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

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1 Farming system archetypes help explain the uptake of agri- 2 environment practices in Europe

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25 **Abstract**

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

50 **Keywords**

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

54 **1. Introduction**

55 Approximately 40% of land in the European Union (EU) is used for agriculture (Eurostat
56 2022a). This area generates ~450 billion Euros annually, which is essential to the European
57 population, including its 20 million farmers (Eurostat 2022b). However, intensive farming,
58 together with climate change impacts (Muluneh et al. 2021, Outhwaite et al. 2022), has led to
59 a dramatic decline in farmland biodiversity (e.g. in avifauna, Common Bird Index; Eurostat
60 2022c, Rigal et al. 2023), soil carbon content and other ecosystem services (Yang et al. 2019).
61 To mitigate these impacts and achieve the EU's climate objectives, a set of agri-environment
62 practices (AEPs) has been implemented under the Common Agricultural Policy (CAP),
63 including Ecological Focus Areas and Agri-Environment-Climate Measures, mandated until
64 2022 under CAP's Pillar I and II, respectively (Pe'er et al. 2022). Despite reducing
65 administration costs, the uniform implementation of these measures across different
66 jurisdictions fails to consider local socio-economic and ecological characteristics, undermining
67 their effectiveness (Candel et al. 2021, Beckmann et al. 2022, Roilo et al. 2023). Therefore,
68 agri-environment policies that are tailored to specific properties of farming systems are likely
69 to be more effective than one-size-fits-all policy measures (Oberlack et al. 2023).

70 Farm typologies can support the development of tailored agricultural policies, as they
71 allow grouping of individual farms with similar characteristics and common responses to
72 environmental and policy drivers (Huber et al. 2024, Ribeiro et al. 2014). As such, they help
73 reduce the complexity of farm properties, thereby eliminating the necessity to address the
74 numerous idiosyncrasies present across a multitude of farms. The purpose of such typologies

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2
3 75 ranges from describing and understanding the diversity in the farming sector to informing
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5 76 policy formulation, implementation and assessment (see Huber et al. 2024 for a review of farm
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7 77 typologies). However, building individual farm typologies is challenging because it requires
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9
10 78 large amounts of data that are difficult to obtain, typically through a large number of direct
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12 79 inquiries to farmers (Ribeiro et al. 2016, Tittonell et al. 2020). Such data collection is costly
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14 80 and time-consuming, often resulting in a relatively small sample size and low geographical
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17 81 coverage.

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19 82 Alternatively, broad typologies of agricultural land-use systems enable contextualising
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21 83 locally specific cases (e.g. farms) within regional to national frameworks (Oberlack et al. 2023,
22
23 84 Ribeiro et al. 2016). These approaches that identify and map archetypal patterns of agricultural
24
25 85 systems have proved useful for modelling land-use policy impacts (Metzger et al. 2013),
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27 86 understanding land-management intensities (Václavík et al. 2013, van der Zanden et al. 2016,
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29 87 Levers et al. 2018, Rega et al. 2020), analysing agri-environmental potentials (Beckmann et al.
30
31 88 2022) and farm management practices (Goodwin et al. 2022), or upscaling regional findings
32
33 89 (Václavík et al. 2016). However, they rely mostly on gridded biophysical (e.g. climate, soil)
34
35 90 and land-use data that do not capture individual farm characteristics. Although a few examples
36
37 91 exist that capture socio-economic and ecological features of individual farms (e.g. Graskemper
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39 92 et al. 2021, Tittonell et al. 2020), these tend to use highly aggregated data and are limited in
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42 93 reproducibility across national and regional contexts. Thus, there is a need for farming system
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44 94 typologies that bridge the gap between understanding the behaviour of individual farms in
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46 95 support of highly targeted but costly incentives and broad, grid-based typologies of agricultural
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48 96 systems that lack the consideration of farm structural characteristics, important for identifying
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50 97 policy target groups.

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52 98 Here, we address this challenge by using archetype analysis, a key methodological
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54 99 approach for organising the complexity of social-ecological systems (Oberlack et al. 2019, Sietz
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3 100 et al. 2019), to develop a generalised typology of farming systems. Farming system archetypes
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5 101 (FSAs) group farms according to their structural characteristics (Huber et al. 2024) into units
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7 102 that are assumed to have similar responses to policy measures. Our approach advances existing
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9 103 typologies by (1) capturing archetypal dimensions of farms crucial for identifying target groups
10
11 104 of agri-environment policies, (2) using readily available national-level data, instead of relying
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13 105 on ad-hoc survey-based information, and (3) providing spatially explicit field-level information
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15 106 aggregated to the farm level across large geographical scales. Exemplified in three case studies
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17 107 in Germany, Czechia and the UK, we identify and map FSAs by geospatial relations of field-
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19 108 level attributes that characterise farms' economic size and specialisation derived from the
20
21 109 Integrated Administration and Control System (IACS). As it is uncertain to what degree such
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23 110 typology can capture patterns of agri-environment policy uptake, we assess the usefulness of
24
25 111 our approach by quantifying the spatial association of FSAs with selected agri-environment
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27 112 practices (cover crops, fallow, organic farming, grassland maintenance, vegetation buffers,
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29 113 conversion to grassland and forest) to understand how different types of farms adopt different
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31 114 AEPs. Finally, we discuss the potential and limitations of our approach, define regional- and
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33 115 farming system-specific patterns of AEP uptake, and argue for better future tailoring of agri-
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35 116 environment policies in European agriculture.
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44 118 **2. Data and methods**

46 119 **2.1 Study area**

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49 120 Our analyses covered three regional case studies that were part of the EU-funded research
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51 121 project BESTMAP (Behavioural, Ecological and Socio-Economic Tools for Modelling
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53 122 Agricultural Policy; Ziv et al. 2020). These areas are traditional farming regions in Europe that
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55 123 are representative of each respective country and cover a cross-section of different farming
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57 124 systems and practices (Ziv et al. 2020): the Mulde river basin in eastern Germany (~51.1° N,
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3 125 12.5° E), southern Moravia in the eastern Czech Republic (~48.9° N, 17.3° E), and the Humber
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5 126 river basin in central United Kingdom (~53.7° N, 0.7° W). The Mulde case study is located at
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7 127 the boundary between temperate and continental climates, where the annual mean temperature
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9 128 and precipitation totals are around 7.0 °C and 830 mm, respectively (Bartkowski et al. 2023,
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11 129 Roilo et al. 2023). While the average farm size of 93 ha in Mulde (maximum farm size of 4 967
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13 130 ha) is comparable to 94 ha in South Moravia (maximum farm size of 6 136 ha), the Czech case
14
15 131 study area has a warmer continental to Pannonian climate with an average annual temperature
16
17 132 of 8.5 °C and rainfall of 660 mm (Bartkowski et al. 2023). In contrast, the farmland in the
18
19 133 Humber river basin is characterised by an oceanic climate, with the annual mean temperature
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21 134 and precipitation totals of 9.6 °C and 630 mm, and by a smaller average farm size of 52 ha. The
22
23 135 soils comprise chernozems, leptosols and cambisols (South Moravia), cambisols and luvisols
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25 136 (Mulde and Humber) and gleysols (Humber). The study area elevations range from ~300 to
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27 137 1 100 m and cover 5 814 km², 2 089 km², and 4 664 km² of total area for Mulde, South Moravia
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29 138 and Humber, respectively, of which 63%, 62%, and 79% is agricultural land (Ziv et al. 2020).
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38 140 **2.2 Farming system archetypes**

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40 141 For identifying farming system archetypes in our case study areas, we used field-level data on
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42 142 land-use management, available as part of the IACS database, to infer features of individual
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44 143 farms, i.e. farm structural characteristics as defined by Huber et al (2024). IACS data serve the
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46 144 purpose of supporting the administration of agricultural subsidies and are collected through
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48 145 farmers' declarations when applying for CAP payments (Santos et al. 2021). When linked to
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50 146 the Land Parcel Identification System (LPIS), a key component of IACS, the data can provide
51
52 147 spatially explicit information on the size and location of each agricultural parcel, the farm that
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54 148 manages the field (anonymised), the type of land cover and crop grown, the farming practice
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56 149 (e.g. conventional vs. organic) and the implemented AEP. The IACS/LPIS datasets for our case
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3 150 studies were provided under license by the national or regional public authorities: (1) the
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5 151 Integriertes Verwaltungs- und Kontrollsystem (InVeKoS) from the Saxon State Ministry for
6
7 152 Energy, Climate Protection, Environment and Agriculture, (2) the Czech Land Registry-LPIS
8
9 153 from the Ministry of Agriculture of the Czech Republic and (3) the LPIS from the UK Rural
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11 154 Payments Agency and Natural England open data geoportal. All data were processed for the
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13 155 most recent year available consistently across all case studies (i.e. 2019) following the General
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15 156 Data Protection Regulation and local data sharing agreements.

