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Divergent agricultural development pathways across farm and landscape scales in Europe: Implications for sustainability and farmer satisfaction

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ABSTRACT

Current agricultural practices in Europe are increasingly aggravating societal and environmental safety concerns. This creates social and regulatory pressures on farmers, which can lead to declining material and social status of farmers, farmer discontent, and anti-regulation protests. These tensions are rooted in conflicting value systems for agricultural development, which can range from productivist pathways (i.e. valuing production above all else) to increasing multifunctionality pathways (i.e. valuing agriculture for its contribution to multiple economic, environmental and societal needs). It is largely unknown to what degree individual farms and agricultural landscapes are transitioning towards increasing productivism or multifunctionality in practice. Here, we mapped landscape changes and interviewed farmers (n = 274) to examine the diversity of agricultural development pathways in 17 study sites across Europe over the last 20 years (2000–2020). We also assessed the associations between the development pathways and farmers' perceptions of socio-economic outcomes, namely job satisfaction, societal valuation, and economic performance. Farm-level development was largely aligned with productivist pathways, while landscape-level changes aligned more closely with an increasing multifunctionality pathway. Farmers on pathways of increasing multifunctionality did not perceive improved outcomes on livelihood indicators as compared to productivist farmers. Furthermore, farms on increasing multifunctionality pathways were concentrated in sites with very high management intensities that face strong pressure from environmental regulations, as well as low-intensity, mountainous sites, where opportunities for intensification are limited. These results suggest that current pathways that increase multifunctionality arise mostly by necessity. Successful agricultural transformation will therefore require policy to create enabling environments that

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provide socioeconomic benefits for farmers to increase multifunctionality, and a civil society and market conditions that value sustainable agriculture.

1. Introduction

Systemic change in the food system is necessary to tackle the many global social and environmental problems related to agricultural production (Campbell et al., 2017; Pe'er et al., 2014; Scown et al., 2020). This requires an "agricultural transformation", comprising both ideological and practical shifts away from the "productivist" development paradigm that has prevailed since the second world war. With productivist development we refer to farming systems aiming to maximize yields and profits (Ilbery and Bowler, 1998). However, in addition to growing environmental pressures, food production systems are affected by many other and often opposing external megatrends, such as energy transitions, globalization, demographic shifts, and climate change, which may further catalyze or impede different kinds of transformation (Debonne et al., 2022; Kienast et al., 2019). Farmers are central actors in this crisis, while often being constrained by economic and political realities (Williams et al., 2023). Also, farmers and their families are bearing the heavy costs of these changes. Global competition and market prices create lock-ins that leave specialization and scale growth as the only viable survival strategies (Mortensen and Smith, 2020), while increasingly stringent environmental regulations demand changes in agricultural practices. Given the complexity of the internal and external drivers, it is not clear where and to what extent pathways that start deviating from the productivist approach (here referred to as increasing multifunctionality pathways) have been taken up by farmers, or how farmers feel about their role in society at this critical juncture.

To assess agricultural development, one can measure alignment between observed development and predefined pathways or scenarios (Mitter et al., 2020; Verkerk et al., 2018). At a most basic level, agricultural development can be conceptually divided into pathways based on changes in agricultural production and sustainability outcomes (Fischer et al., 2017; Helfenstein et al., 2020). Accordingly, increases in production at the cost of other sustainability outcomes, sometimes also called conventional intensification, is here called a productivist pathway, representing the dominant pathway during the industrialization of agriculture for much of the 20th century (Ilbery and Bowler, 1998). On the other hand, shifts towards more multifunctional delivery of multiple ecosystem services are defined as increasing multifunctionality pathways, sometimes also called post-productivism (Wilson, 2002) or "ecological modernization" (Evans et al., 2002). An additional pathway, affecting large areas of the world in both economically developing and developed countries, is the marginalization of farming activities, leading to land abandonment (Li and Li, 2017; Plieninger et al., 2016). With the reform of the common agricultural policy (CAP) in 1999, after which agri-environment schemes became compulsory for all member countries, European agricultural policy has become more aligned with promoting a transformation towards multifunctionality (Galli et al., 2020). The EU spends around 54 billion euros per year under the Common Agricultural Policy, but several studies have pointed out that these efforts have failed to protect biodiversity or reach sustainable development goals (Kleijn et al., 2001; Pe'er et al., 2014; Scown et al., 2020), in part because they do not adequately consider the decision making contexts of farmers (Brown et al., 2021). Better knowledge of the diversity of development pathways at both farm and landscape scales would therefore allow improved tailoring of agricultural policy to local contexts (Oberlack et al., 2023).

Agricultural transformation, i.e., widespread transitions toward multifunctional agriculture, is likely to be fostered if it leads to tangible (such as economic) or intangible (such as improved work satisfaction or societal valuation) rewards for farmers. However, impacts on farmers' social and economic wellbeing are categorically underrepresented in both political and scientific discourses on agricultural sustainability (Janker et al., 2018). This may explain why recent environmental regulations, such as the implementation of a new fertilizer ordinance in Europe, have met stern farmer resistance, and give the impression that agricultural transformation is a burden forced on farmers, sometimes even perceived as an existential threat (van der Ploeg, 2020). Studies on the adoption of sustainable practices have revealed that often internal drivers such as subjective norms or reputation are just as important drivers of decision making as rational economics (Swart et al., 2023). Meeting ambitious environmental goals, such as the Green New Deal, will require winning over the farmers by making multifunctional agriculture economically viable as well as socially attractive.

While earlier studies have quantified land use change or changes in farm management (Levers et al., 2018; Malek and Verburg, 2020), a pan-European assessment of agricultural development at farm and landscape scales that also considers the farmers' perspective is missing. For example, the Farm Accountancy Data Network (FADN) comprises data on farm structure and management from farms across Europe (European Commission, 2022), but, since FADN is not linked to landscape changes, the data are on their own limited in their potential to inform how changes in farm management affect land-use patterns and ultimately sustainability outcomes. Further, other European incentives, such as the Land Use and Coverage Area Frame Survey (LUCAS), monitor changes in land use and land cover across Europe (Palmieri et al., 2011), but without linking these landscape level changes to changes in farm management or farmers' perspective and motivation. A *meta*-analysis of farmer decision making suggests that societal and policy changes have become at least partly adopted by farmers, as the "eco-agriculturalist" type was assigned high probability of occurrence in most of Europe (Malek and Verburg, 2020). However, it is not clear to what degree farm management and landscape change are already on multifunctional pathways, and little is known how different development pathways associate with social and economic outcomes (Latruffe and Schwarz, 2022).

In this study, we aimed to quantify farm and agricultural landscape development in different regions across Europe. Specifically, we asked:

1. How prevalent are increasing multifunctionality pathways at farm and landscape scales?
2. How do farm development pathways align with landscape development pathways?
3. How do farm development pathways associate with farmers' social and economic outcomes?

To address these questions, we studied 17 regions in Europe, spanning a wide range of crop- and livestock-based systems. We systematically quantified changes in farm-management and agricultural landscapes over the past twenty years (2000 to 2020). Our multi-scale and interdisciplinary approach utilized face-to-face interviews with farmers ($n = 274$) to characterize changes in agricultural management and their perceptions of social and economic outcomes, as well as analysis of aerial photographs to quantify changes in land use and landscape structure. At both farm and landscape scales, we used a set of indicators to quantify the alignment of observed/reported changes with three archetypical development pathways: productivist, increasing multifunctionality, and marginalization. Finally, we compared farmer perceptions of social and economic outcomes across different development pathways.

