Title: A farming systems approach to link agricultural policies to biodiversity and ecosystem services.

Running head: A farming systems approach for policy evaluation and design

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In a nutshell

We propose the use of a farming systems approach, based on farm-level spatially explicit agricultural data across Europe, to explore the links between policy design and biodiversity and ecosystem services (BES) outcomes.

Main advantages of the approach include the coherence of management among farms belonging to a given system, allowing the prediction of impacts on BES, and the close dependency of the choice of farming system selection by farmers from policy and other drivers.

The proposed approach has the potential to be used for applied ecological research and for cost-effective policy design and evaluation with lower administrative costs.

Abstract

The Common Agricultural Policy (CAP) affects biodiversity and the provisioning of ecosystem services (BES) in European farmland, but measuring the effectiveness of the variety of CAP instruments in BES delivery is challenging. Here, we propose the use of a farming systems (FS) approach as a cost-effective tool to linking policy design and implementation, with BES outcomes. Based on the use of agricultural management information available from CAP payment agencies, advantages of this approach include: (a) identifying groups of farms sharing coherent management practices; (b) a close link between many FS and the corresponding BES potential; (c) improved modelling of farm management responses to policies and other drivers of change; (d) availability of comparable information across the European Union. We illustrate how this relatively unexplored source of information can be used to support applied ecological research and policy design and evaluation and end with a plea for making these data available across Europe.

1. The need to link agricultural policies to environmental outcomes

A relevant share of European agricultural areas hold significant biodiversity and ecosystem service (BES) values. In fact, ca. 30% of European farmland is considered to be of High Nature Value (Paracchini *et al.* 2008; Oppermann *et al.* 2012), supporting species and habitats of conservation concern. They also provide relevant ecosystem services for the wider society, including cultural landscapes, natural hazard prevention and regulation of water quality (Lomba *et al.* 2019). Most of this land is owned and managed by private economic agents, mostly farmers, rather than conservation organizations. Therefore, agricultural markets, policies and socioeconomic conditions, rather than explicit conservation goals usually drive management decisions.

Taking ca. 40% of the European Union (EU) budget, the Common Agricultural Policy (CAP) is one of the major drivers of agricultural management decisions (Pe'er *et al.* 2014). Since the 1990s, the CAP has been shifting its focus away from food production, market regulation and farmers' income support, towards remunerating the provision of environmental public goods, following societal demands for improved sustainability and environmental performance. This context calls for a reorientation of applied research aimed at supporting conservation policy, so that key elements of the land management (farmers) and policy regimes are fully taken into account when selecting analytical tools and approaches (Malawska *et al.* 2014; Pe'er *et al.* 2019). Here, we propose the exploration of a Farming Systems (FS) approach where FS, defined based on farmer's management choices, potentially act as indicators of BES delivery (Figure 1). This would allow a better linkage between alternative policy options and their respective BES outcomes.

2. The farming systems concept

Different farming system concepts and approaches have been used at least since the 1960s, both for scientific purposes and policy support (Jones *et al.* 2017). Recent developments applicable to the environmental context included the identification of broad types of "high nature value farmlands" (HNVF) delivering relevant BES

(Andersen *et al.* 2003; Lomba *et al.* 2014, 2019), although details of the farming systems underpinning these arable, permanent crop, and livestock-based HNVF have not been assessed. The farming systems (FS) approach adopted here considers the farm as a system and unit of analysis (Reboul 1976; Norman 1980). The farmer pilots the farm according to her/his choices and aspirations, choosing outcomes and means to achieve them (Cochet 2012). The system is open, as it has an environment that affects its state; dynamic, as changes can occur over time in one or more structural properties of the system; and goal-oriented or purposeful (Darnhofer *et al.* 2012). A FS is therefore a group of farms that share a range of land, labor and means of production, as well as similar cropping and livestock sub-system combinations, with associated management decisions regarding e.g. crop types, fertilizer use or livestock rates (Reboul 1976; Ferraton and Touzard 2009). Sub-systems also relate to each other through e.g. forage flows from the crop to the livestock sub-systems or the manure flow in the opposite direction. Some systems may be composed exclusively of a single crop or livestock subsystem (specialized FS) (Figure 2).

