

Grant Proposal

BESTMAP: behavioural, Ecological and Socio-economic Tools for Modelling Agricultural Policy

Guy Ziv[‡], Michael Beckmann[§], James Bullock[‡], Anna Cord[¶], Ruth Delzeit[#], Cristina Domingo[»], Gunnar Dreßler[«], Nina Hagemann[«], Joan Masó[»], Birgit Müller[»], Markus Neteler[^], Anna Sapundzhieva[‡], Pavel Stoev[‡], Jon Stenning[‡], Milica Trajković[‡], Tomáš Václavík[‡]

[‡] University of Leeds, Leeds, United Kingdom

[§] Department of Computational Landscape Ecology, Helmholtz Centre for Environmental Research - UFZ, Leipzig, Germany

[‡] Centre for Hydrology and Ecology, Wallingford, United Kingdom

[¶] Technische Universität Dresden, Dresden, Germany

[#] ifW, Kiel, Germany

[»] CREA, Barcelona, Spain

[«] Helmholtz Centre for Environmental Research - UFZ, Leipzig, Germany

[»] Department of Ecological Modelling, Helmholtz Centre for Environmental Research - UFZ, Leipzig, Germany

[^] Mundialis, Bonn, Germany

[‡] Pensoft Publishers, Sofia, Bulgaria

[‡] National Museum of Natural History and Pensoft Publishers, Sofia, Bulgaria

[‡] Cambridge Econometrics, Cambridge, United Kingdom

[‡] BioSense Institute, Novi Sad, Serbia

[‡] Palacký University Olomouc, Olomouc, Czech Republic

Corresponding author: Guy Ziv (g.ziv@leeds.ac.uk), Pavel Stoev (projects@pensoft.net)

Reviewable

v1

Received: 13 Mar 2020 | Published: 13 Mar 2020

Citation: Ziv G, Beckmann M, Bullock J, Cord A, Delzeit R, Domingo C, Dreßler G, Hagemann N, Masó J, Müller B, Neteler M, Sapundzhieva A, Stoev P, Stenning J, Trajković M, Václavík T (2020) BESTMAP: behavioural, Ecological and Socio-economic Tools for Modelling Agricultural Policy. Research Ideas and Outcomes 6: e52052. <https://doi.org/10.3897/rio.6.e52052>

Abstract

Half of the European Union (EU) land and the livelihood of 10 million farmers is threatened by unsustainable land-use intensification, land abandonment and climate change. Policy instruments, including the EU Common Agricultural Policy (CAP) have so far failed to stop this environmental degradation. BESTMAP will: 1) Develop a behavioural theoretical modelling framework to take into account complexity of farmers' decision-making; 2) Develop, adapt and customize a suite of opensource, flexible, interoperable and customisable computer models linked to existing data e.g. LPIS/IACS and remote sensing e.g. Sentinel-2; 3) Link economic, individual-farm agent-based, biophysical ecosystem

services and biodiversity and geostatistical socio-economic models; 4) Produce a simple-to-use dashboard to compare scenarios of Agri-Environmental Schemes adoption; 5) Improve the effectiveness of future EU rural policies' design, monitoring and implementation.

Keywords

Behavioral change theory, ecosystem services, agricultural economics, rural policy impact assessment, agent-based modelling, biophysical modelling, farming systems archetypes

1. Excellence

Nearly 50% of European Union (EU) land is used for agriculture. These landscapes have been shaped by centuries of large-scale human impacts through traditional land-use systems (i.e. practices that are not part of modern, intensive agriculture; Bignal et al. 1995) intended to fulfil societal demands for agro-ecological products and services (Antrop 2005; Fisher et al. 2009). Today's agricultural landscapes, 'representing the combined work of nature and man' (as defined by UNESCO's World Heritage Committee) are valued for their ecological, social and historic functions (Plieninger et al. 2013, Hartel et al. 2014). However, the ecosystem services (ESS) provided by these agro-ecosystems and their related natural resources – including food, bioenergy, water, carbon storage and biodiversity – are threatened by unsustainable land-use intensification, abandonment, and climate change. To maintain economic growth, as well as nature's benefits to people and the livelihoods of 10 million EU farmers, policy instruments and harmful subsidies must be revised, assisted by new indicators that incorporate well-being, environmental quality, employment and equity, biodiversity conservation and nature's ability to contribute to people (IPBES 2018). However, most Policy Impact Assessment Models (PIAMs) focus on narrow aspects of agricultural economics (e.g. income), ignoring impacts on the wider range of rural natural, social and cultural assets benefiting society. In addition, PIAMs oversimplify the complexity of farmers' decision making, which can lead to incorrect predictions of policy outcomes.

BESTMAP will design, demonstrate and operationalize a suite of open-sourced, flexible, interoperable and customizable computer models overcoming two critical shortcomings in state-of-the-art PIAMs – first, PIAMs oversimplify farmers' behaviour and predict land-use change based only on economic factors; and second, current models cannot evaluate the impacts of alternative farming options on the environment, climate system, delivery of ESS and rural socio-economical status. BESTMAP will link economic modelling, agent-based models grounded in behavioural theory and established ESS models. Utilizing a sophisticated geographic framework of farming system archetypes, empirical social science, machine learning algorithms, assimilation of remotely sensed data and online platforms, BESTMAP will empower policy makers and stakeholders to use PIAMs more effectively. In the long term, BESTMAP will improve the effectiveness of EU policies and transform European policy design, impact assessment and monitoring.

1.1. Objectives

By developing a new modelling framework, BESTMAP aims to improve and contribute to the existing tools used in policy impact assessment, and strengthen PIAM capacity for the EC, national and regional decision-makers and expert personnel. To do this, BESTMAP will use the emerging science of behavioural theory and link economic modelling with individual-farm Agent-Based Models (ABM). BESTMAP will quantitatively model, monitor and map policy change impacts on the environment, climate system, delivery of ESS, as well as socio-economic metrics (e.g. jobs, demographics, local markets). Finally, BESTMAP will use a range of external communication and dissemination activities to build capacity for researchers, national and EU Directorate-General staff and parliamentarians to model policy impacts and improve policy design and monitoring.

Specific objectives of the project include:

1. To design and develop, together with policy-makers, modellers and the farming communities, a new PIAM architecture – the BESTMAP-PIAM. This architecture will rely on modern socio-economic approaches to behavioural change, linking existing economic models, biophysical, statistical/machine-learning and ABMs, and indicator frameworks. It will consider the environmental, social and economic variability of individual farms within/between EU regions, hereafter referred to as “Farming System Archetypes” (FSAs).
2. To operationalize the BESTMAP-PIAM modelling architecture, using co-design workshops, existing geo-referenced datasets, farmers interviews, modelling and analyses and impact-focused dissemination.
3. To demonstrate the approach in five regional Case Studies (CSs) across three EU Member States (Spain, Germany, Czech Republic) and two countries likely to be undergoing rural policy transitions (UK and Serbia), covering diverse agricultural, socio-economic and political backgrounds.
4. To synthesise results in the regional CSs, demonstrate the potential of the approach at EU/Global scales, and build a road-map to upscale the approach to European-wide and international applications.
5. To build capacity and disseminate the results by developing an extendable online dashboard for EC and national policy-makers to use the results created by the BESTMAP-PIAM, training modellers and policy-makers, fostering open-source modelling communities, and linking to other organizations to ensure legacy beyond the project’s lifetime.

1.2. Relation to the work programme

BESTMAP addresses the topic [RUR-04-2018 “Analytical tools and models to support policies related to agriculture and food”](#), the “Socio-economic science and humanities” cross-cutting priority and the “Rural Renaissance” call as detailed in Table 1:

Table 1. BESTMAP's relation to the work programme.	
Specific challenge	How BESTMAP will address the challenge
Development and maintenance of appropriate instruments for use in the [evidence-based policy] design and for the monitoring of their effects	<i>BESTMAP's</i> use of farm-level ABM and spatially-explicit biophysical and geostatistical ESS models is ideal to assess policy impact, while the planned Case Study Base Layer and European Base Layer collated data from e.g. CORINE, Eurostar, Copernicus Land Services and farmer data will support their monitoring at multiple scales .
Taking advantage of new socio-economic approaches and increased possibilities opened up by progress in the ICT area	<i>BESTMAP's</i> ABM social sciences approach is based on the recent " Reasoned Action Approach " (RAA) theory of behavioural change , while the Case Study Base Layer/European Base Layer will build on cloud computing and big-data analysis.
Scope of topic	How BESTMAP will address the scope
Modelling policies - from regional to global	<i>BESTMAP</i> includes detailed modelling in five regional CSs (Mulde, Germany; South Moravia, Czech Republic; Catalonia, Spain; Humber, UK; Vojvodina Province, Serbia), as well as EU scale analysis . In all cases, a global economic model provides input to finer scale models.
Agriculture and the related management of renewable resources	<i>BESTMAP</i> considers different agricultural production systems for food and biofuels (renewable resources) as well as other landscape elements contributing to ESS, e.g. forests, wetlands, hedgerows.
Modelling, environmental and climatic impact of farming, delivery of ESS, modelling of aspects ranging from product/sector to farming systems, structural change including the transfer of production factors such as land, the integration of agriculture in rural society	<i>BESTMAP</i> will model nutrient runoff and Greenhouse Gas emissions (environment and climate system), crop and livestock yields, water provision, avoided sedimentation, nutrient retention (delivery of ESS), biodiversity indicators, farming system archetype patterns and dynamics (modelling of farming systems), changes in field size, farmers' demographics, mechanisation (structural change), jobs, and participation in quality schemes and local markets (integration in rural society).
Establishment of links with biophysical models and geo-referenced datasets	<i>BESTMAP</i> builds on the large number of existing geo-referenced datasets (e.g. Integrated Administration and Control System (IACS), Farm Accountancy Data Network (FADN), INSPIRE, Eurostat) and remote sensing datasets (e.g. Copernicus Land Monitoring Services). The InVEST biophysical models (developed by the Natural Capital Project; Stanford University) will be used in <i>BESTMAP</i> to estimate policy impact on ESS and habitat quality.
Build a highly modular and customisable suite of tools and allow flexible use and further improvements as needs arise	<i>BESTMAP</i> will build and share publicly a set of ESS, biodiversity, socio-economic and ABM models built upon open-source platforms (InVEST, R, Repast/NetLogo/MASON) including documentation to improve these in the future. The policy dashboard will be built with an open Application Programming Interface (API) and will be extendable to include other and/or improved models .

<u>Specific challenge</u>	<u>How BESTMAP will address the challenge</u>
Be compatible with and improve the tools used at the EC	<i>BESTMAP</i> will improve modelling tools used at the EC , e.g. in the Joint Research Centre (JRC). To ensure integration of the system in existing PIAM approaches, guidance on using the architecture with other Computable General Equilibrium (CGE) or Partial Equilibrium (PE) model and integration guidance to other models used by the EC (e.g. MAGNET, CAPRI, Aglink-COSIMO) will be developed. <i>BESTMAP</i> will also improve non-equilibrium model (E3ME) used by the EC to assess energy-environment-economy linkages. To ensure <i>BESTMAP</i> is useful to the EC, one of our partners (CE) regularly perform policy analyses for EC, and two members of the Science Advisory Board (Peter Witzke (EuroCARE) and Ignacio Perez-Dominguez (JRC Seville)) are leading experts in these models.
<u>Socio-economic science and humanities</u>	<u>How BESTMAP will include social science</u>
Take into account the social, economic, behavioural, institutional, historical and/or cultural dimensions, as appropriate, of a societal issue	The RAA theory incorporates social, economic, behavioural, institutional, historical and cultural dimensions , which <i>BESTMAP</i> includes through focus groups and interviews and scales-up using IACS, FADN, INSPIRE, and other survey data.
Contributions from the socio-economic Science and Humanities (SSH) are integrated at various stages	<i>BESTMAP</i> includes SSH researchers from political sciences, environmental and agricultural economics and socio-ecology, who will be an integral part across all work-packages of <i>BESTMAP</i> .
<u>Rural Renaissance call</u>	<u>How BESTMAP will address the call</u>
The design of innovative policy instruments/ approaches and governance models	<i>BESTMAP</i> will explore policy changes that may follow from the UK's exit and Serbian's accession of the EU, to help inform, design and monitor changes to the EU Common Agricultural Policy (CAP).
Focus Areas "Digitising and transforming European industry and services" and "Building a low-carbon, climate resilient future". The actions are expected to support...Sustainable Development Goals (SDGs) in particular SDG 9, 11, 12, 13 and 15	<i>BESTMAP</i> will depend on Big Data, cloud, high-performance computing and artificial intelligence (Digitising and transforming) and improve policy impact analysis on greenhouse gas emissions (Low-carbon). In addition, <i>BESTMAP</i> will synthesize existing knowledge and produce indicators addressing the CAP, the SDGs, COP 21 Paris Climate Agreement, EU Bioeconomy Strategy, Circular Economy Package and other national policies.

1.3 Concept & Methodology

(a) Concept

BESTMAP builds on five concepts:

1. while economic factors (e.g. predicted by CGE/PE models) are an important drivers of farmers' decisions (e.g. on adopting different crop rotations), they equally **depend on their behavioural attitudes, beliefs, social norms and sense of control**;

2. the response of the **rural socio-environmental-economic system can be modelled with an agent-based bottom-up approach** as an emergent property arising from decisions made at a very local scale (farm/field), and influenced by fine-scale environmental and ecological conditions;
3. a **typology of farmers having similar response to policy change** can be defined and mapped (as “Farming System Archetypes”; FSAs) by geospatial relations of existing georeferenced datasets (e.g. IACS/LPIS, FADN, national surveys, remote sensing data), augmented with empirical local socio-economic and sociological data;
4. the same typology also describes the **typical farm-scale composition, configuration and management of its natural resources/assets**, linking FSAs to ESS flows, biodiversity and socio-economic outputs;
5. the utility of such **analytical tools necessitate careful co-design and co-development** with policy makers and stakeholders, translation of the model outputs into policy indicators and developing an interactive dashboard to facilitate and **empower policy-makers to visualize and experiment with trade-offs and synergies of new policies**.

C1. Modelling approaches employed in *BESTMAP*

Agriculture is one of the most complex sectors to model. Besides having a large number of economic and human actors operating at different scales, agriculture is also driven by biophysical and ecological processes from global to sub-meter scales (Fig. 1). State-of-the-art modelling of agro-ecosystems is highly scale and conceptualization dependent influencing how human agencies (i.e. farmers and other people and organizations) affect the dynamics of agroecosystems, and raising the need for better capturing different processes, feedbacks, constraints and socio-economic factors (Preston et al. 2015).

Most agricultural PIAM take a top-down approach, explicitly or implicitly describing drivers at global, continental, national and (less frequently) regional scales – often with very simplistic assumptions or missing details on the accompanying biophysical and socio-economic drivers’ side. Those top-down models are used, however, to predict aggregated changes made at farm level. ***BESTMAP* innovation is to combine these models with a bottom-up approach**, describing the large-scale economic, social and environmental impacts via aggregation of farm level units, considering statistical distributions and correlations at each scale among the economic/human and biophysical drivers. In this sense, *BESTMAP* argues that large scale phenomena such as regional/national food production, employment in agricultural sector or flood risk are **emergent properties of the individual farms multi-actor system**.