2. Methods

2.1. Case study sites and reference intensity characterization

The 17 study sites were selected to cover a broad range of land use histories and agricultural systems in Europe, (Fig. 1). Although each site is only 25 km^2 in extent, a separate analysis showed that these case study sites together are highly representative of 79 % of European agricultural areas (Diogo et al., 2023). The sites are in 12 different countries and span a wide gradient in terms of farm types and intensities (Table 1).

Reference farm intensity describes the current intensity level and was calculated as the average intensity rank of the following indicators: N fertilizer use on the main crop, number of pesticide applications on the main crop, feed import, and livestock density (Helfenstein et al., 2022a). We use the current (i.e., 2020) data to construct the reference intensity indicators, as the historical estimates have higher uncertainty. Unlike in Helfenstein et al., (2022a), ecological focus areas were not included to calculate intensity ranks because triangulation with oral history interviews revealed that ecological focus areas were systematically underestimated by the questionnaire in some study regions (Mohr et al., 2023). Feed imports were calculated as the percent of feed purchased from retailers multiplied by livestock units, to account for import volume. Landscape intensity was calculated as the average intensity rank of the share of cropland area, share of semi-natural habitat area, field size, hedgerow density, and agricultural field tree density. Both of these indicators were then classified into low, moderate and high intensity using tertiles.

2.2. Farm development

A standardized questionnaire was used to ask farmers about perceived changes in land use intensity (Diogo et al., 2022), namely, scale enlargement (farm area, livestock units), specialization (crop diversity, livestock diversity), input intensity (nitrogen use, pesticide use, feed import), and land management intensity (LU density, ecological focus area). These indicators were selected based on their demonstrated ability to capture land use intensity changes in diverse case study settings (Dimopoulos et al., 2023; Emmerson et al., 2016; Herzog et al., 2006). The indicators are thus at an intermediate level of abstraction, which means they do not capture all contextual nuances of individual case study sites, but they allow comparing and thus drawing generalizations between different farm types and geographic regions. The indicators were surveyed by asking farmers about the situation today and how it has changed over the past 20 years (Helfenstein et al., 2022b). For example, “how much agricultural land is managed by the farm today?”, and “how much agricultural land was managed by the farm 20 years ago?” Most often respondents were knowledgeable of the past situation, even if it was before they took over the farm. If not, they could answer “don’t know”. This approach was developed and tested in CH-1 (Helfenstein et al., 2022b) and GR-1 and GR-2 (Dimopoulos et al., 2023) and then applied to the remaining study sites. The full questionnaire can be found in Appendix A.

Overall, 274 interviews were conducted. Farmers were selected from farms located within the study landscape (rather than based on a common attribute), to ensure a high diversity of farm types within each study area, representative of the range of production systems present in most landscapes. In each site, we conducted 15 to 20 face-to-face interviews between October 2020 and September 2021. The site RS-1 was added later and interviews were conducted in April 2022. As farmers were asked about changes over the past twenty years, we do not expect the different survey times to impact the results. In two sites (DE-1, NO-1), personal visits were not possible, so questionnaires were sent by mail

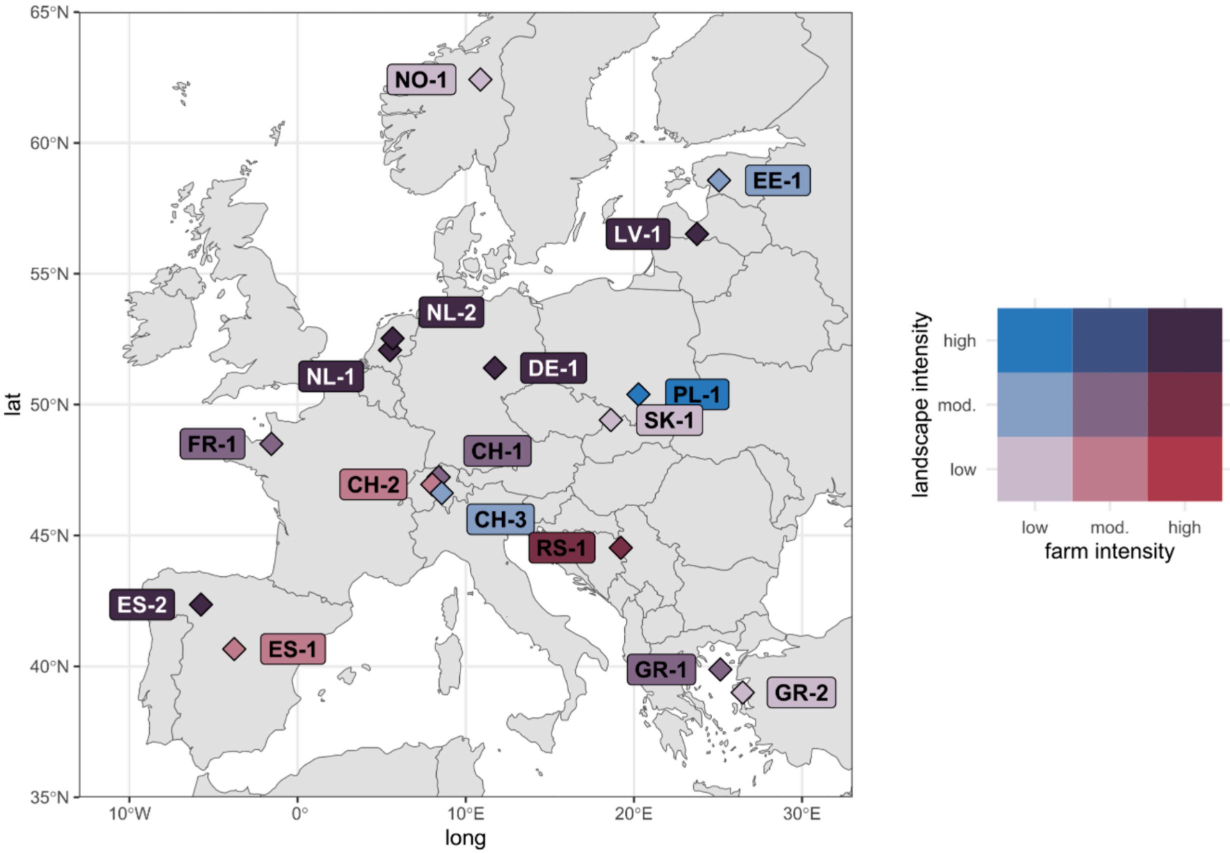

Fig. 1. Location of the 17 study sites across Europe. The colors reflect a two-dimensional intensity tertiles at the farm and landscape scales. See Table 1 for abbreviations of the study sites.