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19 157 Our FSA typology was based on two independently calculated dimensions of the
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21 158 farming system: farm specialisation and economic size. We chose these dimensions because
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23 159 they were computable from the field-level IACS/LPIS data consistently across all case studies
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25 160 and because they represent essential farm structural characteristics (as opposed to farmers'
26
27 161 individual characteristics) recognized as crucial for identifying policy target groups (Huber et
28
29 162 al. 2024). These dimensions also capture archetypal aspects of the farming systems, as the
30
31 163 compatibility of AEPs with established farm practices and economic considerations related to
32
33 164 the farm business were previously identified as the most relevant factors for the uptake of AEPs
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35 165 in our case studies (Bartkowski et al. 2023, Wittstock et al. 2022) and elsewhere (Baaken 2022,
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37 166 Lastra-Bravo et al. 2015). Moreover, these dimensions are available as variables in the Farm
38
39 167 Accountancy Data Network (FADN), the main database that provides harmonised
40
41 168 microeconomic data for farms in the EU derived from national surveys. This allows the future
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43 169 possibility of the FSA approach to be upscaled to other parts of Europe, providing insights into
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45 170 the distribution of FSAs (based on the sample farms anonymously recorded in the database) at
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47 171 the level of NUTS or FADN regions.

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51 172 Farm specialisations were classified as the relative share of the standard crop and animal
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53 173 production according to the FADN classification 'Type of Farming TF8', as defined in Annex
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55 174 IV of EU regulation 2015/220. These FADN categories were used as guidelines for the
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3 175 classification, but the actual farm specialisation was calculated based on field-level IACS
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5 176 attributes. For simplicity, we aggregated the original eight categories into five broad classes of
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8 177 specialisation (Table A1): general cropping ('P1'), horticulture ('P2'), permanent crops ('P3'),
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10 178 grazing livestock ('P4') and mixed. To assign each farm in the IACS data into these categories,
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12 179 we calculated the areas of individual crop or culture types in all fields of each respective farm
13
14 180 and applied the area-based rules defined in EU regulation 2015/220, according to which farms
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16 181 classified as P1, P2, P3 or P4 must dedicate at least $\frac{2}{3}$ of the total farm area to the respective
17
18 182 land-use type. If this area requirement was not met, we classified the farm as a fifth type of
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20 183 specialisation: 'mixed'. For the proportion of each farm specialisation category covered by
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22 184 individual field specialisations, please see Table A5.
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26 185 Economic size represented the total value of standard production, which we calculated
27
28 186 from the area of individual crops and the number of animals at an agricultural holding. For this
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30 187 variable, we simplified the FADN ES6 classification, which categorises farms' economic size
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32 188 according to delimited ranges (EUR; Table A2). This parameter is not directly available in the
33
34 189 IACS data but can be calculated using Standard Output Coefficients (SOC in EUR per hectare,
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36 190 for ~90 crop types) available in Eurostat (2022d). SOC represents the average monetary value
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38 191 of the agricultural output at a farm-gate price, in Euro per hectare or per head of livestock,
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40 192 calculated for different regions in Europe. Therefore, we multiplied the area of each crop
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42 193 (extracted from the IACS data for all fields of each respective farm) by the corresponding SOC
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44 194 value per region, as it is calculated in the 2016 Farm structure survey data using the average of
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46 195 2011–2015 prices. As a result, we classified each farm into one of four categories: '<2 000
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48 196 EUR', 'small', 'medium' or 'large'. Although the criteria for the '<2 000 EUR' category
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50 197 remained unchanged, the 'small', 'medium' and 'large' categories were assigned relative to the
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52 198 distribution of farm sizes in each specialisation category to achieve even distributions across
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54 199 groups, resulting in approximately $\frac{1}{3}$ of the total number of farms (excluding the <2000 EUR
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3 200 farms) being in each category (Table A3). Several issues arose when defining farm
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5 201 specialisation and economic size, e.g. in distinguishing production types, estimating economic
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7 202 value, or data consistency. Please see Table A7 for details on how we addressed them.
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10 203 Finally, the assignment of each farm to a specific FSA category (Table A4) was the
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12 204 result of a combination of economic size (<2 000 EUR, small, medium, large) and specialisation
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14 205 (P1, P2, P3, P4, mixed), which ultimately produced 20 archetypes. As such, the format of
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16 206 archetype analysis represented here is that of the “typology of cases” where each case of a
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18 207 phenomenon (here a farm) is assigned into exactly one archetype with the aim to identify
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20 208 recurrent patterns and provide their “thick description” (spatial and quantitative insights into
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22 209 qualitative narrative) across large numbers of cases (*sensu* Oberlack et al. 2019, Sietz et al.
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24 210 2019).
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212 **2.3 Agri-environment practices**

213 We quantified the association (i.e. spatial overlap) of identified FSAs with agri-environment
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215 214 practices to examine whether different types of farms can help explain the patterns of AEP
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217 215 adoption (Fig. 1). Each member state (or even federal state in the case of Germany) designs its
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219 216 own list of measures available to farmers. Their categorisation and local names differ between
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221 217 case studies, making comparisons challenging. Therefore, we reviewed the conditions of the
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223 218 local measures, including Agri-Environment-Climate Measures and Ecological Focus Areas, as
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225 219 well as organic farming, which belongs under a separate category of agricultural subsidies in
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227 220 the case of Mulde and South Moravia. We selected those AEPs that were common and
228
229 221 comparable across all case studies, grouping them according to their description into seven
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231 222 consistent categories: cover crops, fallow land, organic farming, grassland maintenance,
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233 223 vegetation buffers, conversion to grassland and conversion to forest (see Tables A6 for details
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235 224 on the AEP groups). There were a few types of measures within the national portfolios that
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225 were too specific or unique that they could not have been assigned to one of the seven
226 considered AEPs. For example, “protection of Northern Lapwing” in Czechia, “strip
227 seeding/direct seeding” in Germany, or “skylark plots” in the UK. However, these were either
228 not present in the case study (e.g. in the case of South Moravia), or they covered only a marginal
229 area (e.g. 93 ha of strip seeding in Mulde), thus, they were assumed to have negligible effect on
230 our findings.

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

243 3. Results

244 3.1 Distribution of farming system archetypes

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

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2
3 250 31% of land in the Mulde and around 9% and 6% in South Moravia and Humber, respectively.
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5 251 Regardless of the case study, the remaining FSAs cover less than 10% of the total agricultural
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7 252 area, with horticulture (P2) absent in Humber or covering less than 1% of land in Mulde and
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10 253 South Moravia.

