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Farming system archetypes help explain the uptake of agri-environment practices in Europe

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Abstract

The adoption of agri-environment practices (AEPs) is crucial for safeguarding the long-term sustainability of ecosystem services within European agricultural landscapes. However, the tailoring of agri-environment policies to the unique characteristics of farming systems is a challenging task, often neglecting local farm parameters or requiring extensive farm survey data. Here, we develop a simplified typology of farming system archetypes (FSAs), using field-level data on farms' economic size and specialisation derived from the Integrated Administration and Control System in three case studies in Germany, Czechia and the United Kingdom. Our typology identifies groups of farms that are assumed to react similarly to agricultural policy measures, bridging the gap between efforts to understand individual farm behaviour and broad agri-environmental typologies. We assess the usefulness of our approach by quantifying the spatial association of identified archetypes of farming systems with ecologically relevant AEPs (cover crops, fallow, organic farming, grassland maintenance, vegetation buffers, conversion of cropland to grassland and forest) to understand the rates of AEP adoption by different types of farms. Our results show that of the 20 archetypes, economically large farms specialised in general cropping dominate the agricultural land in all case studies, covering 56% to 85% of the total agricultural area. Despite regional differences, we found consistent trends in AEP adoption across diverse contexts. Economically large farms and those specialising in grazing livestock were more likely to adopt AEPs, with economically larger farms demonstrating a proclivity for a wider range of measures. In contrast, economically smaller farms usually focused on a narrower spectrum of AEPs and, together with farms with an economic value <2 000 EUR, accounted for 70% of all farms with no AEP uptake. These insights indicate the potential of the FSA typology as a framework to infer key patterns of AEP adoption, thus providing relevant information to policy-makers for more direct identification of policy target groups and ultimately for developing more tailored agri-environment policies.

Keywords

agricultural policy, archetype analysis, ecosystem services, farm specialisation, farm typology, spatial classification

1. Introduction

Approximately 40% of land in the European Union (EU) is used for agriculture (Eurostat 2022a). This area generates ~450 billion Euros annually, which is essential to the European population, including its 20 million farmers (Eurostat 2022b). However, intensive farming, together with climate change impacts (Muluneh et al. 2021, Outhwaite et al. 2022), has led to a dramatic decline in farmland biodiversity (e.g. in avifauna, Common Bird Index; Eurostat 2022c, Rigal et al. 2023), soil carbon content and other ecosystem services (Yang et al. 2019). To mitigate these impacts and achieve the EU's climate objectives, a set of agri-environment practices (AEPs) has been implemented under the Common Agricultural Policy (CAP), including Ecological Focus Areas and Agri-Environment-Climate Measures, mandated until 2022 under CAP's Pillar I and II, respectively (Pe'er et al. 2022). Despite reducing administration costs, the uniform implementation of these measures across different jurisdictions fails to consider local socio-economic and ecological characteristics, undermining their effectiveness (Candel et al. 2021, Beckmann et al. 2022, Roilo et al. 2023). Therefore, agri-environment policies that are tailored to specific properties of farming systems are likely to be more effective than one-size-fits-all policy measures (Oberlack et al. 2023).

Farm typologies can support the development of tailored agricultural policies, as they allow grouping of individual farms with similar characteristics and common responses to environmental and policy drivers (Huber et al. 2024, Ribeiro et al. 2014). As such, they help reduce the complexity of farm properties, thereby eliminating the necessity to address the numerous idiosyncrasies present across a multitude of farms. The purpose of such typologies ranges from describing and understanding the diversity in the farming sector to informing policy formulation, implementation and assessment (see Huber et al. 2024 for a review of farm typologies). However, building individual farm typologies is challenging because it requires large amounts of data that are difficult to obtain, typically through a large number of direct inquiries to farmers (Ribeiro et al. 2016, Tittonell et al. 2020). Such data collection is costly and time-consuming, often resulting in a relatively small sample size and low geographical coverage.

Alternatively, broad typologies of agricultural land-use systems enable contextualising locally specific cases (e.g. farms) within regional to national frameworks (Oberlack et al. 2023, Ribeiro et al. 2016). These approaches that identify and map archetypal patterns of agricultural systems have proved useful for modelling land-use policy impacts (Metzger et al. 2013), understanding land-management intensities (Václavík et al. 2013, van der Zanden et al. 2016, Levers et al. 2018, Rega et al. 2020), analysing agri-environmental potentials (Beckmann et al. 2022) and farm management practices (Goodwin et al. 2022), or upscaling regional findings (Václavík et al. 2016). However, they rely mostly on gridded biophysical (e.g. climate, soil) and land-use data that do not capture individual farm characteristics. Although a few examples exist that capture socio-economic and ecological features of individual farms (e.g. Graskemper et al. 2021, Tittonell et al. 2020), these tend to use highly aggregated data and are limited in reproducibility across national and regional contexts. Thus, there is a need for farming system typologies that bridge the gap between understanding the behaviour of individual farms in support of highly targeted but costly incentives and broad, grid-based typologies of agricultural systems that lack the consideration of farm structural characteristics, important for identifying policy target groups.

Here, we address this challenge by using archetype analysis, a key methodological approach for organising the complexity of social-ecological systems (Oberlack et al. 2019, Sietz et al. 2019), to develop a generalised typology of farming systems. Farming system archetypes (FSAs) group farms according to their structural characteristics (Huber et al. 2024) into units that are assumed to have similar responses to policy measures. Our approach advances existing typologies by (1) capturing archetypal dimensions of farms crucial for identifying target groups of agri-environment policies, (2) using readily available national-level data, instead of relying on ad-hoc survey-based information, and (3) providing spatially explicit field-level information aggregated to the farm level across large geographical scales. Exemplified in three case studies in Germany, Czechia and the UK, we identify and map FSAs by geospatial relations of field-level attributes that characterise farms' economic size and specialisation derived from the Integrated Administration and Control System (IACS). As it is uncertain to what degree such typology can capture patterns of agri-environment policy uptake, we assess the usefulness of our approach by quantifying the spatial association of FSAs with selected agri-environment practices (cover crops, fallow, organic farming, grassland maintenance, vegetation buffers, conversion to grassland and forest) to understand how different types of farms adopt different AEPs. Finally, we discuss the potential and limitations of our approach, define regional- and farming system-specific patterns of AEP uptake, and argue for better future tailoring of agri-environment policies in European agriculture.

2. Data and methods

2.1 Study area

Our analyses covered three regional case studies that were part of the EU-funded research project BESTMAP (Behavioural, Ecological and Socio-Economic Tools for Modelling Agricultural Policy; Ziv et al. 2020). These areas are traditional farming regions in Europe that are representative of each respective country and cover a cross-section of different farming systems and practices (Ziv et al. 2020): the Mulde river basin in eastern Germany (~51.1° N, 12.5° E), southern Moravia in the eastern Czech Republic (~48.9° N, 17.3° E), and the Humber river basin in central United Kingdom (~53.7° N, 0.7° W). The Mulde case study is located at the boundary between temperate and continental climates, where the annual mean temperature and precipitation totals are around 7.0 °C and 830 mm, respectively (Bartkowski et al. 2023, Roilo et al. 2023). While the average farm size of 93 ha in Mulde (maximum farm size of 4 967 ha) is comparable to 94 ha in South Moravia (maximum farm size of 6 136 ha), the Czech case study area has a warmer continental to Pannonian climate with an average annual temperature of 8.5 °C and rainfall of 660 mm (Bartkowski et al. 2023). In contrast, the farmland in the Humber river basin is characterised by an oceanic climate, with the annual mean temperature and precipitation totals of 9.6 °C and 630 mm, and by a smaller average farm size of 52 ha. The soils comprise chernozems, leptosols and cambisols (South Moravia), cambisols and luvisols (Mulde and Humber) and gleysols (Humber). The study area elevations range from ~300 to 1 100 m and cover 5 814 km², 2 089 km², and 4 664 km² of total area for Mulde, South Moravia and Humber, respectively, of which 63%, 62%, and 79% is agricultural land (Ziv et al. 2020).

2.2 Farming system archetypes

For identifying farming system archetypes in our case study areas, we used field-level data on land-use management, available as part of the IACS database, to infer features of individual farms, i.e. farm structural characteristics as defined by Huber et al (2024). IACS data serve the purpose of supporting the administration of agricultural subsidies and are collected through farmers' declarations when applying for CAP payments (Santos et al. 2021). When linked to the Land Parcel Identification System (LPIS), a key component of IACS, the data can provide spatially explicit information on the size and location of each agricultural parcel, the farm that manages the field (anonymised), the type of land cover and crop grown, the farming practice (e.g. conventional vs. organic) and the implemented AEP. The IACS/LPIS datasets for our case studies were provided under license by the national or regional public authorities: (1) the Integriertes Verwaltungs- und Kontrollsystem (InVeKoS) from the Saxon State Ministry for Energy, Climate Protection, Environment and Agriculture, (2) the Czech Land Registry–LPIS from the Ministry of Agriculture of the Czech Republic and (3) the LPIS from the UK Rural Payments Agency and Natural England open data geoportal. All data were processed for the most recent year available consistently across all case studies (i.e. 2019) following the General Data Protection Regulation and local data sharing agreements.

Our FSA typology was based on two independently calculated dimensions of the farming system: farm specialisation and economic size. We chose these dimensions because they were computable from the field-level IACS/LPIS data consistently across all case studies and because they represent essential farm structural characteristics (as opposed to farmers' individual characteristics) recognized as crucial for identifying policy target groups (Huber et al. 2024). These dimensions also capture archetypal aspects of the farming systems, as the compatibility of AEPs with established farm practices and economic considerations related to the farm business were previously identified as the most relevant factors for the uptake of AEPs in our case studies (Bartkowski et al. 2023, Wittstock et al. 2022) and elsewhere (Baaken 2022, Lastra-Bravo et al. 2015). Moreover, these dimensions are available as variables in the Farm Accountancy Data Network (FADN), the main database that provides harmonised microeconomic data for farms in the EU derived from national surveys. This allows the future possibility of the FSA approach to be upscaled to other parts of Europe, providing insights into the distribution of FSAs (based on the sample farms anonymously recorded in the database) at the level of NUTS or FADN regions.