Table 1

Study site characteristics. The driving time to the closest town was calculated from the center of the study site on Google Maps and serves as an indicator of remoteness. Farm-scale intensity is determined based on nitrogen fertilizer use, pesticide use, feed import, livestock density (Helfenstein et al., 2022a); landscape-scale intensity is determined based on cropland fraction, fraction of semi-natural habitat, field size, hedgerow density and tree density. Data for livestock density in EE-1 were taken from Herzog et al. (2006). The fraction of cropland in RS-1 was approximated from an aerial photograph, since no landscape analysis was done at that site.

id	site name	country	environmental zones[a]	driving time to closest town of > 10′000 people [min]	cropland as a fraction of total land [%]	livestock density [LU/ha]	farm-scale intensity	landscape-scale intensity	most important products	nr. of interviewed farms
CH-1	Reuss	Switzerland	continental	13	34	2.1	moderate	moderate	milk, pigs, vegetables	20
CH-2	Entlebuch	Switzerland	continental/alpine	41	0	2.0	moderate	low	milk, pigs	21
CH-3	Urserental	Switzerland	alpine	36	0	1.0	low	moderate	milk, lambs, cattle	19
DE-1	Querfurter Platte	Germany	continental	10	97	0.2	high	high	wheat, milk	15
EE-1	Vihtra	Estonia	boreal	49	23	0.2	low	moderate	hay, milk	–
ES-1	Colmenar Viejo	Spain	mediterranean	17	0	1.8	moderate	low	cattle	15
ES-2	St. Maria del Paramo	Spain	mediterranean	19	88	0.4	high	high	corn	20
FR-1	Ille-et-Vilaine	France	atlantic	46	43	1.1	moderate	moderate	milk, cattle	16
GR-1	Lemnos	Greece	mediterranean	322	33	2.3	moderate	moderate	milk, lambs	19
GR-2	Lesvos	Greece	mediterranean	63	0	0.3	low	low	olives	20
LV-1	Lielvircava	Latvia	boreal	20	85	0.0	high	high	cereals	14
NL-1	Scherpenzeel	Netherlands	atlantic	8	26	26.7	high	high	milk, eggs, pigs	16
NL-2	Flevopolder	Netherlands	atlantic	10	75	1.2	high	high	vegetables, potatoes, milk	19
NO-1	Hedmark (Innlandet)	Norway	boreal/alpine	160	0	1.0	low	low	cattle, milk	7
PL-1	Słaboszów	Poland	continental	21	79	0.2	low	high	cereals	20
RS-1	Loznica	Serbia	continental	18	60	0.6	high	moderate	milk	17
SK-1	Turzovka	Slovakia	continental	26	0	1.1	low	low	milk, hay	16

Table 2

Indicators used to measure farm development and landscape development. The last three columns show assumed direction of change for three archetypical development pathways: productivist, increasing multifunctionality and marginalization. NA = not applicable.

	indicator	**unit**	**definition**	**productivist**	**increasing multifunctionality**	**marginalization**
farm development	farm area	ha	agricultural area managed by farm	increase	NA	decrease
	livestock units	LU	livestock units per farm using national livestock unit conversion factors (Agridea 2019)	increase	NA	decrease
	crop diversity	count	number of crop types cultivated per farm	decrease	increase	decrease
	livestock diversity	count	number of livestock categories held per farm	decrease	increase	decrease
	N intensity	kg N/ha	N fertilizer application from all sources on main crop	increase	decrease	NA
	pesticide use	count	number of pesticide applications on main crop	increase	decrease	NA
	feed import	%	percentage of livestock feed purchased from retailer	increase	decrease	NA
	livestock density	LU/ha	livestock units per agricultural area	increase	decrease	NA
	ecological focus area	%	percentage of farm area qualified for agri-environment scheme direct payments	NA	increase	NA
landscape development	abandonment	% area affected	Net conversion of agricultural land to forest and other non-agricultural, semi-natural habitat. A negative value means that agricultural land is expanding	decrease	NA	increase
	deintensification	% area affected	Net conversion of high intensity agricultural land to low intensity agricultural land.	decrease	increase	NA
	crop to grass	% area affected	Net conversion of cropland to grassland	decrease	NA	increase
	field size	ha	median parcel size of intensive agricultural land (crops, intensive grasslands, intensive orchards, and vineyards)	increase	decrease	NA
	tree density	trees ha^{-1}	density of free standing field trees on agricultural land	decrease	increase	increase
	hedge density	m ha^{-1}	density of hedgerows and treelines on agricultural land	decrease	increase	NA

or email after telephone consultation. In several sites (DE-1, FR-1, LV-1, NO-1, NL-1, NL-2, SK-1), it was not possible to find a sufficient number of interview partners within the study area, and the radius for interviews was extended to neighboring farms still operating in a similar landscape. In NO-1 only 7 interviews could be conducted.

All interviews were conducted by persons who spoke the local language and were knowledgeable of agricultural practices in the study landscape (see Helfenstein et al., (2022a) for details). All interviewees provided written consent prior to participating in the study. The experimental design and the questionnaires received ethical clearance from the Ethical Commission of the Swiss Federal Institute of Technology (ETH-EK 2020-N-146), as well as by the relevant authorities in the participating countries where required.

Asymptotic Wilcoxon-Mann-Whitney tests from the “coin” package in R (Hothorn et al., 2008) were used to determine significant changes in farm-scale indicators. This modified version of a Wilcoxon signed-rank test was used because it can deal with ties. For all analyses, p-values less than 0.05 were considered statistically significant.

2.3. Landscape development

Our analysis of landscape change considered three indicators for land cover changes (agricultural abandonment, deintensification of agriculture, and crop to grass conversion) as well as three indicators for changes in landscape structure (field size, field tree density, and hedgerow density) (Table 2). The indicators were selected to reflect the importance of both land cover and landscape structure for biodiversity and other ecosystem services (Sirami et al., 2019). We used orthophotos (geometrically corrected aerial photographs) because of their high spatial resolution, allowing for the precise identification, comparison (between two timesteps), and quantification of landscape elements, as well as the distinction between similar land covers (Billeter et al., 2008; Geiger et al., 2010). The approach was tested on the study sites CH-1 (Helfenstein et al., 2022a) and GR-1 and GR-2 (Dimopoulos et al., 2023), and subsequently applied to all case study sites, except for RS-1, because we could not access any historical orthophotos of that region. Aerial images were acquired from the official geoinformation authority of the respective study country (see Table B1 for imagery sources). While our aim was to map changes from 2000 to 2020, the time span had to be adjusted for each case study site based on the availability of aerial imagery (Table B1). The mapping was preceded by a preliminary literature review, a web-based search using online mapping services, and exchanges with local project partners about land use and agricultural conditions in the study area. Auxiliary data derived from orthophotos of other time points or topographic maps supplemented photo interpretation throughout the analysis. For several study sites (FR-1, GR-2, NL-1, and ES-1), seasonal or year-to-year differences in normalized difference vegetation indices (NDVI) were calculated from Landsat satellite imagery to assist aerial photograph interpretation (Dimopoulos et al., 2023).

Land-use was defined based on the European Nature Information System (EUNIS) habitat classification (EEA, 2019). We mapped the broadest EUNIS classes that occurred in the study sites: croplands, grasslands, forests, settlements, barren lands, wetlands, shrub plantations, orchards, and heathlands (see Table B2 for a complete list of mapped land covers and their definitions). While EUNIS focuses on land cover, our study focused on agricultural land-use intensity. Hence, based on local expert knowledge, we added levels of land-use intensity to several EUNIS classes. Firstly, grassland was divided into high intensity grassland (grassland mown or grazed more than 3 times per year) and low intensity grassland (including also flower strips and fallows) and field margin vegetation. Also, olive orchards were divided into high intensity orchards (no understory vegetation visible) and low intensity orchards (understory vegetation visible) following Dimopoulos et al. (2023). Other fruit and nut orchards were divided into high-stem orchards, where single trees were visible, and intensive orchards, where trees are too small to be identified individually (<2 m diameter) and in tight rows. To determine the area of land-use conversions for each study site, land-use classes of both timespans were cross tabulated.