Fig. 1 puts *BESTMAP* in context of the current state-of-art in PIAM. The current approach (often used by the EC for impact assessment) uses either Computable General Equilibrium (CGE) or Partial Equilibrium (PE) models to forecast how a new policy, impacting subsidies, tariffs or quotas, will change macro-economic measures at large regional scales such as countries, regions, subcontinental (e.g. Eastern Europe), or whole continents. Those outputs are typically in the form of changes in total production, prices and costs at a

range of economic and agricultural sectors. Some of these CGE/PE models include a land allocation sub-module, which allows land-use to change based on strict economic rules. **BESTMAP is designed to be compatible with and improve such tools.** In particular, our approach uses the output of such top-down models, which we inform by stakeholder workshops at EU scale (see Sec. C1.1), and explores those outputs in a set of representative case study areas with individual farm (i.e. bottom-up) ABMs (Sec. C1.2). The decision rules and agents' attributes of the ABMs are populated based on information gathered by analysis of existing geospatial data, our own interviews and *BESTMAP* modelling work (Sec. M3). The output of the ABMs indicate changes within each case-study in farming systems (land-use, intensity, management type etc.), ESS, biodiversity, and socio-economic aspects. Thus, *BESTMAP* both 'extends' the CGE/PE model to include behavioural characteristics (Sec. C1.3) in predicting policy impact on farming systems, and 'translates' the outputs of CGE/PE models to cover ESS, biodiversity and socio-economic aspects.

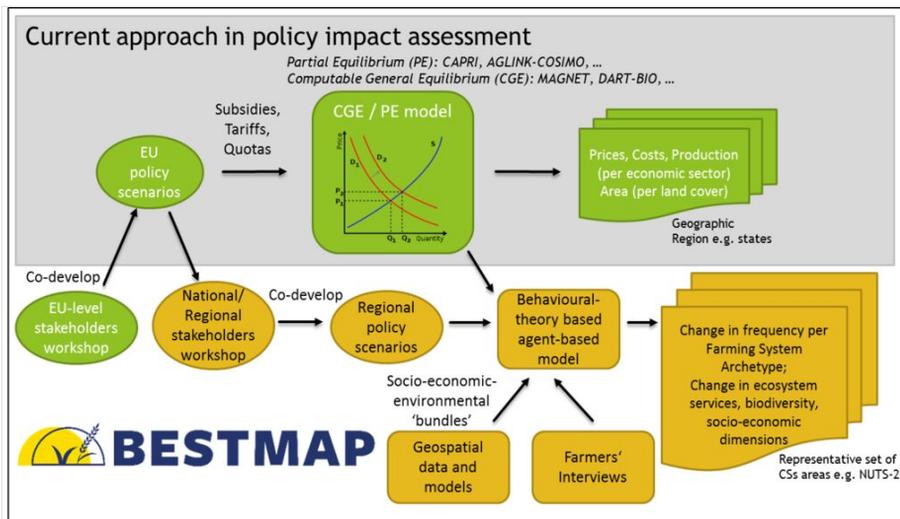


Figure 1. doi

Top-level conceptual framework of *BESTMAP*. *BESTMAP* combining existing global/EU scale (green) models used by the EC, in particular Partial Equilibrium (PE) and Computable General Equilibrium (CGE) models with regional analyses (yellow) by

1. formalizing engagement with stakeholders to define scenarios;
2. using existing geospatial data and empirical data collection to map farming systems based on a novel concept of Farming System Archetypes (FSA) namely farms with a characteristic bundle of ESS, biodiversity, socio-economics and behavioural characteristics of decision-making agents (i.e. farmers);
3. linking economic (typically global) large scale economic based PE/CGE to agent-based models;
4. describing changes in FSAs's distribution, ESS, biodiversity and socio-economics in a representative sample of case study areas.

C1.1. Economic modelling for agricultural impact assessment

Global economic models, either PE or CGE, solve for balance between supply and demand with flexible prices. Their structure allows analysis of the impact of changes in supply (e.g. due to yield changes under climate change) or demand (e.g. biofuel targets) on prices, trade, production, and land allocation (e.g. Boulanger and Philippidis 2015, Kavallari et al. 2014). Most models are based on a large number of non-linear relationships describing how production would change if the constituents (“factors”) or demand changes, often in a non-linear way. Parameterizing those models necessitates a large volume of data on trade flows, production, tariffs, quotas etc. A popular choice for such information is the Global Trade Analysis (GTAP) dataset, which models such as MAGNET and the Dynamic Applied Regional Trade (DART-BIO) are based on. *BESTMAP* will have, as a starting point for stakeholder engagement during co-design workshops, a narrative focusing on the incorporation of agriculture into COP-21 Paris Agreement commitments by Member States, as recently proposed in EC communication COM/2016/0482. For this purpose, an ideal economic model should incorporate energy sector feedbacks (i.e. a CGE model), and separate out biofuels from food – both criteria met by DART-BIO.

C1.2. Agent-based modelling (ABM) in agricultural decision making

In *BESTMAP*, the outputs of the DART-BIO (Sec. C1.1) will be linked to an ABM to model farmers’ decision making, including the influence of exogenous factors (from the CGE model) such as prices but also endogenous factors such as social interactions between farmers. In recent years, ABMs have been proposed as an alternative tool to predict impacts of agricultural policies (Reidsma et al. 2018; Berger and Troost 2013). ABMs are process-based simulations that represent decisions of individual ‘agents’ (such as farmers), their interactions with other agents as well as the environment. ABMs can explore land-use patterns and social-ecological consequences at different spatial and temporal scales and can make use of quantitative and qualitative data for model parameterization.

Agricultural ABMs such as AGRIPOLIS or MP-MAS are grounded in agricultural economics and assume that socio-economic factors drive farmers’ decisions (cf. Happe et al. 2008, Troost and Berger 2014). Similarly, the JRC’s EU-wide Individual Farm Model for Common Agricultural Policy Analysis (IFM-CAP) assumes farmers are profit-maximizers (Louhichi et al. 2017). A recent quantitative review of land-use ABMs shows that in the majority of human decision-making models do not explicitly based on any theory, and those that do mostly use the expected utility theory (Groeneveld et al. 2017). Furthermore, most ABMs only consider economic factors in the decision-making process, whereas factors such as social norms, learning, adaptation or uncertainty are only rarely included. In contrast, empirical research suggests that farmers do not behave like *homo economicus*, and often make sub-optimal decisions, rely on limited information or are influenced by others (cf. Stuart et al. 2014, Läßle and Kelley 2013). In addition, factors such as farmers’ attitudes, values and long-term experiences with respect to specific regional land-use practices are of importance (cf. review in Lesch and Wachenheim 2014). ABMs provide the opportunity to include such micro-level data, which can be gathered through surveys or interviews, in the models. Doing so can substantially improve the representation of decision-making in

models (Filatova et al. 2013). While there are some ABMs that take such factors into account for local to regional case studies (cf. Valbuena et al. 2010, Malawska and Topping 2016, Zagaria et al. 2017), the bulk of land-use ABMs do not take social science theories into account. *BESTMAP* will address this challenge by **explicitly incorporating farmer's behaviour into an ABM, building on empirical data** (Sec. M3.2) **and established theory of human decision** (Sec. C1.3).

C1.3. Reasoned Action Approach (RAA) to human decision

A wide range of theories on human behaviour have been developed in the social sciences, psychology and economics, focussing on diverse aspects such as individual and group decision-making, learning or social influence. Whereas some theories are more generic (e.g. bounded rationality), others focus on specific aspects of decision-making processes. Table 2 gives an overview on behavioural theories that can be used in ABMs, although challenges associated with selecting, formalizing and implementing social science theories in simulation models limited their application to date (Schlüter et al. 2017; Groeneveld et al. 2017).

Table 2.

Overview of selected behavioural theories, their origin and field of application. *BESTMAP* will use the 'Reasoned Action Approach', adapted from Schlüter et al. (2017).

Name of theory	Field of application	Theory considers...					Reference (see Schlüter et al. 2017 for details)
		Utility maximization	Limited cognitive capacity	Aspiration level/ satisfaction	Reinforcement/ social influence	Risk aversion	
Rational choice theory <i>Actors are self-interested, goal-oriented utility maximizers. They possess perfect knowledge and unlimited cognitive capacity to determine optimal choice.</i>	Economics; Political science; Psychology; International relations; Natural resource use	Yes	No	No	No	Yes	Simon (1978), Frank (1987), Monroe (2001)

<p>Bounded rationality <i>Rationality of actors is limited by available information and cognitive capacity. Behavioural choice may be realized through utility maximization, but also by reaching an aspiration level or following a heuristic.</i></p>	<p>Economics; Political science; Psychology; International relations; Natural resource use</p>	<p>Yes</p>	<p>Yes</p>	<p>Yes</p>	<p>No</p>	<p>No</p>	<p>Simon (1955), Gigerenzer and Selten (2001)</p>
<p>Reinforcement learning <i>Positive behavioural outcomes reinforces the behaviour of an actor who will deliberate about alternative behaviours if need satisfaction drops below a certain level.</i></p>	<p>Psychology; Neuroscience</p>	<p>No</p>	<p>No</p>	<p>Yes</p>	<p>Yes</p>	<p>No</p>	<p>Pavlov (1927), Skinner (1953), Graybiel (2008)</p>
<p>Descriptive norms <i>Actors observe the behaviour of others, which can have an impact to the actor's own behaviour.</i></p>	<p>Psychology; Environmental sciences</p>	<p>No</p>	<p>No</p>	<p>No</p>	<p>Yes</p>	<p>No</p>	<p>Cialdini et al. 1990</p>

Prospect theory <i>Actors have a degree of risk aversion and bias a rational decision towards avoiding loss over a possible gain.</i>	Economics; Environmental management	Yes	No	No	No	Yes	Kahneman and Tversky (1979), Hastie and Dawes (2001)
Reasoned Action Approach (RAA) <i>Intention towards a behaviour depend on its attitudes towards the behaviour, perceived norm and perceived behavioural control.</i>	Environmental psychology; Environmental management	Yes	Yes	Yes*	Yes	Yes*	Ajzen (2012), Ajzen (1991)

* can be modelled through attitudes of ABM agents

For the implementation of ABMs, *BESTMAP* will use the RAA, an extension of the ‘Theory of Planned Behaviour’ (cf. Fishbein and Ajzen 2010) and a **coherent social-science behavioural theory of human decision making**. The RAA states that an actor’s behavioural decisions depends on three characteristics: attitude (beliefs about outcomes of specific behaviours), perceived norm (e.g. social pressure), and perceived behavioural control (subsuming actors’ autonomy and capacity). These three elements form the intention of an actor to perform a specific behaviour. The actor’s behaviour is mediated by intentions as well as behavioural and actual control (e.g. limitations in skills, resources). This theory has been empirically tested (e.g. Bechini et al. 2015) and implemented in ABMs (Kaufmann et al. 2009, Martinovska Stojcheska et al. 2016) using multi-attribute subjective utility functions (Schwarz and Ernst 2009) or coupling with Bayesian Belief Networks (cf. Poppenborg and Koellner 2014).

In *BESTMAP*, we will operationalize the RAA in the form of specific quantitative and qualitative (categorical/ordinal) attributes in the ‘Farmer’ agents which determine their decisions (Sec. M3.5). These attributes will take role in ‘perceiving’ external drivers such as policy change and economic price shocks etc. They will also determine other rules that affect ‘Field’ agents, such as his/her crop rotation etc.

C1.4. Ecosystem Services (ESS) modelling

ESS are a useful framework to communicate and analyse the ecological and socio-economic impacts of land-use decisions. ESS approach at a European scale is driven by Action 5 of the EU Biodiversity Strategy to 2020, which calls for Member States to map and assess the state of ecosystems and their services before 2020. A commonly used European classification of ESS is CICES (<https://cices.eu>). In Table 3 we summarise the CICES ESS provided by agricultural land or most impacted by agricultural land-use.

Table 3. Key ESS for rural agricultural land, using the CICES classification.		
CICES Section & Division	Description	Important processes affecting ESS
Provisioning - Biomass	Cultivated crops, livestock, fibres and other materials from plants, animals	Crops grown/breeds used, agricultural management methods
Regulation & Maintenance - Regulation	Control of erosion rates	Cultivation methods, cover crops, livestock densities
	Regulating water flows	Water use, attenuating surface flows, water infiltration and holding
	Pollination of cultivated plants	Habitat for pollinators, pesticide use
	Habitat protection	Providing habitats for wild plants and animals
	Pest control	Habitat for predators of agricultural pests, pesticide use
	Quality of freshwaters	Use and runoff of pesticides, herbicides, phosphorous, nitrogen, etc. soil erosion
	Climate regulation	Greenhouse gas storage, emissions & sequestration
	Air quality	Pollution from fertiliser use, livestock, etc (Ammonia, Nitrogen oxides)
Cultural - Direct	Recreation. observing & studying nature. cultural values, aesthetic appreciation	Land use, accessibility, non-agricultural features
Cultural - Indirect	Biotic components with non-use value	Conserving biodiversity on farmed & non-farmed areas

Some economic models have been linked with global ESS models (e.g. EUCLIMIT, SEAMLESS-IF, MACSUR projects). However, these ESS models are typically of coarse scale, often based on weighted indirect proxies/indicators, poorly validated (i.e. with *in-situ* or remote sensing data) and focus on emissions/pollution with little consideration of the

capacity of the natural environment to mitigate these (via regulating services). ESS modelling approaches vary greatly in complexity, resources requirements and accuracy – from the Capacity Matrix approach (Jacobs et al. 2015) based exclusively on expert-opinion, via quantitative proxies assigned per land-use type based on literature/experts, simple biophysical models (e.g. InVEST toolset) and resource-demanding complex process-based models (e.g. Soil and Water Assessment Tool (SWAT) model). **Improving the spatial resolution, validating models using appropriate data and striking a better balance between complexity (and scalability) and biophysical realism of ESS models** is a significant challenge *BESTMAP* will address (Sec. M3.3).

C2. Typology and mapping of agricultural Farming System Archetypes (FSAs)

Unlike many models based on land use/land cover, *BESTMAP-PIAM* will build on a new typology of FSAs. A new typology/framework is needed because farming systems and their changes are characterized by

- land-use categories and conversions among them,
- changes in land-use intensities and management practices (e.g. density of cropping, mechanization, fertilizer application, crop rotations), but also by
- socioeconomic factors and their dynamics (e.g. land tenure and ownership, size of the fields/agricultural holding).

Understanding land use, land use intensities and socioeconomic factors is crucial to design and implement effective policy measures tailored for the specific farming system and to assess their impact on the agro-ecosystems and the ESS they provide. Therefore, a system approach that identifies archetypical farming patterns, considering both the natural and social potential of rural areas (Erb et al. 2013) may provide a more integrative understanding of agricultural systems.

Fig. 2 shows the conceptual framework used in *BESTMAP* to define FSAs. In brief, FSAs are typical systems representations of coupled-human-and-nature systems focused on agricultural farmlands. An FSA would have characteristic inputs, outputs, unintended outcomes, system properties/natural capital, production systems/fields and most importantly characteristics of the land manager/farmer. FSAs build upon rural typology for strategic European policies (van Eupen et al. 2012) and the Land System Archetypes developed at global (Václavík et al. 2013) and European scales (Levers et al. 2018; see Fig. 3 as an example). *BESTMAP* will extend these previous frameworks by **accounting for additional parameters crucial for farming systems and implementing the FSAs approach at the individual farm level** (Sec. M3.4).

C3. BESTMAP-PIAM – an improved architecture for Policy Impact Assessment Modelling (PIAM)

BESTMAP proposes a new architecture – the *BESTMAP-PIAM* - for integrating economic, biophysical and statistical/machine learning models for improved policy impact assessment (Fig. 4). Within this framework, a “decision” (e.g. change from one type of FSA to another) is made by individual actors at the farm level. Those FSAs are initially derived from

geospatial data, and refined following ESS modelling and interview campaign collecting socio-economic data. Global/EU level policy and other global drivers impact those agents, either via economic changes (estimated using any CGE / PE model, demonstrated in *BESTMAP* with DART-BIO model) or other drivers as defined within stakeholders' workshops. The change in distribution of FSAs is translated into change in ESS, biodiversity and socio-economic outputs (as FSAs are defined having a typical 'bundle' of these) and, together with the uncertainty on these, are translated into policy-relevant indicators (Sec. C3.1) that are aggregated (across regions) and made accessible to policy makers using an online dashboard (Sec. C3.2).

