," Land Economics, pp. 38–52, 1994.
22. ^ 1 2 3 4 E. E. Agency, Land in Europe: prices, taxes and use patterns. EEA Copenhagen, 2010.
23. ^ 1 2 S. Kay, "Land grabbing and land concentration in Europe," Amsterdam: TNI, 2016.
24. ^ 1 2 V. Burja, A. Tamas-Szora, and I. B. Dobra, "Land Concentration, Land Grabbing and Sustainable Development of Agriculture in Romania," Sustainability, vol. 12, no. 5, p. 2137, 2020.
25. ^ I. L. C. (ILC), "Tirana Declaration: Securing Land Access for the Poor in Times of Intensified Natural Resources Competition," 2011.
26. ^ 1 2 S. Kay, J. Peuch, and J. Franco, "Extent of Farmland Grabbing in the EU," Study for the European Parliament's Committee on Agriculture and Rural Development, Available at http://www. europarl. europa. eu/RegData/etudes/STUD/2015/540369/IPOL_STU (2015) 540369_EN. pdf, 2015.
27. ^ A. Fonseca M. B. .. Burrell, A. .. Gay, H. .. Henseler, M. .. Kavallari, A. .. M'Barek, R. .. .. & Tonini, "Impacts of the EU biofuel target on agricultural markets and land use: a comparative modelling assessment," Report no JRC, vol. 58484, 2010.
28. ^ 1 2 J. Loughrey, T. Donnellan, and K. Hanrahan, "The agricultural land market in the EU and the case for better data provision," EuroChoices, 2019.
29. ^ C. Gutzler et al., "Agricultural land use changes–a scenario-based sustainability impact assessment for Brandenburg, Germany," Ecological indicators, vol. 48, pp. 505–517, 2015.
30. ^ 1 2 3 P. Feichtinger and K. Salhofer, "The valuation of agricultural land and the influence of government payments," 2011.
31. ^ D. A. Hennessy, "The production effects of agricultural income support policies under uncertainty," American Journal of Agricultural Economics, vol. 80, no. 1, pp. 46–57, 1998.
32. ^ N. H. Chau and H. De Gorter, "Disentangling the consequences of direct payment schemes in agriculture on fixed costs, exit decisions, and output," American Journal of Agricultural Economics, vol. 87, no. 5, pp. 1174–1181, 2005.
33. ^ 1 2 S. Kilian and K. Salhofer, "Single payments of the CAP: where do the rents go?," Agricultural Economics Review, vol. 9, no. 389-2016–23339, 2008.
34. ^ 1 2 3 4 S. Kilian, J. Anton, N. Roder, and K. Salhofer, "Impacts of 2003 CAP reform on land prices: From Theory to Empirical Results," 2008.
35. ^ L. Latruffe and C. Le Mouël, "Capitalization of government support in agricultural land prices: What do we know?," Journal of economic surveys, vol. 23, no. 4, pp. 659–691, 2009.
36. ^ A. Swinbank and S. Tangermann, "A bond scheme to facilitate CAP reform," 2004.
37. ^ P. Ciaian, d'Artis Kancs, and M. Espinosa, "The impact of the 2013 CAP reform on the decoupled payments' capitalisation into land values," Journal of Agricultural Economics, vol. 69, no. 2, pp. 306–337, 2018.
38. ^ J. Smith P. .. Gregory, P. J. .. Van Vuuren, D. .. Obersteiner, M. .. Havlík, P. .. Rounsevell, M. .. .. & Bellarby, "Competition for land," Philosophical Transactions of the Royal Society B: Biological Sciences, vol. 365, no. 1554, pp. 2941–2957, 2010.
39. ^ 1 2 3 4 5 6 7 L. Latruffe, J. J. Minviel, and J. Salanié, "The role of environmental and land transaction regulations on agricultural land price: The example of the French region Brittany," 2013.
40. ^ B. J. Sherrick, "Understanding Farmland Values in a Changing Interest Rate Environment," Choices, vol. 33, no. 1, pp. 1–8, 2018.
41. ^ D. Ricardo, Principles of political economy and taxation. G. Bell and sons, 1891.
42. ^ J. Von Thunen, Isolated State (English edition, ed. P. Hall). Pergamon Press, London.(German edition published in 1822), 1826.
43. ^ 1 2 3 4 5 6 E. Koomen, J. Buurman, and others, "Economic theory and land prices in land use modeling," in 5th AGILE Conference on Geographic Information Science, Palma (Balearic Islands Spain) April 25th-27th, 2002, vol. 7.
44. ^ A. Kellerman, "Determinants of rent from agricultural land around metropolitan areas," Geographical Analysis, vol. 10, no. 1, pp. 1–12, 1978.