[FIGURA A FAZER- Angela]

Figure 2 – Conceptual representation of farming systems (FS). Each symbol corresponds to a farm along two axes representing livestock densities (y-axis) and a pasture-cropland gradient (x-axis). Farmers are clustered into three types of FS (crops, sheep and cattle). Although farms within a given FS show some management variability along these axes, they are expected to be more similar among themselves than farms belonging to different FS.

3. Farming systems as a tool to link policies to environmental outcomes

The potential of a FS approach as a tool to explore the policy-BES link is based on four key aspects described below.

3.1 Management coherence

Farms operating under a specific FS are managed in a goal-oriented way in which individual management decisions are best understood as a whole, or system, of strongly inter-related and context-responsive decisions. For example: using a particular fertilizer or herbicide is often required to introduce a genetically improved, more productive variety of maize; raising cows in a region with cold winters or dry summers requires harvesting hay, silage or another form of conserved forage for the cold or dry season. Therefore, farm-level management practices with implications for BES are not independent of each other, but linked together as a "bundle" of practices. One advantage of this interdependent nature of practices is that farm management details with important BES impacts (e.g. harvest dates, use of agro-chemicals, type of mechanical operations) can potentially be inferred from FS (Ribeiro *et al.* 2016a). This detailed information is usually not available from existing agricultural farm-level data sources and obtaining it often requires costly farm surveys.

A potential problem with policy-making approaches based on the setting of management targeting specific BES is that this might result in prescription of management practices that are not coherent with each other and/or with other management practices required under a specific FS management. Consequently, such combinations may look ideal from the conservationist point of view, but as a "Frankenstein" set of practices to the farmer (e.g. trying to delay harvesting dates to protect bird nests in a system where silage is required). In fact, there is evidence that farmers engaging in agri-environment schemes are more keen to adopt familiar practices causing lower levels of disruption to their normal agricultural activities, rather than complex management requirements (Van Herzele *et al.* 2013; Lastra-Bravo *et al.* 2015; Nilsson *et al.* 2019). Therefore, an approach based on choosing, among the existing FS, those that have better BES performance would be much more easily accepted by farmers than requirements to adopt ad hoc sets of practices.

3.2 Links between farming systems, biodiversity and ecosystem services

Different FS include specific field and farm-level agricultural practices (crop selection, livestock management, maintenance of non-crop elements) to which biodiversity components respond. For example, studies on High Nature Value grasslands in southern Portugal enabled us to understand the impacts of changing livestock management (Reino *et al.* 2010) and crop types (Delgado and Moreira 2002) on bird diversity in the region. Agricultural practices that are known to affect BES, such as harvest dates, stocking rates or pesticide usage, are strongly dependent on FS type (Ribeiro et al., 2016). Also depending on the FS, farms may retain non-crop elements such as woods, scrubland, rough pastures, hedgerows for crop protection or small dams for irrigation or drinking purposes. These create distinct landscape patterns across FS (Ribeiro *et al.* 2016b) likely delivering different biodiversity and ecosystem service (e.g. water quality, natural hazard prevention, and cultural services) outcomes (Power 2010). In short, contrasting FS are expected to hold varying BES potential, particularly if they are based on distinct crop types and grazing regimes.

FS can be characterized according to three main dimensions, which impact differently on BES: (1) Production intensity, which can be measured as output per hectare of land (yields of specific crops, or total farm output in euros per hectare), as per-hectare use of yield-raising inputs (e.g. fertilizers, pesticides, irrigation water) or as stocking rates; (2) Specialization pattern, i.e. the weight of different activities in the farm as a whole, measured through either shares of total area used by these activities (e.g. 25% of farmland with wheat) or shares of total outputs (e.g. milk represents 80% of the total output in euros); and, (3) Dependency on human labor, which reflects labor intensity of the FS (e.g. manual horticultural crops versus mechanized field crops or low-intensity livestock raising). The full use of these dimensions may be helpful to more clearly identify the drivers of the observed impacts of agriculture on BES, and widens the scope of commonly used approaches focused mostly on the impacts of production intensity alone (e.g. Green *et al.* 2005; Tscharntke *et al.* 2012).