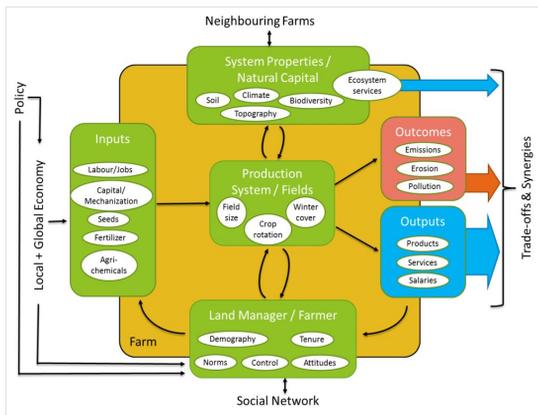


Figure 2. doi

The conceptualization of Farming System Archetypes (FSAs) in *BESTMAP* is an extension of land-use intensity framework from Erb et al. 2013 to include the land manager/farmer and its behavioural characteristics (based here on the RAA). FSA have a typical 'bundle' of ESS, outputs, outcomes, inputs and farmer characteristics.

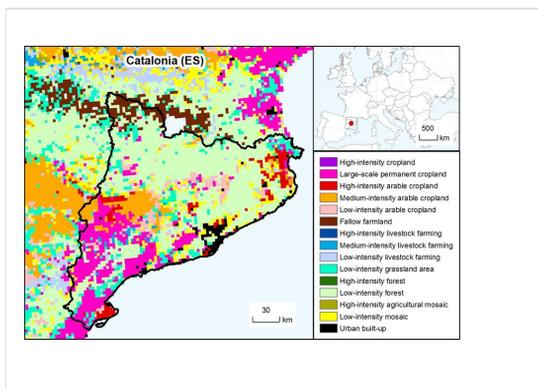


Figure 3. doi

The Land Systems Archetypes mapped by Levers et al. (2018) for one of *BESTMAP* case study areas in Catalonia. Land Systems Archetypes were derived at 3km resolution for Europe based on CORINE land cover, downscaled ecological and economic data. *BESTMAP* aims to map Farming System Archetypes (FSAs) at the farm level.

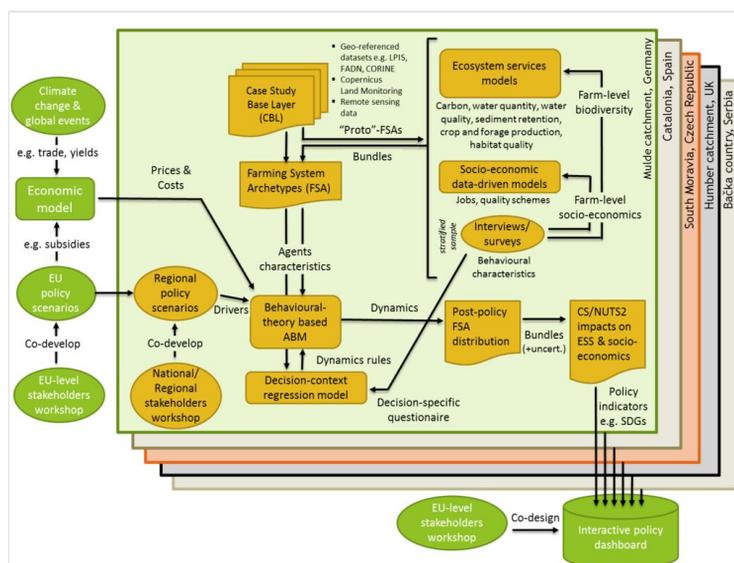


Figure 4. [doi](#)

BESTMAP conceptual framework for policy impact assessment modelling, combining actions at EU scale (green), and activities within a representative set of case studies (orange; demonstrated in five areas within *BESTMAP*). The framework combines workshops (ovals), modelling (rounded rectangles) and interviews (ovals) producing several datasets (curved rectangles) and an online interactive dashboard (barrel shape). At the EU level, *BESTMAP* will co-design with policy-makers and stakeholders policy scenarios which, with existing scenarios of climate change and other global events, will input into the global economic models (here DART-BIO CGE model, but also MAGNET, CAPRI etc.). Georeferenced data layers ("Case Study Base Layers"; CBL) will be collated from existing sources including the Land Parcel Identification System (LPIS), Farm Accountancy Data Network (FADN), CORINE land-use/land cover, INSPIRE Geportal, Copernicus Land Monitoring, national/regional datasets and existing remote sensing products. This will be used to define 'prototype' Farm System Archetypes (FSAs) which help stratify and design the interview campaign in each of the case studies. *BESTMAP* will collect demographic, behavioural characteristics and socio-economic information using semi-structured interviews (with harmonized protocols). Ecosystem services models (here the InVEST biophysically based models, but simpler e.g. capacity matrix or more complex e.g. SWAT models can in be used in the future) will estimate ESS, environmental/climatic impacts and biodiversity provided by different farming units. The 'bundle' of ESS, geostatistically modelled socio-economics and behavioural characteristics will add to the CBL and define the final typology of FSAs in the case study. A generic ABM template based on the RAA behavioural theory will be locally adapted by the same interviews/surveys, and driven by the outputs (prices and costs of commodities, energy etc.) from the global economic model (DART-BIO) as well as narratives and drivers arising from a national/regional workshop interpreting the EU-level policy. The change in FSAs resulting from those scenarios via the ABM will translate to change in ESS and socio-economics defining the FSA 'bundles' including their uncertainty. Those impacts at the case study level will be translated into stakeholders-defined policy indicators (e.g. of the SDGs) and visualized using a standard interactive web-based data portal policy dashboard, the use of which will be the focus of training and dissemination activities.

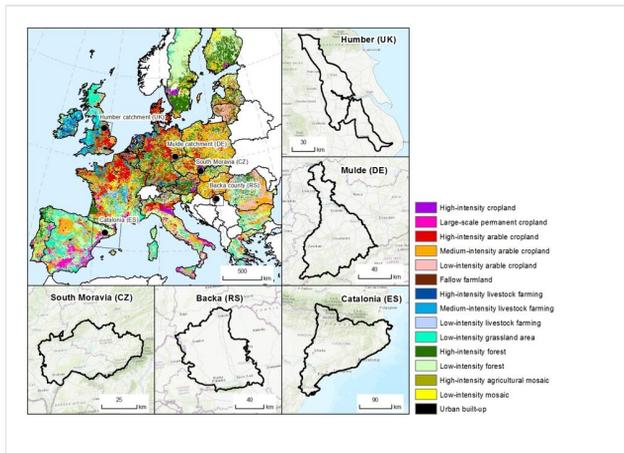


Figure 5. [doi](#)

BESTMAP demonstration case studies: overview of CS locations in the context of Land Systems Archetypes mapped by Levers et al. 2018 at 3km resolution for Europe. No land system archetypes shown for Serbia as the mapping included EU countries only. Insets show the exact boundaries of CS areas.

The implementation of BESTMAP-PIAM in *BESTMAP* can, in principle, be extended to cover the entire EU with FSAs and ABMs developed at NUTS-2 scale. Given the resources such an endeavour will require, it is much more efficient to **use representative sample of case studies in each Member State** – and *BESTMAP* will develop a metric to estimate how representative the case studies in *BESTMAP* are and how many are needed to cover larger geographic regions (Sec. M4). In addition, *BESTMAP* includes a task to develop an initial European-wide model by scaling up the ABMs developed in the CSs. **A roadmap to explore the research, capacity, regulatory and financing challenges and options to scale up the project will be developed.**

The conceptual architecture of BESTMAP-PIAM is highly flexible. In particular it can:

1. Use any economic CGE / PE model outputs, including those used in recent assessment of CAP reforms produced by JRC (European Commission 2018b) including MAGNET, CAPRI, AGLINK-COSIMO or GLOBIOM-EU. *BESTMAP* will provide guidance on how to link the ABM models to these examples.
2. Use dynamic (i.e. non equilibrium) economic models, as long as they provide information on changes in relevant costs and prices affecting farmers. *BESTMAP* will test that using partner CE E3ME, a model used by the EC to assess energy-environment-economy linkages.
3. Work at the regional scale with more CSs from one particular country/region, or at global scale if CSs from across the globe are developed. *BESTMAP* will produce guidelines and 'templates' for implementing new CSs. Similarly, the economic model can be country-specific or global (as per DART-BIO).

4. Use more complex ESS models e.g. SWAT, or simpler models e.g. expert-opinion based Capacity Matrix approach. Field measured ESS (e.g. using soil samples, water quality kits) can also be used. *BESTMAP* will describe several such options and their pros and cons in the roadmap.

C3.1. Indicators to measure policy impact

To make use of the modelled impacts of policy on different FSAs, *BESTMAP* will **link ESS, biodiversity and socio-economic outputs models to existing or currently developed indicators, in particular those related to SDGs and CAP monitoring**. The 2030 Agenda on Sustainable Development describes 17 Goals. SDGs such as No Poverty (SDG 1), Zero Hunger (SDG 2), Reduced Inequalities (SDG 10), Climate Action (SDG 13) and Life on Land (SDG 15) have direct relation to the new CAP (European Commission 2018a), but agricultural policies are indirectly related to nearly all SDGs. The SDGs have been translated into 169 Targets, which are integrated and indivisible, and carefully balanced economic growth, social inclusion and environmental sustainability (Griggs et al. 2013). In turn, the 169 Targets are supported by an initial set of 244 indicators that requires the use of multiple types of data (United Nations 2016; Anderson et al. 2017). In addition, Eurostat already monitors 28 agri-environmental indicators related to the CAP (based on EC COM/2006/0508), and a performance model for the CAP is being drawn by Member States under the CAP Strategy Plans for 2021-2027. This Common Monitoring and Evaluation Framework includes a large set of performance indicators (European Commission 2018a).

C3.2. Interactive dashboard for policy-makers

Existing PIAMs are complex, requiring specialist expertise to run, analyse and report. At present, policy-makers (and their aides and supporting EC staff) rely on impact assessment reports developed early on in the life-cycle of new rural policy. As a result, they have no control over the scenarios explored, and changes made to the policy during parliamentary debates and due to the involvement and consultation of other political actors and stakeholders are not reflected in their impact assessment and underlying models. Interactive dashboards aim to alleviate those constraints, by **allowing stakeholders (as well as scientists and the public) to explore a much larger number of options (pre-computed or computed on-the-fly) and visualize the impacts of such changes on different dimensions (e.g. indicators) and, in the case of large areas, on their spatial heterogeneity**. The dashboard approach helps with monitoring the overall evolution of some variables and numerical indicators as well as visualizing their geospatial distribution to determine the hot spots where new policies are having negative impacts. Importantly, **the underlying models and their assumptions, the data used etc. will be made transparent** within those dashboards. These dashboards will allow policy makers and expert practitioners to simulate future scenarios and compare policy alternatives leading to new recommendations. Such decision-supporting tools will become the cockpit of decision-making, by radically transforming policy-making, democratizing impact assessment and providing much greater control, transferability and accountability of the policy process as a whole.

(b) Methodology

How *BESTMAP* may work in practice? Hypothetical example in a CS region

The following example demonstrates how *BESTMAP* will work within each of the individual CS areas (Sec. M2). In our initial EU-level stakeholders workshop in Brussels (Sec. M1), a need to better understand the impact of including the agricultural sector's role in achieving Paris agreement commitments is raised. This is brought to a CS stakeholders workshop where a plausible scenario of new Agri-Environmental Scheme options for setting aside agricultural land to become permanent meadow and accumulate carbon in soil is seen as a way to accomplish this EU-level goal in the local CS context, and a hypothetical monetary value of the subsidy is agreed on. This (or other options mentioned by stakeholders) may have impacts across the agricultural sector and wider economic system—which *BESTMAP* will explore using a CGE model to get net effect on producers' revenues and subsidies (Sec. M3.1). We will use this information in interviews with a sample of farmers in the CS area (Sec. M3.2). Farmers will be asked about the likelihood they will adopt this option (e.g. permanent meadows) given different levels of economic incentives. We will ask them also other demographic, socio-economic and behavioural questions. The latter will follow the RAA regarding their attitudes, perceived norms, and behavioural control. Questions on how they would be influenced by peers will also be asked. Combining data harmonized from existing geo-referenced datasets (Sec. M2.1) e.g. IACS, FADN, and the field interviews, we will generate a typology of farms or FSAs using a mixed hypothesis-driven and data-based approach (Sec. M3.4). Biophysical models, calibrated and validated using existing in-situ datasets (Sec. M3.3), and geostatistical socio-economic models of e.g. labour and demographics will link each FSA to a 'typical' bundle of ESS, socio-economics and behavioural characteristics. The transition probability among FSAs, e.g. from farm without permanent meadows, to a farm with on average 10% land area as permanent meadows, will be established from interviews and regression analyses using FSA characteristics. These dynamic rules will populate an ABM (Sec. M3.5) which predicts the distribution of FSAs for different levels of subsidy for permanent meadows. Based on the 'typical' bundles per FSA, the 'average' change (and uncertainty thereof) in a set of ecosystem services (e.g. carbon storage, water quantity and quality, wildlife habitat quality) and socio-economic aspects (e.g. jobs, demographics, quality schemes) from introducing this new EU level policy will be derived for each CS. These outputs, and existing policy-indicators derived from them (Sec. M5.1), will be visualized in an interactive online policy dashboard (M5.2), showing impacts within a CS and across CS regions using a geospatial framework. Workshops and training with decision-makers will support implementation and dissemination, leading to increased transparency and accountability in policy-making process.

M1. Co-designed policy scenarios driving modelling approaches in *BESTMAP*

The *BESTMAP* co-design and co-development phase will organize stakeholder/policy-maker workshops and focus groups to discuss policy scenarios. These will be at both EU level and with national and local stakeholders at each CS. At the EU level, we will identify key areas for future rural policy which can have significant influence on ESS

and socio-economic aspects. The modelling platform SUPREMA had similar EU level workshops, and *BESTMAP* will build on the knowledge gathered by those. ***BESTMAP* will also build on the long history of scenarios development** in the Global Environmental Outlook 4/5, Millennium Ecosystem Assessment, and the Special Report on Emissions Scenarios (SRES) by the Intergovernmental Panel on Climate Change (IPCC). More recently, the FP7 OpenNESS project developed policy scenarios based on varying levels of shared responsibility to ESS and coherence of policies impacting ESS and biodiversity (Priess et al. 2018). As a starting point, several options will be explored in *BESTMAP* EU-level policy workshop:

1. A focus on including carbon sequestration in agricultural land into implementation of the COP-21 Paris Agreement. This explicitly appeared in EC regulation 2018/841 from May 2018, according to which “Each Member State shall account for emissions and removals resulting from managed cropland ...” and *The Future of Food and Farming* COM(2017) 713 “CAP objectives would fulfil the EU Treaty obligations but also ... climate change (COP 21)” and “The EU 2030 Climate and Energy targets ... agriculture should make a fair contribution to these targets”
2. A focus on maintaining small or medium sized farming systems, mentioned in *Next Steps for a sustainable Europe* COM(2018) 98 “Changes to the system of direct payments could provide an opportunity to focus payments .. on small and medium sized farms [80% of direct payments go to 20% of farmers]”
3. An emphasis on “public funds for public goods” spearheaded by UK post-Brexit discussion as in e.g. *Health and Harmony: the future for food, farming and the environment in a Green Brexit* “our [UK] new agricultural policy to be underpinned by payment of public money for the provision of public goods”

Based on the outcomes of the workshop, *BESTMAP* will either adapt existing scenarios (e.g. from OpenNESS or SUPREMA) or create new scenarios. Those scenarios will estimate the extra (or reduction of) subsidies for sectors within the CS regions, as well as other factors important in the economic model (Sec. M3.1). At the national and regional scale, stakeholder’s workshops will translate those EU level policy scenarios into specific predicted changes in the rural agricultural landscape, and into narratives about the change in procedure (application, monitoring, compliance) expected to affect farmer’s decisions (i.e. non-economic drivers).