Farm specialisations were classified as the relative share of the standard crop and animal production according to the FADN classification 'Type of Farming TF8', as defined in Annex IV of EU regulation 2015/220. These FADN categories were used as guidelines for the classification, but the actual farm specialisation was calculated based on field-level IACS attributes. For simplicity, we aggregated the original eight categories into five broad classes of specialisation (Table A1): general cropping ('P1'), horticulture ('P2'), permanent crops ('P3'), grazing livestock ('P4') and mixed. To assign each farm in the IACS data into these categories, we calculated the areas of individual crop or culture types in all fields of each respective farm and applied the area-based rules defined in EU regulation 2015/220, according to which farms classified as P1, P2, P3 or P4 must dedicate at least ⅔ of the total farm area to the respective land-use type. If this area requirement was not met, we classified the farm as a fifth type of specialisation: 'mixed'. For the proportion of each farm specialisation category covered by individual field specialisations, please see Table A5.

Economic size represented the total value of standard production, which we calculated from the area of individual crops and the number of animals at an agricultural holding. For this variable, we simplified the FADN ES6 classification, which categorises farms' economic size according to delimited ranges (EUR; Table A2). This parameter is not directly available in the IACS data but can be calculated using Standard Output Coefficients (SOC in EUR per hectare, for ~90 crop types) available in Eurostat (2022d). SOCs represent the average monetary value of the agricultural output at a farm-gate price, in Euro per hectare or per head of livestock, calculated for different regions in Europe. Therefore, we multiplied the area of each crop (extracted from the IACS data for all fields of each respective farm) by the corresponding SOC value per region, as it is calculated in the 2016 Farm structure survey data using the average of 2011–2015 prices. As a result, we classified each farm into one of four categories: '<2 000 EUR', 'small', 'medium' or 'large'. Although the criteria for the '<2 000 EUR' category remained unchanged, the 'small', 'medium' and 'large' categories were assigned relative to the distribution of farm sizes in each specialisation category to achieve even distributions across groups, resulting in approximately ⅓ of the total number of farms (excluding the <2000 EUR farms) being in each category (Table A3). Several issues arose when defining farm specialisation and economic size, e.g. in distinguishing production types, estimating economic value, or data consistency. Please see Table A7 for details on how we addressed them.

Finally, the assignment of each farm to a specific FSA category (Table A4) was the result of a combination of economic size (<2 000 EUR, small, medium, large) and specialisation (P1, P2, P3, P4, mixed), which ultimately produced 20 archetypes. As such, the format of archetype analysis represented here is that of the "typology of cases" where each case of a phenomenon (here a farm) is assigned into exactly one archetype with the aim to identify recurrent patterns and provide their "thick description" (spatial and quantitative insights into qualitative narrative) across large numbers of cases (*sensu* Oberlack et al. 2019, Sietz et al. 2019).

2.3 Agri-environment practices

We quantified the association (i.e. spatial overlap) of identified FSAs with agri-environment practices to examine whether different types of farms can help explain the patterns of AEP adoption (Fig. 1). Each member state (or even federal state in the case of Germany) designs its own list of measures available to farmers. Their categorisation and local names differ between case studies, making comparisons challenging. Therefore, we reviewed the conditions of the local measures, including Agri-Environment-Climate Measures and Ecological Focus Areas, as well as organic farming, which belongs under a separate category of agricultural subsidies in the case of Mulde and South Moravia. We selected those AEPs that were common and comparable across all case studies, grouping them according to their description into seven consistent categories: cover crops, fallow land, organic farming, grassland maintenance, vegetation buffers, conversion to grassland and conversion to forest (see Tables A6 for details on the AEP groups). There were a few types of measures within the national portfolios that were too specific or unique that they could not have been assigned to one of the seven considered AEPs. For example, "protection of Northern Lapwing" in Czechia, "strip seeding/direct seeding" in Germany, or "skylark plots" in the UK. However, these were either not present in the case study (e.g. in the case of South Moravia), or they covered only a marginal area (e.g. 93 ha of strip seeding in Mulde), thus, they were assumed to have negligible effect on our findings.

For every farm in our case studies, we extracted the area (ha) of all field parcels that the farm manages and the presence or absence of each of the seven AEP categories. For all FSAs, we then calculated the relative number (percentage) of farms and the area of their fields with a given AEP implemented. Conversely, for all seven AEPs, we calculated the relative number (percentage) of farms that adopted the given AEP and the respective area of fields with that AEP per each FSA. To analyse the rate of adoption (overall uptake), we calculated what percentage of farms and their respective field area are present with at least one AEP, relative to the total number of farms in the case study and the total area of agricultural land. Similarly, we performed the same procedure for all seven AEPs regardless of their FSA. All analyses were conducted in R version 4.0.2 (R Core Team 2020), Python 3 (Van Rossum and Drake 2009) and ArcGIS 10.2 (ESRI). An overview of the data processing steps is given in Tables A1-A7.

3. Results

3.1 Distribution of farming system archetypes

Combining economic size and specialisation, the Mulde, South Moravia and Humber case studies show distinct spatial patterns of FSAs (Fig. 2). With 85% of land area in Humber, 77% in South Moravia, and 56% in Mulde, economically large farms with general cropping (P1) dominate the agricultural land in our case studies (Fig. 3). The second most widespread specialisation is mixed farming, also practised mostly by economically large farms, covering

31% of land in the Mulde and around 9% and 6% in South Moravia and Humber, respectively. Regardless of the case study, the remaining FSAs cover less than 10% of the total agricultural area, with horticulture (P2) absent in Humber or covering less than 1% of land in Mulde and South Moravia.

In terms of the number of farms, however, economically large farms with general cropping (P1) do not dominate the distribution pattern (Fig. 3). Although economically large P1 farms remain the prevalent farm type in Humber, accounting for 56% of farms, and represent a significant portion of farms in Mulde (20%) and South Moravia (13%), grazing livestock farms (P4) of small and <2 000 EUR economic sizes are the most frequent FSAs in the latter two case studies. This underscores the relationship between a farm's economic size and the extent of its cultivated area across all case studies. Furthermore, it translates into small farms being more evenly engaged in the remaining specialisations. Specifically, the proportions of farms engaged in livestock grazing (P4), as opposed to area proportions, are higher by ~20 to 25% in Humber, ~40 to 50% in Mulde, and by 10 to ~25% in South Moravia. The permanent crop production (P3; mostly orchards and vineyards) in Humber and Mulde is very low (<1% of farms) but ~30% of farms (of varying economic size) in South Moravia are dedicated to this specialisation. This is in contrast with the area proportions (3%), which implies that farms focusing on vineyards and orchards are limited in land area. Similar to the area proportions, the number of farms with horticulture (P2) is negligible in all case studies (<1%).

3.2 Adoption of agri-environment practices

The spatial association of identified FSAs and adopted practices shows marked differences in adoption rates between case studies (Tables A8), with 64%, 52% and 43% of farms implementing at least one AEP in Mulde, South Moravia and Humber, respectively. Yet, the FSA typology effectively discerned distinct patterns of AEP adoption that are similar across all case studies (Fig. 4 and A1). For example, economically large general cropping (P1) farms in Humber adopt predominantly vegetation buffers (43% of farms) and fallow land (41% of farms), while comparable farms in South Moravia and Mulde adopt a wider range of AEPs, encompassing cover crops (40 and 29%), fallow land (12 and 26%), organic production (16 and 2%), grassland maintenance (17 and 12%) and vegetation buffers (10 and 29% of farms in South Moravia and Mulde, respectively) (Fig. 4, right panel). However, a consistent pattern emerges across all three case studies, indicating that cover crops, fallow land and vegetation buffers are predominantly embraced by general cropping (P1) and mixed farms, especially in the large economic size category (Fig. 4, left panel). Conversely, the adoption of organic farming and grassland maintenance occurs across a wider range of farm specialisations but they are more prevalent among medium and small farms, and in the case of South Moravia also in grazing livestock (P4) farms with economic size <2 000 EUR.

There is also a clear trend in terms of economic size, revealing that larger farms in all case studies adopt AEPs more frequently (Tables A9–10). Large farms also have the tendency to adopt a wider range of AEPs (Fig. 4, right panel; Table A11), with a mean number of adopted AEPs being 1.78, 1.11 and 0.73 for Mulde, South Moravia and Humber, respectively. In contrast, economically smaller farms adopt AES less frequently (Tables A9–10) and are more likely to adopt only a few types of AEPs (Table A11), with a mean number of adopted AEPs being 0.62, 0.68 and 0.04 for small farms and 0.54, 0.38 and 0.05 for <2 000 EUR farms in Mulde, South Moravia and Humber, respectively. Small and <2 000 EUR farms, which often focus on grazing livestock (P4), typically prefer grassland maintenance in all case studies, ranging from 83% of farms in Mulde to 68% in South Moravia and 46% in Humber. Simultaneously, these FSAs implement organic farming in both Mulde and South Moravia (11 and 30% of farms, respectively), while in Humber, they focus on fallow land (26%) or conversion to forest (22%). Permanent crop farms (P3) are an exception in the AEP adoption trends, as they tend to adopt a limited assortment of AEPs across all economic sizes in the case of Mulde, or prioritise mostly organic farming in the case of South Moravia.

3.3 Non-adoption of agri-environment practices

We also quantified the relative number of farms and land area with no uptake of agri-environment practices (Figs. 5–6; Tables A8–A10). Combining all specialisations, there is a clear trend of small and <2 000 EUR farms accounting for around 70% of all farms across the case studies with no AEP uptake (Fig. 5). In terms of specialisation, non-adopting farms in Mulde and Humber are mostly grazing livestock farms (P4; both ~60%), unlike in South Moravia where non-adopting farms are mostly those focused on general cropping (P1; 30%) and permanent crops (P3; 30%) (Fig. 5). Considering the relative agricultural area where no AEP is implemented, general cropping (P1) and grazing livestock (P4) farming are the dominant farm specialisation in all three case studies representing ca 70–80% of all land (Fig. 5), with South Moravia having the largest proportion of non-adoption concentrated in farms of a single FSA (P1 large, 55% of all fields with no AEP).