3.3 Close response to policy and other drivers

A farmer’s decision to adopt a given FS is influenced by: (a) the socioeconomic or biophysical characteristics of the farm e.g. farm size, slope, soil quality, rainfall, availability of water for irrigation; (b) the attributes of the farmer and household, e.g. available family labor and their skills, investment capacity or attitudes towards risk; (c) the territorial attributes of the region in which the farm is located, e.g. labor market, technical advice or access to input and output markets; and, (d) the market and policy environment, such as prices for different possible inputs and outputs, and available policies, e.g. whether policy income support is coupled or decoupled from production. Most of these factors act either as drivers or as constraints in the decision-making process that leads to the choice of FS (Figure 3); farmers in similar driver contexts will tend to choose the same FS, and farms operating within the same FS are expected to show similar responses to biophysical, market and policy drivers (Dixon *et al.* 2001). This enables the exploitation of such close relationships for modelling and prediction purposes, e.g. to predict FS shift based on policy change as in Ribeiro et al. (2018) (see section 4).

3.4 Availability of EU level information on farm management

A basic requirement to develop a FS typology is to have access to farm-level data. Ideally, such data should cover a large range of farm management aspects. Such detailed data are often not available or accessible to researchers and its collection typically requires costly and time consuming farm surveys. One alternative to farm surveys that has recently attracted attention is the EU Integrated Administration and Control System (IACS) database (Beaufoy and Marsden 2011; Beaufoy *et al.* 2012; Keenleyside, C, Beaufoy, G, Tucker, G, and Jones 2014; Lomba *et al.* 2017). These data are collected on a yearly basis through farmers declarations when applying for CAP payments and include information on livestock and land use/cover at farm-parcel level, with the significant advantage of being spatially explicit through links to the Land Parcel Identification System (LPIS). Although IACS/LPIS data are primarily collected for EU policy implementation purposes (management of CAP payments), there seems to be a recent trend towards making this data available to other stakeholders, which will boost research opportunities by providing access to a highly detailed agricultural database (parcel level), annually updated and potentially available at EU level (Tóth and Kučas 2016). Such data has recently been used in FS research (Ribeiro *et al.* 2014, 2016a; Lomba *et al.* 2017) and in the estimation of spatio-temporal choice models to predict FS choice in distinct policy scenarios (Ribeiro *et al.* 2018).

4. Strengths and weaknesses of a Farming Systems approach for applied ecological research and policy design and evaluation

The proposed FS approach to link agricultural policies to BES outcomes has several possible applications in two main areas: applied research, and policy design and evaluation. These applications, as well as some of their strengths and weaknesses, are addressed in the following sections.

4.1 Applied ecological research

The further development of the approach requires additional research, carried out in different policy, socioeconomic and ecological contexts, to demonstrate its general usefulness and to identify where and why it may have some limitations for specific purposes. Three priorities are suggested for this additional research: (1) modelling FS dynamics (in time and space) in relation to policy incentives and other drivers (e.g. Ribeiro *et al.* 2014); (2) identifying FS associated with higher BES potential in different contexts (see proposed methodological approach in Panel S1), and (3) understanding under which circumstances FS can (or cannot) be approximately taken as good BES proxies. The latter is particularly important because, from the ecological point-of-view, FS act as relatively distant indicators of the real proximate drivers of BES, and therefore they may show weak relationships with intended BES outcomes, which are influenced by other drivers. In these cases, more detailed descriptions of proximate drivers, such as non-crop elements and habitat structure and spatial configuration, may be required to understand the implications for BES.