***BESTMAP* and Brexit** – in March 2019, the UK intend to leave the EU. The implications on agriculture and trade within the UK, between the UK and remaining EU-27, between UK and third-party countries (e.g. new bilateral agreements) and the spill-over effects globally are highly uncertain. The DART-BIO model economic analysis ‘baseline’ uses the latest available GTAP 9 whose base year is 2011, before the 2016 UK Referendum. We expect that during the project, clarity on the form of Brexit will emerge. Recently, UK government documents on ‘no-deal’ Brexit (dated 23 August 2018) ensure farming subsidies to keep at their current levels. It is also unlikely that new economic base datasets implementing the post-Brexit global economy will be available during *BESTMAP* implementation, although this would be a topic we aim to explore in exploitation plan. For the UK case study, we will

use expert-opinion from previous workshops, published studies and our own focus group to change DART-BIO outputs and account for Brexit impacts.

M2. Developing demonstration case studies

BESTMAP will model the effects of policy scenarios on the dynamics of farming systems in five regional case studies across three EU Member States (Spain, Germany, Czech Republic) and two countries possibly undergoing major rural policy transitions in the near future (UK and Serbia) (European Commission 2018b). ***BESTMAP* case studies cover diverse biophysical, socio-economic and political backgrounds.** These study areas were selected because:

1. they represent a major agricultural area representative for each respective country (Fig. 6);
2. they cover a cross-section of different farming systems and practices;
3. they have been undergoing changes as a result of land-use drivers and policy interventions;
4. they were subject to previous research, so basic spatial data, agricultural statistics and other ancillary information are available for these regions.

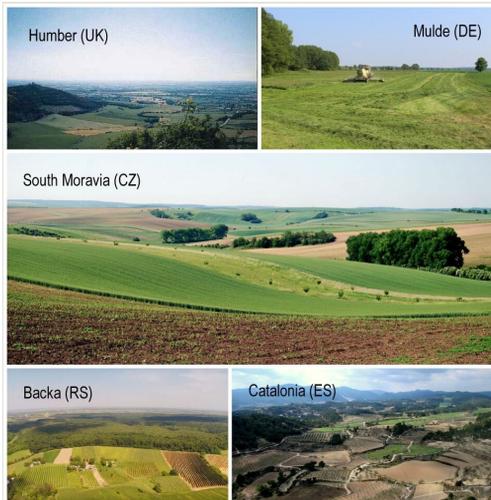


Figure 6. [doi](#)

Typical agricultural landscapes of *BESTMAP* demonstration case studies.

The size of the case studies is approximately corresponding to a NUTS-2 level or is defined by a catchment boundary.

To ensure a **consistent approach across regional CSs**, which is key for synthesis activities, a 'protocol' will be developed early in the project. A national stakeholders' workshop will inform the specific decision context implemented in the ABM for that CS, e.g. switching to organic farming, adopting soil management, converting food to biofuel crops

etc. *BESTMAP* partners have previous research, data infrastructure and farmers' networks within the CSs areas, which together span a range of climatic regions, institutional structures and management histories (see description below and statistics in Table 4). In each CS, *BESTMAP* will collect empirical data to parameterize the RAA-based ABM (Sec. M3.2), calibrate/validate biophysical ESS and biodiversity models (Sec. M3.3) and construct data-driven models for socio-economic aspects (Sec. M3.2). *BESTMAP* will **reconvene the stakeholders from the initial workshop to provide feedback on the results** in key points along the project.

Table 4.

Regional case studies in *BESTMAP*.

	Humber (UK)	Mulde (DE)	South Moravia (CZ)	Bačka (RS)	Catalonia (ES)
Total area (km ²)	4,664	5,814	2,089	8,218	31,206
Elevation (m) mean, min, max	20, -13, 265	409, 71, 1213	298, 151, 963	80, 0, 641	350, 0, 2100
Precipitation (mm) mean	626	828	657	613	575
Predominant terrain	Flat to hilly	Flat to hilly, including steep valleys	Mostly flat	Flat to hilly	Heterogeneous
Temperature (°C) mean	9.6	6.9	8.5	16	13.9
Field size (ha) mean	N.D.	6.3	6.1	5.4	0.7
Farm size (ha) mean	90	157	96	10.6	19
Land in agriculture	Cropland (78.9%)	Cropland (54%); grassland (9%)	Cropland (57%), pastures (5%)	Cropland (84%)	Cropland (27%)
Main crops (in order of prevalence)	Cereal crops, oilseeds, root crops	Winter grains, oilseed rape, maize	Cereals, maize, rape seed	Cereal, sugar beet, pastures, orchards	Grain, olives, forage
Other agricultural uses	Livestock (pigs, sheep, cattle)	Intensive and extensive grasslands	Viticulture, orchards, extensive grasslands	Vegetables	Viticulture, orchards, rice

Humber Catchment (UK) drains a major area of mixed agricultural land and semi-natural habitats in the northeast of England. The study area is typical for the North East region,

and contains a wide range of farming systems that are present in other parts of England, Wales and Scotland including some more intensively farmed areas such as the South West. The southern section of the region drains via the River Ancholme into the Humber estuary, or further south drains through the River Eau towards the Wash. The centre of the region is an area of largely flat land, dominated by drained peatlands.

Mulde River Basin (DE) is located in the western part of Saxony and includes the so-called "Saxon Loess fields". The study area is representative for wider regions in Central Germany that are characterized by fertile soils, relatively flat terrain and intensive agriculture use. It ranges from the Pleistocene lowlands in the north to the Ore Mountains in the south. The catchment area of the Mulde river has already been affected several times by floods, of which the event in 2002 had catastrophic proportions. The Mulde river basin is increasingly affected by land-use changes and conflicts related to bioenergy and intensification threatening ESS and biodiversity.

South Moravia (CZ) is a traditional agricultural region located in the southeast part of the Czech Republic at the border with Slovakia. The study area is representative of other areas in Central Europe that are characterized by flat terrain with fertile soils and a diversity of environmental conditions, landscape structure and farming practices. It lies in the lower Morava river basin and extends across two administration units (Jihomoravský and Zlínský kraj). The region underwent significant changes in the landscape structure, land-use intensities and property rights in the post-war period and also in the post-communist era as a result of land-use and economic changes and policy interventions. Agricultural holdings range from small family farms to very large agro-businesses.

Bačka County (RS) is located in the Autonomous Province of Vojvodina which is divided into three main counties: Banat, Bačka and Srem. The study area is an archetype of a flat, fertile agricultural area within the larger Pannonian Plain. Around 35% of all Serbian agricultural area is in Vojvodina. The county is crisscrossed by parts of the Danube–Tisza–Danube Canal system. The average age of holders of family agricultural holdings is 59 years with decreasing tendency in the last few years. The study area presents a unique case for agricultural policies modelling and its influence and significance because it belongs to a non-EU country that is currently undergoing a transitional and transformational phase.

Catalonia (ES) is located in the Northeast of the Iberian Peninsula, covering around 32 000 km² of which around 9000 km² are dedicated to agriculture. This study area is characteristic for its heterogeneous agricultural landscape, with predominance of small and medium-sized farms making it a perfect representative study site of Southern Europe. Agriculture lands are distributed in a mosaicked land cover mixed with areas of natural and semi-natural vegetation, including coniferous, sclerophyllous and deciduous forests. The rural community is organized according to irrigation communities, obligatory associations that group users with the right to use a certain concession of public water, both superficial and underground in a given concession area.

M2.1. Collecting geospatial data into a Case Study Base Layer

For all analyses to be conducted in the five CSs (M3.2 to M3.5), *BESTMAP* will collect a high-resolution dataset (“Case Study Base Layer” see Table 5). The main spatial unit of the Case Study Base Layer will be individual fields nested within farms as available through existing geo-referenced EU and national datasets including the IACS Land Parcel Identification System (LPIS), and INSPIRE Cadastral Parcels. In the near future, IACS will further include information on land declared as Ecological Focus Area (EFA) through remote sensing (e.g. from the SEN4CAP project). *BESTMAP* will explore if such data can be incorporated in the FSA and ABM analyses and, thus, included in Case Study Base Layer. **All geospatial data included in the Case Study Base Layer will be harmonized** (i.e. upscaled or downscaled) to field and farm level and linked to individual farm businesses. Specific CS regions will have their own datasets (see Sec. 3.1), which will be integrated as well into the Case Study Base Layer spatial database in a way that allows performing the same analyses across all CSs. As part of developing the *BESTMAP* proposal, **we contacted key data providers to clarify data policies for these datasets and ensure *BESTMAP* will gain access to that data** (Sec. 4.3). *BESTMAP* will incorporate additional layers that are crucial to define FSAs, such as crop type and rotation – either directly from LPIS, derived using LUCAS database (cf. van der Zanden et al. 2016) or from remote sensing (Sec. M3.4.1). Data going back about 5 years will be collected in the Case Study Base Layer, and this will be updated during *BESTMAP*. The Case Study Base Layer will be used to develop the FSAs within each CS (Sec. M3.4).

Table 5.

Datasets included in Case Study Base layer and European Base Layer.

Dataset name	Information included	Type of data	Covers	Target Layer	Relevant for
Integrated Administration and Control System (IACS)	All CAP related data, including Land Parcel Identification System (LPIS) and land ownership information. New datasets including maps of Ecological Focus Areas (e.g. hedgerows) are already available for some CSs.	Polygons per individual land parcels	EU but country specific dataset	Case Study	FSAs, ABMs, ESS models
AgroSens	Serbian data platform including information on land parcels, crop types. Meteorological data and remote sensing data	Raster, tabular and parcel polygons	RS	Case Study	FSAs, ABMs, ESS models
INSPIRE Geoportal	Farm polygons (cadastral units)	Polygons	EU	Case Study/ European	ABMs

Dataset name	Information included	Type of data	Covers	Target Layer	Relevant for
EEA Waterbase	Status, quality and quantity of Europe's water resources, and on the emissions to surface waters from point and diffuse sources of pollution	Water-body specific database	EU	Case Study/ European	ESS models
Crop type classification	Major crops mapped based on phenology per field derived from Sentinel-2	20m raster	DE, UK	Case Study	FSAs, ABMs, ESS models
Farm Accountancy Data Network (FADN)	Income of agricultural holdings and the impacts of the CAP	NUTS3 / 10km	EU	Case Study/ European	FSAs, ABMs, ESS models
CORINE Land Cover	Inventory of land cover in 44 classes	Polygons or 100m raster	EU	Case Study/ European	FSAs, ABMs, ESS models
ESA CCI Land Cover	Annual global land cover maps 1995-2015 based on remote sensing	20m raster	Global	European	ESS models
EU statistics on income and living conditions (EU-SILC)	Cross-sectional and multidimensional microdata on income, poverty, social exclusion and living conditions	NUTS-1	EU	European	socio-economic models
Agri4Cast	Agri-Meteorological and Crop data	25 km	EU	European	ESS models
EU-DEM	Digital elevation map for Europe	25m raster	EU	Case Study/ European	ESS models
European Soil Database (ESDB)	Information on soils in EU	1 km raster	EU	European	ESS models
WorldClim	Climatic information	30 secs	Global	European	ESS models
Global-Aridity/ Global-PET	Climatic information related to evapotranspiration processes and rainfall deficit	30 secs	Global	European	ESS models
Global Runoff Data Centre	Runoff data	Stations (points)	Global	European	ESS models

Dataset name	Information included	Type of data	Covers	Target Layer	Relevant for
Land Use and Coverage Area frame Survey (LUCAS)	Land-use and land cover, field size	points	EU	European	ESS models
LUCAS soil database	Topsoil properties	Points (ca 20,000 points)	EU	European	ESS models
European Soil Data Centre ESDAC	Rainfall erosivity	30 secs	Global	European	ESS models
Living forest biomass and carbon stock	Forest carbon stock	1 km	EU	European	ESS models
EUROSTAT agricultural production	Annual crop production data	NUTS-2	EU	European	ESS models
Butterfly monitoring data	Annual butterfly transects	Points	15 Member States incl DE, UK	European	ESS models
European Social Survey ESS	Surveys of individual attitudes	NUTS-3	EU	European	European ABM
Beneficiaries of CAP payments	Payments made to farms under CAP	Individual farms + NUTS-2	EU	European	European ABM
Farm Structure Survey	Information on individual farms including area, livestock heads, labour force, monetary outputs etc.	NUTS-2	EU	European	European ABM

M2.2. Testing case studies representativeness

Case studies conducted in a set of contrasting European agricultural landscapes (Fig. 5) are a central element of the *BESTMAP* project. These case studies are rooted in a particular environmental, socio-economic and policy context and, therefore, **provide unique insights on the local circumstances, context-dependent aspects of farmer's behaviour and resulting impacts** of rural policies on local ecosystem services. Despite these opportunities, a consequence of the CS-based approach is that the unique context may provide a limitation to the generalization and transferability of results (Potschin and Haines-Young 2012). Insights into policy effects hence may be biased if based on an unrepresentative selection of case study information. Therefore, *BESTMAP* CSs will be

evaluated for their representativeness in order to (i) identify areas that have similar biophysical and socio-economic circumstances and systems of governance thereby (ii) to assess the possible transfer of CS results to other regions facing similar policy challenges, and finally (iii) to determine how many CSs would be needed in different countries/geographies to get a representative sample of CSs. Using a European-wide FSA classification (Sec. M4), we will **compare the FSAs developed in each BESTMAP CS to the European-wide FSAs and to other existing typologies** (e.g., agricultural landscape topology developed by van der Zanden et al. 2016, typologies focusing on the multi-functionality and societal demands of rural zones developed by Pinto-Correia et al. 2016). We will use MapCurves, a goodness-of-fit test for the spatial concordance of categorical maps (Hargrove et al. 2006) to assess the relationships among the selected typologies and to test if each typology captures different dimensions as compared to the other datasets.

M3. Modelling approaches employed in BESTMAP

M3.1. Economic modelling using DART-BIO

BESTMAP will use producer prices, as estimated from DART-BIO CGE model, as part of the 'instrumental attitudes' of individual agents in the RAA-based ABM. Alongside with developing the CS modelling, *BESTMAP* will consider a number of different global trends on global and European economies, and their impact on producer prices in each Member State. **The DART model is a global multi-sectoral, multi-regional recursive-dynamic CGE model.** It was developed at the Kiel Institute for the World Economy and has been widely applied to analyse international climate policies (e.g. Klepper and Peterson 2006), environmental policies (Weitzel et al. 2012), energy policies (e.g. Klepper and Peterson 2006), and biofuel policies (e.g. Calzadilla et al. 2016), and global mid-term scenarios (Delzeit et al. 2018). **DART-BIO is a version of the DART model with a detailed representation of the agricultural sector, land-use and conventional biofuels.** It has been used in interdisciplinary studies to address potential trade-offs between food security and biodiversity (Delzeit et al. 2016) and the simulation of global biomass potentials via a hard-link with a crop growth model (Mauser et al. 2015).

M3.2. Socio-economic and behavioural data collection and extrapolation

Potential farmers for interview in the case study regions will be identified through the LPIS/ AgroSense (for RS) data (in CSs where the contact information is included); through local administrations / offices / trusts / societies; farmers associations (see Sec 4.3); land registry and from previous interviewees. The interview phase will start with contacting local farmers' networks / key farmers, discuss with them the project aims and potential obstacles, and get them to help build the communication material for that CS. In addition, we will identify what *BESTMAP* can offer local farmers to motivate their engagement such as results, 'scorecard' comparing their farm to peers, publicity or remote sensed information on their fields (e.g. crop health indicators). Afterwards, communication materials will be developed and send out to farmers to request their consent to participate. Those communication materials will be tailored to farmers, emphasizing the ethos of *BESTMAP* to include "farmers' voice" in policy analysis and go beyond pure economic

decisions. Semi-structured face-to-face interviews based on a common questionnaire will be conducted in each CS. Following a pilot stage, **BESTMAP aims to interview about 50-70 farmers in each CS**. The timing and location of these interviews is critical – *BESTMAP* will aim to do these in the farmhouses or nearby public spaces, during events farmers already visit (e.g. local agricultural shows) and off peak busy periods (summer). Part of the questionnaires will be the same as in EU-wide social and socio-economic surveys, to help compare with microdata at aggregated scales (Sec. M4).