Abandonment was calculated as the net conversion of agricultural land to forest and deintensification as the net conversion of high intensity agricultural land to low intensity agricultural land. High intensity agricultural land use was defined as croplands, intensive grasslands, intensive olive orchards, intensive (lowstem) orchards, and vineyards. Low intensity agricultural land use was defined as low intensity grasslands, low intensity olive orchards, field margin vegetation, high-stem orchards, shrub plantations, and wooded pastures (Table B2).

Changes in median field sizes were calculated for cropland and high intensity grasslands only, and excluding parcels cut off by the edge of the study perimeter. Trees and hedges were only digitized on agricultural land (i.e., excluding trees or hedgerows in home gardens, wetlands, forest or other land uses). Tree density was calculated as the number of field trees divided by the total agricultural area, while hedge density was calculated as the total length of hedgerows and treelines divided by the total agricultural area. For field size, a Wilcoxon test for unpaired samples was used to determine differences between time points (Bauer, 1972).

2.4. Alignment with archetypical pathways

We applied archetype analysis as a methodological approach to investigate the alignment of the changes reported in the case studies with the development pathways considered. Archetype analysis enables the identification of recurrent combinations of social-ecological attributes and/or processes from a set of cases, by drawing upon a broad portfolio of methods for configurational comparative analysis (Sietz et al., 2019). In this sense, an archetype can be understood as a representative pattern of social-ecological interactions that appears repeatedly across different contexts and/or systems (Bennett et al., 2005; Oberlack et al., 2019).

In our study, we applied a “weight of evidence” approach wherein each development pathway is considered to comprise a representative combination of changes in a set of indicators. We consider these pathways as “archetypical” as they describe empirically recurrent trajectories in European farming systems, which are relevant at an intermediate level of abstraction and hypothetically generate distinct sustainability outcomes (Oberlack et al., 2019). In contrast to many other analyses of land system archetypes, we define the pathways *ex-ante* and assess an empirical observation (farm or landscape) to align with a particular pathway if multiple indicators change in the direction characteristic of that pathway. For example, a reduction in input intensity is characteristic of an increasing multifunctionality pathway (Table 2). This change could be driven by the farmer’s own personal attitudes, market prices, societal preferences, or state-driven regulations (Helfenstein et al., 2020). Our measurement of the development pathways focuses on the manifested outcomes of these interacting drivers, rather than the underlying values and motivations of all relevant actors.

We defined productivist pathways as those where indicators indicate an increasing land use intensity, including agricultural inputs, scale enlargement, and specialization (Table 2) (Diogo et al., 2022). In terms of landscape development, productivist pathways are characterized by the spread of more intensive land uses and the simplification of landscape structure (Van Zanten et al., 2014), i.e. increasing field size and decreasing tree and hedge density.

Increasing multifunctionality pathways were assumed to be characterized by indicators implying a reduction in land-use intensity, a reduction in negative environmental externalities and/or an increase in positive externalities, e.g. biodiversity. Aside from decreasing input intensity and land management intensity, we also considered livestock and crop diversification to be integral for increasing multifunctionality pathways. Our definition of increasing multifunctionality pathways is development towards more multifunctional, environmentally-friendly use of existing agricultural land, rather than a reduction of agricultural activities. Hence, we assumed that land abandonment and grass-to-crop conversion are not typical features of this pathway (Table 2). Similarly, we do not consider changes in farm area or the number of livestock per farm (as opposed to livestock density) as evidence for or against increasing multifunctionality, because those indicators are not directly related to sustainability outcomes (Herzog et al., 2006). Although the absolute value of ecological focus areas may be underestimated in some study regions and was thus not considered to calculate reference intensity, the relative change is still informative for assessing development pathways and was thus included in the analysis of farm development.

The marginalization pathway was defined by indicators that indicate a ceasing of agricultural activity. At the farm-scale, we assumed this would manifest in decreasing farm size and the giving up of certain production types, i.e. a reduction in crop and livestock diversity (Table 2). Although decreasing input intensity is in some cases also a sign of marginalization, our conversations with farmers revealed that in most cases they would continue business as usual, but on less land. Due to this ambivalence, we did not assume indicators of input intensity to be features of a marginalization pathway (Table 2). At the landscape scale, we assumed marginalization would be characterized by land abandonment, increased conversion of crops to grassland, and increasing tree density.

We calculated the alignment score between each observed unit (farm or landscape) and the respective pathways in two ways.

1. The first approach (shown in the main results) was sensitive to the magnitude of change, i.e. large changes in one indicator could overshadow smaller changes in other indicators. First, we calculated the relative change of each indicator (Törnqvist et al., 1985). We then min–max transformed each indicator to range between -1 and $+1$ and selected the relevant indicators (Table 2) for each pathway. We reversed indicator values (multiplication by -1) if the archetypical pathway represented a negative development for that indicator (Table 2). Finally, we calculated the alignment score as the arithmetic mean of the scaled indicators. The more positive the alignment score, the stronger the alignment of the respective farm or landscape with the respective pathway. Since there is some overlap between characteristics of individual pathways (e.g. increasing tree density can be both a sign of increasing multifunctionality and marginalization pathways), the pathways are not mutually exclusive, and each observational unit may display alignment with multiple pathways.
2. The second approach considered only the direction of change and was used as a sensitivity analysis to test the robustness of the first approach (results shown in Appendix B). High membership scores are attained by those observational units with many indicators pointing in the same direction as the archetype. In this second approach, the magnitude of change does not matter, as long as it is above a "no change threshold" (here 5 %) (Verkerk et al., 2018). For details on this approach, please see Helfenstein et al., (2022b).

After alignment score calculation, we clustered sites to group similar development patterns using hierarchical clustering based on euclidean distance between alignment scores. We applied four common clustering methods (average linkage, single linkage, complete linkage, and Ward's method) to explore the stability of the clusters (Gareth et al., 2013). The clustering relates only to the changes over the 20-year period, but we also discuss these results considering the sites' reference intensity characterizations. Our overall assessment of each site's development therefore contains two dimensions, respectively representing the current intensity levels and archetypical changes.

2.5. Farmer's perceptions of social and economic outcomes

Farmer's perceptions of social and economic outcomes (satisfaction for short) was assessed with three indicators: change in job satisfaction, perceived societal valuation, and satisfaction with the farm economic situation. As part of the farmer interviews described above, farmers were asked to rate the change in these indicators over the past twenty years. More specifically, farmers were asked if the current situation was "better", "the same", or "worse" for each indicator. We tested the relationship between the farm development pathway and each indicator using cross tabulation and Pearson's chi-square test (Agresti, 2007). For this analysis, we assigned each farm to the farm development pathway with which it had the strongest alignment.

3. Results and discussion

3.1. Farm development

Productivist pathways were the most common at the farm scale. When assigning observed farm development to the pathway with which it had the highest alignment, 47 % of farms were on a productivist pathway, followed by 34 % on increasing multifunctionality pathways and 19 % on marginalization pathways. By clustering study sites based on the share of farms on each pathway, four clusters could be identified: strong productivist sites, productivist sites, increasing multifunctionality sites, and marginalization sites (Fig. 2).

The cluster with 'strong productivist' developments comprised PL-1 and ES-2. In these sites, over 80 % of farms had the highest alignment score with the productivist pathway. Both study sites were cropland-dominated, and characterized by increasing farm size, N fertilizer use, and pesticide applications (Fig. B1). Though displaying similar directions of change, the two study sites had very different intensity levels. While PL-1 was an intensifying low-intensity site, ES-2 was an intensifying high intensity site. For example, reported median N fertilizer use on the main crop increased from 20 to 50 kg N ha^{-1} in PL-1 and from 307 to 329 kg N ha^{-1} in ES-2 (Fig. B1).