4.2 Policy design and evaluation

A relevant policy application for the proposed FS approach is in *ex ante* evaluations of the environmental effects of major policy reforms. In fact, changes in the policy and market price environment in which farmers make their FS choices, such as CAP reforms or international trade liberalization agreements, may lead to massive FS change at a broad, supranational scale, with potential impacts on BES (Santos *et al.* 2016). In these cases, the proposed approach may be used to model the effects of policies as drivers of FS choice; the estimated choice models can then be used to predict how farmers would change (or keep) their FS under different alternative policy options and enable the estimation of spatio-temporal FS choice-models with economic data, which can be used to simulate scenarios of policy change (e.g. the introduction of a policy paying a premium to farms operating a particular FS, previously selected for its high BES provision) (Ribeiro *et al.* 2018). Assessing which FS have higher BES potential will provide the final link to deliver an *ex ante* evaluation of these different policy options.

Another important application for the proposed approach is found in the context of the ongoing debate on how to reform the CAP so that public funds are progressively directed to pay for environmental public goods demanded by society as a whole (Santos *et al.* 2016). In this context, two alternative paths have been advocated: (1) widening broad scale policies (e.g. Pillar I Greening measures under the last CAP reform, or Eco-schemes, their likely successor in the upcoming CAP reform), versus (2) deepening targeted incentives promoting specific environmental public goods in particular areas (typically the focus of Pillar 2 agri-environment schemes). The former has the advantage of reducing transaction costs, but at the expense of lower conservation effectiveness, as conservation objectives and management prescriptions are often poorly specified, while the latter are tailored to meet biodiversity conservation objectives at the local or regional levels, but at the expense of high administrative costs (Ribeiro *et al.* 2016a). Alternative approaches are thus required to strike the right balance between scheme precision and administrative costs (Vatn 2002), by keeping more focused management prescriptions while reducing transaction costs (Poláková *et al.* 2011). The FS framework might provide a relatively simple and practical way to progress along these lines. For example, it could be applied to policy design within the 1st pillar of the future CAP, e.g. in the upcoming Eco-schemes, as a convenient compromise between highly targeted agri-environment schemes and broad-brush horizontal policies. Box 1 provides a step-by-step illustration of how this could be done: after identifying the existing FS that have the best performance in terms of BES, policy support would be redirected towards those farms that adopt those targeted FS as a premium support on top of the pillar 1 base payment level. This premium payment would be justified by the actual provision of public goods by a farmer under a particular FS (Cooper *et al.* 2009), which would be a major policy improvement vis a vis the current payment level, which is based on the individual or regional level of historical support. Farmers would keep this premium support level while their management actions are kept inside the range of existing variability in the targeted FS. This policy design approach would keep both private and public transaction costs at a low level, as it is grounded on the existing administrative framework for data collection from farmers, and would not require further control measures to check whether farmers are complying with additional management commitments.

The proposed FS approach should not be compared with those of locally targeted Agri-environmental management commitments or result-based approaches (Burton and Schwarz 2013), but with those of the current Single Payment and Greening schemes, which have been strongly criticised for their weak effectiveness not only by researchers (Pe'er *et al.* 2019) but also by the European Court of Auditors (European Court of Auditors 2017). However, when BES delivery potential is not significantly different across FS, detailed agri-environmental commitments or result-based approaches will be required, but with higher transacion costs.

Another possible limitation of the proposed FS approach is that developing a FS typology from data observed in the past may hinder the full consideration of the potential role of agricultural innovation in better addressing the BES issues at stake. For this reason, the FS typology will have to be regularly updated with new data, e.g. in the course of regular reviews of the CAP.

5. Conclusions: a plea for data availability

We believe there is a strong potential in a FS approach to better link policy options to environmental outcomes. Contrasting with the often scarce EU-wide information from ecological studies, a huge amount of information has been gathered by agricultural agencies across European countries for administrative and farmer payment purposes, but this spatial-explicit time series of farm-level data are notoriously difficult to get in most EU countries, due to data confidentiality limitations (Andersen *et al.* 2003). We therefore recommend that these data should be made available for research purposes, as they have a strong potential for being used for policy design and evaluation. This should include the identification of research priorities and the co-design of research questions together with agricultural agencies.