11
12 254 In terms of the number of farms, however, economically large farms with general
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14 255 cropping (P1) do not dominate the distribution pattern (Fig. 3). Although economically large P1
15
16 256 farms remain the prevalent farm type in Humber, accounting for 56% of farms, and represent a
17
18 257 significant portion of farms in Mulde (20%) and South Moravia (13%), grazing livestock farms
19
20 258 (P4) of small and <2 000 EUR economic sizes are the most frequent FSAs in the latter two case
21
22 259 studies. This underscores the relationship between a farm's economic size and the extent of its
23
24 260 cultivated area across all case studies. Furthermore, it translates into small farms being more
25
26 261 evenly engaged in the remaining specialisations. Specifically, the proportions of farms engaged
27
28 262 in livestock grazing (P4), as opposed to area proportions, are higher by ~20 to 25% in Humber,
29
30 263 ~40 to 50% in Mulde, and by 10 to ~25% in South Moravia. The permanent crop production
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32 264 (P3; mostly orchards and vineyards) in Humber and Mulde is very low (<1% of farms) but
33
34 265 ~30% of farms (of varying economic size) in South Moravia are dedicated to this specialisation.
35
36 266 This is in contrast with the area proportions (3%), which implies that farms focusing on
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38 267 vineyards and orchards are limited in land area. Similar to the area proportions, the number of
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40 268 farms with horticulture (P2) is negligible in all case studies (<1%).

41 42 43 44 45 46 47 48 49 270 **3.2 Adoption of agri-environment practices**

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51 271 The spatial association of identified FSAs and adopted practices shows marked differences in
52
53 272 adoption rates between case studies (Tables A8), with 64%, 52% and 43% of farms
54
55 273 implementing at least one AEP in Mulde, South Moravia and Humber, respectively. Yet, the
56
57 274 FSA typology effectively discerned distinct patterns of AEP adoption that are similar across all
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3 275 case studies (Fig. 4 and A1). For example, economically large general cropping (P1) farms in
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5 276 Humber adopt predominantly vegetation buffers (43% of farms) and fallow land (41% of
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7 277 farms), while comparable farms in South Moravia and Mulde adopt a wider range of AEPs,
8
9 278 encompassing cover crops (40 and 29%), fallow land (12 and 26%), organic production (16 and
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11 279 2%), grassland maintenance (17 and 12%) and vegetation buffers (10 and 29% of farms in South
12
13 280 Moravia and Mulde, respectively) (Fig. 4, right panel). However, a consistent pattern emerges
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15 281 across all three case studies, indicating that cover crops, fallow land and vegetation buffers are
16
17 282 predominantly embraced by general cropping (P1) and mixed farms, especially in the large
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19 283 economic size category (Fig. 4, left panel). Conversely, the adoption of organic farming and
20
21 284 grassland maintenance occurs across a wider range of farm specialisations but they are more
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23 285 prevalent among medium and small farms, and in the case of South Moravia also in grazing
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25 286 livestock (P4) farms with economic size <2 000 EUR.

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30 287 There is also a clear trend in terms of economic size, revealing that larger farms in all
31
32 288 case studies adopt AEPs more frequently (Tables A9–10). Large farms also have the tendency
33
34 289 to adopt a wider range of AEPs (Fig. 4, right panel; Table A11), with a mean number of adopted
35
36 290 AEPs being 1.78, 1.11 and 0.73 for Mulde, South Moravia and Humber, respectively. In
37
38 291 contrast, economically smaller farms adopt AEPs less frequently (Tables A9–10) and are more
39
40 292 likely to adopt only a few types of AEPs (Table A11), with a mean number of adopted AEPs
41
42 293 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
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44 294 Mulde, South Moravia and Humber, respectively. Small and <2 000 EUR farms, which often
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46 295 focus on grazing livestock (P4), typically prefer grassland maintenance in all case studies,
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48 296 ranging from 83% of farms in Mulde to 68% in South Moravia and 46% in Humber.
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50 297 Simultaneously, these FSAs implement organic farming in both Mulde and South Moravia (11
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52 298 and 30% of farms, respectively), while in Humber, they focus on fallow land (26%) or
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54 299 conversion to forest (22%). Permanent crop farms (P3) are an exception in the AEP adoption
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3 300 trends, as they tend to adopt a limited assortment of AEPs across all economic sizes in the case
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5 301 of Mulde, or prioritise mostly organic farming in the case of South Moravia.

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8 303 **3.3 Non-adoption of agri-environment practices**

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10 304 We also quantified the relative number of farms and land area with no uptake of agri-
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12 305 environment practices (Figs. 5–6; Tables A8–A10). Combining all specialisations, there is a
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14 306 clear trend of small and <2 000 EUR farms accounting for around 70% of all farms across the
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16 307 case studies with no AEP uptake (Fig. 5). In terms of specialisation, non-adopting farms in
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18 308 Mulde and Humber are mostly grazing livestock farms (P4; both ~60%), unlike in South
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20 309 Moravia where non-adopting farms are mostly those focused on general cropping (P1; 30%)
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22 310 and permanent crops (P3; 30%) (Fig. 5). Considering the relative agricultural area where no
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24 311 AEP is implemented, general cropping (P1) and grazing livestock (P4) farming are the
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26 312 dominant farm specialisation in all three case studies representing ca 70–80% of all land (Fig.
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28 313 5), with South Moravia having the largest proportion of non-adoption concentrated in farms of
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30 314 a single FSA (P1 large, 55% of all fields with no AEP).

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33 315 While non-adopters represent 36%, 48% and 58% of all farms in Mulde, South Moravia
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35 316 and Humber, respectively (Table A8), AEPs are applied on average on only 1.3–5.6% of
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37 317 agricultural land across all case studies (Fig. 6). The area-related data indicate similar patterns
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39 318 across AEPs except for organic farming and grassland maintenance that, in the case of South
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41 319 Moravia and Humber, cover a larger farm area. The least common practices are conversion to
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43 320 grassland and conversion to forest, which are implemented by less than 1% of farms in Mulde
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45 321 and Humber. Conversion to forest does not exist as an agricultural measure in South Moravia,
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47 322 while only 3% of farms implement conversion to grassland, fallow land, or vegetation buffers.

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45 324 **4. Discussion**
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7 325 Our results indicate that farming system archetypes, based on two principal dimensions of
8 326 farming systems (i.e. farm specialisation and economic size) derived from IACS data, can be
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10 327 used to infer key patterns of AEP adoption, thus providing relevant information to policy-
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12 328 makers for developing more tailored agri-environment policies. Since we built our typology
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14 329 with empirically derived data on farm characteristics and assessed its usefulness with real
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16 330 records of AEP uptake, we adhered to the principles of empirical validity, which ranks high
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18 331 amongst the diverse forms of validation in archetype analysis (Eisenack et al. 2019, Piemontese
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20 332 et al. 2022). The fact that certain AEP categories correlated with the expected FSAs (e.g. cover
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22 333 crops with general cropping systems, or grassland maintenance with grazing livestock farms)
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24 334 is also an example of the general validity of our approach.
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30 335 As opposed to previous farming system approaches that relied on non-spatial survey
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32 336 data (e.g. Graskemper et al. 2021, Ribeiro et al. 2016) or gridded biophysical data (e.g.
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34 337 Beckmann et al. 2022, Goodwin et al. 2022, van der Zanden et al. 2016), we used spatially
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36 338 explicit, high-resolution (i.e. field- and farm-level) parameters that are relevant for agri-
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38 339 environment policies. While only a two-dimensional classification appears limiting to capturing
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40 340 real-world complexity, a total of twenty FSAs can effectively describe archetypal aspects of
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42 341 farming systems while being understandable and usable by policy-makers. We also argue that
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44 342 policy-making at the farm level ought to be based on simple and robust rather than complex
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46 343 and noisy data (Benton 2007). As these two dimensions are being collected as part of the FADN
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48 344 records at the level of FADN survey regions in the entire EU (although without the information
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50 345 on spatial locations of the surveyed farms), this allows potential upscaling of our approach and
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52 346 calculating the frequencies of FSAs in the NUTS or FADN regions based on the sample farms
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54 347 recorded in the database. Extrapolating our typology would improve economic and structural
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3 348 understanding of European farming systems, facilitate decision-making at large geographical
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5 349 and administrative scales, and bridge the gap between researchers and policy-makers (Evans et
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7 350 al. 2017, Oberlack et al. 2023).