The largest cluster, with 6 members, consisted of the sites with mostly productivist farm pathways: CH-1, CH-2, ES-1, FR-1, GR-1, LV-1, and RS-1 (Fig. 2). All sites with moderate intensity levels were in this cluster. Sites in this group displayed productivist tendencies, but had more varying indicator development compared to sites in the strong productivist group (Fig. B2). For example, farmers in CH-1 reported some developments aligning with a productivist pathway, such as significant increases in farm size and number of livestock units and reducing livestock diversity (Fig. B1). However, they also reported significant increases in ecological focus areas (Fig. B1). Another example is GR-1, which displayed increasing farm size, decreasing crop diversity, and increasing feed import, but also decreasing livestock density (Fig. B1). This highlights that development in most sites is mixed, likely due to the interplay of multiple internal and external drivers. Also, often farms within the same study area pursued different development pathways.

The increasing multifunctionality cluster contained 5 sites: CH-3, DE-1, NL-1, NL-2, and NO-1. Interestingly, three of these sites were among the most intensive in our study. NL-2 and DE-1 were intensive arable farming areas, while NL-1 had by far the highest livestock density of all sites covered in this study (Fig. 2). While these very intensive farms are likely the result of productivist changes in the past, we now see farmers in these high intensity sites taking measures that are characteristic for an increasing multifunctionality pathway due to rising pressure from environmental legislation, forcing them to reduce N fertilizer and pesticide input (Fig. B1). This confirms a foresight study on mega-trends affecting European agriculture, which argued that overstepping of environmental boundaries is likely to be a major driver of farm system change (Debonne et al., 2022). Indeed, according to the environmental stringency index, Germany and the Netherlands had more restrictive environmental regulations than Spain (OECD, 2022), where, as discussed above, we observed an intensive study site that was intensifying further. However, as evidenced by recent farmer protests in

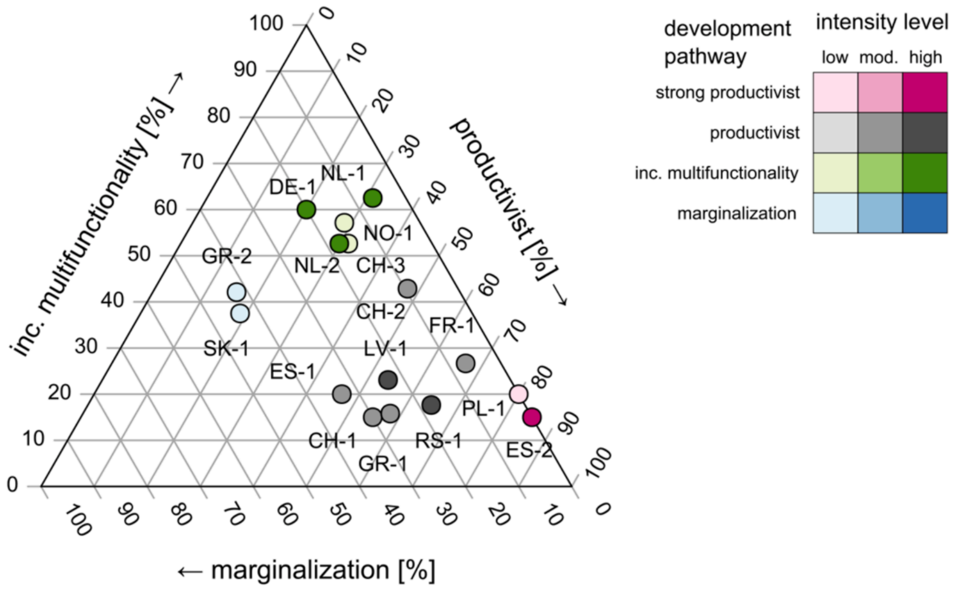

Fig. 2. Farm development pathways for each study site. The plot shows the percentage of farms in each study site with the highest agreement with each of the three pathways. For example, in GR-2, 42% of farms were on increasing multifunctionality pathways, 42% on marginalization pathways, and 16% on productivist pathways. The coloring is based on the current intensity level and the clusters of farm-level development pathways (2000–2020).

both the Netherlands and Germany, a policy-forced transition to increasing multifunctionality pathways may be met with considerable farmer resistance (van der Ploeg, 2020).

The other two sites of the increasing multifunctionality cluster (CH-3 and NO-1) were both low intensity, mountainous sites. These sites likely experienced fundamentally different drivers leading to increasing multifunctionality farm pathways than the highly intensive sites in Germany and the Netherlands. With limited options for intensification due to difficult topography, reducing inputs or diversifying by investing in niche markets or off-farm activities may pay off economically (van der Ploeg et al., 2019). The other study sites not part of this cluster but also with significant numbers of farmers on increasing multifunctionality pathways were also in mountainous environments (CH-2, GR-2, and SK-1) (Fig. 2, Fig. B2). Conversion to organic farming may be another strategy to compete in marginal environments, in line with increasing multifunctionality pathways (Rosati and Aumaitre, 2004). Indeed, we observed that mountainous study sites had the highest proportions of organic farmers (CH-3 = 37 %, GR-2 = 25 %, SK-1 = 25 %), compared to 11 % across all study sites. This reflects the distribution of organic farms across Europe, which are also concentrated in more mountainous areas (Debonne et al., 2022).

While marginalization pathways were less numerous overall, two sites had significantly more farms on marginalization pathways than the others: GR-2 and SK-1 (Fig. 2). Both of these were mountainous study sites with low intensity farming. The prevalence of marginalization in mountainous areas was to be expected given the plethora of literature analyzing land abandonment in less-favored areas (Li and Li, 2017). Marginalization was less prevalent in the Swiss and Norwegian mountainous sites (CH-2, CH-3, and NO-1), where farmers receive more direct payments from the government. However, it is interesting to note that almost every study site had some farms on marginalization pathways (Fig. B2), likely a consequence of scale enlargement and the disappearance of smaller farms across Europe (Burton and Fischer, 2015).

To internally validate the alignment scores, we triangulated them with data on farm systems (organic vs. non-organic). We found that organic farms had a higher median increasing multifunctionality score (Kruskal-Wallis rank sum test $\chi^2 = 5.7$, $p = 0.02$), while tending to have a lower marginalization score than non-organic farms ($\chi^2 = 3.1$, $p = 0.08$), though the latter test was not significant (Fig. B3). Since organic farming is associated with increasing multifunctionality but not with marginalization, this independent test supports the validity of the alignment scores (Crowder and Reganold, 2015). Sensitivity analysis also revealed that the results were generally robust to different approaches. Overall, 70 % of farms were assigned to the same archetypical pathway with both approaches (Table B3). The productivist pathway was still the most prevalent with 47 %, followed by increasing multifunctionality with 35 % and marginalization with 18 %. This suggests that our conclusions about farm development pathways are robust to different approaches for calculating pathway membership and that our approach was able to differentiate successfully between marginalization and increasing multifunctionality pathways, which was not possible in earlier studies (Levers et al., 2018; van Vliet et al., 2015). However, the prevalence of marginalization was likely underestimated in our study because we only interviewed active farmers. Farmers that gave up their farms over the past twenty years were not included in the study design.

3.2. *Landscape development*

At the landscape scale, changes indicative of increasing multifunctionality were more prevalent than those for productivist pathways. Clustering the sites based on the alignment score with each pathway resulted in five clusters: increasing multifunctionality, strong productivist, productivist, strong marginalization, and marginalization (Fig. 3).