While non-adopters represent 36%, 48% and 58% of all farms in Mulde, South Moravia and Humber, respectively (Table A8), AEPs are applied on average on only 1.3–5.6% of agricultural land across all case studies (Fig. 6). The area-related data indicate similar patterns across AEPs except for organic farming and grassland maintenance that, in the case of South Moravia and Humber, cover a larger farm area. The least common practices are conversion to grassland and conversion to forest, which are implemented by less than 1% of farms in Mulde and Humber. Conversion to forest does not exist as an agricultural measure in South Moravia, while only 3% of farms implement conversion to grassland, fallow land, or vegetation buffers.

4. Discussion

Our results indicate that farming system archetypes, based on two principal dimensions of farming systems (i.e. farm specialisation and economic size) derived from IACS data, can be used to infer key patterns of AEP adoption, thus providing relevant information to policy-makers for developing more tailored agri-environment policies. Since we built our typology with empirically derived data on farm characteristics and assessed its usefulness with real records of AEP uptake, we adhered to the principles of empirical validity, which ranks high amongst the diverse forms of validation in archetype analysis (Eisenack et al. 2019, Piemontese et al. 2022). The fact that certain AEP categories correlated with the expected FSAs (e.g. cover crops with general cropping systems, or grassland maintenance with grazing livestock farms) is also an example of the general validity of our approach.

As opposed to previous farming system approaches that relied on non-spatial survey data (e.g. Graskemper et al. 2021, Ribeiro et al. 2016) or gridded biophysical data (e.g. Beckmann et al. 2022, Goodwin et al. 2022, van der Zanden et al. 2016), we used spatially explicit, high-resolution (i.e. field- and farm-level) parameters that are relevant for agri-environment policies. While only a two-dimensional classification appears limiting to capturing real-world complexity, a total of twenty FSAs can effectively describe archetypal aspects of farming systems while being understandable and usable by policy-makers. We also argue that policy-making at the farm level ought to be based on simple and robust rather than complex and noisy data (Benton 2007). As these two dimensions are being collected as part of the FADN records at the level of FADN survey regions in the entire EU (although without the information on spatial locations of the surveyed farms), this allows potential upscaling of our approach and calculating the frequencies of FSAs in the NUTS or FADN regions based on the sample farms recorded in the database. Extrapolating our typology would improve economic and structural understanding of European farming systems, facilitate decision-making at large geographical and administrative scales, and bridge the gap between researchers and policy-makers (Evans et al. 2017, Oberlack et al. 2023).

Aside from the evident benefits, the applicability of FSAs by policy-makers is associated with limitations. Farm specialisation, affecting the compatibility of measures with established farm practices, and economic parameters, including income stability and long-term certainty about land management, have been found to strongly correlate with AEP uptake (Lastra-Bravo et al. 2015, Paulus et al. 2022, Bartkowski et al. 2023). However, our typology does not consider potentially important social parameters, such as personal views, behavioural attitudes or community-oriented factors, e.g. peer pressure (Lastra-Bravo et al. 2015, Cullen et al. 2020, Brown et al. 2021, Leonhardt et al. 2022). Similarly, the local-scale environmental context (e.g. soil quality or landscape structure) can also affect the action space in which farmers operate (Alarcón-Segura et al. 2023, Wittstock et al. 2022). Therefore, a simplified, although robust, typology with emphasis on a few farm descriptors cannot fully explain the complexity of AEP adoption and placement.

Although the IACS/LPIS data proved crucial for delineating FSAs at a spatial resolution not attainable through conventional agricultural statistics or resource-intensive farm surveys, their use presented substantial challenges. Obtaining the data from regional or national authorities was difficult due to confidentiality issues and restrictions on sharing. Inconsistencies existed among case studies in terms of available variables and data structures. Crucially, because the IACS data are collected directly from CAP beneficiaries, their reliability and accuracy may vary. The database also lacks certain vital information, e.g. on land tenure and ownership, which could further enhance the analysis of FSAs. While in our case studies, all farms were recipients of some form of agricultural regulation or subsidy (e.g. the basic payment, CAP Pillar 1) and thus had records in the IACS/LPIS database, there are likely marginal regions in the EU not covered by the data, where agriculture operates independently from CAP support.

Nonetheless, the identified FSAs were able to capture the different patterns of AEP adoption by different types of farms in three European case studies and, thus, provided insights into the potential reasons behind the patterns of AEP adoption (Figs. 2–6). The dominant adoption of AEPs, especially cover crops, fallow land and vegetation buffers, by economically large farms with general cropping (Tables A9–A10) is likely due to their higher financial turnover and availability of suitable field parcels (Pavlis et al. 2016). Indeed, economically large farms with higher profits and larger administrative capacity exhibit greater adoption of AEPs (Wynn et al. 2001, Mettepenningen et al. 2013), though its rate remains target- (e.g., biodiversity conservation; Gailhard and Bojnec 2015), and production-specific (Sattler and Nagel 2010). Although it could be expected that large agri-businesses focused on high-intensity management and for-profit crop production may less likely engage in agri-environment programmes, previous studies have shown that greater profit margins, sufficient administrative capacity and a larger area of managed land allow higher AEP uptake in these types of farms, while AEPs are perceived as a form of income diversification (Bartkowski et al. 2023, Paulus et al. 2022).

The extent to which AEPs are adopted by economically large farms also varies between regions (Mann 2005, Defrancesco et al. 2008), which appears relevant for our case studies that experienced different political histories. The predominance of fallow in Humber, applied on 55% of the field parcels where farms practise general cropping (Fig. A1), is likely related to the tradition of crop rotation in Great Britain, with the aim of restoring soil fertility and preventing pest outbreaks (Angus et al. 2009). In South Moravia and Mulde, the tendency of economically large, general cropping (P1) farms to adopt cover crops and vegetation buffers may be a consequence of the past negative experience with the industrial model of agricultural production

397 on large field blocks in the socialist period (Zagata et al. 2020). However, it may also stem from
398 factors associated with established routines, indicating that farmers are prone to selecting
399 measures that can be integrated into their farm operations without much additional effort
400 (Wittstock et al. 2022). In addition, this trend is partly explained by the fact that certain types
401 of cover crops and vegetation buffers in Germany and Czechia are implemented as part of
402 Ecological Focus Areas, which are compulsory for farms over 15 ha on at least 5% of their
403 arable land (Alarcón-Segura et al. 2023). Attributing the adoption of specific AES to a particular
404 factor, however, is difficult and requires a better understanding of the political, historical and
405 social background, which is beyond the scope of our study.

406 Our results also show that economically smaller farms exhibit lower adoption rates and
407 are more likely to adopt a narrower range of AEPs than economically larger farms. For instance,
408 medium and small farms with permanent crops and grazing livestock predominantly implement
409 grassland maintenance and, in the case of South Moravia and Mulde, organic farming (Figs. 4,
410 A1). However, compared to farms with general cropping (as discussed earlier), grassland farms
411 across all categories of economic sizes generally exhibit higher adoption rates (Tables A9–A10)
412 as shown also in other studies (Wilson and Hart 2000, Paulus et al. 2022). This tendency is
413 attributed to their location in less crop-favourable and thereby less profitable conditions, often
414 at higher elevations with lower temperatures and more rainfall (southern part of Mulde and
415 eastern part of South Moravia). Their lower incomes from agricultural production could be
416 compensated by, e.g., result-based payments (Bartkowski et al. 2021), likely increasing
417 competition with economically larger farms, for which production profits highly outweigh the
418 AEP payments. Combined with the absence of agrochemicals in organic farming, higher
419 financial turnover for small and medium farms would not only stabilise soil parameters but also
420 strengthen local markets (Jouzi et al. 2017). However, the road to enhancing landscape
421 sustainability and bolstering ecosystem resilience appears to be less assured in regions where

AEP diversity is limited (Boetzl et al. 2021, Ortiz et al. 2021, Winqvist et al. 2011), such as in the Humber (Figs. 4, A1), where grazing livestock (P4) farms show negligible adoption of organic farming, focusing mostly on grassland maintenance and fallows.

Another notable trend that emerged from our analysis is that economically small farms and farms with an economic value <2 000 EUR across most farm specialisations are the ones that are the most unlikely to engage in any AEP (Figs. 4, 5; Tables A9–A10). Apart from the lack of administrative capacity (Wittstock et al. 2022, Bartkowski et al. 2023), some possible explanations may be the absence of suitable land parcels (Pavlis et al. 2016) and insufficient outreach by policy-makers towards small farms to adopt agri-environment measures (Coyne et al. 2021). The availability of advisory services, combined with low bureaucratic burdens, proved highly relevant to increasing AES adoption (Massfeller et al. 2022). In northern England, where the Humber case study is located, improving communication and engagement motivated small dairy farmers to participate in agri-environment schemes designed by private producers, leading to additional profits and improved ecosystem services (Coyne et al. 2021). Since the effectiveness of these strategies appears promising (Reed et al. 2014), we argue that developing tailored agri-environment policies and strengthening the cooperation between farmers, private producers and public agencies would likely increase AEP adoption and generate economic momentum.

