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Tipping points and farmer decision-making in European permanent grassland (PG) agricultural systems

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A R T I C L E I N F O

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A B S T R A C T

Permanent grasslands (PG) provide multifunctional ecosystem services (ES) in Europe and globally, which are threatened by both increased farming intensity and land use change in marginal areas. Farm management decisions can represent critical thresholds, or behavioural "tipping points", in the agricultural system. Decisions are influenced by a combination of agronomic, policy and social factors. Transformation of PG systems can be facilitated through positive tipping points and relevant policy implementation to ensure sustainable PG systems. The aim of this research was to understand the drivers of decisions regarding land use changes and management towards critical positive and negative tipping points across five biogeographic zones in Europe. Interview methodology assessed farmers' preferences and priorities regarding the adoption of sustainable PG systems. Participants were selected from five case study countries, each representing a different biogeographic zone in Europe (Continental/Pannonian: Czech Republic, Boreal: Sweden, Mediterranean: Spain, Alpine: Switzerland, and Atlantic: UK). The sample also covered three farming intensity types within these biogeographic zones: high input/intensive conventional farms ($\geq$1.0 LU/ha); low input/extensive conventional farms ($<$1.0 LU/ha); and certified organic farms. In total, 373 farm interviews were obtained from the case study countries between October 2020 and October 2021. The analysis focuses on drivers of change and considers tipping points across these countries, considering case studies of land use changes (specifically land abandonment) and land management practices (specifically changes in stocking rates). The most common reasons for PG management changes towards either intensification or extensification were economic. Farmers require policy support to increase provision of non-market ES, while rebalancing subsidies can deliver environmental ES at scale through abandonment (e.g., through the creation of specific habitats that support some threatened species). Agri-environment schemes (AES)and subsidies could be more flexible to allow farmers to better adapt grassland management to local production conditions and unpredictable circumstances such as droughts, floods, or market shocks. To maintain PG that delivers more goods and services, financial compensation for ES delivery was perceived to be the most significant support mechanism needed, while easier access to ES provision expertise through extension or consultancy services is considered important factor.

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1. Introduction

Permanent grassland (PG) is one of the most prevalent agricultural land uses in Europe, covering 34% of the total agricultural area (Eurostat, 2020). Well-managed PG landscapes can be multi-functional, delivering a variety of Ecosystem Services, with wide-ranging benefits for environmental systems and social well-being (Bengtsson et al., 2019; Habel et al., 2013; Huber et al., 2022; O'Mara, 2012). PG offer value within agri-food systems through their provision of fodder for livestock production (Hejcman et al., 2013; O'Mara, 2012). Further, they provide some of the most biodiverse semi-natural habitats in Europe (Plieninger et al., 2021; Schils et al., 2022). PG play an important role in erosion control, water flow regulation, carbon storage, and maintenance of soil fertility (De Deyn et al., 2012; Milazzo et al., 2023; Oyesiku-Blakemore and Dondini, 2022; Vaida et al., 2021). In addition, PG are culturally and socially important for recreation, education, and their aesthetic value, particularly where they offer access and engagement for the public, encompass traditional farming practices central to rural communities, and create varied, biodiverse habitats for nature (De Deyn et al., 2012; Vaida et al., 2021). While biomass production for (e.g., livestock feed or renewable energy) represnts a valued (provisioning) ecosystem service, other ecosystem services are not valued in the same way through markets (e.g. because of externalities and public goods) and because some are traded off between each other (e.g. see Bengtsson et al., 2019).

The multifunctionality delivered by PG is challenged by high management intensity and land abandonment, which in turn can be driven by changing socio-economic conditions and food markets, and changes in climatic systems and events, including floods and droughts (Milazzo et al., 2023; Wallace and Chappell, 2020). This research aimed to understand factors influencing current and future farm management decision-making in PG systems, and to identify drivers of (positive and negative) "tipping points" related to land use and management change. This was done through identification of small changes (e.g. relation to economic performance or policy support) resulting in substantive change in the area or quality of PGs (Elliott et al., 2024).