With 10 members, the increasing multifunctionality cluster was by far the largest. The cluster contained both sites with highly intensive landscapes (DE-1, NL-1, NL-2, PL-1), moderately intensive landscapes (CH-1, CH-3, FR-1, and GR-1) and low intensity landscapes (ES-1, NO-1). The two most important developments explaining the high alignment scores with increasing multifunctionality pathways were net conversions from high intensity to low intensity agricultural land (observed in 56 % of study sites) and the expansion of hedgerows (observed in 69 % of study sites, Fig. B4). While several authors have reported the disappearance of hedgerows (Arnaiz-Schmitz et al., 2018; Cornulier et al., 2011), our study showed that hedge density increased for the majority of sites, both for those with a long tradition of hedges (FR-1, NL-1) and for those with few hedges (e.g. CH-3, NL-2, and PL-1) (Fig. B4).

However, even sites with high increasing multifunctionality scores had development in opposing directions. For example, in FR-1, which had the highest increasing multifunctionality score, we also observed

Fig. 3. Landscape-scale development pathways. The plots show the alignment score between each study site and each pathway. Study sites are divided into clusters (a-e) based on hierarchical clustering of the pathway alignment scores.

significant increases in field size (Fig. B4). In fact, significant increases in field size were observed for 7 study sites. Though absolute increases in median field size were small for most sites (<0.3 ha), these relatively small changes can hide potentially large landscape impacts. For example, when analyzed over all study sites, the amount of cropland in 10–50 ha fields grew by 59 % from 2,026 to 3,226 ha over the study period, while the amount of cropland in the smallest field class (0—1 ha) decreased by 30 % from 2,001 to 1,391 ha (Fig. B5). While being economically more efficient, larger fields support less biodiversity (Fahrig et al., 2015). This suggests that in order to stop further biodiversity decline in agricultural landscapes, more needs to be done to incentivize farmers to maintain fine-grained landscapes (Clough et al., 2020).

The most persistent study site, characterized by minor landscape change and weak alignment with all pathways (Fig. 3a), was GR-1. This confirms an earlier study using satellite remote sensing and oral history interviews, which revealed that GR-1 was unusual in its persistence in the face of global mega-trends (Dimopoulos and Kizos, 2020).

The most notable intensification occurred in ES-2, the sole site in the strong productivist cluster (Fig. 3b). The landscape in ES-2 underwent fundamental land reconsolidation during the study period, as a result of which 84 ha of field margin vegetation and 5 ha of low intensity grassland were converted to crops (Appendix C), and landscape structure was drastically simplified. Median field size increased from 1.7 to 4.2 ha, while more than half of all hedges were removed (Fig. B4). The two sites in the productivist cluster, CH-2 and LV-1, showed similar, but less extreme, developments (Fig. 3c). For example, though almost half of all field trees were removed in CH-2, hedge density increased by 2 m ha^{-1}, corresponding to an increase of 18 % (Fig. B4).

The site with the highest marginalization score was SK-1, which was the sole site of the strong marginalization cluster (Fig. 3d). SK-1 is a site with low landscape intensity (Fig. 1, table 1). Marginalization in SK-1 was manifested by widespread land abandonment; a total of 172 ha, corresponding to 24 % of agricultural land in the study area that changed to forest during the study period. Two other sites (EE-1 and GR-2) also showed considerable alignment with marginalization pathways (Fig. 3e). Both of these sites were also characterized by considerable land abandonment, though productivist developments were also evident in EE-1, namely increasing field size and decreasing hedge density (Fig. B4). However, the main cause for decreasing hedge density in EE-1 was that fields with high hedge densities were abandoned at higher rates. While GR-2 had a low landscape intensity, EE-1 had a moderate landscape intensity. Thus, we saw that landscape development indicative of marginalization was more common in low or moderate intensity landscapes than high intensity landscapes.

The sensitivity analysis showed that 75 % of landscapes were assigned to the same pathway under both approaches (Table B4). Only considering the number of indicators aligning with each archetype and not the magnitude resulted in twice as many landscapes being assigned to the marginalization pathway.

3.3. Relationship between farm and landscape development

The main difference between the farm and landscape levels (Fig. 4) is that increasing multifunctionality pathways were considerably more prevalent at the landscape scale (10 sites) than at the farm scale (5 sites). Several reasons may explain this pattern. Firstly, when it comes to practices that enhance ecosystem services and biodiversity, farmers have been shown to prefer to set aside areas or plant hedgerows, which in our study was captured in landscape development, rather than changing on-field management practices, which in our study were captured with farm development indicators (Kleijn et al., 2019). Often these measures are strongly subsidized by European, national or local schemes, and add to the income of farmers. Secondly, farmers are not the only actors shaping rural landscapes, as planting of trees or conversions of land use may also be initiated by the municipality or other stakeholders. For example, in CH-1, a large part of deintensification was due to an increase in protected wetland area, which was not based on the farmers' choice, but on decisions of the regional government (Helfenstein et al., 2022b). Finally, changes in livestock farming are often crucial for farm development but have limited spatial signature. Hence, farm and landscape development are not nested but rather

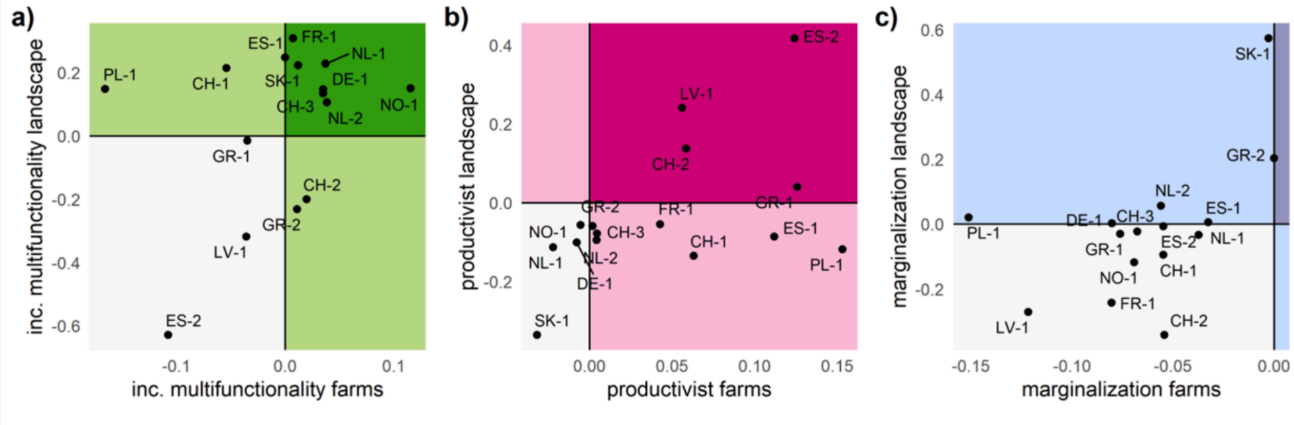

Fig. 4. Relationship between farm and landscape development scores for (a) increasing multifunctionality, (b) productivism (b), and marginalization (c). The x-axis shows the median alignment score of all farms in the study site, while the y-axis shows the alignment score at the landscape level.

complementary, since they consider different aspects of agricultural development. Our study thus reinforces the importance of looking at multiple scales in agricultural assessments (Chopin et al., 2021; Goodwin et al., 2022).