As exemplified in three case study regions in Europe, our typology presents a specific example of a simple farming system approach, as called for by Ribeiro et al. (2016) or Santos et al. (2021), which can be understood by decision-makers, adopted for different regional or national contexts based on FADN or CAP payments data, and has implications for all stages of the policy process (Huber et al. 2024). With respect to policy formulation, FSAs help account for the heterogeneity of farm structures, allowing decision-makers to consider diversity in policy responses, while acknowledging that it is unrealistic to tailor incentives to individual farms. FSAs also support policy implementation by identifying target groups to which policy instruments can be tailored or opportunities to apply existing policies in targeted ways. Finally, FSAs can strengthen policy evaluation by enhancing our understanding of whether a policy instrument achieved a certain goal, or how interventions can be disseminated in regions with different farm structures (Huber et al. 2024). As such, FSAs could be applied to policy design not only within Pillar II (Rural Development) but also Pillar I of the future CAP (e.g. the forthcoming Eco-schemes) as a cost-effective compromise between highly targeted agri-environment measures and broad-brush horizontal policies (Santos et al. 2021). Specific examples of FSA application include their use as eligibility criteria for certain types of schemes, design of differentiated AEP contracts based on FSA dimensions (with respect to contract length, payment levels, conditions, etc.), or targeted information dissemination via advisory services and informational nudges (Wallander et al. 2023). They all represent opportunities to stimulate AEP uptake and ultimately improve ecosystem services provided by agricultural landscapes.

5. Conclusions

Based on farm-level attributes of working farms derived from field-level data, we developed a new typology of farming systems and examined the relationships between farming system archetypes and the adoption of agri-environmental practices in three agricultural regions in Europe. By this approach, we (1) illustrated the credibility of FSAs as a cost-effective instrument to define farming contexts in which the implementation of agri-environment practices occurs, and (2) tested whether the division of farms into groups with similar structural characteristics is a viable criterion for understanding the uptake agri-environment policies in Europe. The FSA typology demonstrated its capability to discern distinct patterns of AEP adoption, supporting the arguments that agri-environment policies could be planned based on simple farm-level eligibility criteria (Ribeiro et al. 2016). In order to adapt existing agri-environment strategies to a more sustainable future, FSAs should be extrapolated to a European scale, while decision-makers should better target small farms that are less likely to adopt agri-environment measures. This could be achieved by reducing administrative burdens for small farms and improving targeted communication towards them. Future research should attempt to test whether the common knowledge base built on the FSA typology can in practice make a substantial impact on the effectiveness of policy formulation, implementation and evaluation.

Conflict of interests

The authors declare no conflict of interests.

Data availability

Input data from 'IACS/LPIS' databases are available upon request from the Ministry of Agriculture of the Czech Republic, Saxon State Ministry for Energy, Climate Protection, Environment and Agriculture (Germany), and Rural Payments Agency (UK). The processed data are available from the corresponding author upon reasoned request.

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Figures and tables

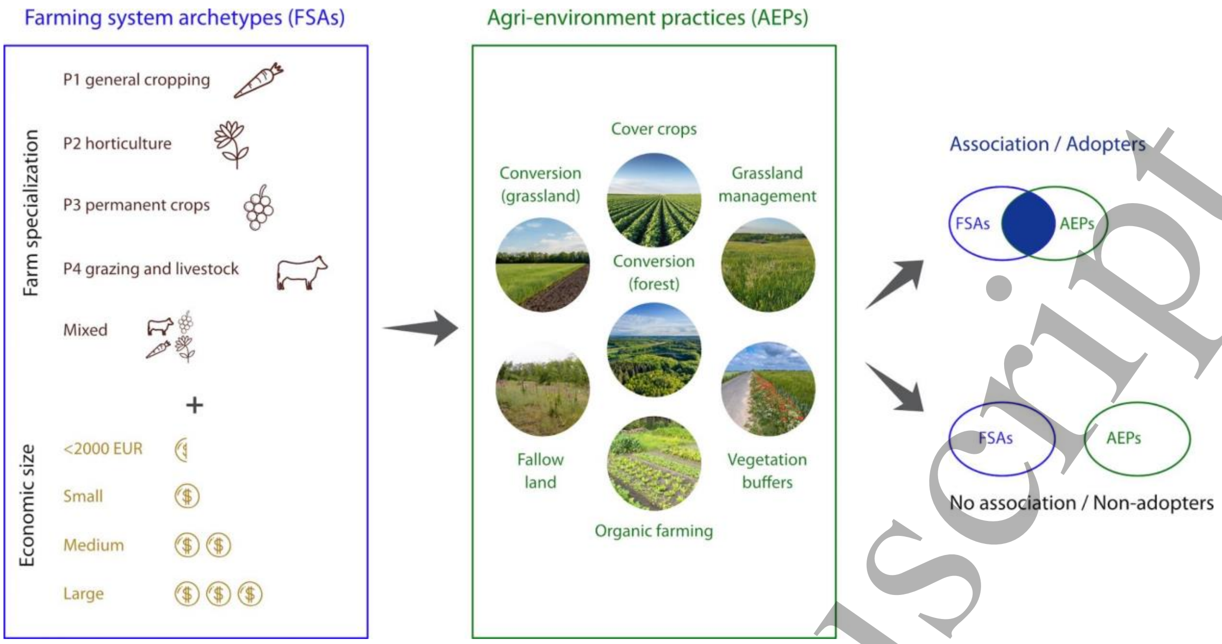

Figure 1. Study design. Conceptual approach and data included in the development of farming system archetypes and subsequent spatial overlap with agri-environment practices.

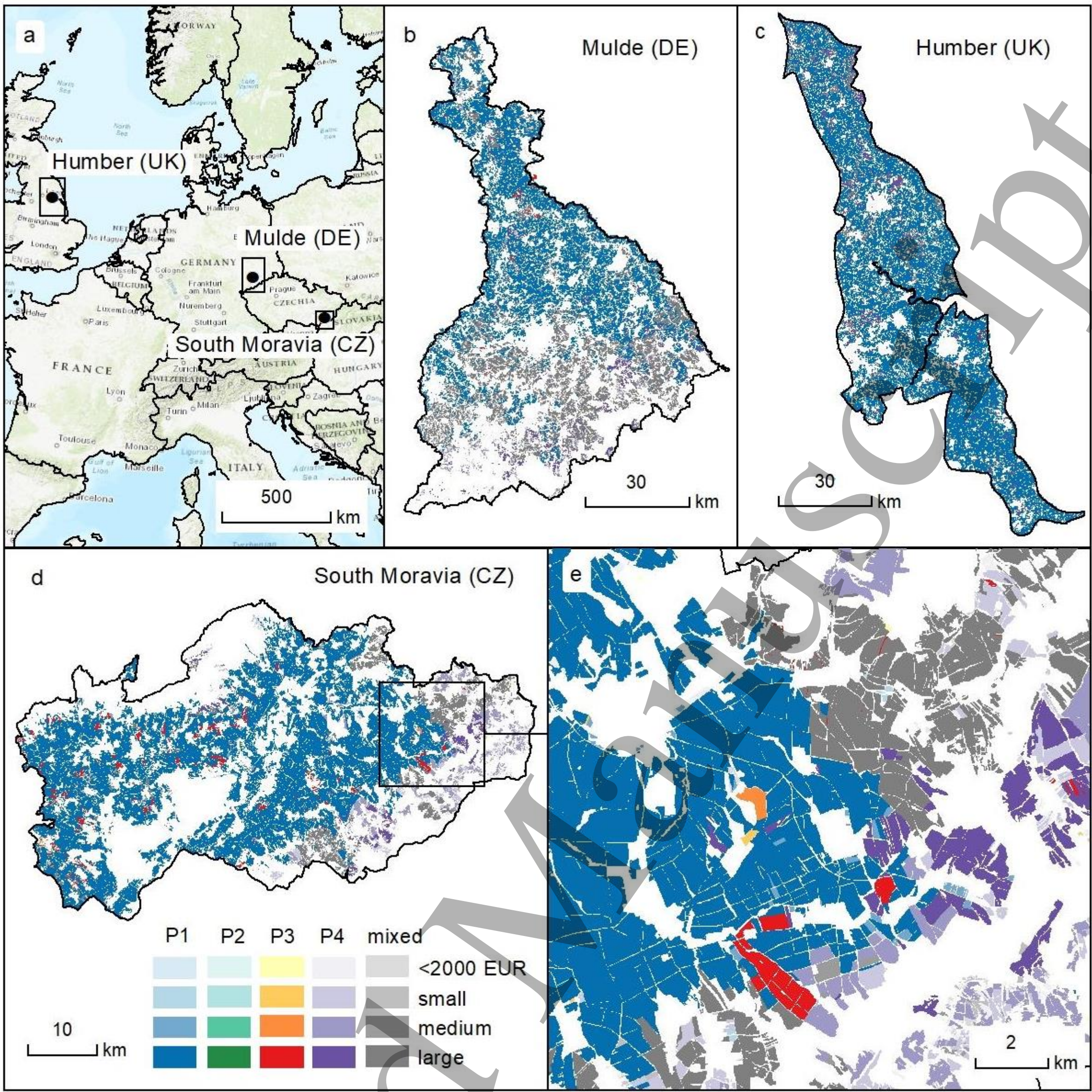

Figure 2. Distribution of farming system archetypes. (a) Location of case study regions in Europe: Mulde in Germany (b), Humber in the United Kingdom (c), and South Moravia in the Czech Republic (d) with map inset to see an example of the field-level data (e). Colour indicates farm specialisation and tone indicates economic size.