However, even when farm-level information is not accessible, the FS principle can be extended to available regional-level statistics, at least for research purposes, e.g. using EUROSTAT data to derive "farming landscape systems" across European NUT regions and explore large-scale patterns of associated BES (Santos *et al.* 2016).

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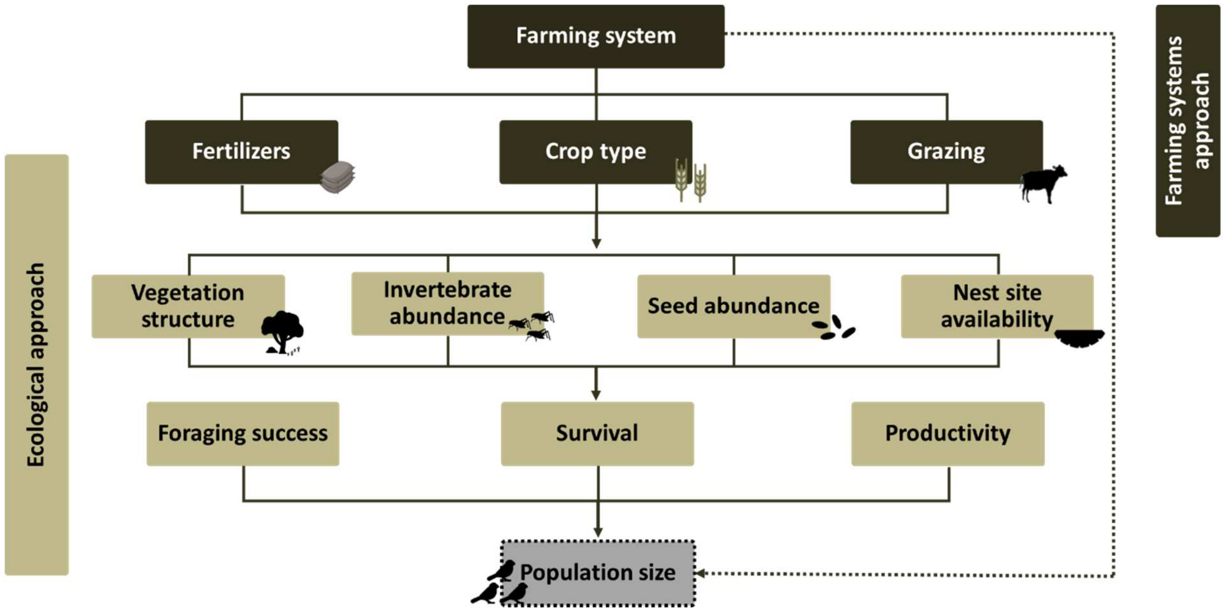


Figure 1 – Contrasting a traditional *ecological approach* and a *farming systems approach* as tools to link agricultural management to biodiversity, using a grassland bird population (light gray box at the bottom) as an example of a biodiversity target/indicator. Whereas the ecological approach is focused on measuring the impacts of proximal ecological drivers, such as habitat and food resources (brown boxes) on biodiversity outcomes, the farming systems approach explores the link (dashed line) between top-level management decisions (dark gray boxes), as drivers of the chain of top-down events (e.g. farming system will determine fertilizer use, which will determine vegetation structure, which will impact on foraging success), and final biodiversity outcomes.