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10 351 Aside from the evident benefits, the applicability of FSAs by policy-makers is
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12 352 associated with limitations. Farm specialisation, affecting the compatibility of measures with
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14 353 established farm practices, and economic parameters, including income stability and long-term
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16 354 certainty about land management, have been found to strongly correlate with AEP uptake
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18 355 (Lastra-Bravo et al. 2015, Paulus et al. 2022, Bartkowski et al. 2023). However, our typology
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20 356 does not consider potentially important social parameters, such as personal views, behavioural
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22 357 attitudes or community-oriented factors, e.g. peer pressure (Lastra-Bravo et al. 2015, Cullen et
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24 358 al. 2020, Brown et al. 2021, Leonhardt et al. 2022). Similarly, the local-scale environmental
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26 359 context (e.g. soil quality or landscape structure) can also affect the action space in which farmers
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28 360 operate (Alarcón-Segura et al. 2023, Wittstock et al. 2022). Therefore, a simplified, although
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30 361 robust, typology with emphasis on a few farm descriptors cannot fully explain the complexity
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32 362 of AEP adoption and placement.

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35 363 Although the IACS/LPIS data proved crucial for delineating FSAs at a spatial resolution
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37 364 not attainable through conventional agricultural statistics or resource-intensive farm surveys,
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39 365 their use presented substantial challenges. Obtaining the data from regional or national
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41 366 authorities was difficult due to confidentiality issues and restrictions on sharing. Inconsistencies
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43 367 existed among case studies in terms of available variables and data structures. Crucially,
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45 368 because the IACS data are collected directly from CAP beneficiaries, their reliability and
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47 369 accuracy may vary. The database also lacks certain vital information, e.g. on land tenure and
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49 370 ownership, which could further enhance the analysis of FSAs. While in our case studies, all
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51 371 farms were recipients of some form of agricultural regulation or subsidy (e.g. the basic payment,
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3 372 CAP Pillar 1) and thus had records in the IACS/LPIS database, there are likely marginal regions
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5 373 in the EU not covered by the data, where agriculture operates independently from CAP support.
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8 374 Nonetheless, the identified FSAs were able to capture the different patterns of AEP
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10 375 adoption by different types of farms in three European case studies and, thus, provided insights
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12 376 into the potential reasons behind the patterns of AEP adoption (Figs. 2–6). The dominant
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14 377 adoption of AEPs, especially cover crops, fallow land and vegetation buffers, by economically
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16 378 large farms with general cropping (Tables A9–A10) is likely due to their higher financial
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18 379 turnover and availability of suitable field parcels (Pavlis et al. 2016). Indeed, economically large
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20 380 farms with higher profits and larger administrative capacity exhibit greater adoption of AEPs
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22 381 (Wynn et al. 2001, Mettepenningen et al. 2013), though its rate remains target- (e.g.,
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24 382 biodiversity conservation; Gailhard and Bojnec 2015), and production-specific (Sattler and
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26 383 Nagel 2010). Although it could be expected that large agri-businesses focused on high-intensity
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28 384 management and for-profit crop production may less likely engage in agri-environment
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30 385 programmes, previous studies have shown that greater profit margins, sufficient administrative
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32 386 capacity and a larger area of managed land allow higher AEP uptake in these types of farms,
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34 387 while AEPs are perceived as a form of income diversification (Bartkowski et al. 2023, Paulus
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36 388 et al. 2022).
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42 389 The extent to which AEPs are adopted by economically large farms also varies between
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44 390 regions (Mann 2005, Defrancesco et al. 2008), which appears relevant for our case studies that
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46 391 experienced different political histories. The predominance of fallow in Humber, applied on
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48 392 55% of the field parcels where farms practise general cropping (Fig. A1), is likely related to the
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50 393 tradition of crop rotation in Great Britain, with the aim of restoring soil fertility and preventing
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52 394 pest outbreaks (Angus et al. 2009). In South Moravia and Mulde, the tendency of economically
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54 395 large, general cropping (P1) farms to adopt cover crops and vegetation buffers may be a
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56 396 consequence of the past negative experience with the industrial model of agricultural production
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3 397 on large field blocks in the socialist period (Zagata et al. 2020). However, it may also stem from
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5 398 factors associated with established routines, indicating that farmers are prone to selecting
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7 399 measures that can be integrated into their farm operations without much additional effort
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10 400 (Wittstock et al. 2022). In addition, this trend is partly explained by the fact that certain types
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12 401 of cover crops and vegetation buffers in Germany and Czechia are implemented as part of
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14 402 Ecological Focus Areas, which are compulsory for farms over 15 ha on at least 5% of their
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16 403 arable land (Alarcón-Segura et al. 2023). Attributing the adoption of specific AES to a particular
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18 404 factor, however, is difficult and requires a better understanding of the political, historical and
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21 405 social background, which is beyond the scope of our study.

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24 406 Our results also show that economically smaller farms exhibit lower adoption rates and
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26 407 are more likely to adopt a narrower range of AEPs than economically larger farms. For instance,
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28 408 medium and small farms with permanent crops and grazing livestock predominantly implement
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30 409 grassland maintenance and, in the case of South Moravia and Mulde, organic farming (Figs. 4,
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32 410 A1). However, compared to farms with general cropping (as discussed earlier), grassland farms
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34 411 across all categories of economic sizes generally exhibit higher adoption rates (Tables A9–A10)
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36 412 as shown also in other studies (Wilson and Hart 2000, Paulus et al. 2022). This tendency is
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38 413 attributed to their location in less crop-favourable and thereby less profitable conditions, often
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40 414 at higher elevations with lower temperatures and more rainfall (southern part of Mulde and
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42 415 eastern part of South Moravia). Their lower incomes from agricultural production could be
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44 416 compensated by, e.g., result-based payments (Bartkowski et al. 2021), likely increasing
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46 417 competition with economically larger farms, for which production profits highly outweigh the
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48 418 AEP payments. Combined with the absence of agrochemicals in organic farming, higher
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50 419 financial turnover for small and medium farms would not only stabilise soil parameters but also
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52 420 strengthen local markets (Jouzi et al. 2017). However, the road to enhancing landscape
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54 421 sustainability and bolstering ecosystem resilience appears to be less assured in regions where
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3 422 AEP diversity is limited (Boetzl et al. 2021, Ortiz et al. 2021, Winqvist et al. 2011), such as in
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5 423 the Humber (Figs. 4, A1), where grazing livestock (P4) farms show negligible adoption of
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7 424 organic farming, focusing mostly on grassland maintenance and fallows.

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10 425 Another notable trend that emerged from our analysis is that economically small farms
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12 426 and farms with an economic value <2 000 EUR across most farm specialisations are the ones
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14 427 that are the most unlikely to engage in any AEP (Figs. 4, 5; Tables A9–A10). Apart from the
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16 428 lack of administrative capacity (Wittstock et al. 2022, Bartkowski et al. 2023), some possible
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18 429 explanations may be the absence of suitable land parcels (Pavlis et al. 2016) and insufficient
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20 430 outreach by policy-makers towards small farms to adopt agri-environment measures (Coyne et
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22 431 al. 2021). The availability of advisory services, combined with low bureaucratic burdens,
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24 432 proved highly relevant to increasing AES adoption (Massfeller et al. 2022). In northern
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26 433 England, where the Humber case study is located, improving communication and engagement
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28 434 motivated small dairy farmers to participate in agri-environment schemes designed by private
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30 435 producers, leading to additional profits and improved ecosystem services (Coyne et al. 2021).
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32 436 Since the effectiveness of these strategies appears promising (Reed et al. 2014), we argue that
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34 437 developing tailored agri-environment policies and strengthening the cooperation between
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36 438 farmers, private producers and public agencies would likely increase AEP adoption and
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38 439 generate economic momentum.