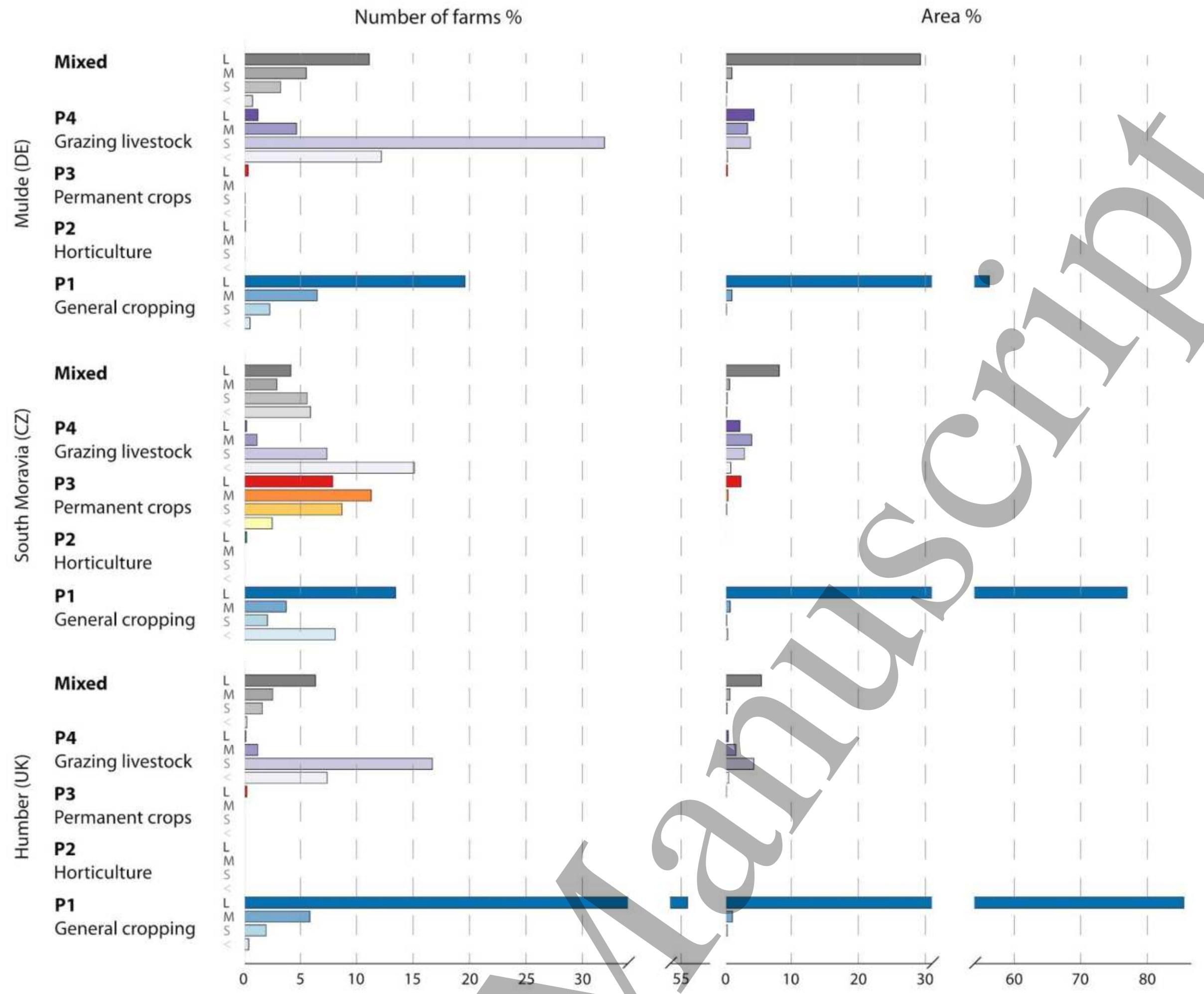

Figure 3. Statistical description of farming system archetypes. Relative number (left) and area (right) of farms by farming system archetypes (rows) for the Mulde, South Moravia and Humber case studies (top, middle and bottom). Total number of farms for Mulde: n=3162, South Moravia: n=1103 and Humber: n=3527. Abbreviations: < = less than 2 000 EUR, S = small, M = medium, and L = large farms.

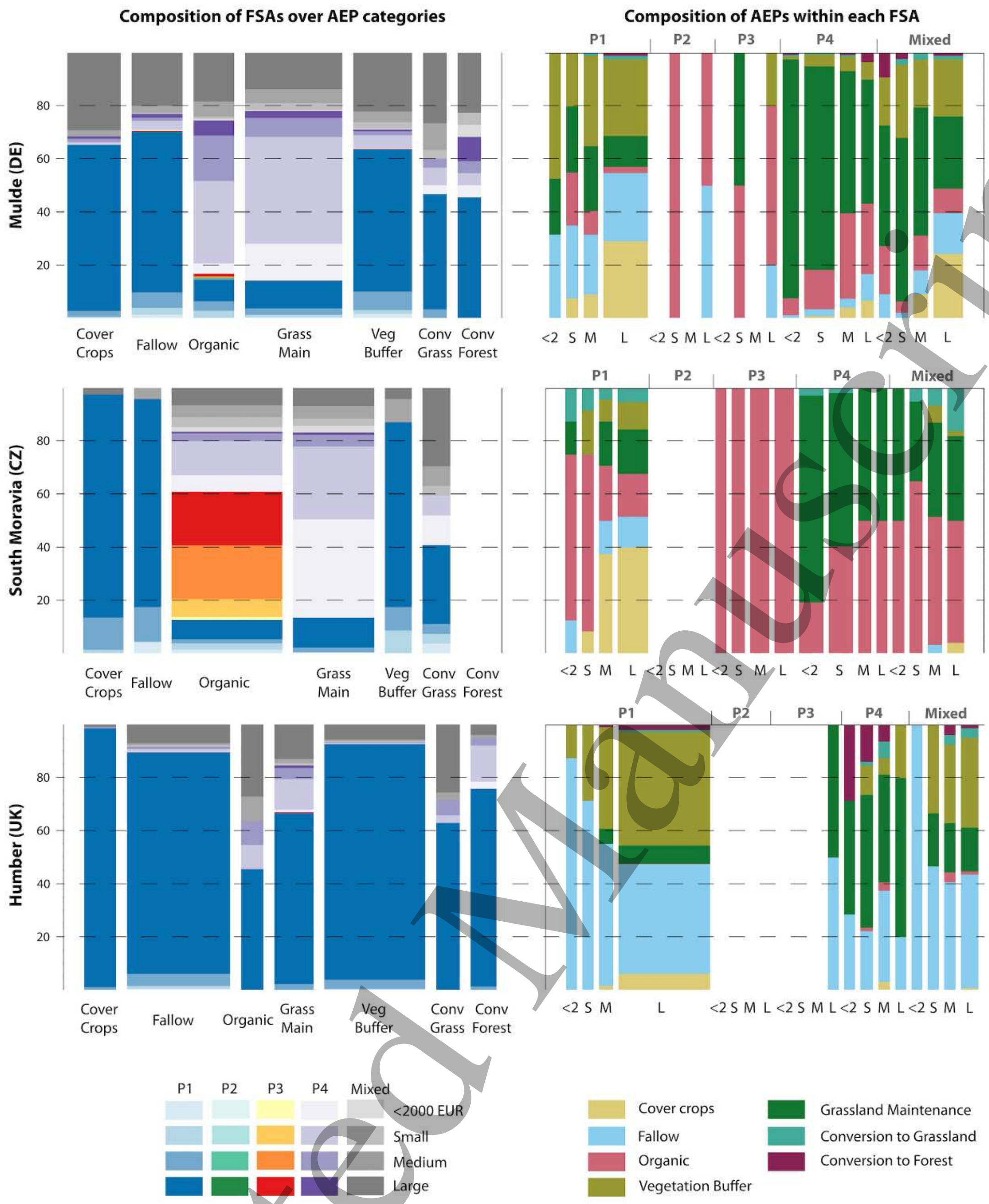

Figure 4. Farming system archetypes vs. agri-environment practices. The association between farming system archetypes (expressed in % of the total number of farms within each category) and the adoption of agri-environment practices in the Mulde (top panel), South Moravia (middle panel) and Humber (bottom panel) case studies. Above a fixed, minimum width, the bar width is proportional to the percentage of the total number of farms in a given case study. Note that there is no 'Conversion to Forest' AEP identified in South Moravia. Abbreviations: <2 = less than 2 000 EUR, S = small, M = medium, and L = large farms.

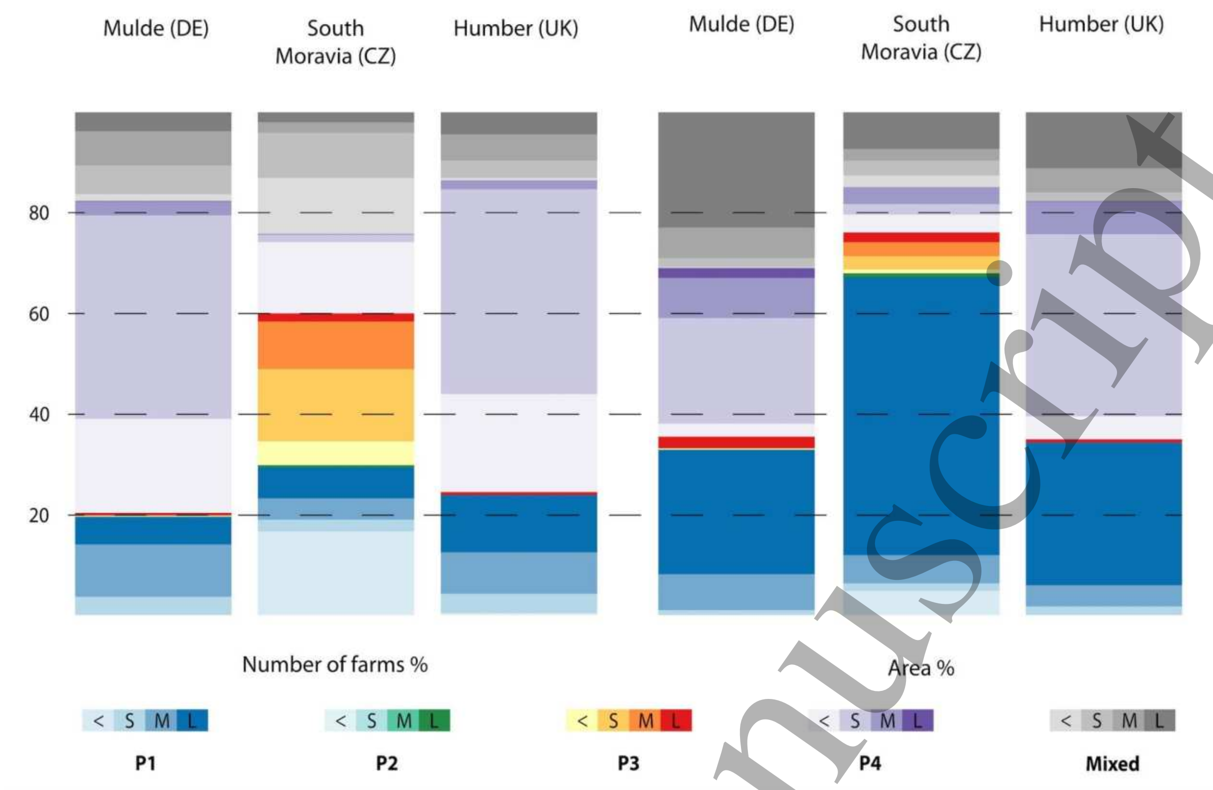

Figure 5. Non-adoption of agri-environment practices. Relative composition of farming system archetypes (vertical axis) for farms that do not engage in any considered agri-environment practices: relative number of farms (left) and relative area coverage (right). For full adoption/non-adoption rates per farming system and case study, please see Tables A8–A10. Abbreviations: < = less than 2 000 EUR, S = small, M = medium, and L = large farms.