Regression models (e.g. constrained and/or regularized linear models) and/or machine-learned models (e.g. Random Forest) will **up-scale the farm level data to all farm polygons within the CS**. Specifically, *BESTMAP* will collect data on farming activities (irrigation, fertilizer use, mowing frequency, yields), labour (number of workers, income), mechanization (type of equipment used), participation in quality schemes, markets (local vs. export) and farmers' demographics (e.g. age, education, experience). In addition, we will collect behavioural characteristics of individual farmers. These will include general questions, using a tailor made questionnaire based on the RAA (see Table 6) as well as questions related to participation in specific decision-contexts e.g. converting strips to permanent meadows or other specific changes envisioned in the national stakeholder workshop. We will **check how well those decision-context specific responses can be predicted from socio-economic and RAA generic questions** using logistic regression models. If possible, this will allow future policy scenarios to use a smaller sample (or just use sample/census RAA characteristics, if that was part of surveys such as FADN or the new Integrated Farm Statistics survey). We will ask questions about the social network farmers – with whom they interact, and how these contacts influences their beliefs, norms and sense of control.

Table 6.

Examples of the types of behavioural related data to be collected in interviews.

RAA generic questions	
Beliefs	How important is it for you to improve biodiversity in the agriculture areas you farm? How significant do you feel the following cultivation methods are in contributing to improving biodiversity? Setting aside land, tillage practices, organic farming, ...
Norms	Who are important people/institutions that you would consider in your farming decisions? How strongly do you agree with the following statements? Most people who are important to you think that you should adopt...Most people who are important to you think that you should only consider economic return in your decision-making.
Control	What are barriers preventing you from adopting...? How confident are you that you could overcome the barriers that prevent you from...? How often do you feel you have control over the following outcomes? Water use efficiency / Fertilizer use efficiency / ...

M3.3. Calibrating and validating InVEST ecosystem service and biodiversity models

BESTMAP approach is to use a compromise between simplicity (e.g. Capacity Matrix approach) and accuracy (as with most detailed process-based models; see Fig. 7 for an overview). The Python-based open-source InVEST models are widely used set of biophysically based ESS models. These **landscape scale models work with meaningful (10-30m) spatial scale and context, run quickly and to take advantage of readily available data** (Sharp et al. 2015). Parameterization of these models (for each type of land cover, possibly stratified by the FSA at farm level) will use a combination of existing geo-referenced data sources, literature review and meta-analysis, remote-sensed proxies (e.g. integrated NDVI proxy for crop yield), in-situ data, and farmers' records. InVEST model outputs will be aggregated to individual farms. Importantly, ***BESTMAP* selected those ESS and models for which CS specific geo-referenced datasets to calibrate/validate InVEST models were identified** (Table 7).

Table 7. InVEST models used in <i>BESTMAP</i> .		
Model and short description	Model application in <i>BESTMAP</i>	Refs
Carbon model: Includes above- and belowground biomass, soil, and dead organic matter. Estimates the net amount of carbon stored in a land parcel over time.	Map carbon storage densities to each FSA based on land-use type, management (including cropping types and patterns, livestock type and density, cultivation practices, cover crops) and climate, soil and topographic characteristics	Jiang et al. (2013)
Water quantity model: Estimating water run-off as precipitation minus evapotranspiration, not separating surface, sub-surface and shallow groundwater flows.	Using land use from CORINE. root restricting layer depth and AWC from ESDB. precipitation data from WorldClim and PET from the CGIAR-CSI Global-Aridity and Global-PET Database. EEA Waterbase and/or CS streamflow stations data will be used for calibration and validation.	Redhead et al. (2016)
Water quality model: Computes a long-term nutrient mass balance assuming nutrient sources associated with different FSAs and retention properties (e.g. LULC, slope) of pixels belonging to the same flow path.	Using data on each FSA (including from interviews) estimate nutrient load applied to the land and the proportional retention of that nutrient load.	Redhead et al. (2018)
Sediment delivery model: USLE equation-based estimated eroded sediment and proportion reaching the catchment outlet based on topography and land-use	Using similar data to water quality model. Information on rainfall erosivity and soil erodibility will be accessed from the ESDAC and LUCAS databases and literature searches.	Sharp et al. 2015

Model and short description	Model application in <i>BESTMAP</i>	Refs
Crop production model: Data-driven yield model, covering 175 crops worldwide, and a regression based model that accounts for fertiliser application rates on 12 crops based on annual precipitation & number of growing degrees days	Use local/regional data to estimate intensification level (yield percentile). Use future climate projections (e.g. from CMIP5) to project yields assuming no technological changes	Monfreda et al. 2008; Mueller et al. 2012
Biodiversity (habitat quality) model: Impact of different land-uses, linear and aerial features in the quality of habitat for indicator taxa.	Use existing data of abundance / likelihood of presence for indicator species (e.g. birds or butterflies, although the decision will depend on the CS) to calibrate model	Sharp et al. 2015

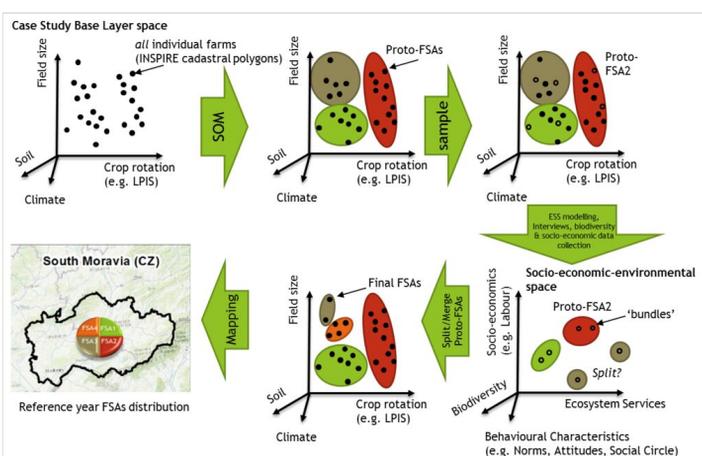


Figure 7. [doi](#)

BESTMAP workflow to map FSAs, defined as having a characteristic bundle of ESS (and dis-services e.g. pollution), biodiversity, socio-economic and behavioural characteristics. Geospatial datasets (the Case Study Base Layer) will be used to approximate these FSAs (the “Proto-FSAs” clusters) in the first step; followed by interviews, field data collection and modelling to assign values on ESS, biodiversity, socio-economic aspects and behaviour for a stratified sample of proto-FSAs farms. The proto-FSAs will likely share “socio-economic-environmental” space and will be split/merged to minimize (but not eliminate) that overlap by changing the clustering in Case Study Base Layer space, defining the final FSAs and their spatial distribution.

M3.4. Establishing typology of Farming System Archetypes

BESTMAP will extend previous land systems typologies (Sec. C2) and apply them at the scale of individual farms. What is the best operational definition of FSAs, and which Case Study Base Layer variables should be considered in the final definition is one of the research questions of *BESTMAP*. This is critical as it will determine the balance between the level of detail captured by FSAs, the *BESTMAP*-PIAM general applicability and its scalability. First, we will generate ‘Proto-FSAs’ using either a self-organizing map (SOM)

bottom-up, data-driven classification approach (Agarwal and Skupin 2008) refined by semi-supervised clustering (Bair 2013) or hierarchical decision tree and experts assessment (e.g. van Asselen and Verburg 2012). These Proto-FSAs will be based on crop type and rotation, field and farm size, gathered in the Case Study Base Layer (Sec. M2.1). Later, we will also use the extrapolated/estimated values for e.g. mechanization, intensity, and yield to finalize the FSAs. *BESTMAP* will also trial remote sensed data to map FSAs (Sec. M3.4.1).

M3.4.1. Exploring state-of-art Remote Sensing for mapping Farming System Archetypes

BESTMAP will also **explore how additional remote sensed data can help improve and possible scale-up the FSA mapping**. Sentinel-2 satellite imagery will be radiometrically and atmospherically corrected (top-of-canopy reflectance) using partner MUNDIALIS' automated, cloud based processing chain actinia (<https://actinia.mundialis.de>). Cloud free image composites will be created and based on these, suitable vegetation indices (see Table 8) for all CSs. Based on these time series, important phenological metrics for agricultural land will be extracted (e.g. maximum, minimum, and average vegetation index value of the growing season). MUNDIALIS are also experts in Sentinel-1 synthetic aperture radar (SAR) processing. SAR has the advantage of not being impacted by clouds. The intensity of reflected microwave (backscatter) can be related to vegetation structure and soil conditions. With multiple passes of the same sensor (Interferometric SAR; InSAR), it is possible to infer changes in vegetation from the correlation between returned phases of the signal (i.e. coherence). Satellite remote sensing can predict crop growth and yield at different scales, for example using optical vegetation indices (Moriondo et al. 2007; Bolton and Friedl 2013) or SAR backscatter (Vreugdenhil et al. 2018). For CSs where in-situ yield data will be made available, crop yield modelling will be attempted at the field level with regression techniques, using co-variates such as vegetation indices, SAR backscatter, or fine-scale topography etc. For grasslands, cutting and mowing frequency will be assessed based vegetation indices temporal dynamics (Franke et al. 2012; Gómez Giménez et al. 2017, Griffiths and Hostert 2017 and backscatter time series from pre-processed Sentinel-1 time-series (Howison et al. 2018; Tamm et al. 2016).

Table 8.

Example of vegetation index computable from Sentinel-2. *BESTMAP* will explore which indices complement other data best to report on land use intensity and other dimensions of the FSAs.

Index	What does the index capture	Reference
Greenness Index (GI)	Measure of vegetation vigour or biomass	Jordan (1969)
Normalized Difference VI (NDVI)	Measure of healthy, green vegetation	Rouse et al. (1974)
Soil adjusted Vegetation Index (SAVI)	Like NDVI but soil colour, soil moisture, and saturation effects from high density vegetation	Huete (1988)

Index	What does the index capture	Reference
Enhanced Vegetation Index (EVI)	Healthy, green vegetation, less sensitive to saturation and reduce atmospheric influences	Huete et al. (2002)
Green–RedEdge NDVI (GRNDVI)	Vegetation health and plant stress, biomass	Löw et al. (2012)
Modified Chlorophyll Absorption Ratio Index (MCARI)	Variations in chlorophyll concentrations and leaf area index (LAI)	Daughtry et al. (2000)
Normalized Difference Water Index (NDWI)	Measure of vegetation water content	Gao (1996)

M3.5. Multi-level Agent-Based Modelling

BESTMAP we will develop ABMs to investigate and represent the decision-making of farmers, including the influence of exogenous factors such as existing and new policies on farm management. The **ABM specifications will create individual farmers and representing their behaviour** (how they ‘perceive’ exogenous drivers, e.g. become informed on policy change and/or economic price/cost changes, how farmers interact and farmer/field agents interact, how farmers attributes change over time and the rules that govern these attributes). The model will **create a realistic, spatially explicit dynamic environment** (based on rules that govern diversification i.e. new fields within farm, homogenization, merge/splitting of farms, and inter-generational transitions) and **embed relevant policy within the computer environment** (new and existing policies implemented by farmers, water companies, advisory bodies etc.). The basic entities and their attributes are shown in Fig. 8. The model will be simulated at yearly time steps. At the end of each time step, a new spatial distribution of FSAs is calculated, and using the bundles of ESS and socio-economic per FSA, the impacts on these dimensions will be derived.

An initial basic model prototype will be jointly developed for CSs that will be theoretically based on the RAA and empirically informed by knowledge from Brussels level experts and stakeholders. In the second step, the prototype will be adapted to the specific CS context, based on empirical data gathered through questionnaires/interviews (Sec. M3.2). To parameterize the model, we will use

- biophysical data such as soil condition, climate, crop production levels obtained from the Case Study Base Layer,
- socio-economic data from the quantitative farmer interviews,
- producer prices information from DART-BIO and
- behavioural data on farmer decision-making based on the FSAs.

Methods such as pattern-oriented modelling (Grimm et al. 2005) will be used to facilitate model calibration and reduce parameter uncertainty. If possible, we will also use historical data (temporal data within the Case Study Base Layer) to validate the model dynamics. To account for the model stochasticity, e.g. in farmer behaviour, we will use suitable statistical

methods (i.e. *Monte Carlo* methods) to analyse model results and will conduct extensive sensitivity and uncertainty analysis (Saltelli et al. 2004; Thiele et al. 2014).

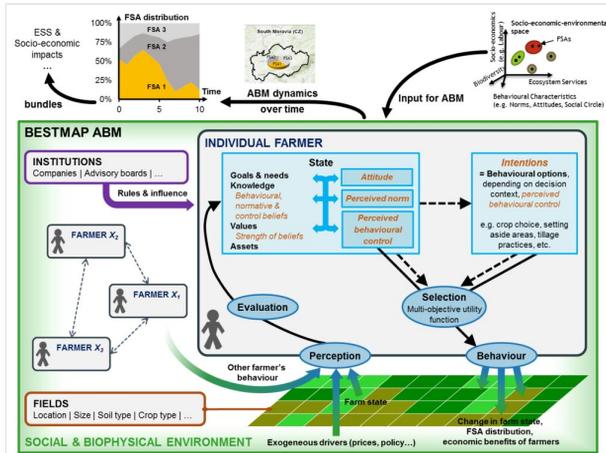


Figure 8. doi

BESTMAP ABM concept. Individual farmer's decision-making is modelled using the RAA (orange elements). Each farmer agent has an internal state that is characterized by goals & needs (profit maximization, safety first, risk aversion, etc.), knowledge (education, farming strategies, beliefs about consequences of different practices, etc.), values (social norms, strength of beliefs, value of conservation or biodiversity, etc.) and assets (monetary resources, production means, information, etc.). These shape farmer's attitude towards different behaviours (e.g. pro or contra organic farming), perceived norm (social pressure or other farmer's behaviour) and perceived behavioural control (agent's capacity to perform certain behaviours). Every farmer agent can perceive the state of the farming system (e.g. yields, ESS provision), the behaviour of other farmers as well as exogenous drivers (e.g. price or policy changes). Evaluating these lead to changes in attitudes or perceived norm, which can expand or reduce its behavioural options. Each behavioural option represents an intention to perform a certain behaviour (e.g. adopting a different crop choice or setting aside land). Using a multi-objective utility function, the farmer agent will select a specific behavioural option that will change the state of its farm's fields and provide some economic benefit to the farmer. Specifically, farmer's decisions can lead to changes in cropping system, farm and field size, or in farm ownership, which allows us to analyse/model structural change.