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40 440 As exemplified in three case study regions in Europe, our typology presents a specific
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42 441 example of a simple farming system approach, as called for by Ribeiro et al. (2016) or Santos
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44 442 et al. (2021), which can be understood by decision-makers, adopted for different regional or
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46 443 national contexts based on FADN or CAP payments data, and has implications for all stages of
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48 444 the policy process (Huber et al. 2024). With respect to policy formulation, FSAs help account
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50 445 for the heterogeneity of farm structures, allowing decision-makers to consider diversity in
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52 446 policy responses, while acknowledging that it is unrealistic to tailor incentives to individual
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3 447 farms. FSAs also support policy implementation by identifying target groups to which policy
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5 448 instruments can be tailored or opportunities to apply existing policies in targeted ways. Finally,
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7 449 FSAs can strengthen policy evaluation by enhancing our understanding of whether a policy
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9 450 instrument achieved a certain goal, or how interventions can be disseminated in regions with
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11 451 different farm structures (Huber et al. 2024). As such, FSAs could be applied to policy design
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13 452 not only within Pillar II (Rural Development) but also Pillar I of the future CAP (e.g. the
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15 453 forthcoming Eco-schemes) as a cost-effective compromise between highly targeted agri-
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17 454 environment measures and broad-brush horizontal policies (Santos et al. 2021). Specific
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19 455 examples of FSA application include their use as eligibility criteria for certain types of schemes,
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21 456 design of differentiated AEP contracts based on FSA dimensions (with respect to contract
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23 457 length, payment levels, conditions, etc.), or targeted information dissemination via advisory
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25 458 services and informational nudges (Wallander et al. 2023). They all represent opportunities to
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27 459 stimulate AEP uptake and ultimately improve ecosystem services provided by agricultural
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29 460 landscapes.
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38 462 **5. Conclusions**

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40 463 Based on farm-level attributes of working farms derived from field-level data, we developed a
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42 464 new typology of farming systems and examined the relationships between farming system
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44 465 archetypes and the adoption of agri-environmental practices in three agricultural regions in
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46 466 Europe. By this approach, we (1) illustrated the credibility of FSAs as a cost-effective
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48 467 instrument to define farming contexts in which the implementation of agri-environment
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50 468 practices occurs, and (2) tested whether the division of farms into groups with similar structural
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52 469 characteristics is a viable criterion for understanding the uptake agri-environment policies in
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54 470 Europe. The FSA typology demonstrated its capability to discern distinct patterns of AEP
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56 471 adoption, supporting the arguments that agri-environment policies could be planned based on
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3 472 simple farm-level eligibility criteria (Ribeiro et al. 2016). In order to adapt existing agri-
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5 473 environment strategies to a more sustainable future, FSAs should be extrapolated to a European
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7 474 scale, while decision-makers should better target small farms that are less likely to adopt agri-
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9 475 environment measures. This could be achieved by reducing administrative burdens for small
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11 476 farms and improving targeted communication towards them. Future research should attempt to
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13 477 test whether the common knowledge base built on the FSA typology can in practice make a
14
15 478 substantial impact on the effectiveness of policy formulation, implementation and evaluation.
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21 480 **Conflict of interests**

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23 481 The authors declare no conflict of interests.
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28 483 **Data availability**

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30 484 Input data from 'IACS/LPIS' databases are available upon request from the Ministry of
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32 485 Agriculture of the Czech Republic, Saxon State Ministry for Energy, Climate Protection,
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34 486 Environment and Agriculture (Germany), and Rural Payments Agency (UK). The processed
35
36 487 data are available from the corresponding author upon reasoned request.
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488