Despite the lack of a clear connection between most farm-scale indicators and landscape indicators used in this study, all members of the cluster of "increasing multifunctionality" farms at the farm scale all also had high increasing multifunctionality scores at the landscape scale (appearing in the upper right quadrant of Fig. 4a). Similarly, ES-2 was a member of the strong productivist cluster for both the farm and the landscape scale analyses (Fig. 4b). Overall, marginalization scores were most consistent between farm and landscape levels (Fig. 4c). This can be explained by the fact that marginalization at the farm scale has a direct impact on land abandonment, whereas all but one indicator (namely ecological focus area) used to distinguish between productivist and increasing multifunctionality pathways at the farm scale do not have a direct landscape impact visible on aerial photographs.

3.4. Relationship between farm development pathway and farmer satisfaction

Job satisfaction was relatively stable overall, with most farmers reporting the same level of job satisfaction today as 20 years ago, and there was no relationship between job satisfaction and farm development pathways (Fig. 5a). In terms of differences between study sites, farmers in LV-1 reported the most consistent increase in job satisfaction, while farmers in DE-1 reported the most consistent decrease in job satisfaction (Fig. B6).

Unlike for job satisfaction, we observed widespread deterioration of perceived societal valuation. 60 % of respondents reported that societal valuation had decreased (Fig. 5b). Deteriorating perceived societal valuation was observed in all study sites except LV-1, PL-1, and SK-1, which are all in Eastern Europe (Fig. B6). While we did not systematically ask why perceived societal valuation decreased, topics such as negative portrayal of farmers as environmental polluters in the media (agribashing, see also van der Ploeg (2020)) came up frequently in conversations. Though one may expect that farmers who are taking steps to reduce environmental pollution experience improved societal valuation, we did not find any evidence that the farm development pathways affected perceived societal valuation ($\chi^2 = 8.4$ (4), $p = 0.08$). There was also no difference in perceived societal valuation between organic and non-organic farmers ($\chi^2 = 0.55$ (4), $p = 0.75$). The lack of association between farm pathway and perceived societal valuation may reflect that farmers identify first and foremost as farmers, independent of their own practices, or that our rather simple questionnaire does not capture all the relevant contextual nuances that may explain the observed patterns.

Change in satisfaction with the farm economic situation was associated with farm development pathways ($\chi^2 = 14.1$ (4), $p = 0.007$). Overall, 42 % of respondents reported that the economic situation of the farm was worse today compared to 20 years ago, 23 % said it was the same and 35 % better (Fig. 5c). However, farmers whose farm was on a marginalization pathway had the largest share, 61 % of respondents,

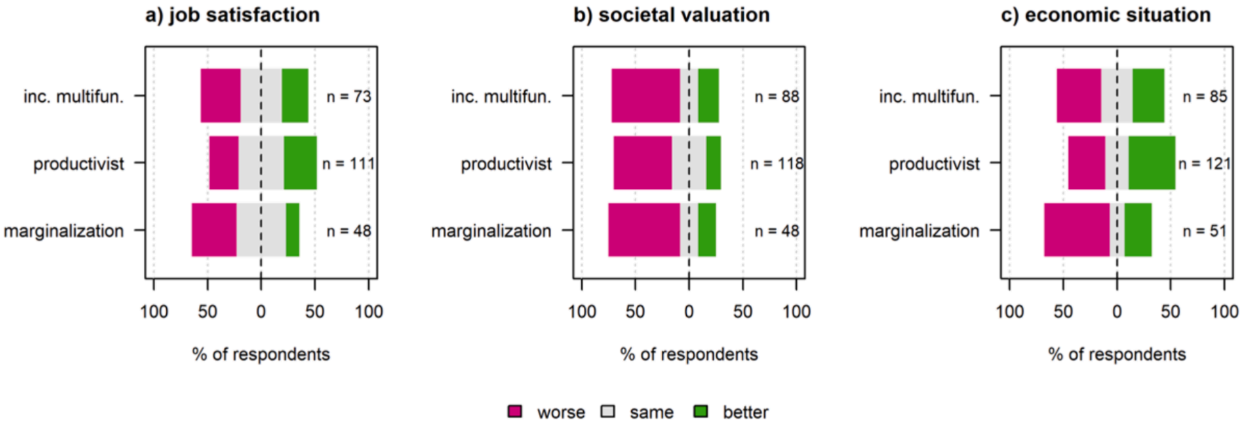

Fig. 5. Relationship between farm development pathways and farmer satisfaction. There was no significant relationship with job satisfaction (a, $\chi^2 = 7.4$ (4), p = 0.11) or perceived societal valuation (b, $\chi^2 = 8.4$ (4), p = 0.08), while there was a significant relationship with economic situation (c, $\chi^2 = 14.1$ (4), p = 0.007). Inc. multifun. = increasing multifunctionality.

reporting worsening of the economic situation. Also, economic improvement was more common with farmers on the productivist pathway (44 %) than on increasing multifunctionality (29 %) pathways. While it was to be expected that marginalization is related to economic decline (Leal Filho et al., 2017; van Vliet et al., 2015), it was surprising that still 25 % of farms on the marginalization pathway report improving economic situations. This may be because in some cases phasing out agricultural activity can be attractive economically, for example when land or infrastructure can be sold profitably, or when reducing agricultural activity allows taking up non-agricultural activities that yield a better income. Meanwhile, we expected that increasing multifunctionality pathways would lead to economic improvements due to compensation payments by agri-environment schemes (Scown et al., 2020). The fact that farmers on increasing multifunctionality pathways experience worse economic situations than farmers on productivist pathways suggests that current economic incentives are still not enough to counteract market forces for productivism.

3.5. *Implications for agricultural policy*

Knowledge on pathways chosen by farmers and the impact this has on their satisfaction is relevant for tailoring effective future policies. On the level of agricultural policy and societal paradigms, a transition from the productivist orientation to integration of agriculture within broader rural economic and environmental objectives already started in the 1980s (Ilbery and Bowler, 1998) and led to concrete policy reforms in Europe, such as when agri-environment schemes became compulsory for all member countries in 1999 (Galli et al., 2020). However, there was likely a significant time lag before this transition in societal preferences affected land use decisions (Malek and Verburg, 2020). Our study now shows that increasing multifunctionality pathways were found on farms and in agricultural landscapes over the past two decades, but that this shift was not unanimous and many regions continued to intensify in a productivist manner.

Our study provides evidence that farmers' decisions remain largely dominated by productivist principles, when not limited by environmental regulations or biophysical conditions. The results thus provide further evidence that European agricultural policy reforms have been insufficient to meaningfully improve sustainability (Pe'er et al., 2020). There is therefore a need to redesign agri-food systems such that farmers are better incentivized to change their behavior. Our analysis suggests that this could be accomplished in two ways.

First, policy must create a socioeconomic playing field that privileges multifunctional agriculture, while considering risks of leakage between land use activities. Our results indicate that farmers still prefer to engage with policy measures that align with their economic objectives or provide additional sources of income, as was already the case in the early 2000 s (see, e.g., (Burton and Wilson, 2006; Walford, 2003)). In this regard, our study suggests that landscape-level diversification is currently easier to meet than farm-level transitions. Both interviews and landscape mapping showed that many farmers are willing to set aside a small fraction of farm area given current compensation schemes, confirming Kleijn et al. (2019). However, there is a risk that landscape diversification takes place while simultaneously intensifying on the rest of the farm. Policy design must therefore consider potential leakage effects across scales, while working to improve the economic incentives for multifunctional agriculture. The archetypical development pathways described in our study could help to tailor such policies to local contexts (Oberlack et al., 2023), as they reveal the site-specific status and trends of agricultural (de)intensification and thus provide information on the decision-making contexts of farmers (i.e., the extent to which agri-food systems currently facilitate increasing multifunctionality at farm- and landscape-level). Finally, in line with other research (Malek and Verburg, 2020; Shucksmith, 1993; Wilson, 2002), our results reveal the co-existence of different pathways within landscapes, underscoring the inevitable diversity of responses to policy changes (Schaub et al., 2023).