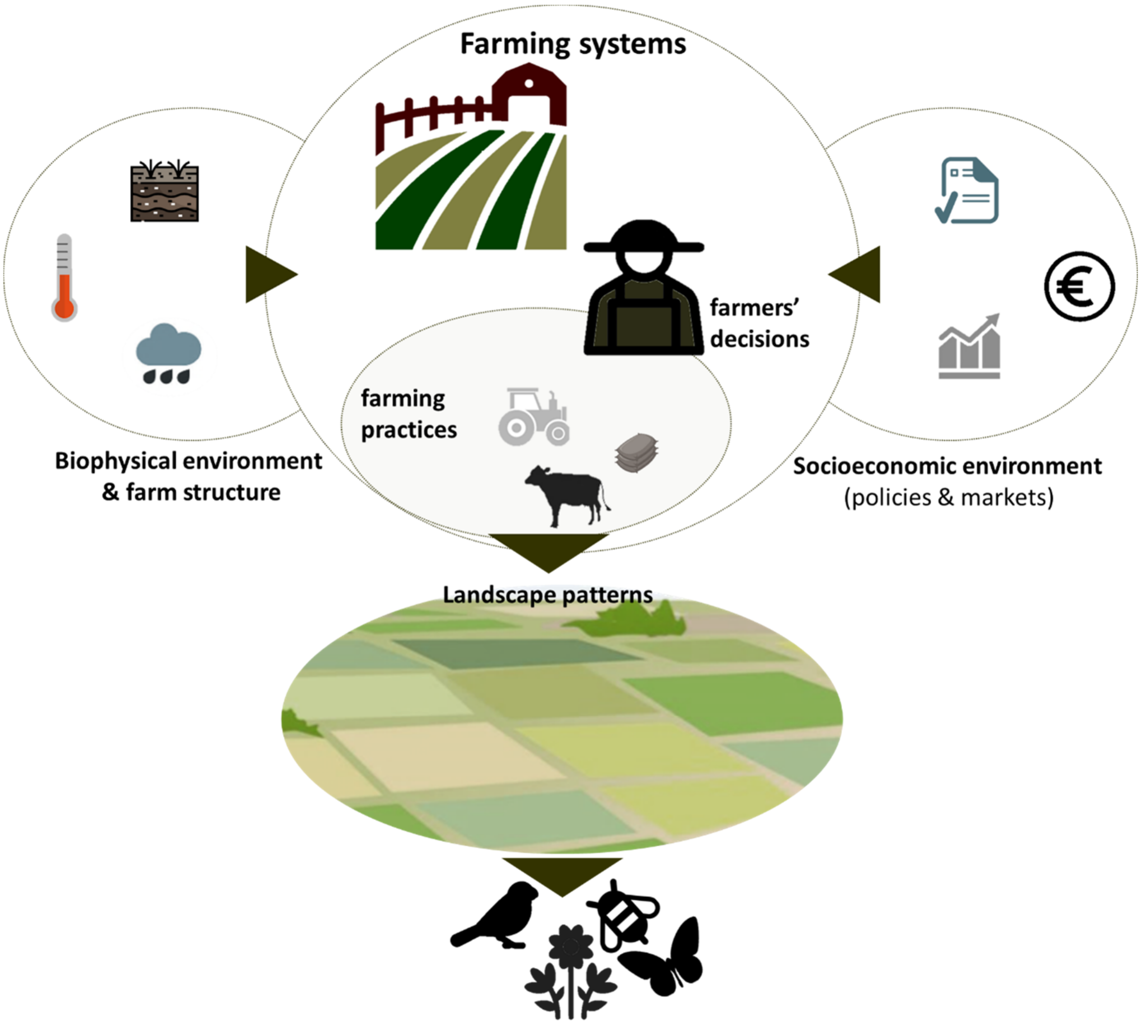


Figure 3 - Conceptual framework of the farming systems approach linking agricultural policies to biodiversity and ecosystem services. Drivers of farming system selection include the biophysical environment and farm structure, and the socioecomonic environment. The decision will affect farming pracices and landscape patterns, key drivers of biodiversity and ecosystem services.