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50 494 Landscape and Biodiversity).
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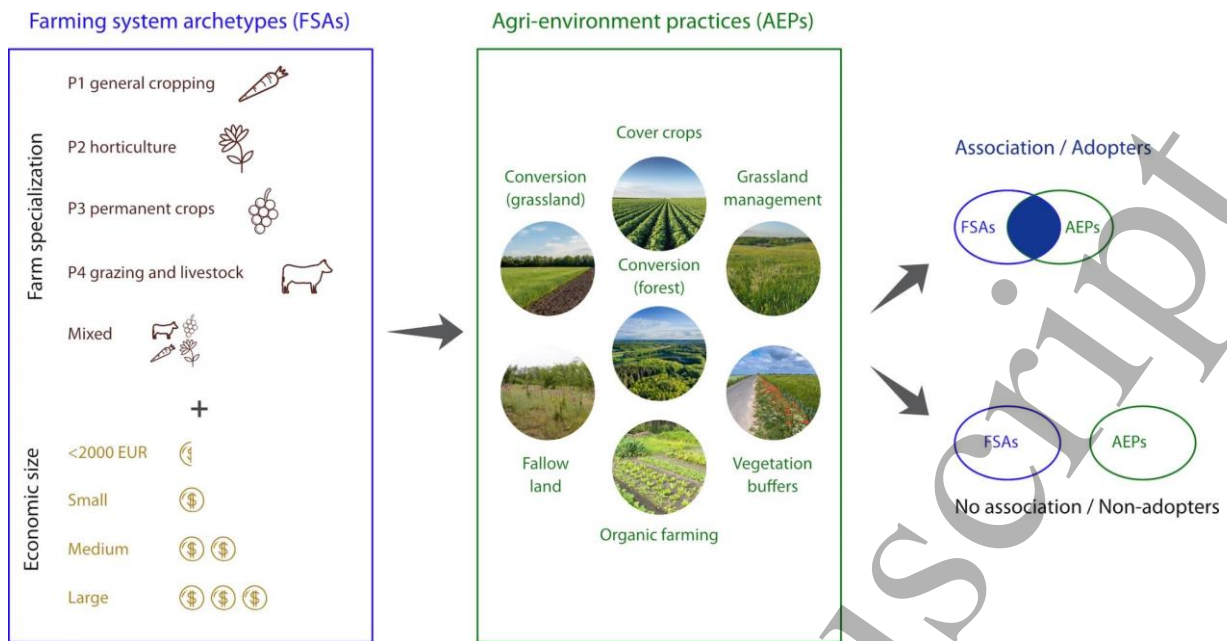
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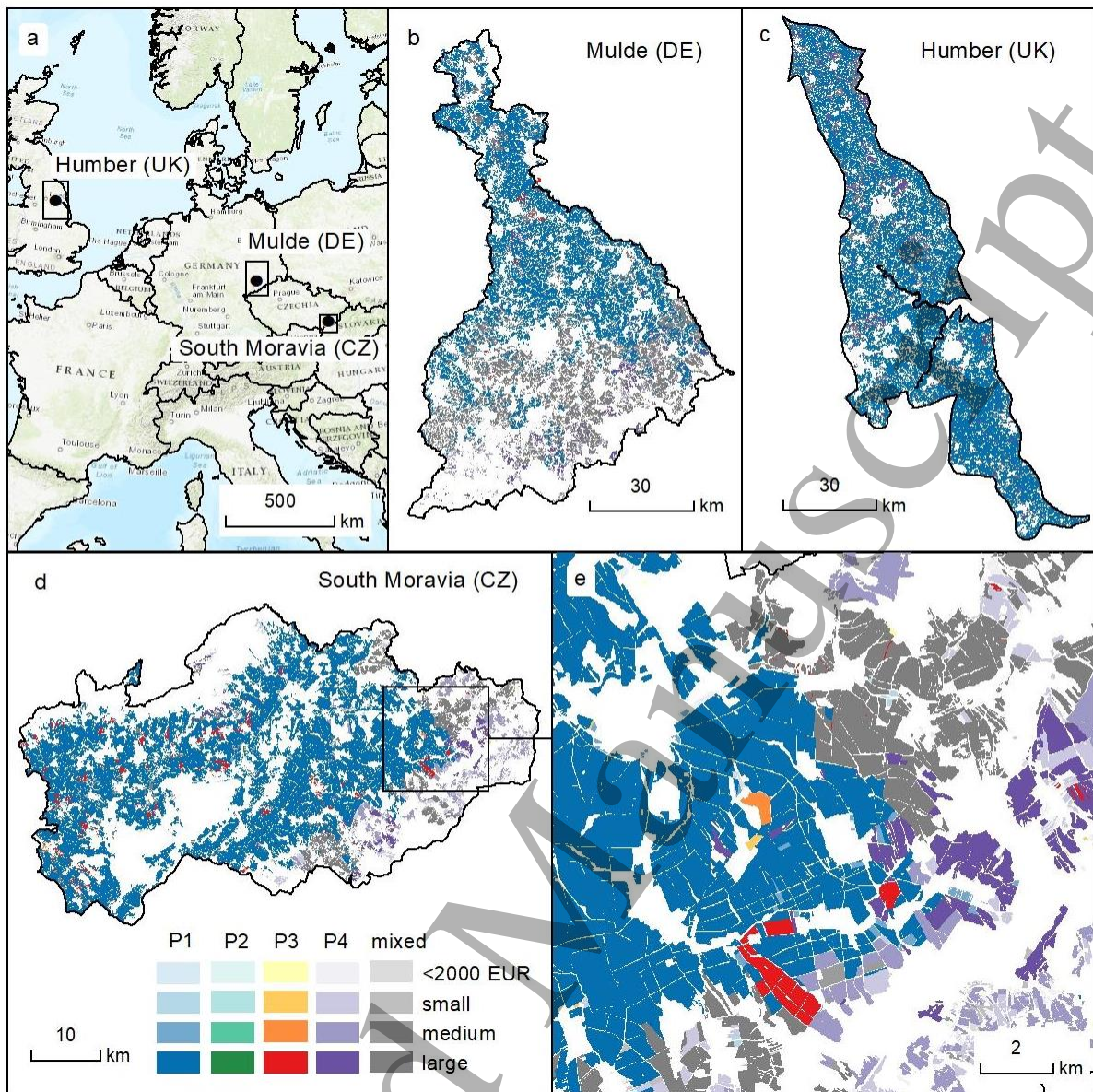
51 662 **Figures and tables**
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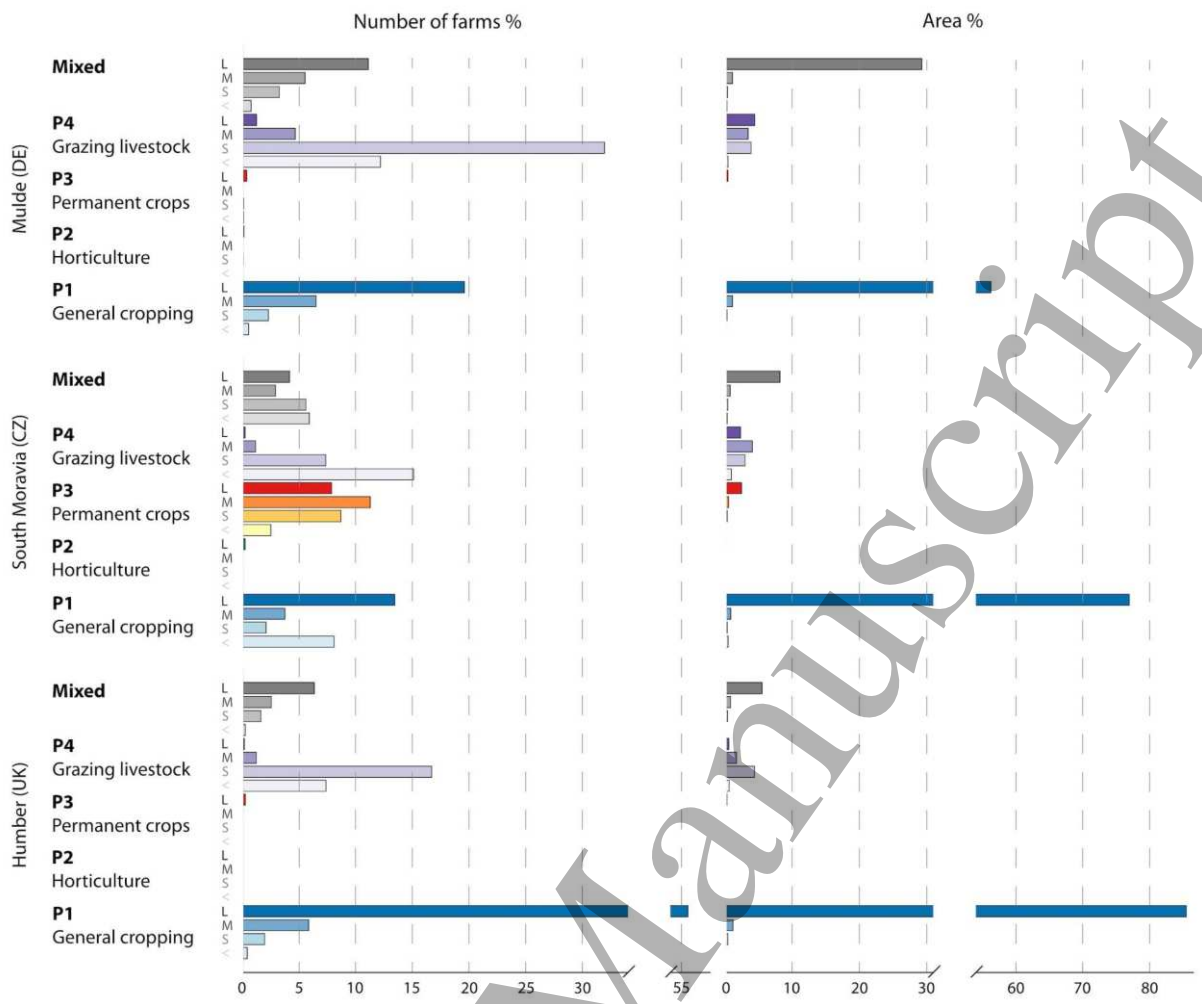
665 **Figure 1. Study design.** Conceptual approach and data included in the development of farming
 666 system archetypes and subsequent spatial overlap with agri-environment practices.

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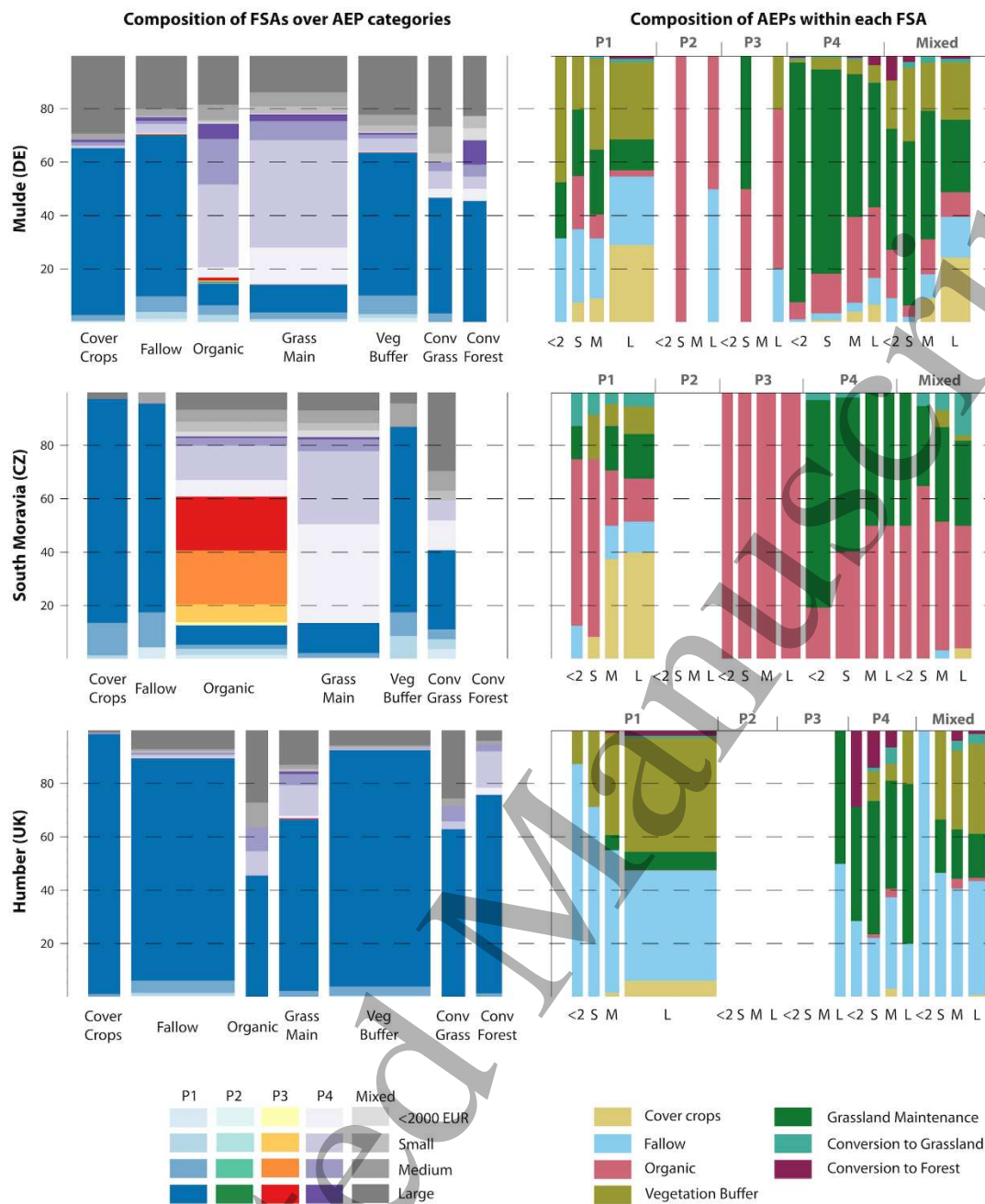
669 **Figure 2. Distribution of farming system archetypes.** (a) Location of case study regions in
 670 Europe: Mulde in Germany (b), Humber in the United Kingdom (c), and South Moravia in the
 671 Czech Republic (d) with map inset to see an example of the field-level data (e). Colour indicates
 672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