45. ^ 1 2 3 W. Alonso and others, “Location and land use. toward a general theory of land rent.,” Location and land use. Toward a general theory of land rent., 1964.
46. ^ E. Ustaoglu and B. Williams, “Determinants of urban expansion and agricultural land conversion in 25 EU countries,” Environmental management, vol. 60, no. 4, pp. 717–746, 2017.
47. ^ 1 2 3 T. Filatova, D. Parker, and A. Van der Veen, “Agent-based urban land markets: agent’s pricing behavior, land prices and urban land use change,” Journal of Artificial Societies and Social Simulation, vol. 12, no. 1, p. 3, 2009.
48. ^ 1 2 3 4 5 R. Chakir and A. Lungarska, “Agricultural land rents in land use models: a spatial econometric analysis,” 2015.
49. ^ B. Gloy, C. Hurt, M. Boehlje, and C. Dobbins, “Farmland values: current and future prospects,” Center for Commercial Agriculture Staff Paper, Department of Agricultural Economics, Purdue University, 2011.
50. ^ 1 2 J. L. Cervelló Royo R. E. .. Segura García del Río, B. .. & Pérez-Salas Sagreras, “Land value and returns on Farmlands: an analysis by Spanish Autonomous Regions,” SPANISH JOURNAL OF AGRICULTURAL RESEARCH. REVISTA DE INVESTIGACION AGRARIA, vol. 10, no. 2, pp. 271–280, 2012.
51. ^ 1 2 3 4 A. Borchers, J. Ifft, and T. Kuethe, “Linking the price of agricultural land to use values and amenities,” American journal of agricultural economics, vol. 96, no. 5, pp. 1307–1320, 2014.
52. ^ Ł. Czyżewski B. .. Kułyk, P. .. & Kryszak, “Drivers for farmland value revisited: adapting the returns discount model (RDM) to the sustainable paradigm,” Economic research-Ekonomska istraživanja, vol. 32, no. 1, pp. 2080–2098, 2019.
53. ^ P. Koguashvili and B. Ramishvili, “Specific of agricultural land’s price formation,” Annals of Agrarian Science, vol. 16, no. 3, pp. 324–326, 2018.
54. ^ 1 2 3 4 5 6 G. Mela, D. Longhitano, and A. Povellato, “Agricultural and non-agricultural determinants of Italian farmland values,” 2016.
55. ^ 1 2 3 4 5 6 A. Grau, S. Jasic, M. Ritter, and M. Odening, “The impact of production intensity on agricultural land prices,” 2019.
56. ^ K. Happe, K. Kellermann, and A. Balmann, “Agent-based analysis of agricultural policies: an illustration of the agricultural policy simulator AgriPoliS, its adaptation and behavior,” Ecology and Society, vol. 11, no. 1, 2006.
57. ^ 1 2 D. Maes and S. van Passel, “An empirical economic model to reveal behaviour characteristics driving the evolution of agriculture in Belgium.,” 2014.
58. ^ 1 2 A. Möhring, G. Mack, A. Zimmermann, A. Ferjani, A. Schmidt, and S. Mann, “Agent-Based Modeling on a National Scale–Experience from SWISSland,” Agroscope Science, vol. 30, no. 2016, pp. 1–56, 2016.
59. ^ 1 2 3 4 5 E. Letort, P. Dupraz, L. Piet, and others, “The impact of environmental regulations on the farmland market and farm structures: An agent-based model applied to the Brittany region of France,” 2017.
60. ^ 1 2 3 V. Beckers, J. Beckers, M. Vanmaercke, E. Van Hecke, A. Van Rompaey, and N. Dendoncker, “Modelling farm growth and its impact on agricultural land use: A country scale application of an agent-based model,” Land, vol. 7, no. 3, p. 109, 2018.
61. ^ 1 2 3 4 5 6 J. Wasson, D. M. McLeod, C. T. Bastian, and B. S. Rashford, “The effects of scenic and environmental amenities on agricultural land values,” 2010.
62. ^ 1 2 3 T. Eisenhauer and M. Mitchell, Factors that Drive Canadian Farmland Values. Toronto: Bonnefield Financial, 2011.
63. ^ 1 2 3 4 P. Nilsson and S. Johansson, “Location determinants of agricultural land prices,” Jahrbuch für Regionalwissenschaft, vol. 33, no. 1, pp. 1–21, 2013.
64. ^ 1 2 3 4 5 6 J. Choumert-Nkolo and P. Phelinas, “Determinants of agricultural land values in Argentina,” 2014.