696 

697 **Figure 6. Overall uptake of agri-environment practices.** Relative number of farms (% of the
698 total number of farms) and their respective farm area with adoption or no adoption of a particular
699 agri-environment practice. Note that there is no 'Conversion to Forest' AEP identified in South
700 Moravia, represented here as full non-adoption.
701

Appendices

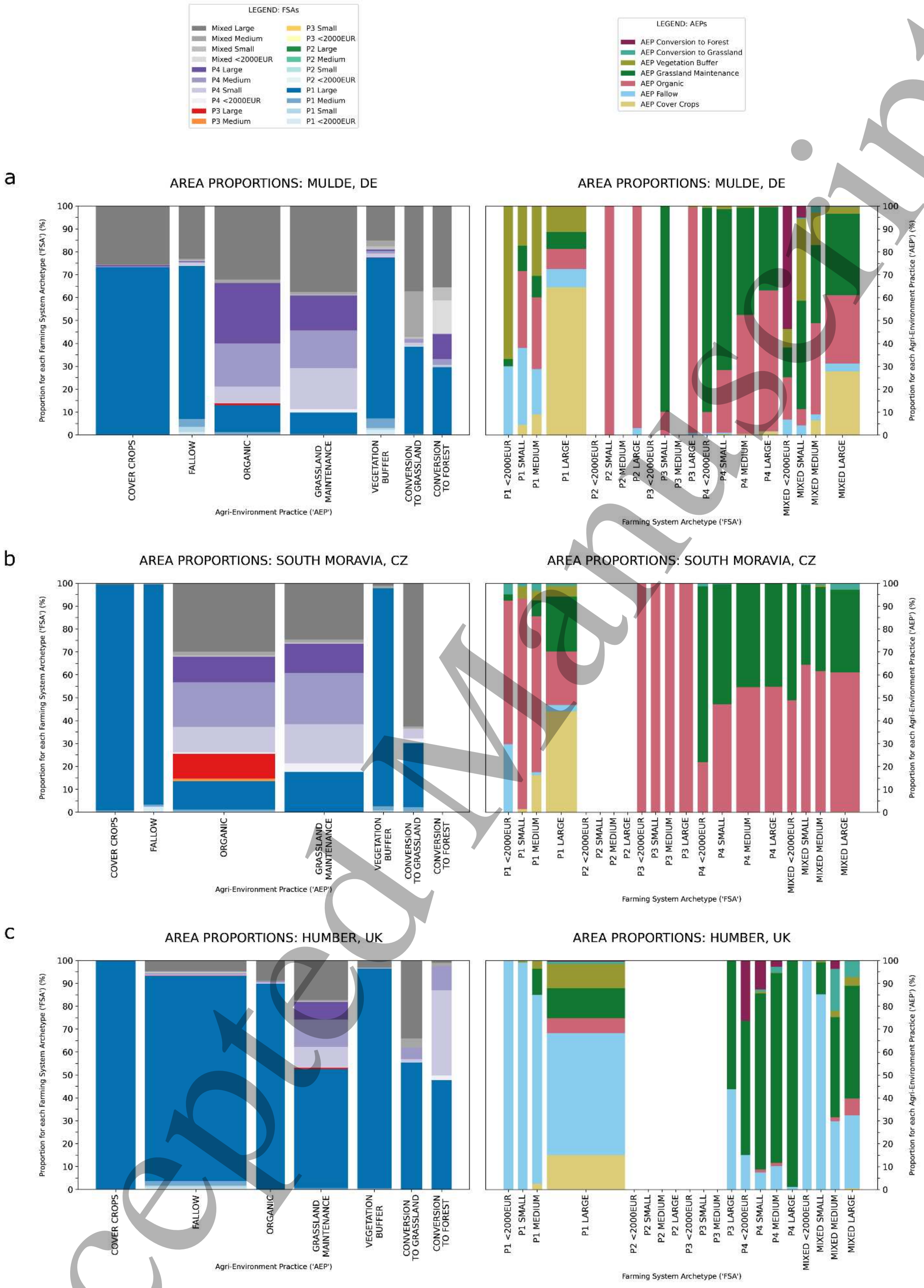

Figure A1. Farming system archetypes vs. agri-environment practices. The association between farming system archetypes (expressed in relative area coverage) and the adoption of agri-environment practices in the Mulde (a,d), South Moravia (b,e) and Humber (c,f) case studies. Above a fixed, minimum width, the bar width is proportional to the percentage of the total sample in a given case study. Note that there is no ‘Conversion to Forest’ AEP identified in South Moravia.

Table A1. The association between the four farm specialisations, the original TF8 categories, and the crop types defined by the Farm Accountancy Data Network (FADN). The category TF7 (granivores, pigs and poultry) was not used in our farm specialisation because it was either not represented in the case study or the information was not part of the IACS records.

Farm specialisation	TF8 category	Consists of (FADN code)	Consists of (FADN description)
General cropping (P1)	Fieldcrops (TF1)	P15	cereals
		2.01.02.	dried pulses and protein crops
		2.01.03.	potatoes
		2.01.04.	sugar beet
		2.01.06.02.	hops
		P16	oilseeds
		2.01.06.09.	flax
		2.01.06.10.	hemp
		2.01.06.11.	other fibre crops
		2.01.06.12.	aromatic plants, medicinal and culinary plants
		2.01.06.99.	other industrial crops not mentioned elsewhere
		2.01.07.01.01	fresh vegetables, melons, strawberries — outdoor or under low (not accessible) protective cover — open field
		C1 2.01.10.	arable land seed and seedlings

		2.01.11.	other arable land crops
		2.01.12.	fallow land
		FCP1	forage for sale
Horticulture (P2)	Horticulture (TF2)	2.01.07.01.02.	fresh vegetables, melons, strawberries — outdoor or under low (not accessible) protective cover — market gardening
		2.01.07.02.	fresh vegetables, melons, strawberries — under glass or other (accessible) protective cover
		2.01.08.01	flowers and ornamental plants — outdoor or under low (not accessible) protective cover
		2.01.08.02.	flowers and ornamental plants — under glass or other (accessible) protective cover
		2.06.01.	mushrooms
		2.04.05.	nurseries
Permanent crops (P3)	Wine (TF3) + Other permanent crops (TF4)	2.04.01.	fruit and berry plantations
		2.04.04.	vineyards
		2.04.06.	other permanent crops
		2.04.07.	permanent crops under glass
Grazing livestock and forage (P4)	Milk (TF5) + other grazing livestock (TF6)	GL	grazing livestock
		FCP4	forage for grazing livestock
Mixed	Mixed (TF8)	combination	combination

Table A2. Monetary thresholds for the ES6 classes that define the economic farm size.

ES6 class	Lower bound (EUR)	Upper bound (EUR)
1	2 000	<8 000
2	8 000	<25 000
3	25 000	<50 000

4	50 000	<100 000
5	100 000	<500 000
6	500 000	

Table A3. Assignment of the ES6 classes to economic farm size.

Farm specialisation	ES6 classes included (S = small, M = medium, L = large) Percentage of farms assigned to farm size (per farm specialisation)		
General cropping (P1)	S = 1 23.6	M = 2 35.6	L = 3-6 40.7
Horticulture (P2)	S = 1-2 32.9	M = 3-4 35.8	L = 5-6 31.4
Permanent crops (P3)	S = 1 15.3	M = 2 48.2	L = 3-6 36.5
Grazing livestock and forage (P4)	S = 1-2 43.3	M = 3-4 33.8	L = 5-6 22.9
Mixed	S = 1 35.2	M = 2 28.6	L = 3-6 36.3

Table A4. Definition of the FSA using farm specialisation and economic farm size.

FSA	General cropping P1	Horticulture P2	Permanent crops P3	Grazing livestock and forage P4	Mixed
<2 000 EUR	P1 <2 000	P2 <2 000	P3 <2 000	P4 <2 000	Mixed <2 000
Small	P1 small	P2 small	P3 small	P4 small	Mixed small
Medium	P1 medium	P2 medium	P3 medium	P4 medium	Mixed medium
Large	P1 large	P2 large	P3 large	P4 large	Mixed large

Table A5. The proportion of each farm specialisation category (rows) covered by individual field specialisations (columns).