M4. Upscaling and testing the *BESTMAP* approach at EU and global scale

BESTMAP will make use of a bottom-up, data-driven approach that assesses the potential transferability of CS findings (sensu Václavík et al. 2016) at the national level or across Europe. For all analysis to be conducted at EU scale *BESTMAP* will generate a consistent "European Base Layer" for each NUTS-2 units across Europe. Identification and review of relevant biophysical data at European level (e.g. EEA Integrated Data Platform, CORINE, ESA CCI land cover; LUCAS; GlobCover, WorldClim) will lead to a selection of appropriate layers and downscaling and upscaling algorithms. **Data will also be collated from aggregated and/or microdata from EU-wide social and socio-economic sources** such as the FADN, Labour Force Survey (LFS), European Working Conditions Survey, Statistics

on Income and Living Conditions (EU-SILC), European system of integrated social protection statistics (ESSPROS), Continuous Vocational Training Survey (CVTS), Adult Education Survey (AES), Community Statistics on Information Society (CSIS), Farm Structure Survey (FSS) and the European Social Survey (<http://www.europeansocialsurvey.org/>). The **joint variables (e.g. demographic) in microdata datasets will be used to generate synthetic farm-level populations (with combined variables) using microsimulation methods** (Lovelace and Dumont 2016). Farms with similar characteristics will be grouped with the help of statistical clustering methods to produce FSAs at European-wide scale. This analysis will also be used to identify those areas that are under or not-well represented in *BESTMAP* and need further attention in future research. Finally, based on these European-wide FSAs, *BESTMAP* will attempt to map ESS and biodiversity across Europe (Sec. M4.1) and build those outputs into a behavioural-based ABM at European-scale (Sec. M4.2).

M4.1. European-wide ecosystem services modelling

BESTMAP will try using the European-wide FSAs and a subset of the InVEST models for which EU-wide validation data currently exist, to **test if these simple biophysical models, which have been successfully calibrated/validated at UK scale (Redhead et al. 2018, Redhead et al. 2016), can also work well at EU scale**. The models to be used will include

1. the InVEST water quantity model (using root restricting layer depth and plant available water content (ESDB), precipitation (WorldClim) and average annual potential evapotranspiration (CGIAR-CSI), and GRDC monthly flow through weirs in many hundreds of EU stations);
2. the InVEST carbon model (using soil carbon from LUCAS, literature meta-analyses including Smith 2004 and Janssens et al. 2005);
3. the Crop Production model (using aggregated area statistics from Eurosar/FAO to estimate percentile yield at each NUTS-2 region for each of the 175 crop types); and
4. the Habitat Quality model (using widely surveyed indicator taxonomic species, for example butterflies *currently* monitored in 15 Member States).

M4.2. European-wide Agent-Based Modelling

There are different approaches to upscaling of ABMs (Zimmermann et al. 2015). Some studies have used agents which represent larger scale geographies, e.g. entire regions as 'virtual farms'. Others have created agents representing groups of farms (e.g. one agent per FSA), or a non-representative sample (e.g. the raw FADN microdata). While an approach of modelling each farm is clearly the best from aggregation bias and sampling bias, this is not technically feasible at the scale of the EU. ***BESTMAP* will use a representative sample per NUTS-2 unit, building on the European FSAs and microsimulation approach** described above. In particular, some of the variables in those EU-wide surveys are closely linked with our FSA conceptual framework (Fig. 4) – farm classification; owned, rented or share cropped; assets; quotas; debts; inputs; crops

(including yield); livestock; other activities & subsidies (FADN); holdings based on their type of farming and their economic size (FSS); attitudes to climate change and energy, welfare attitudes (ESS); personal and social well-being; economic morality (European Social Survey); eSkills and protection of personal identity (CSIS) and breakdown of the amounts of payments for each individual CAP measures (https://ec.europa.eu/agriculture/cap-funding/beneficiaries/shared_en).

To build a European-wide ABM, *BESTMAP* will assign attributes and behavioural rules to synthetically derived representative populations within each NUTS-2 based on similarly metric to the FSAs with CS ABMs. A cross-validation approach (i.e. using four CSs for training and comparing model on the fifth) will be used to validate the model. **The European-wide ABM will be calibrated to reproduce micro-scale and macro-scale properties in CS scale, as well as large scale historical trends** [e.g. from Eurostar/ FAOSTAT data, from CORINE land-use change, from land systems archetypes change 1990-2006 of Levers et al. (2018)] This ABM and ESS models at European-wide scale will be incorporated into an online Virtual Lab (Sec. M5.2).

M5. Building capacity

Communication, dissemination and capacity building (particularly training) activities will lay a solid foundation for responding to the needs and specific requests of identified stakeholders (EU DG staff, Members of the European Parliament (MEPs) and the EC, local government agencies, other researchers). *BESTMAP* activities will include

1. focus groups and interviews to assess the needs and capacity for *BESTMAP*-PIAM, and provide qualitative feedback on *BESTMAP* methodologies, tools and outputs,
2. co-development of policy-relevant indicators with stakeholders and modellers (Sec. M5.1),
3. technical trainings to assist users to use the *BESTMAP* online policy dashboard and the Virtual Lab (Sec. M5.2).

Those events will take place in Brussels (organized by local partner RISE) and in each CS. Capacity building will additionally include effective use of social media, such as LinkedIn, Facebook, SlideShare and Twitter overseen by a social media officer appointed by the GA.

A variety of dissemination materials will be produced, including mini user guides, open access scientific papers, policy briefs and videos. These will use current rural policy debates to introduce modelling innovation to non-experts. Training materials such as CS booklets and data packages, user guides, technical models descriptions, webinar and open online course (e.g. using *FutureLearn*) will build capacity for different audiences.

M5.1. Producing indicators for decision-makers

BESTMAP will map the ESS, socio-economic models and biodiversity impact outputs from the ABMs to existing and under-development SDGs and CAP indicators. An initial mapping performed during proposal preparation shows that *BESTMAP* models are related

to many of the CAP Strategic Plans output, results and impact indicators as well as 10 of the SDGs and respective indicators. **The list of indicators will be presented, reviewed and discussed with stakeholders and decision makers in a Brussels workshop.** This will help *BESTMAP* to validate, reduce or extend the list according to stakeholders' expertise and needs. Results of this workshop are expected to impact on future list on indicators adopted by the EC, so will be elevated to interested organizations.

M5.2. Implementing an integrated modelling and dashboard system

BESTMAP will adopt a **rapid application development where an initial implementation of the system is presented to the users (i.e. policy makers and modellers) and iteratively co-designed and refined.** It will offer open access to the individual component for its integration into other bigger systems, possibly from SUPREMA or other RUR-04 funded projects. The diversity of data platforms and models (Case Study Base Layer, FSA mapping, DART-BIO CGE model, ABM, InVEST ESS models, geostatistical models of socio-economic aspects etc.) represents diversity in inputs, execution platforms and combinable results. Instead of imposing a common infrastructure (e.g. programming language), the policy dashboard aggregating regional CS results will use pre-computed economic scenarios (from DART-BIO), ABM runs and ESS and socio-economic analyses. **The dashboard user interface will allow easy selection and comparison of different policy scenarios, their impacts within each case study area, and comparisons across CSs.** It will also include data quality indicators (following ISO 19157 and QualityML - FP7 GeoViQua) and be exposed as OGC Web Map Services.

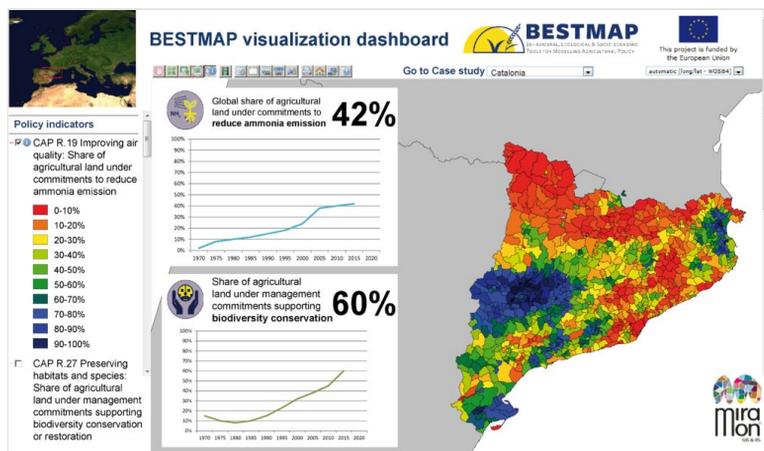


Figure 9. [doi](#)

BESTMAP dashboard mock-up, visualizing the impact of the policies through the policy indicators.

In addition, *BESTMAP* will develop (in collaboration with LifeWatch-ERIC) a Virtual Lab for the European-wide models (Fig. 9). *BESTMAP* will encapsulate most of these modelling components in a virtualized environment (VM) exposed as a web service, with a user interface (website) interacting via an open-source Application Programming Interface (API).

The Virtual Lab will allow using either *BESTMAP* pre-computed scenarios or uploading (in agreed format, metadata and semantics) the output of few economic models (e.g. DART-BIO, CAPRI and MAGNET). The VM will use a workflow manager (e.g. Apache Taverna) to run the European-wide ABM (based on a FSA distribution for reference year of ca. 2020) and predict change in the farming system and ESS at European scale (see Sec. 5.1). LifeWatch-ERIC agreed to incorporate this as a **permanent Virtual Lab on their ICT server and maintain support after *BESTMAP* project ends** (see letter of support, Sec. 4.3).

M6. Data management and community building

It is central to *BESTMAP* exploitation and innovation potential that outputs produced by the project are available, discoverable, and usable by others. Those outputs include the economic model (DART-BIO) outputs, the Case Study Base Layer and European Base Layer databases (limited by data privacy and secondary data licences), the FSAs we identified, the ESS/biodiversity/socio-economical models (including their parameterization for different CSs and at European scale), the ABMs, the policy scenarios (co-developed in both Brussels and national/regional workshops), the analyses of policy scenarios impacts, and the produced policy dashboard and the Virtual Lab (for the European-wide models). To make our outputs available, the **Data Management Plan will list all outputs and define how these should be deposited into permanent repositories** (e.g. GitHub, Zenodo, CoMSES Net (aka OpenABM)) with sufficient meta-data to be discoverable, e.g. including JSON-LD mark-up to be listed by Google Dataset Search <https://toolbox.google.com/datasetsearch>. The project will adopt a single 'OpenBESTMAP' identity (e.g. username) across multiple community websites to develop a link to the project during and after its lifetime. Instead of creating our own community website (which will unlikely sustain after the project), *BESTMAP* will **actively engage in existing developers communities** including NetLogo, ModelingCommons (<http://blog.modelingcommons.org>), CoMSES Net (www.comses.net), Ecosystem Services Partnership (www.es-partnership.org), Natural Capital Project (<https://forums.naturalcapitalproject.org>), European Social Simulation Association (<http://www.essa.eu.org>), Integrated Assessment Modelling Consortium (<http://www.globalchange.umd.edu/iamc>) and others.

M7. Social Science and Humanities and Inter-Disciplinary issues

BESTMAP directly addresses three social issues

1. the lack of farmers' decision-making process in models used to explore policy impact,
2. the lack of consideration to ESS and some socio-economic aspects in those models, which may lead to unintended detrimental impacts often impacting already marginalized people, and
3. the lack of capacity of policy makers / decision makers to get hands-on and up-to-date predictions on modifications to policy during the process of policy making.

To address these issues, we will consider the social dimension (e.g. by exploring how the incorporation of ABMs change policy impact assessment), economic dimension (e.g. with the business model and cost analysis to up-scale the project outputs), behavioural dimension (with planned interview campaigns), institutional issue (e.g. with capacity building and training workshops to help exploitation of outputs) and cultural dimension (with communication and dissemination events aimed to bring *BESTMAP* objectives to stakeholders in each CS region).

***BESTMAP* consortium includes social science experts from multiple social and behavioural sciences.** These include economics (environmental and agricultural economist R. Delzeit, IfW), political science (O. Fritsch, UNIVLEEDS), geography (A. Heppenstall, UNIVLEEDS), and sociology (Nina Hagemann, UFZ, social-ecological modeller B. Müller, UFZ). Their contribution will be essential in all stages of the proposed project, in particular in planned Brussels and national/regional workshops, building economic model (DART-BIO) scenarios and outputs, producing protocols and leading interview campaigns across five CS regions, and creating, calibrating and validating individual ABMs at the CS level and one at the European scale.

***BESTMAP* is multi-disciplinary, inter-disciplinary and trans-disciplinary.** Beyond the listed social sciences expertise, the project involves experts in ESS/biodiversity (G. Ziv, M. Beckmann, J. Bullock, T. Václavík), agro-ecology (B. Kunin, B. Šarapatka), remote sensing (A. Cord, C. Domingo, M. Neteler), ICT and data standards (J. Masó), communication and publishing (L. Penev, PENSOFT), business development (H. Pollitt, CE), and national/international development (A. Williams). *BESTMAP* include experts from academia, non-profit and SMEs. Many of the tasks and activities within the project involve expertise of multiple disciplines. Furthermore, ***BESTMAP* has strong element of co-design and co-development with policy-makers and decision-makers, as well as with other modellers.**

M8. Sustainability and Climate Change issues

Agriculture contributes to 10% of the EU's total greenhouse gas emissions. These emissions have declined by 24% since the early 1990s, while the total output of agricultural production has been maintained thanks to better land management using modern technologies, improved knowledge and specific practices to combat climate change (EC 2015). *BESTMAP* models strive to take into account issues related to the reduction of soil fertility due to erosion (SDG 2), water quantity and quality (SDG 6), and chemical releases into the water (SDG 12), resource-efficient agriculture (SDG 9) and climate action in general (SDG 13, UN Paris Agreement), aiming to verify the difference in barriers to adapt climate focused CAP with the usage of RAA-based ABM.

M9. Gender and geographic balance

BESTMAP project considers gender balance and other equality issues in accordance with the main EU documents on research and innovation, including the Regulation No. 1291/2013 of the European Parliament and of the Council of 11 December 2013

establishing Horizon 2020, European Strategy of Responsible Research and Innovation (RRI), and ERC Gender Equality Plan 2014-2020.

Consortium structure: *BESTMAP* project governance is carefully designed to achieve gender and age balance, and the basic premise of the project is to equally involve representatives of both genders to decision-making processes at all levels and phases of the project. The Deputy Coordinator and two of the Consortium Coordination Team are females. The ratio of male to female team members involved in *BESTMAP* is nearly 1:1 (see Sec. 4.1). In addition, partners' teams will actively support (mentoring of) young women and men at early stage of their careers both in terms of career building and in other project activities.

Project recruitment: Recruitment of PhDs and post docs will follow announcements in the national / international press. Partners will be instructed to offer positions in gender-sensitive ways. All EU partners will be required to fully respect the local legislation on awarding of maternity / paternity leaves. Non-EU partners will follow best practices and regulations in their own country. All partners will be required to offer flexible working hours as much as possible to their appointed personnel. This will be stated in the job description.

Methodology: Gender and equality issues will be emphasised in balanced empirical data collection (Sec. M3.2) and community and capacity building (Sec. M5). Data will be obtained via questionnaires, interviews, focus groups, and other approaches, and analysed in a gender-sensitive way. Gender, age, socio-economic specifics, accessibility and physical impairment will be taken into account also as selection principles in recruitment of interviewees (farmers, agricultural advisors, policy-makers, etc.). Employing intersectional approach, gender variables will be intersected with other variables to obtain more complex and valid results and to avoid making general conclusions based on partial data.

Geographical and socio-cultural balance: Consortium members and the CSs were selected to represent various geographic, climatic and socio-economic backgrounds, various traditions and cultures, and they also reflect different human-nature relations. Following the principles of gender and social equity, partners will contribute their specific know-how in common effort to design and test the *BESTMAP-PIAM* in five regional case studies throughout Europe.

1.4 Ambition

BESTMAP's ambition is to empower EU and regional policy makers to better understand the assets and long-term drivers of rural territories and land-use and establish how they are impacted by current and future policies leading to better informed decisions. The ground-breaking nature of this project lies in the sophisticated co-design of core project elements, innovative and congruent data collection and provision, ambitious modelling and synthesis activities and the plans for legacy building that goes beyond the project. A fundamental understanding of the underlying concepts of land-use and human behaviours, knowledge, tools, experiences and skills form the basis of this project.