673

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

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681 **Figure 4. Farming system archetypes vs. agri-environment practices.** The association

682 between farming system archetypes (expressed in % of the total number of farms within each

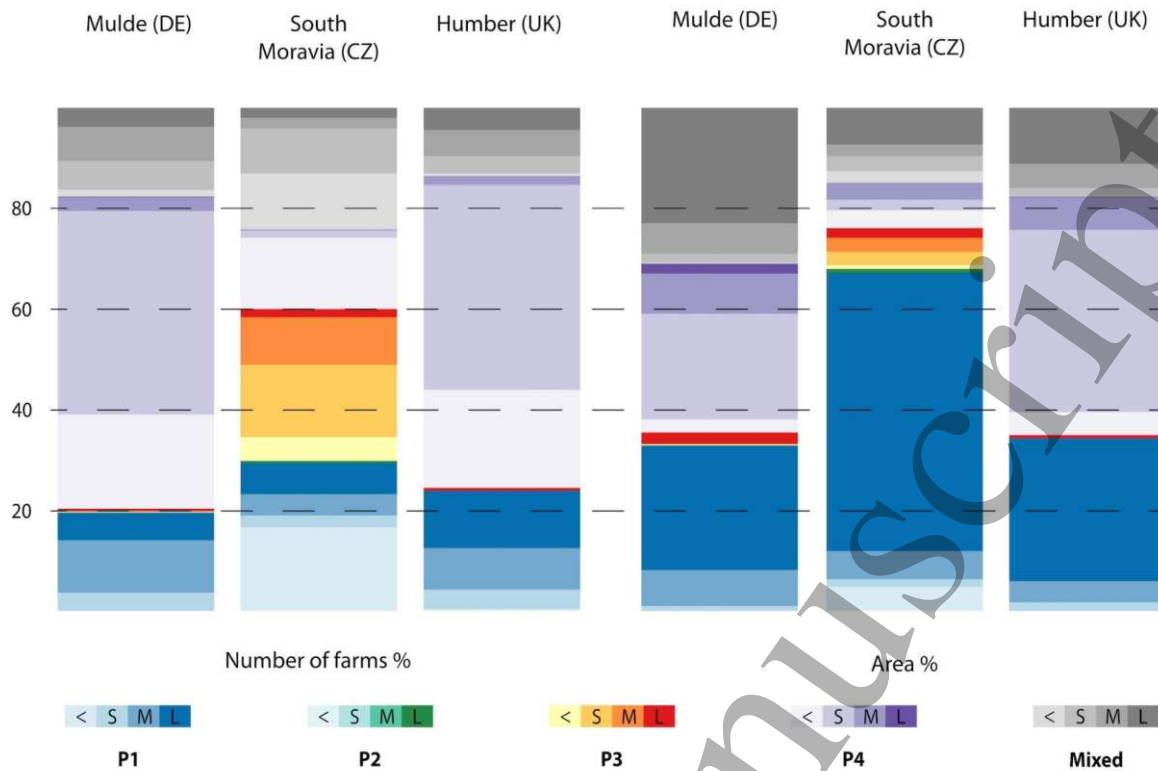
683 category) and the adoption of agri-environment practices in the Mulde (top panel), South

684 Moravia (middle panel) and Humber (bottom panel) case studies. Above a fixed, minimum

685 width, the bar width is proportional to the percentage of the total number of farms in a given

686 case study. Note that there is no ‘Conversion to Forest’ AEP identified in South Moravia.

687 Abbreviations: <2 = less than 2 000 EUR, S = small, M = medium, and L = large farms.



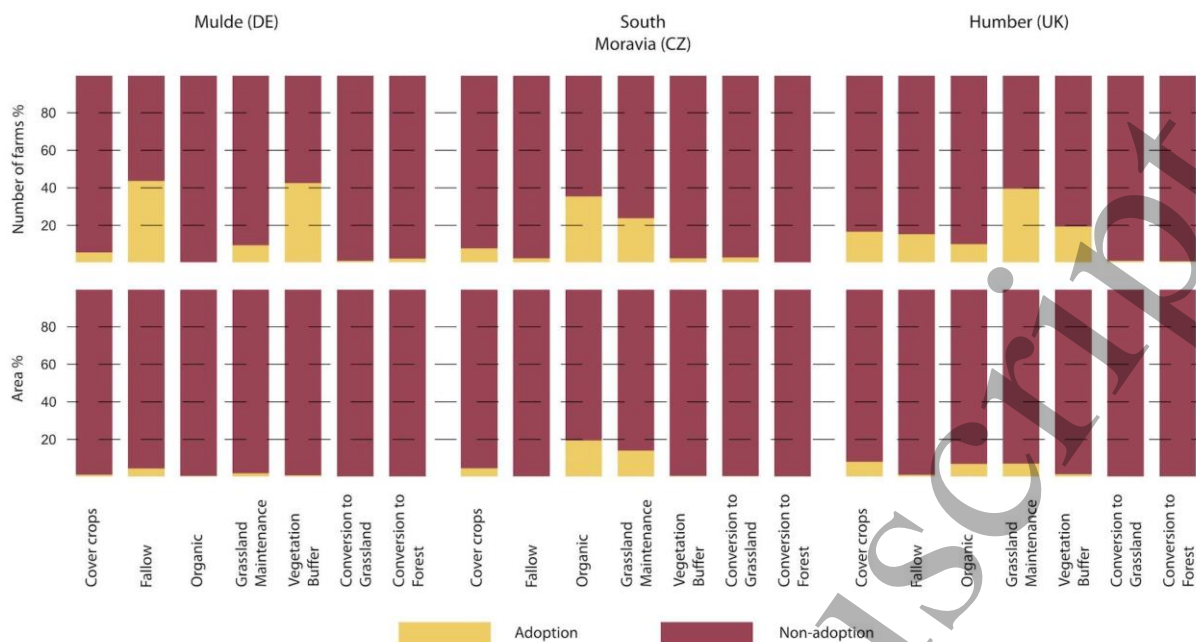
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689 **Figure 5. Non-adoption of agri-environment practices.** Relative composition of farming
 690 system archetypes (vertical axis) for farms that do not engage in any considered agri-
 691 environment practices: relative number of farms (left) and relative area coverage (right). For
 692 full adoption/non-adoption rates per farming system and case study, please see Tables A8–A10.