Farm specialisation	P1			P2			P3			P4		
Mulde (DE)	min	median	max	min	median	max	min	median	max	min	median	max
P1	66.8	88.8	100.0	0.1	1.2	20.4	0.0	1.2	26.4	0.1	14.9	33.2
P2	2.5	5.6	8.6	66.7	81.6	89.7	0.0	0.0	0.0	7.0	10.3	33.3
P3	1.8	3.0	12.8	5.4	7.5	14.0	76.8	91.9	100.0	1.8	9.1	23.2
P4	0.1	15.7	33.1	0.0	1.0	28.2	1.0	9.3	21.2	66.9	100.0	100.0

mixed	12.0	51.0	66.7	0.1	8.3	56.9	0.5	34.5	64.7	0.2	48.1	66.6
South Moravia (CZ)												
P1	67.3	99.3	100.0	0.0	0.0	0.7	0.0	0.0	32.7	0.0	0.0	30.2
P2	0.0	1.9	3.5	95.3	98.1	100.0	0.0	0.0	1.2	0.0	0.0	0.0
P3	0.0	0.0	32.5	0.0	0.0	0.0	67.5	100.0	100.0	0.0	0.0	28.2
P4	0.0	0.0	32.8	0.0	0.0	0.0	0.0	0.0	31.0	67.2	96.6	100.0
mixed	0.0	39.1	66.4	0.0	0.0	45.6	0.0	37.9	66.7	0.0	38.5	66.7
Humber (UK)												
P1	66.0	95.9	100.0	0.0	0.0	10.4	0.0	0.0	31.4	0.0	3.9	34.0
P2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P3	0.0	0.0	33.3	0.0	0.0	0.0	66.7	91.5	100.0	0.0	1.4	25.8
P4	0.0	0.0	34.0	0.0	0.0	4.7	0.0	0.0	25.0	66.0	100.0	100.0
mixed	0.0	52.5	65.9	0.0	0.0	45.4	0.0	0.0	62.9	0.0	46.5	66.0

Table A6. Attribution of region-specific schemes to AEP groups. The names represent the original AEP titles from the IACS/LPIS database.

1. Cover crops	
Objective: reduce soil erosion and nitrogen leaching, improve physical soil characteristics and soil biology, increase soil organic carbon	
DE	• AL4 (Anbau von Zwischenfrüchten - catch/cover crops) • EFA Nr. 52 ('Zwischenfrucht / Gründecke')
CZ	• EFA VYM_OP_PP_MPL ('Catch crop')
UK	• SW6 ('Winter cover crops') • EFA CA01 ('Catch crop') • EFA CA02 ('Cover crop')
2. Fallow	
Objective: create semi-natural habitats, restore soil nutrients, improve pollination and biological pest control	
DE	• AL5a ('Selbstbegrünte einjährige Brache') • AL5b ('Selbstbegrünte mehrjährige Brache') • GL3 ('Bracheflächen und Brachestreifen im Grünland') • EFA Nr. 62 ('Brachen ohne Erzeugung')
CZ	• EFA VYM_OP_PP_UHOZ ('Fallow with vegetation cover')
UK	• GS1 ('Take small areas out of management') • EFA FA01 ('Land lying fallow')

3. Organic/integrated production	
Objective: maintain semi-natural habitats, reduce agrochemical use/pollution, improve physical soil characteristics and soil biology, mitigate climate change	
DE	• OEBL
CZ	• VYM_OP_EZ_EZ ('Organic farming') • VYM_OP_AEKO_IPO ('Integrated fruit production') • VYM_OP_AEKO_IPV (same as VYM_OP_AEKO_NOV) ('Integrated grapevine production') • VYM_OP_AEKO_ZOV ('Basic vineyard protection') • VYM_OP_AEKO_IPV (same as VYM_OP_AEKO_NOV) ('Additional vineyard protection')
UK	• OT1 ('Organic land management - improved permanent grassland') • OT2 ('Organic land management - unimproved permanent grassland') • OT3 ('Organic land management - rotational land') • OT5 ('Organic land management - top fruit') • OR1 ('Organic conversion – improved permanent grassland') • OR2 ('Organic conversion – unimproved permanent grassland') • OR3 ('Organic conversion – rotational land') • OR5 ('Organic conversion - top fruit')
4. Grassland maintenance	
Objective: conserve grassland species, create habitats, reduce nitrogen loads	
DE	• GL1(a-c) ('Artenreiches Grünland Ergebnisorientierte Honorierung') • GL2(a-h) ('Biotoppflegemahd mit Erschwernis') • GL4(a-b) ('Naturschutzgerechte Hütehaltung und Beweidung') • GL5(a-e) ('Spezielle artenschutzgerechte Grünlandnutzung')
CZ	• VYM_OP_AEKO_ZAKL ('General extensive meadow and pasture maintenance'), VYM_OP_AEKO_MVLH ('Mesophilic and hygrophilic meadows fertilized'), VYM_OP_AEKO_MVLN ('Mesophilic and hygrophilic meadows non-fertilized'), VYM_OP_AEKO_HSLH ('Mountain and arid meadows fertilized') • VYM_OP_AEKO_HSLN ('Mountain and arid meadows non-fertilized') • VYM_OP_AEKO_PODM ('Permanently wet and peat meadows'), VYM_OP_AEKO_MODR ('Protection of Lycaenidae butterflies') • VYM_OP_AEKO_CHRAS ('Corn crake protection') • VYM_OP_AEKO_SSTAV ('Dry steppe meadows and heaths') • VYM_OP_AEKO_DBP ('Species-rich pastures')
UK	• GS2 ('Permanent grassland with very low inputs (outside SDAs = severely disadvantaged areas)') • GS5 ('Permanent grassland with very low inputs (in SDAs)') • GS6 ('Management of species-rich grasslands') • GS7 ('Restoration towards species-rich grassland') • GS9 ('Management of wet grassland for breeding waders')
5. Buffer areas/vegetation strips	
Objective: reduce soil erosion and pollutant input into water bodies, create and connect habitats, improve pollination, conserve wildflower species	
DE	• AL1 ('Grünstreifen auf Ackerland') • AL5c ('Mehrjährige Blühflächen') • AL5d ('Einjährige Blühflächen')

	• EFA Nr. 54 (‘Streifen am Waldrand (ohne Produktion)’) • EFA Nr. 56 (‘Pufferstreifen AL’) • EFA Nr. 57 (‘Feldrand / Pufferstreifen GL’) • EFA Nr. 58 (‘Feldrand / Pufferstreifen auf AL’) • EFA Nr. 65 (‘Bienenweide einjährig’) • EFA Nr. 66 (‘Bienenweide mehrjährig’) • EFA Nr. 78 (‘Feldraine CC’)
CZ	• VYM_OP_AEKO_KBP (‘Biobelts - Fodder vegetated strip’) • VYM_OP_AEKO_NBP (‘Biobelts - Pollinators vegetated strips’)
UK	• SW1 (‘4 to 6 metre buffer strip on cultivated land’) • SW2 (‘4 to 6 metre buffer strip on intensive grassland’) • SW3 (‘In-field grass strips’) • SW4 (‘12 to 24 metre watercourse buffer strips on cultivated land’) • SW11 (‘Riparian management strip’) • AB1 (‘Nectar flower mix’), AB3 (‘Beetle banks’) • AB8 (‘Flower rich margins and plots’) • WT2 (‘Buffering in-field ponds and ditches on arable land’) • EFA BF15 (‘A buffer strip of permanent grassland and field margin of temporary grassland or fallow land that you want to use as part of your ecological focus area.’)
6. Land use conversion from arable to grassland	
Objective: restore habitats, reduce soil erosion and nitrogen loads, conserve grassland species, mitigate climate change, improve carbon sequestration	
DE	• K1 (‘Stilllegung von Ackerland für Zwecke der Biotopentwicklung’) • K2 (‘20jährige Ackerstilllegung für Zwecke der Biotopgestaltung und des Umweltschutzes’) N3-AL (‘Langfristige Stilllegung landwirtschaftlicher Nutzfläche zur Biotopentwicklung auf Ackerflächen’) • N3-GL (‘Langfristige Stilllegung landwirtschaftlicher Nutzfläche zur Biotopentwicklung auf Grünland’) • G 10 (‘Umwandlung von Ackerland in Dauergrünland’)
CZ	• Conversion of arable land into grassland… VYM_OP_AEKO_ZBS (‘...using normal seed mixture’) • VYM_OP_AEKO_ZDOS (‘...using species-rich seed mixture’) • VYM_OP_AEKO_ZDRS (‘...using regional seed mixture’) • VYM_OP_AEKO_ZBSV (‘...along water body using normal seed mixture’) • VYM_OP_AEKO_ZDOSV (‘...along water body using species-rich seed mixture’) • VYM_OP_AEKO_ZDRSV (‘...along water body using regional seed mixture’)
UK	• SW7 (‘Arable reversion to grassland with low fertilizer input’)
7. Land use conversion from agriculture to forest	
Objective: restore habitats, reduce soil erosion and nitrogen leaching, mitigate climate change, improve carbon storage and sequestration	
DE	• EVP groß (‘Einkommensverlustprämie groß’) • EVP klein (‘Einkommensverlustprämie klein’) • EFA nr. 61 (‘Aufforstungsflächen’)
CZ	• No agricultural policy identified.
UK	• WGC (‘Woodland Creation Grant’ scheme)

AEPs not considered in the analysis (not assigned to any of the 7 AEP groups above)		
DE	• AL2 ('Streifensaat/Direktsaat') • AL6 ('Naturschutzgerechte Ackerbewirtschaftung') • AL7 ('Überwinternde Stoppel')	93 ha 599 ha 1570 ha
CZ	• VYM_OP_AEKO_IPJ ('Integrated production of vegetables and strawberries') • VYM_OP_AEKO_CCH ('Protection of Northern Lapwing')	no records in case study
UK	• AB4 ('Skylark plots') • AB5 ('Nesting plots for lapwing and stone curlew') • AB6 ('Enhanced overwinter stubble') • AB9 ('Winter bird food') • AB11 ('Cultivated areas for arable plants') • AB15 ('Two year sown legume fallow') • AB16 ('Autumn sown bumblebird mix')	no records in case study

Table A7. Technical notes on methods of FSA classification.