BESTMAP draws upon what is already known in practice and science and combines this with new innovative approaches by identifying spatially related units in Europe's agricultural landscapes through farming system archetypes (FSA) and the implementation of key stakeholder behaviours and individual decision making in PIAM. The project will model the impact of policies changes at various geographic scales allowing deducing the local effects of global and EU-wide events. Through modelling the delivery of ESS at various scales, *BESTMAP* will help to harmonize the possibilities with the expectations societies have on the agricultural sector and rural areas which go well beyond food production. Through the development of a highly modular and customisable suite of tools and visualizations in the *BESTMAP* dashboard legacy beyond the project will be ensured that will allow flexible use and further improvements as needs arise. *BESTMAPs* results will substantially improve the capacity to model policies dealing with agriculture in the short term and will lead to improved, evidence-based policy design, impact assessments and monitoring in the long term.

Scientific and Technical Ambition

BESTMAP has strong ambition to push the state-of-art across multiple domains. Table 9 lists examples of the expected scientific contributions of the project:

Table 9. Scientific and technical advances expected in <i>BESTMAP</i> , referenced to Implementation task numbers (e.g. Task 3.2).	
Gaps in the state-of-the-art	Advances beyond state-of-the-art by <i>BESTMAP</i>
Farmers' decision making Existing PIAMs ignore farmers' decision making and work at a spatial scale too coarse to accurately model ESS impacts.	<i>BESTMAP</i> will link economic models (Task 2.4), behavioural-theory based ABM (Task 4.1) and proven high-resolution ESS models (Task 3.2) to work through these shortcomings. <i>BESTMAP</i> will demonstrate the feasibility of such integrated system (Task 4.4), and evaluate in what way its policy predictions differ from current PIAMs.
Underlying land-use data Most current ESS model frameworks use simple 'land-use/land cover' as their geographic reference system.	<i>BESTMAP</i> will use a more consistent system of "Farming System Archetypes" (FSAs), combining land-use/land cover with intensity, cropping system and rotation and field size (WP3). <i>BESTMAP</i> will map FSAs at regional CSs and EU level (Task 5.2), including demonstrating the use of state-of-art remote sensing (Task 5.3), and explore what are the key drivers differentiating FSAs within and across CSs.
Implementation of decision making at larger scales Current behavioural model approaches are mainly restricted to localized scales.	<i>BESTMAP</i> will explore the feasibility of upscaling ABM results (WP5) based on European Base Layer and Case Study Base Layer data harmonization, FSA mapping and ESS and socio-economic models at European scale (Task 5.2).

Gaps in the state-of-the-art	Advances beyond state-of-the-art by <i>BESTMAP</i>
<p>Upscaling individuals' behaviour Most computational approaches in social science are struggling with upscaling individual behaviours to large scales.</p>	<p><i>BESTMAP</i> will explore up-scaling of regional ABMs (Task 5.2), based on microsimulations of farm-level agents at larger scale, using weighted data from regional CS ABM dynamical rules and a metric of similarity based on agent characteristics. This approach is readily transferable to other social science questions where the challenge is to understand the impact of aggregated individual behaviour.</p>
<p>Disparity and lack of homogenization in geospatial data sources Existing datasets are distributed in different formats and locations, and lack a consistent temporal and spatial reference system.</p>	<p><i>BESTMAP</i> will combine (Task 3.1) multiple data sources, mostly existing geospatial datasets (e.g. IACS, LPIS, FADN, INSPIRE), and socio-economic statistics into Case Study Base Layers and a European Base Layer to ensure the unified use and analyses across all CS and at European scale. Those databases will be made publicly available as Deliverables.</p>
<p>Mapping of ESS Most efforts using modelling tools such as InVEST are typically using indirect proxies and/or not rigorously validating the outputs.</p>	<p><i>BESTMAP</i> will follow example used in UK by UKRI (Redhead et al. 2018) where each ESS model was calibrated and validated using standard cross-validation and/or data splitting methods. It will demonstrate methodologies to validate those models across different CS geographies, as well as in the European task (Task 5.2) for a selected number of ESS models.</p>
<p>Lack of knowledge on new CAP policy impacts on the environment and society Policy debates about the impact of COP21 on agriculture (and vice versa) as well as other topics (e.g. UK Brexit) necessitates increased capacity for impact assessment.</p>	<p><i>BESTMAP</i> will explore several co-designed policy scenarios, and predict their impacts at European scale (from DART-BIO (Task 2.4) and from a European-wide model (Task 5.2) and in a set of five CSs that is typical for their countries (WP4). Developing those outputs into an online policy dashboard and a Virtual Lab (Task 6.4) will be a technical development that can help in this issue.</p>
<p>Discussions on policy targets/ indicators is disconnected from data Ongoing efforts to monitor CAP and SDG goals created a large number of targets, but getting these mapped into data (including remote sensed data) and outputs (e.g. of ESS models) is lacking.</p>	<p><i>BESTMAP</i> workshops will link existing indicators / targets to geospatial data and to ESS / socio-economic model outputs used in the project (Task 2.1). The ongoing work to operationalize that mapping will collimate with actual translation of outputs to indicators (Task 4.3) and the development of the policy dashboard (Task 6.4).</p>

Gaps in the state-of-the-art	Advances beyond state-of-the-art by <i>BESTMAP</i>
<p>Remote sensing algorithms of agricultural intensity lack accuracy While some remote sensing algorithms are well developed, others including mapping mowing frequency and agricultural productivity (yield/intensity) are still at their infancy.</p>	<p><i>BESTMAP</i> will demonstrate the use of recently launched ESA satellites Sentinel-1 and Sentinel-2 to monitor mowing frequency and crop intensity. This task (Activity 5.3.1) will be led by SME MUND working in the field of remote sensing geospatial data services. <i>BESTMAP</i> will improve on automated pipelines for imagery pre-processing, and on machine-learning algorithms for crop type, mowing frequency and crop yields mapping – testing new data fusion combining optical and radar data. In particular, we will explore what type of vegetation indices produced by Sentinel-2, focusing on the three Red-Edge, SWIR and NIR bands, best characterize heterogeneity within different cropping systems (i.e. as indicators of yield/intensity).</p>

Innovation and Capacity Building Ambition

BESTMAP has ambitious innovation potential across all aspects of the proposal. The details of the planned innovation will be elaborated in the Commercialization and Exploitation Plan (CEP) in Sec 2.2. At the long-term, there is greater potential for innovation (i.e. future exploitation leading to different types of benefits) from the project objectives, concepts, approach and new organizational and service models:

1. The **objectives to design and demonstrate a new framework** (linking stakeholders knowledge, economic models, geospatial data collected by ongoing surveys, ESS/biodiversity/socio-economic models, ABMs and information technology (policy dashboard) can be exploited for other research, and for developing new commercial services
2. The **concept of ‘farming system archetypes’ is a novel development** of existing ‘land systems’ approach, adding the psychology and socio-economic dimensions to it. If proven useful (in *BESTMAP*) this concept can change the current land-use/land cover paradigm in future modelling programmes
3. Our **approach to linking models, in particular in developing the Virtual Lab** combining CGE, ESS and ABM models using workflow management software has great potential. Integrated models are typically difficult to set up and execute, and this template (which will be published on e.g. GitHub) can be exploited by others for similar efforts
4. The **organizational model wherein policy-makers can explore the impact of changing policy using a simple ‘dashboard’** thus allowing them much deeper understanding of the impact, eliminating bottlenecks associated with modelling expertise, and making decision-making more transparent and democratic. If such approach would be adopted by other policy areas, both at the EU/EC and national levels, it would be a ground breaking change in making evidence-based decision becoming a reality
5. New **service models using remote-sensing to monitor agricultural landscapes** are in high demand. This is especially true since the EC is moving from On-The-Spot Check (i.e. sample based) to “CAP monitoring” (whole landscape) (see

working paper DS/CDP/2017/03). The automatic Sentinel-2 data analysis pipeline which SME MUND will improve in *BESTMAP* can be exploited in many ways to provide near real time monitoring of agricultural areas

Technology Readiness Level (TRL)

The overall goal of *BESTMAP* is to reach a TRL 5 or 6 (technology validated/demonstrated in relevant environment) for the proposed modelling architecture. Different components of the project will reach other TRL levels. For example, the pre-processing system for remote sensed data by MUND is at TRL 7, the InVEST platform is already at TRL 9 while for some of socio-economic models, it is likely that TRL 3 (proof of concept) or 4 (validated at lab) will be the maximum we can reach. For the online data visualization and the policy dashboard, an implementation at regional CS will reach TRL 7 (demonstrated in operational environment) or higher. The Plan for Exploitation will discuss a roadmap to increase the TRL of the project outputs during and after *BESTMAP*.

Grant title

This project receives funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 817501.

References

- Agarwal P, Skupin A (2008) Self-organising maps: applications in geographic information science. John Wiley & Sons, Ltd <https://doi.org/10.1002/9780470021699>
- Ajzen I (1991) The theory of planned behavior. *Organizational behavior and human decision processes* 50 (2): 179-211. [https://doi.org/10.1016/0749-5978\(91\)90020-t](https://doi.org/10.1016/0749-5978(91)90020-t)
- Ajzen I (2012) The theory of planned behavior. In: Lange PAMV, Kruglanski AW, Higgins ET (Eds) *Handbook of theories of social psychology*.
- Anderson K, Ryan B, Sonntag W, Kavvada A, Friedl L (2017) Earth observation in service of the 2030 Agenda for Sustainable Development. *Geo-spatial Information Science* 20 (2): 77-96. <https://doi.org/10.1080/10095020.2017.1333230>
- Antrop M (2005) Why landscapes of the past are important for the future. *Landscape and Urban Planning* 70: 21-34. <https://doi.org/10.1016/j.landurbplan.2003.10.002>
- Bair E (2013) *Wiley interdisciplinary reviews: computational statistics*. Wiley Online Library 5 (5): 349-361. [https://doi.org/10.1002/\(issn\)1939-0068](https://doi.org/10.1002/(issn)1939-0068)
- Bechini L, Costamagna C, Zavattaro L, Grignani C, Bijttebier J, Ruyschaert G (2015) Barriers and drivers towards the incorporation of crop residue in the soil. Analysis of Italian farmers' opinion with the theory of planned behaviour. *Italian Journal of Agronomy* 10 (4). <https://doi.org/10.4081/ija.2015.663>
- Berger T, Troost C (2013) Agent-based modelling of climate adaptation and mitigation options in agriculture. *Journal of Agricultural Economics* 65 (2): 323-348. <https://doi.org/10.1111/1477-9552.12045>

- Bignal E, McCracken D, Corrie H (1995) Defining European low-intensity farming systems: the nature of farming. In: McCracken D, Bignal E, Wenlock S (Eds) *Farming on the edge: the nature of traditional farmland in Europe*. Joint Nature Conservation Committee, Peterborough, 29-37 pp.
- Bolton D, Friedl M (2013) Forecasting crop yield using remotely sensed vegetation indices and crop phenology metrics. *Agricultural and Forest Meteorology* 173: 74-84. <https://doi.org/10.1016/j.agrformet.2013.01.007>
- Boulanger P, Philippidis G (2015) The EU budget battle: assessing the trade and welfare impacts of CAP budgetary reform. *Food Policy* 51: 119-130. <https://doi.org/10.1016/j.foodpol.2015.01.004>
- Calzadilla A, Delzeit R, Klepper G (2016) Analysing the effect of the recent EU-biofuels proposal on global agricultural markets. *Global Economic Models (CGE)*.
- Cialdini R, Reno R, Kallgren C (1990) A focus theory of normative conduct: recycling the concept of norms to reduce littering in public places. *Journal of Personality and Social Psychology* 58 (6): 1015-1026. <https://doi.org/10.1037/0022-3514.58.6.1015>
- Daughtry C, Walthall C, Kim MS, Brown de Colstoun E, E MJ (2000) Estimating corn leaf chlorophyll concentration from leaf and canopy reflectance. *Remote Sensing of Environment* 74 (2): 229-239. [https://doi.org/10.1016/s0034-4257\(00\)00113-9](https://doi.org/10.1016/s0034-4257(00)00113-9)
- Delzeit R, Zabel F, Meyer C, Václavík T (2016) Addressing future trade-offs between biodiversity and cropland expansion to improve food security. *Regional Environmental Change* 17 (5): 1429-1441. <https://doi.org/10.1007/s10113-016-0927-1>
- Delzeit R, Klepper G, Zabel F, Mauser W (2018) Global economic–biophysical assessment of midterm scenarios for agricultural markets—biofuel policies, dietary patterns, cropland expansion, and productivity growth. *Environmental Research Letters* 13 (2). <https://doi.org/10.1088/1748-9326/aa9da2>
- Erb K, Haberl H, Jepsen MR, Kuemmerle T, Lindner M, Müller D, Verburg PH, Reenberg A (2013) A conceptual framework for analysing and measuring land-use intensity. *Current Opinion in Environmental Sustainability* 5 (5): 464-470. <https://doi.org/10.1016/j.cosust.2013.07.010>
- European Commission (2018a) Commission staff working document - impact assessment. SWD (2018) 301 final. URL: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=SWD%3A2018%3A301%3AFIN>
- European Commission (2018b) Regulation of the European Parliament and of the Council. 392 final. European Commission URL: https://ec.europa.eu/commission/sites/beta-political/files/budget-may2018-cap-strategic-plans_en.pdf
- Filatova T, Verburg P, Parker DC, Stannard CA (2013) Spatial agent-based models for socio-ecological systems: Challenges and prospects. *Environmental Modelling & Software* 45: 1-7. <https://doi.org/10.1016/j.envsoft.2013.03.017>
- Fishbein M, Ajzen I (2010) *Predicting and changing behavior*. Psychology Press, New York. <https://doi.org/10.4324/9780203838020>
- Fisher B, Turner RK, Morling P (2009) Defining and classifying ecosystem services for decision making. *Ecological Economics* 68 (3): 643-653. <https://doi.org/10.1016/j.ecolecon.2008.09.014>
- Franke J, Keuck V, Siegert F (2012) Assessment of grassland use intensity by remote sensing to support conservation schemes. *Journal for Nature Conservation* 20 (3): 125-134. <https://doi.org/10.1016/j.jnc.2012.02.001>