65. ^ 1 2 3 4 B. P. Reydon, L. E. A. Plata, G. Sparovek, R. G. B. Goldszmidt, and T. S. Telles, “Determination and forecast of agricultural land prices,” Nova Economia, vol. 24, no. 2, pp. 389–408, 2014.
66. ^ 1 2 3 4 K. Kocur-Bera, “Determinants of agricultural land price in Poland–a case study covering a part of the Euroregion Baltic,” Cahiers Agricultures, vol. 25, no. 2, p. 25004, 2016.
67. ^ 1 2 3 4 5 J. W. Bórawski P. .. Bełdycka-Bórawska, A. .. Szymańska, E. J. .. Jankowski, K. J. .. & Dunn, “Price volatility of agricultural land in Poland in the context of the European Union,” Land use policy, vol. 82, pp. 486–496, 2019.
68. ^ 1 2 3 4 5 F. Lehn and E. Bahrs, “Analysis of factors influencing standard farmland values with regard to stronger interventions in the German farmland market,” Land Use Policy, vol. 73, pp. 138–146, 2018.
69. ^ 1 2 3 4 5 V. Rutkauskas and L. Gudauskaitė, “Explaining the Changes of Agriculture Land Prices in Lithuania,” Ekonomika (Economics), vol. 97, no. 1, pp. 63–75, 2018.
70. ^ M. Pflüger and T. Tabuchi, “The size of regions with land use for production,” Regional Science and Urban Economics, vol. 40, no. 6, pp. 481–489, 2010.
71. ^ 1 2 3 4 5 J. V. Olsen et al., “Evaluating land prices under environmental regulation,” 2019.
72. ^ 1 2 3 4 Z. Takáč I. .. Lazíková, J. .. Rumanovská, Ľ. .. Bandlerová, A. .. & Lazíková, “The Factors Affecting Farmland Rental Prices in Slovakia,” Land, vol. 9, no. 3, p. 96, 2020.
73. ^ S. Rahman, “Determinants of agricultural land rental market transactions in Bangladesh,” Land Use Policy, vol. 27, no. 3, pp. 957–964, 2010.
74. ^ 1 2 3 J. Cymerman and W. Cymerman, “Spatial Diversification of Development of the Agricultural Property Market in Poland,” MS&E, vol. 471, no. 10, p. 102016, 2019.
75. ^ 1 2 3 I. H. Kobe, O. E. Olamide, F. S. Bamidele, A. T. Benedict, B. K. Yemisi, and D. A. Kamal, “Economic Assessment of Agricultural Land Market in Rural Nigeria: Pattern and Drivers,” Journal of Land and Rural Studies, vol. 6, no. 1, pp. 50–66, 2018.
76. ^ 1 2 M. Patton, P. Kostov, S. McErlean, and J. Moss, “Assessing the influence of direct payments on the rental value of agricultural land,” Food Policy, vol. 33, no. 5, pp. 397–405, 2008.
77. ^ 1 2 3 A. Źróbek-Różańska and J. Zielińska-Szczepkowska, “National Land use Policy against the misuse of the agricultural land—Causes and effects. Evidence from Poland,” Sustainability, vol. 11, no. 22, p. 6403, 2019.
78. ^ 1 2 3 C. Troost and T. Berger, “Dealing with uncertainty in agent-based simulation: farm-level modeling of adaptation to climate change in Southwest Germany,” American Journal of Agricultural Economics, vol. 97, no. 3, pp. 833–854, 2015.
79. ^ I. Dullinger et al., “A socio-ecological model for predicting impacts of land-use and climate change on regional plant diversity in the Austrian Alps,” Global change biology, vol. 26, no. 4, pp. 2336–2352, 2020.
80. ^ 1 2 3 N. B. Villoria and J. Liu, “Using explicit data to improve our understanding of land supply responses: An application to the cropland effects of global sustainable irrigation in the Americas,” Land use policy, vol. 75, pp. 411–419, 2018.

8 Conclusions

This Deliverable has reviewed the ample extant literature in the area of policy impact assessment, the socio-economic impacts of agriculture and its impact on rural areas, environmental and climatic impact of agriculture as well as ecosystem services, agricultural output and input markets, with a focus on the special input which is land. Besides providing a detailed analysis of the dataset most commonly and recently employed in empirical work, the review has dealt also with the methodologies employed.

The review has highlighted the increased reliance on both farm-level (or highly disaggregated) data and models which allow for a more granular representation of farmers' behavior in response also to very targeted policy measures, such as those of Pillar II of the CAP. The review has provided the AGRICORE partners involved in the development of the five modules interacting with the ABM model (WP3) with the information from the previous modeling efforts which will allow for exploring which gaps can be filled by an ambitious, yet realistic, endeavor. To reach the goal of functioning modules and suite, modelers will have to prioritize the avenues for development, while being conscious of the technical capability of the infrastructure the AGRICORE suite will run on.

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

Deliverable Number	**Deliverable Title**	**Lead beneficiary**	**Type**	**Dissemination Level**	**Due date**
D10.1	Project management handbook	IDE		Internal	