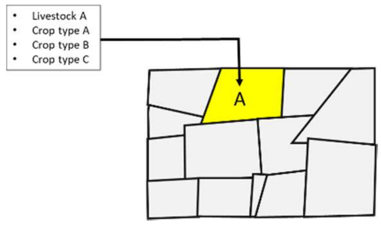
BOX 1

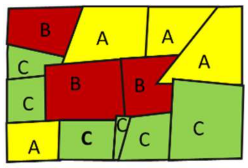
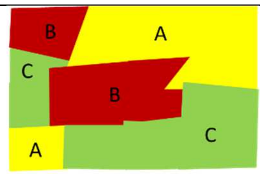
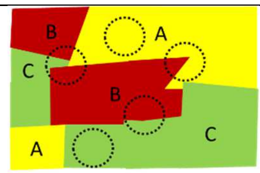
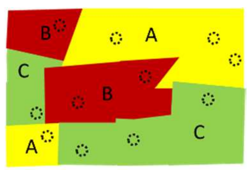
How to design policies that support targeted FS to address BES issues?
A step-by-step approach using IACS/LPIS data

1. **For a given administrative region, define the BES issues to be addressed by agricultural policies** in this region, e.g. threatened species conservation, fire hazard reduction, water quality improvements and/or landscape conservation.
2. **Develop a FS typology for that region**. See details in Panel 1.
3. **Assess the BES value of each FS in the region**. Map the region's FS and evaluate, through published literature or dedicated field surveys (Panel S1) the spatial associations between FS and the indicators of priority BES issues in the region.
4. **Assess whether supporting targeted FS is an effective way to address priority BES in the region.** FS associated to higher values of priority BES issues will potentially be selected as candidates for targeting for support. Compare the average and variability of each priority BES indicator across FS. Effectively addressing BES delivery through supporting targeted FS requires that differences across FS are significant. If this is not the case, FS are not sufficiently associated to BES outcomes, and thus and alternative approaches (e.g. detailed agri-environmental commitments or result-based approaches) are required to induce the desirable changes in BES delivery.
5. **Assess FS dynamics as a basis to decide whether to support targeted FS**. Assess recent trends in FS in the region, using IACS time-series data if possible, or agricultural statistics in alternative. If FS selected in step 4 as candidates for support are stable and at a good level, do nothing; if these FS are declining or at a low level for effective BES provision, implement a policy payment to farms operating these FS; the payment level must be set to promote farmers' effective uptake of such FS to meet the desired level of BES provision.
6. **Operation phase**: In operation phase, data collected from farmers' annual applications to CAP payments is used to annually reclassify the farms under the existing FS typology for the region, following an automatic procedure within the IACS system; those classified in the FS selected for support in step 5 will receive the premium policy payment;
7. **Post-implementation phase:** The FS typology should be updated after a few years (e.g. during CAP reviews) to accommodate any regional agricultural changes, including new FS with better BES performance.

Panel S1 - A recipe on how to explore the links between farming systems types and biodiversity and ecosystem service (BES) outcomes.

<table>
<tr><td>Get farm-level data from the Integrated Administration and Control System (IACS) and the Land Parcel Identification System (LPIS) from the national CAP paying agency for all farms in the region.

Use the IACS data to characterize each farm as regards e.g. cropping pattern shares of the utilized agricultural area, livestock density and composition and other FS-based farm characterization variables.</td><td>
</td></tr>
<tr><td>Derive a typology of farming systems, through multivariate statistics (e.g. cluster analysis), yielding groups of farms managed under the same farming system (FS types: A, B, C…)

Carefully choose the right number of clusters (farming systems) that reflects the known FS heterogeneity in the region (seek help from local agricultural experts, if necessary).</td><td></td></tr>
<tr><td>1. Merge boundaries of adjacent farm sharing the same FS to yield a “landscape of farming systems”.</td><td></td></tr>
<tr><td>2. Characterize the BES associated to each FS. Assessing the BES potential at landscape scale can be done in two ways: (i) If farm sizes are large, merging the boundaries of adjacent farms with similar FS will result in geographical blocks with similar management, which can be linked to block-specific landscape-level BES; (ii) If farm sizes are smaller and FS very heterogeneous in space, then an arbitrary region can be selected, which would be characterized by its composition of FS, and this information linked to biodiversity and ecosystem service provisioning at the selected spatial level.</td><td>
</td></tr>
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