693 Abbreviations: < = less than 2 000 EUR, S = small, M = medium, and L = large farms.

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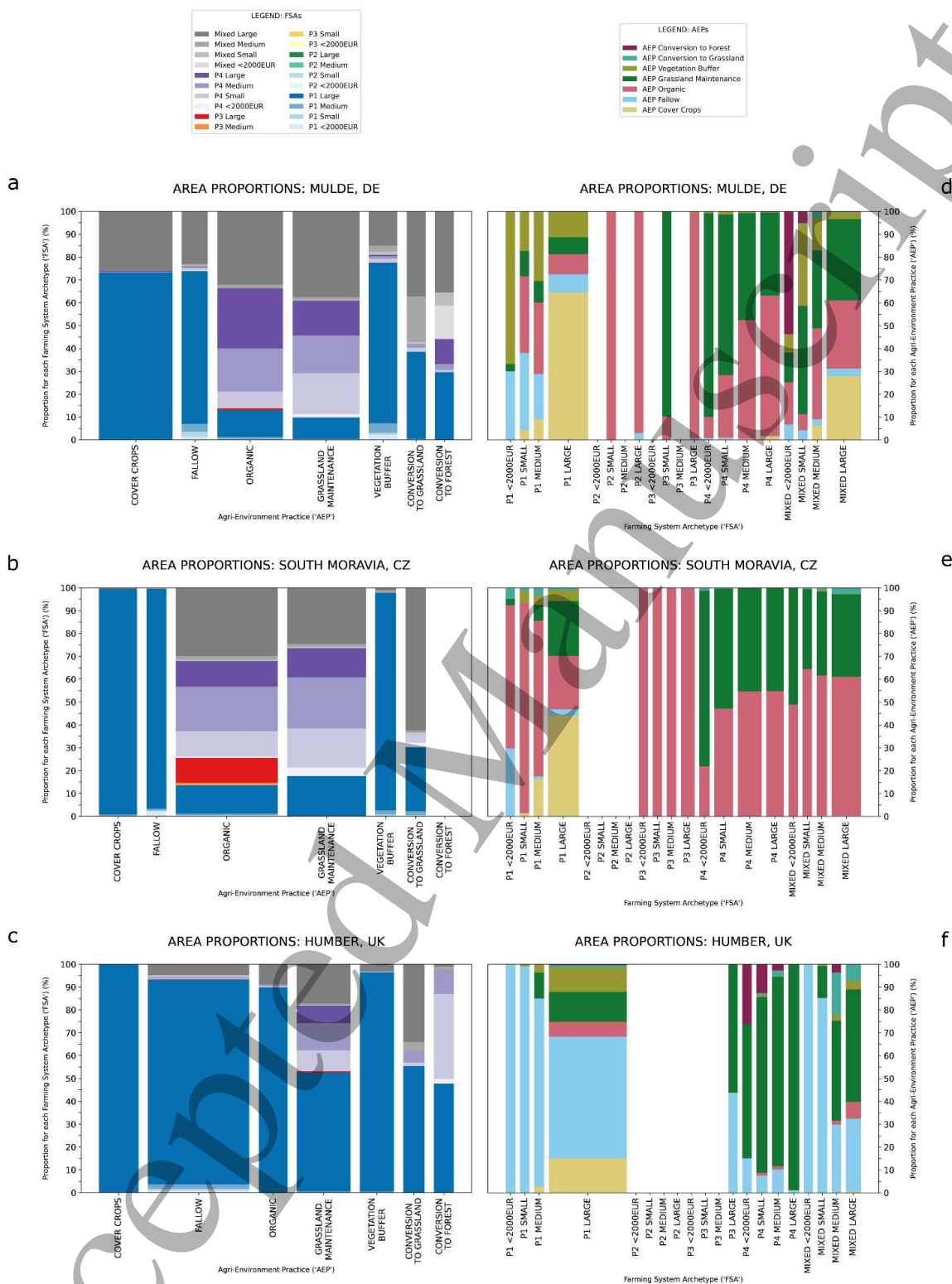


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697 **Figure 6. Overall uptake of agri-environment practices.** Relative number of farms (% of the
 698 total number of farms) and their respective farm area with adoption or no adoption of a particular
 699 agri-environment practice. Note that there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

701

702 Appendices



703
 704 **Figure A1. Farming system archetypes vs. agri-environment practices.** The association
 705 between farming system archetypes (expressed in relative area coverage) and the adoption of

706 agri-environment practices in the Mulde (a,d), South Moravia (b,e) and Humber (c,f) case
 707 studies. Above a fixed, minimum width, the bar width is proportional to the percentage of the
 708 total sample in a given case study. Note that there is no 'Conversion to Forest' AEP identified
 709 in South Moravia.

710
 711 **Table A1.** The association between the four farm specialisations, the original TF8 categories,
 712 and the crop types defined by the Farm Accountancy Data Network (FADN). The category TF7
 713 (granivores, pigs and poultry) was not used in our farm specialisation because it was either not
 714 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)
2.04.04.	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

715

716 **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	

717

718 **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
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

719

720 **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

721

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

Farm specialisation	P1			P2			P3			P4		
	min	median	max	min	median	max	min	median	max	min	median	max
Mulde (DE)												
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

724

725 **Table A6.** Attribution of region-specific schemes to AEP groups. The names represent the
 726 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	<ul style="list-style-type: none"> • AL4 (Anbau von Zwischenfrüchten - catch/cover crops) • EFA Nr. 52 ('Zwischenfrucht / Gründecke')
CZ	<ul style="list-style-type: none"> • EFA VYM_OP_PP_MPL ('Catch crop')
UK	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • AL5a ('Selbstbegrünte einjährige Brache') • AL5b ('Selbstbegrünte mehrjährige Brache') • GL3 ('Bracheflächen und Brachestreifen im Grünland') • EFA Nr. 62 ('Brachen ohne Erzeugung')
CZ	<ul style="list-style-type: none"> • EFA VYM_OP_PP_UHOZ ('Fallow with vegetation cover')
UK	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • OEBL
CZ	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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 crane protection') • VYM_OP_AEKO_SSTAV ('Dry steppe meadows and heaths') • VYM_OP_AEKO_DBP ('Species-rich pastures')
UK	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • AL1 ('Grünstreifen auf Ackerland') • AL5c ('Mehrjährige Blühflächen') • AL5d ('Einjährige Blühflächen')

	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • VYM_OP_AEKO_KBP ('Biobelts - Fodder vegetated strip') • VYM_OP_AEKO_NBP ('Biobelts - Pollinators vegetated strips')
UK	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • 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	<ul style="list-style-type: none"> • EVP groß ('Einkommensverlustprämie groß') • EVP klein ('Einkommensverlustprämie klein') • EFA nr. 61 ('Aufforstungsflächen')
CZ	<ul style="list-style-type: none"> • No agricultural policy identified.
UK	<ul style="list-style-type: none"> • WGC ('Woodland Creation Grant' scheme)

AEPs not considered in the analysis (not assigned to any of the 7 AEP groups above)		
DE	<ul style="list-style-type: none"> ● AL2 ('Streifensaat/Direktsaat') ● AL6 ('Naturschutzgerechte Ackerbewirtschaftung') ● AL7 ('Überwinternde Stoppel') 	93 ha 599 ha 1570 ha
CZ	<ul style="list-style-type: none"> ● VYM_OP_AEKO_IPJ ('Integrated production of vegetables and strawberries') ● VYM_OP_AEKO_CCH ('Protection of Northern Lapwing') 	no records in case study
UK	<ul style="list-style-type: none"> ● 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

727

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729 **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/.

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732 **Table A8.** Number and percentage of farms that have no AEP or are implementing at least
733 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

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735 **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

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737 **Table A10.** Percentage (of all farms in each case study) of AEP adopters/non-adopters within
738 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

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740 **Table A11.** Mean number/standard deviation of AEPs implemented by farms in a given FSA
741 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

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