Definition of a Farm in 'IACS/LPIS' data. In the Mulde (DE) and Humber (UK) data, an anonymous farm business ID was supplied which could be used to group each field in these case study regions into a farm. However, in the South Moravia (CZ) data there is no such farm business ID. Accordingly, we had to use information available on the 'user' of each field that is eligible to apply for agricultural subsidies. To our knowledge, all farms in our case studies are recipients of some form of agricultural subsidy (e.g. the basic payment, CAP Pillar 1) and, thus, they have records in the ICAS/LPIS database.
Farm specialisation classification in 'IACS/LPIS' data – Distinguishing market sale vs. direct sale and in/out of glasshouses (P1 vs. P2). An issue emerged in the distinction between P1 and P2 as it was hard using our data to distinguish between vegetable types (e.g. whether in glasshouses, and whether they were for market or direct sale). Accordingly, for the Humber (UK) and Mulde (DE) case study regions OpenStreetMap data was investigated, to attempt to identify the approximate magnitude of glasshouses as agricultural land use in these regions. Few glasshouses were identified in the areas studied (using exploratory techniques). If a glasshouse was identified, it was often found to encapsulate a small proportion of farm fields and did not allow allocation of the entire field, surrounding fields, or complete farm as a horticulture (P2) farm specialisation designation for the purposes of FSA classification. As such, we did not include glasshouses as a consideration for FSA farm specialisation classification in the Humber (UK) and Mulde (DE) case study regions. Additionally, as we do not have 'market gardening' data needed to categorise fresh fruit and vegetables as P2, they are all currently being categorised as P1. Given P2 farms are currently only being identified based on other land uses (i.e. flowers and nurseries), we may have underestimated the total coverage of P2 farms (and also possibly underestimated the economic size for these sites owing to the price differentials with market gardening prices).
Farm specialisation classification in 'IACS/LPIS' data – Distinguishing between general cropping and livestock farming (P1 vs. P4). As we had poor information on livestock farms, we assigned this farm specialisation category on the basis that they needed, and could therefore be defined by, the presence of permanent grassland. Animal shelter data was not available frequently enough in the Humber (UK) data, though this did contain information on temporary/permanent grasslands, which was accordingly coded as P1 and P4 respectively for farm specialization. Mulde (DE) and South Moravia (CZ) also contained data on permanent/temporary grassland. The assumption remains that permanent grassland defines P4.
Economic size classification issues in 'IACS/LPIS' data and FADN data' – Standard Output coefficient issues for 'IACS/LPIS' data. For matching crops with their corresponding standard output multiplier in Eurostat it is sometimes not clear which value to choose. An example of this is the Humber (UK) case study region in which all permanent grassland has been assigned to to the 'pasture and meadow' (coefficient = €237.28 per/ha) version of the 'permanent grassland and meadow', even though the 'rough grazings' variant of this category is plausible alternative (coefficient = €1.25 per/ha). In general, where a Standard Output Coefficient (SOC) value could not be found for a given crop/land use we used a crop that was most similar or a value from the larger agricultural group. Winter and summer crop varieties were given equal SOCs. In the Humber (UK) case study

region it was not clear if fields with the category 'wooded land' were P3 (permanent crops) or should be excluded. Woodland was excluded from the Humber (UK) data.
Economic size classification issues in 'IACS/LPIS' data and FADN data' – Economic size classification issues for FADN data. Farms with <2 000EUR economic value are not classified under the ES6 groupings, hence our special classification for farms with total economic size values below this lower bound. As FADN does not survey these 'very small' farms, a different approach to their upscaling to European level through FADN would have to be arranged. Similarly, FADN does not also have an economic size classification for 'mixed' farm specialization.
Data inconsistency issues and errors – South Moravia (CZ) parcels. In the Czech LPIS for a few parcels (N=32, <0.5% in 2018; N=64, <0.5% in 2019) the area of the parcel is smaller than the total crop cover. These few cases have been neglected, since they would neither influence the farm specialisation nor the economic farm size.
Data inconsistency issues and errors – Other BESTMAP project case study regions (see Ziv et al. 2020). A full documentation of these and other issues relating to the implementation of these Farming System Archetypes in all 5 BESTMAP project case study regions (Mulde, Humber, South Moravia, Catalonia and Bačka) is due to be made publicly available (CC BY 4.0) as part of the publication of the EU Horizon 2020 BESTMAP Project Report "Deliverable 3.5: Farming System Archetypes for each CS" through ARPHA Preprints by Pensoft. When published, this will be available in the BESTMAP project collection at: https://riojournal.com/topical_collection/148/.

Table A8. Number and percentage of farms that have no AEP or are implementing at least one AEP.

	Adopters	Non-adopters	Total	Adopters %	Non-adopters %
Mulde (DE)	2020	1142	3162	63.9	36.1
South Moravia (CZ)	576	527	1103	52.2	47.8
Humber (UK)	1499	2028	3527	42.5	57.5
Total	4624	3168	7792	-	-
Mean	-	-	-	52.9	47.1

Table A9. Number of AEP adopters/non-adopters by FSA

Mulde (DE)	<2000 EUR	Small	Medium	Large	Total
P1	21/7	30/55	88/121	506/58	645/241
P2	0/0	1/0	0/0	3/1	4/1
P3	0/2	2/0	0/3	5/6	7/11
P4	257/254	543/416	107/27	34/1	941/698
mixed	9/13	36/59	101/81	277/38	423/191
Total	287/276	612/530	296/232	825/104	**2020/1142**
South Moravia (CZ)	<2000 EUR	Small	Medium	Large	Total
P1	7/100	10/14	20/21	105/27	142/162
P2	0/0	0/0	0/1	0/2	0/3
P3	7/47	28/77	75/43	73/7	183/174
P4	95/77	67/6	10/1	2/0	174/84
mixed	10/47	16/38	20/10	31/9	77/104
Total	119/271	121/135	125/76	211/45	**576/527**
Humber (UK)	<2000 EUR	Small	Medium	Large	Total
P1	2/31	12/80	57/169	1293/597	1364/877
P2	0/0	0/0	0/0	0/0	0/0

P3	0/0	0/0	0/0	1/10	1/1
P4	3/291	19/553	6/34	1/4	29/882
mixed	0/10	5/49	11/74	89/126	105/259
Total	5/332	36/682	74/277	1384/737	**1499/2028**

Table A10. Percentage (of all farms in each case study) of AEP adopters/non-adopters within each FSA

Mulde (DE)	<2000 EUR	Small	Medium	Large	Total
P1	0.7/0.2	0.9/1.7	2.8/3.8	16.0/1.8	20.4/7.5
P2	0.0/0.0	0.0/0.0	0.0/0.0	0.1/0.0	0.1/0.0
P3	0.0/0.1	0.1/0.0	0.0/0.1	0.2/0.2	0.3/0.4
P4	8.1/8.0	17.2/13.2	3.4/0.9	1.1/0.0	29.8/22.1
mixed	0.3/0.4	1.1/1.9	3.2/2.6	8.8/1.2	13.4/6.1
Total	9.1/8.7	19.3/16.8	9.4/7.4	26.2/3.2	**63.9/36.1**
South Moravia (CZ)	<2000 EUR	Small	Medium	Large	Total
P1	0.6/9.1	0.9/1.3	1.8/1.9	9.5/2.4	12.8/14.7
P2	0.0/0.0	0.0/0.0	0.0/0.1	0.0/0.2	0.0/0.3
P3	0.6/4.3	2.5/7.0	6.8/3.9	6.6/0.6	16.5/15.8
P4	8.6/7.0	6.1/0.5	0.9/0.1	0.2/0.0	15.8/7.6
mixed	0.9/4.3	1.5/3.4	1.8/0.9	2.8/0.8	7.0/9.4
Total	10.7/24.7	11.0/12.2	11.3/6.9	19.1/4.0	**52.2/47.8**
Humber (UK)	<2000 EUR	Small	Medium	Large	Total
P1	0.1/0.9	0.3/2.3	1.6/4.8	36.7/16.9	38.7/24.9
P2	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.0
P3	0.0/0.0	0.0/0.0	0.0/0.0	0.0/0.3	0.0/0.0
P4	0.1/8.3	0.5/15.7	0.2/1.0	0.0/0.1	0.8/25.1
mixed	0.0/0.3	0.1/1.4	0.3/2.1	2.5/3.6	2.9/7.4
Total	0.1/9.4	1.0/19.3	2.1/7.9	39.2/20.9	**42.5/87.5**

Table A11. Mean number/standard deviation of AEPs implemented by farms in a given FSA and case study

Mulde (DE)	<2000 EUR	Small	Medium	Large	Total
P1	0.93/0.65	0.51/0.78	0.56/0.76	1.80/1.12	1.35/1.16
P2	0.00/0.00	1.00/0.00	0.00/0.00	0.75/0.43	0.80/0.40
P3	0.00/0.00	1.00/0.00	0.00/0.00	0.46/0.50	0.39/0.49
P4	0.52/0.54	0.64/0.64	1.13/0.83	1.71/0.81	0.67/0.67
mixed	0.55/0.72	0.50/0.69	0.74/0.78	1.80/1.16	1.24/1.14
Total	0.54/0.56	0.62/0.66	0.76/0.82	1.78/1.12	0.97/0.98
South Moravia (CZ)	<2000 EUR	Small	Medium	Large	Total
P1	0.07/0.30	0.50/0.71	0.63/0.72	1.18/0.91	0.66/0.86
P2	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
P3	0.13/0.34	0.27/0.44	0.64/0.48	0.91/0.28	0.51/0.50
P4	0.70/0.71	1.55/0.66	1.82/0.57	2.00/0.00	1.00/0.81
mixed	0.21/0.49	0.37/0.62	1.10/0.94	1.25/0.89	0.64/0.84
Total	0.38/0.62	0.68/0.80	0.77/0.70	1.11/0.78	0.69/0.77

Humber (UK)	<2000 EUR	Small	Medium	Large	Total
P1	0.06/0.24	0.13/0.34	0.25/0.43	0.75/0.69	0.67/0.68
P2	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00	0.00/0.00
P3	0.00/0.00	0.00/0.00	0.00/0.00	0.09/0.29	0.09/0.29
P4	0.01/0.10	0.05/0.25	0.33/1.01	0.20/0.40	0.04/0.30
mixed	0.00/0.00	0.09/0.29	0.17/0.53	0.59/1.03	0.40/0.87
Total	0.05/0.21	0.04/0.23	0.24/0.55	0.73/0.73	0.48/0.68