Second, society must sympathize with the complexities of farming and positively value farmers' contributions to sustainability. Our results suggest that farmers overall feel decreasingly valued by society, and those on multifunctional pathways are not significantly better off. Such discontent is exacerbated when farmers are forced to overhaul their current practices to meet stringent sustainability regulations (Van der Ploeg, 2020) or when locked-in situations are in the way of transition (Williams et al., 2023). Mitigating risks of future resistance will be challenging, but could involve efforts to change farmers' attitudes towards sustainability, which is a key driver of their decisions to adopt sustainable management practices (Swart et al., 2023). Farmers' socio-economic discontent also stems in part from the passive roles they frequently play in agricultural value chains (Williams et al., 2023), demonstrating the potential benefits of social innovations that foster collaborative relationships with upstream and downstream actors (De Herde et al., 2020). Such social determinants of farmer decision-making are often undervalued in both research and policy (Brown et al., 2021; Swart et al., 2023), so further work is needed to better understand these factors and design strategies to change both farmer attitudes and societal perceptions of agriculture.

3.6. *Methodological considerations and future research*

Our analysis of agricultural development pathways contributes to knowledge about land- and socio-ecological system archetypes in Europe by adding the currently missing farm- and landscape-level perspective for intensity changes in agricultural systems. Existing studies (Levers et al., 2018; Pacheco-Romero et al., 2021; Václavík et al., 2013) rely on indicator sets pertaining to general land-use extent and intensity, environmental conditions, and socio-economic conditions (including ecosystem service supply and demands), and usually map land-system archetypes as static patterns (but see Levers et al., 2018) or focus on the local to regional level. We here compiled a comprehensive indicator set on farm- and landscape level intensity indicators for case study regions representative of about 80 % of European farmland (Diogo et al., 2023), focusing on both starting conditions as well as changes over a 20-year period. Also, our analysis considered the six dimensions of validation outlined for archetype research (Piemontese et al., 2022) (see Table B5). This allowed us to go beyond currently available information by analyzing more nuanced intensity changes in Europe's agricultural system, in particular enabling us to differentiate between different forms of de-intensification such as marginalization versus increasing multifunctionality.

The quantitative and qualitative indicators used in this study facilitated comparisons between diverse study sites, but they inevitably abstract contextual nuances and can be contested. For example, not all hedgerows provide the same environmental benefits, and our measure of hedgerow density neglects any such qualitative aspects (Litza et al., 2022). While our study provides useful information about recent development trajectories that serve as an indication of processes currently taking place within these regions, our assessment does not predict future development trajectories. European agriculture faces an array of interacting pressures that may halt or reverse recent trends (Debonne et al., 2022). Future research needs to compare the observed development with projected exogenous trends or normative scenarios in terms of food production and sustainability outcomes (see e.g. (Mitter et al., 2020; Röös et al., 2022)). This will require tackling delicate questions about how to compare different food (and non-food) products with non-monetary services and values (Helfenstein et al., 2020). It will also be interesting to evaluate how unexpected events (such as pandemics or war) affect future development pathways.

4. Conclusions

Transformation of agricultural systems towards sustainability is necessary to mitigate environmental degradation and rural collapse. In

Europe, billions of euros have been spent to catalyze more multifunctionality in the agricultural sector. Our analysis of 17 study sites revealed a wide variability of agricultural development pathways, both within and between study sites. Increasing multifunctionality landscape development was prevalent in a majority of agricultural landscapes, mostly through the net conversion of high-intensity agricultural land to low-intensity agricultural land (wildflower strips, low intensity grasslands, etc) and the spread of hedgerows. This can be interpreted as tangible results of investment in agri-environmental schemes. However, at the farm scale, productivist pathways still tended to prevail, with scale enlargement and specialization, and in some cases input intensification, still the dominant processes of farm development.

The perception was widespread among farmers that societal valuation of their work has decreased over the past twenty years, an impression that was consistent for farmers from all development pathways. Also, we did not see any evidence for improved job satisfaction or economic situation for farms on increasing multifunctionality relative to productivist pathways. Achieving agricultural transformation will therefore require an enabling environment in which farmers are valued, both economically and socially, for their contributions to sustainability. Towards this end, we conclude that: (1) farmer satisfaction must be better represented in scientific discourse and political agendas, (2) steps taken by farmers to reach sustainability goals need to be recognized and acknowledged by civil society to build trust, and (3) more social and economic incentives are needed to motivate farmers for the fundamental changes ahead.

CRediT authorship contribution statement

Julian Helfenstein: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Validation, Visualization, Writing – original draft, Writing – review & editing. **Samuel Hepner:** Formal analysis, Investigation, Writing – review & editing. **Amelie Kreuzer:** Formal analysis, Methodology, Writing – review & editing. **Gregor Achermann:** Formal analysis, Investigation, Writing – review & editing. **Tim Williams:** Conceptualization, Writing – review & editing, Writing – original draft. **Matthias Bürgi:** Conceptualization, Funding acquisition, Project administration, Writing – review & editing. **Niels Debonne:** Conceptualization, Writing – review & editing. **Thymios Dimopoulos:** Investigation, Writing – review & editing. **Vasco Diogo:** Conceptualization, Writing – review & editing. **Wendy Fjellstad:** Investigation, Writing – review & editing. **Maria Garcia-Martin:** Investigation, Writing – review & editing. **Józef Hernik:** Investigation, Writing – review & editing. **Thanasis Kizos:** Investigation, Writing – review & editing. **Angela Lausch:** Investigation, Writing – review & editing. **Christian Levers:** Conceptualization, Writing – original draft, Writing – review & editing. **Jaan Liira:** Investigation, Writing – review & editing. **Franziska Mohr:** Conceptualization, Methodology, Writing – review & editing. **Gerardo Moreno:** Investigation, Writing – review & editing. **Robert Pazur:** Investigation, Writing – review & editing. **Tomasz Salata:** Investigation, Writing – review & editing. **Beatrice Schüpbach:** Investigation, Methodology, Writing – review & editing. **Rebecca Swart:** Conceptualization, Methodology, Writing – review & editing. **Peter H. Verburg:** Conceptualization, Funding acquisition, Writing – review & editing. **Anita Zarina:** Investigation, Writing – review & editing. **Felix Herzog:** Conceptualization, Funding acquisition, Supervision, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

All data needed to evaluate the conclusions in the paper are present in the paper and/or the appendices. Farmer interview datasets cannot be shared for privacy protection reasons.

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Author contributions

JH, MB, ND, VD, CL, FM, RS, PV, TW, and FH developed the original research question. JH designed the questionnaire with help from MS, RS, FM and FH. JH, GA, TD, WF/WD, MG, JHer, TK, AL, FM, GM, RP, RS, and AZ conducted / oversaw face-to-face interviews and assisted in data interpretation. AK, SH, JH, and GA did landscape mapping and spatial analysis. JH synthesized landscape and farm scales and calculated pathway membership; JH wrote the manuscript, which was commented and revised by all authors.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.gloenvcha.2024.102855.

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