- Frank R (1987) If homo economicus could choose his own utility function, would he want one with a conscience? *American Economic Review* 77 (4): 593-504.
- Gao B (1996) NDWI—A normalized difference water index for remote sensing of vegetation liquid water from space. *Remote Sensing of Environment* 58 (3): 257-266. [https://doi.org/10.1016/s0034-4257\(96\)00067-3](https://doi.org/10.1016/s0034-4257(96)00067-3)
- Gigerenzer G, Selten R (2001) *Bounded rationality: The adaptive toolbox*. The MIT Press
- Gómez Giménez M, de Jong R, Della Peruta R, Keller A, Schaepman M (2017) Determination of grassland use intensity based on multi-temporal remote sensing data and ecological indicators. *Remote Sensing of Environment* 198: 126-139. <https://doi.org/10.1016/j.rse.2017.06.003>
- Graybiel A (2008) Habits, rituals, and the evaluative brain. *Annual Review of Neuroscience* 31 (1): 359-387. <https://doi.org/10.1146/annurev.neuro.29.051605.112851>
- Griffiths P, Hostert P (2017) Integration of sentinel-2 and landsat data for phenological characterization of semi-natural vegetation. Boston University
- Griggs D, Stafford-Smith M, Gaffney O, Rockström J, Öhman M, Shyamsundar P, Steffen W, Glaser G, Kanie N, Noble I (2013) Sustainable development goals for people and planet. *Nature* 495 (7441): 305-307. <https://doi.org/10.1038/495305a>
- Grimm V, Revilla E, Berger U (2005) Pattern-oriented modeling of agent-based complex systems: lessons from ecology. *Science* 310 (5750): 987-991. <https://doi.org/10.1126/science.1116681>
- Groeneveld J, Müller B, Buchmann CM, Dressler G, Guo C, Hase N, Hoffmann F, John F, Klassert C, Lauf T, Liebelt V, Nolzen H, Pannicke N, Schulze J, Weise H, Schwarz N (2017) Theoretical foundations of human decision-making in agent-based land use models – a review. *Environmental Modelling & Software* 87: 39-48. <https://doi.org/10.1016/j.envsoft.2016.10.008>
- Happe K, Balmann A, Kellermann K, Sahrbacher C (2008) Does structure matter? The impact of switching the agricultural policy regime on farm structures. *Journal of Economic Behavior & Organization* 67 (2): 431-444. <https://doi.org/10.1016/j.jebo.2006.10.009>
- Hargrove W, Hoffman F, Hessburg P (2006) Mapcurves: a quantitative method for comparing categorical maps. *Journal of Geographical Systems* 8 (2): 187-208. <https://doi.org/10.1007/s10109-006-0025-x>
- Hartel T, Fischer J, Câmpeanu C, Milcu AI, Hanspach J, Fazey I (2014) The importance of ecosystem services for rural inhabitants in a changing cultural landscape in Romania. *Ecology and Society* 19 (2). <https://doi.org/10.5751/es-06333-190242>
- Hastie R, Dawes RM (2001) *Rational choice in an uncertain world: the psychology of judgment and decision making*. SAGE Publications, Inc
- Howison R, Piersma T, Kentie R, Hooijmeijer JEW, Olf H (2018) Quantifying landscape-level land-use intensity patterns through radar-based remote sensing. *Journal of Applied Ecology* 55 (3): 1276-1287. <https://doi.org/10.1111/1365-2664.13077>
- Huete A, Didan K, Miura T, Rodriguez EP, Gao X, Ferreira LG (2002) Overview of the radiometric and biophysical performance of the MODIS vegetation indices. *Remote Sensing of Environment* 83 (1): 195-213. [https://doi.org/10.1016/s0034-4257\(02\)00096-2](https://doi.org/10.1016/s0034-4257(02)00096-2)
- Huete AR (1988) A soil-adjusted vegetation index (SAVI). *Remote Sensing of Environment* 25 (3): 295-309. [https://doi.org/10.1016/0034-4257\(88\)90106-x](https://doi.org/10.1016/0034-4257(88)90106-x)

- IPBES (2018) Summary for policymakers of the regional assessment report on biodiversity and ecosystem services for Europe and Central Asia of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services. IPBES
- Jacobs S, Burkhard B, Van Daele T, Staes J, Schneiders A (2015) 'The Matrix Reloaded': A review of expert knowledge use for mapping ecosystem services. *Ecological Modelling* 295: 21-30. <https://doi.org/10.1016/j.ecolmodel.2014.08.024>
- Janssens IA, Freibauer A, Schlamadinger B, Ceulemans R, Ciais P, Dolman AJ, Heimann M, Nabuurs G-, Smith P, Valentini R, Schulze E- (2005) The carbon budget of terrestrial ecosystems at country-scale – a European case study. *Biogeosciences* 2 (1): 15-26. <https://doi.org/10.5194/bg-2-15-2005>
- Jiang M, Bullock J, Hooftman DP (2013) Mapping ecosystem service and biodiversity changes over 70 years in a rural English county. *Journal of Applied Ecology* 50 (4): 841-850. <https://doi.org/10.1111/1365-2664.12093>
- Jordan CF (1969) Derivation of leaf area index from quality of light on the forest floor. *Ecology* 50 (4): 663-666. <https://doi.org/10.2307/1936256>
- Kahneman D, Tversky A (1979) Prospect theory: an analysis of decision under risk. *Econometrica* 47 (2): 263-291. <https://doi.org/10.2307/1914185>
- Kaufmann P, Stagl S, Franks D (2009) Simulating the diffusion of organic farming practices in two New EU Member States. *Ecological Economics* 68 (10): 2580-2593. <https://doi.org/10.1016/j.ecolecon.2009.04.001>
- Kavallari A, Smeets E, Tabeau A (2014) Land use changes from EU biofuel use: a sensitivity analysis. *Operational Research* 14 (2): 261-281. <https://doi.org/10.1007/s12351-014-0155-8>
- Klepper G, Peterson S (2006) Emissions trading, CDM, JI, and more: the climate strategy of the EU. *The Energy Journal* 27 (2): 1-26. <https://doi.org/10.5547/issn0195-6574-ej-vol27-no2-1>
- Läßle D, Kelley H (2013) Understanding the uptake of organic farming: Accounting for heterogeneities among Irish farmers. *Ecological Economics* 88: 11-19. <https://doi.org/10.1016/j.ecolecon.2012.12.025>
- Lesch WC, Wachenheim CJ (2014) Agribusiness & applied economics report. North Dakota State University
- Levers C, Müller D, Erb K, Haberl H, Jepsen MR, Metzger M, Meyfroidt P, Plieninger T, Plutzer C, Stürck J, Verburg P, Verkerk P, Kuemmerle T (2018) Archetypical patterns and trajectories of land systems in Europe. *Regional Environmental Change* 18 (3): 715-732. <https://doi.org/10.1007/s10113-015-0907-x>
- Louhichi K, Ciaian P, Espinosa M, Colen L, Perni A, Paloma SGy (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: 250-264. <https://doi.org/10.1016/j.landusepol.2017.04.010>
- Lovelace R, Dumont M (2016) Spatial Microsimulation with R. Chapman and Hall/CRC <https://doi.org/10.1201/b20666>
- Löw F, Schorcht G, Michel U, Dech S, Conrad C (2012) Per-field crop classification in irrigated agricultural regions in middle Asia using random forest and support vector machine ensemble. *Earth Resources and Environmental Remote Sensing/GIS Applications III* <https://doi.org/10.1117/12.974588>

- Malawska A, Topping CJ (2016) Evaluating the role of behavioral factors and practical constraints in the performance of an agent-based model of farmer decision making. *Agricultural Systems* 143: 136-146. <https://doi.org/10.1016/j.agsy.2015.12.014>
- Martinovska Stojcheska A, Kotevska A, Bogdanov N, Nikolić A (2016) How do farmers respond to rural development policy challenges? Evidence from Macedonia, Serbia and Bosnia and Herzegovina. *Land Use Policy* 59: 71-83. <https://doi.org/10.1016/j.landusepol.2016.08.019>
- Mauser W, Klepper G, Zabel F, Delzeit R, Hank T, Putzenlechner B, Calzadilla A (2015) Global biomass production potentials exceed expected future demand without the need for cropland expansion. *Nature Communications* 6 (1). <https://doi.org/10.1038/ncomms9946>
- Monfreda C, Ramankutty N, Foley J (2008) Farming the planet: 2. Geographic distribution of crop areas, yields, physiological types, and net primary production in the year 2000. *Global Biogeochemical Cycles* 22 (1). <https://doi.org/10.1029/2007gb002947>
- Monroe KR (2001) Paradigm Shift: From rational choice to perspective. *International Political Science Review* 22 (2): 151-172. <https://doi.org/10.1177/0192512101222002>
- Moriondo M, Maselli F, Bindi M (2007) A simple model of regional wheat yield based on NDVI data. *European Journal of Agronomy* 26 (3): 266-274. <https://doi.org/10.1016/j.eja.2006.10.007>
- Mueller ND, Gerber JS, Johnston M, Ray DK, Ramankutty N, Foley JA (2012) Closing yield gaps through nutrient and water management. *Nature* 490 (7419): 254-7. <https://doi.org/10.1038/nature11420>
- Pavlov IP (1927) *Conditioned Reflexes: An investigation of the physiological activity of the cerebral cortex*. Oxford University Press, New York.
- Pinto-Correia T, Guiomar N, Guerra CA, Carvalho-Ribeiro S (2016) Assessing the ability of rural areas to fulfill multiple societal demands. *Land Use Policy* 53: 86-96. <https://doi.org/10.1016/j.landusepol.2015.01.031>
- Plieninger T, Bieling C, Ohnesorge B, Schaich H, Schleyer C, Wolff F (2013) Exploring futures of ecosystem services in cultural landscapes through participatory scenario development in the Swabian Alb, Germany. *Ecology and Society* 18 (3). <https://doi.org/10.5751/es-05802-180339>
- Poppenborg P, Koellner T (2014) A Bayesian network approach to model farmers' crop choice using socio-psychological measurements of expected benefits of ecosystem services. *Environmental Modelling & Software* 57: 227-234. <https://doi.org/10.1016/j.envsoft.2014.03.006>
- Potschin M, Haines-Young R (2012) Landscapes, sustainability and the place-based analysis of ecosystem services. *Landscape Ecology* 28 (6): 1053-1065. <https://doi.org/10.1007/s10980-012-9756-x>
- Preston BL, King AW, Ernst KM, Absar SM, Nair SS, Parish ES (2015) Scale and the representation of human agency in the modeling of agroecosystems. *Current Opinion in Environmental Sustainability* 14: 239-249. <https://doi.org/10.1016/j.cosust.2015.05.010>
- Priess J, Hauck J, Haines-Young R, Alkemade R, Mandryk M, Veerkamp C, Gyorgyi B, Dunford R, Berry P, Harrison P, Dick J, Keune H, Kok M, Kopperoinen L, Lazarova T, Maes J, Pataki G, Preda E, Schleyer C, Görg C, Vadineanu A, Zulian G (2018) New EU-scale environmental scenarios until 2050 – Scenario process and initial scenario applications. *Ecosystem Services* 29: 542-551. <https://doi.org/10.1016/j.ecoser.2017.08.006>

- Redhead J, May L, Oliver T, Hamel P, Sharp R, Bullock J (2018) National scale evaluation of the InVEST nutrient retention model in the United Kingdom. *Science of The Total Environment* 666-677. <https://doi.org/10.1016/j.scitotenv.2017.08.092>
- Redhead JW, Stratford C, Sharps K, Jones L, Ziv G, Clarke D, Oliver TH, Bullock JM (2016) Empirical validation of the InVEST water yield ecosystem service model at a national scale. *Science of The Total Environment* 1418-1426. <https://doi.org/10.1016/j.scitotenv.2016.06.227>
- Reidsma P, Janssen S, Jansen J, van Ittersum M (2018) On the development and use of farm models for policy impact assessment in the European Union – A review. *Agricultural Systems* 159: 111-125. <https://doi.org/10.1016/j.agsy.2017.10.012>
- Rouse JW, Haas RH, Schell JA, Deering DW (1974) Monitoring vegetation systems in the Great Plains with ERTS. *Goddard Space Flight Center 3d ERTS-1 Symp.*
- Saltelli A, Tarantola S, F C, Ratto M (2004) *Sensitivity analysis in practice: a guide to assessing scientific models.* John Wiley & Sons, Ltd
- Schlüter M, Baeza A, Dressler G, Frank K, Groeneveld J, Jager W, Janssen M, McAllister RJ, Müller B, Orach K, Schwarz N, Wijermans N (2017) A framework for mapping and comparing behavioural theories in models of social-ecological systems. *Ecological Economics* 131: 21-35. <https://doi.org/10.1016/j.ecolecon.2016.08.008>
- Schwarz N, Ernst A (2009) Agent-based modeling of the diffusion of environmental innovations — An empirical approach. *Technological Forecasting and Social Change* 76 (4): 497-511. <https://doi.org/10.1016/j.techfore.2008.03.024>
- Sharp R, Tallis HT, Ricketts T, et al. (2015) InVEST user guide. <http://data.naturalcapitalproject.org/nightly-build/invest-users-guide/html/>. Accessed on: 2017-12-31.
- Simon H (1955) A behavioral model of rational choice. *The Quarterly Journal of Economics* 69 (1). <https://doi.org/10.2307/1884852>
- Simon H (1978) Rationality as process and as product of thought. *The American Economic Review* 2: 1-16.
- Skinner BF (1953) *The behavior of organisms.* Appleton-Century-Crofts, New York.
- Smith P (2004) Carbon sequestration in croplands: The potential in Europe and the global context. *European Journal of Agronomy* 20 (3): 229-236. <https://doi.org/10.1016/j.eja.2003.08.002>
- Stuart D, Schewe RL, McDermott M (2014) Reducing nitrogen fertilizer application as a climate change mitigation strategy: Understanding farmer decision-making and potential barriers to change in the US. *Land Use Policy* 36: 210-218. <https://doi.org/10.1016/j.landusepol.2013.08.011>
- Tamm T, Zalite K, Voormansik K, Talgre L (2016) Relating Sentinel-1 interferometric coherence to mowing events on grasslands. *Remote Sensing* 8 (10). <https://doi.org/10.3390/rs8100802>
- Thiele J, Kurth W, Grimm V (2014) Facilitating parameter estimation and sensitivity analysis of agent-based models: a cookbook using NetLogo and 'R'. *Journal of Artificial Societies and Social Simulation* 17 (3). <https://doi.org/10.18564/jasss.2503>
- Troost C, Berger T (2014) Dealing with uncertainty in agent-based simulation: farm-level modeling of adaptation to climate change in southwest Germany. *American Journal of Agricultural Economics* 97 (3): 833-854. <https://doi.org/10.1093/ajae/aau076>
- United Nations (2016) <http://ggim.un.org/knowledgebase/KnowledgebaseArticle51479.aspx>. Accessed on: 2017-12-31.

- Václavík T, Lautenbach S, Kuemmerle T, Seppelt R (2013) Mapping global land system archetypes. *Global Environmental Change* 23 (6): 1637-1647. <https://doi.org/10.1016/j.gloenvcha.2013.09.004>
- Václavík T, Langerwisch F, Cotter M, Fick J, Häuser I, Hotes S, Kamp J, Settele J, Spangenberg JH, Seppelt R (2016) Investigating potential transferability of place-based research in land system science. *Environmental Research Letters* 11 (9). <https://doi.org/10.1088/1748-9326/11/9/095002>
- Valbuena D, Verburg P, Veldkamp A, Bregt A, Ligtenberg A (2010) Effects of farmers' decisions on the landscape structure of a Dutch rural region: An agent-based approach. *Landscape and Urban Planning* 97 (2): 98-110. <https://doi.org/10.1016/j.landurbplan.2010.05.001>
- van Asselen S, Verburg P (2012) A Land System representation for global assessments and land-use modeling. *Global Change Biology* 18 (10): 3125-3148. <https://doi.org/10.1111/j.1365-2486.2012.02759.x>
- van der Zanden E, Levers C, Verburg P, Kuemmerle T (2016) Representing composition, spatial structure and management intensity of European agricultural landscapes: A new typology. *Landscape and Urban Planning* 150: 36-49. <https://doi.org/10.1016/j.landurbplan.2016.02.005>
- van Eupen M, Metzger MJ, Pérez-Soba M, Verburg PH, van Doorn A, Bunce RG (2012) A rural typology for strategic European policies. *Land Use Policy* 29 (3): 473-482. <https://doi.org/10.1016/j.landusepol.2011.07.007>
- Vreugdenhil M, Wagner W, Bauer-Marschallinger B, Pfeil I, Teubner I, Rüdiger C, Strauss P (2018) Sensitivity of Sentinel-1 backscatter to vegetation dynamics: an Austrian case study. *Remote Sensing* 10 (9). <https://doi.org/10.3390/rs10091396>
- Weitzel M, Hübler M, Peterson S (2012) Fair, optimal or detrimental? Environmental vs. strategic use of border carbon adjustment. *Energy Economics* 34: 198-207. <https://doi.org/10.1016/j.eneco.2012.08.023>
- Zagaria C, Schulp CE, Kizos T, Gounaridis D, Verburg P (2017) Cultural landscapes and behavioral transformations: An agent-based model for the simulation and discussion of alternative landscape futures in East Lesvos, Greece. *Land Use Policy* 65: 26-44. <https://doi.org/10.1016/j.landusepol.2017.03.022>
- Zimmermann A, Möhring A, Mack G, Ferjani A, Mann S (2015) Pathways to truth: comparing different upscaling options for an agent-based sector model. *Journal of Artificial Societies and Social Simulation* 18 (4): 11. <https://doi.org/10.18564/jasss.2862>