The balance of Ecosystem Service delivery is important for the development of sustainable agricultural systems. For PG systems, the challenge of optimising productivity and supporting biodiversity and other Ecosystem Services requires co-development with farmers and policy makers to ensure sustainable PG systems and relevant policy development and implementation (www.super-g.eu). This balance of Ecosystem Service delivery is affected by farmers' farming and land management decisions. These, in turn, are influenced by a complex interaction between multiple factors such as (perceived) benefits and risks associated with certain management practices), personal attributes and farm attributes (e.g., agronomic and geographical characteristics). As these may directly influence farmer perceptions of benefits, costs and risks associated with decisions, they subsequently influence attitudes towards practice adoption (Dessart et al., 2019; Dominati et al., 2019). Farmers' personal characteristics, including those associated with socio-demographic factors such as age and educational levels (Tindale et al., 2019; Yigezu et al., 2018) and individual values, beliefs and world views associated with farming and the environment (Barnes et al., 2022; Mills et al., 2017; Lamarque et al., 2014) have been reported to inform their decision-making. In addition, farm attributes such as farm type, size, location, agronomic conditions (e.g., climate and land quality), whether land is owned or tenured and the degree of land fragmentation (Hansson and Ferguson, 2011; Hayden et al., 2021), have also been found to influence farmers' decisions. Policy contexts that relate to farmers' income sources (e.g., agricultural incentives such as subsidies) can impede or facilitate adoption of certain management practices (Herzon and Mikk, 2007; Li et al., 2020).

Farmers' decisions regarding changes to PG systems, either through land management (i.e., starting/stopping or changing intensity and timing of specific practices such as grazing, fertilisation, reseeding, cutting, mowing) or land use change (i.e., conversion of PG to other agricultural and non-agricultural land use, or land abandonment) can be understood as critical thresholds, or behavioural "tipping points", in the agricultural system (Pasucul et al., 2022). A "positive" tipping point is here understood to refer to an emerging "change" in the system (in this case related to farming activities), which facilitates rapid transformations in individual and collective actions to counteract the negative impacts of climate change (e.g., see Tabara et al., 2018). Conversely, a "negative" tipping point will result in transformations towards climate degradation (Milkoreit et al., 2018). The concept of tipping points describes critical thresholds where triggers (interventions, changes in state, decisions) create self-reinforcing feedbacks that lead to large or long-term consequences on the evolution of a system, profoundly altering its modes of operation (Food and Land Use Coalition, 2021; Gladwell, 2006; Lenton et al., 2022). Changes can be non-linear due to the complex connections between ecosystem processes, functions, and benefits to humans (Costanza et al., 2017) and can be difficult to reverse once "critical" (ecological or social) thresholds have been crossed. For example, tipping points represent an abrupt break from path dependencies, potentially leading to positive or negative transformational change (Hanger-Kopp et al., 2022).

The tipping points concept has been applied to ecological, climatic and geological systems (e.g. development of "planetary boundaries") (Rockström et al., 2009), but is increasingly recognised as an interdisciplinary concept, applied to social as well as environmental change in order to solve complex global problems, such as climate change and nature restoration (e.g. Chapman et al., 2022; Jordan et al., 2010; Lenton, 2020; Otto et al., 2020). The terminology around "adaptation" tipping points is used to assess under what conditions policies are no longer able to achieve their objectives (Van Ginkel et al., 2020; Werners et al., 2013). The study of *negative* tipping points has contributed to the identification of the risks of sudden (and in some cases irreversible and catastrophic) decline in the condition of ecosystems, together with potential negative implications for human well-being (Mace et al., 2015). *Positive* tipping points (where feedbacks induce beneficial change and build system resilience) have increasingly become a focus of system transformation in the face of change. This includes climate change (Tàbara et al., 2018), and food and land use transformations, which are motivated by the need to mitigate climate change, safeguard biological diversity, ensure healthier diets for all, improve food security, and create more inclusive and resilient rural economies (e.g. Food and Land Use Coalition, 2021). In agricultural systems, feedbacks are important between the type and nature of farmer decision-making and ecological change on the farm. This has further consequences for the system conditions, future management decisions, and ability to deliver Ecosystem Services (Chapman et al., 2022). Farmer decisions represent critical behavioural points at which the system could be transformed. Understanding the drivers of farmer decision-making in different contexts could help to identify the (policy) interventions (e.g. land tenure policy and incentive programmes) that may trigger farmer decisions leading to positive tipping points towards sustainable land management, and disincentivise those resulting in negative tipping points (Chapman et al. ibid). This research aimed to understand factors influencing current and future farm management decision-making in PG systems, and to identify drivers of (positive and negative) tipping points related to land use and management change. It should be noted that the data collection combined quantitative survey-based data collection with qualitative semi-structured interviews. Here we report only the results of the qualitative data analysis derived from the interview data. Three hundred and seventy-three farmer interviews across five case study countries covering the Mediterranean, Atlantic, Continental, Alpine, Pannonian and Boreal regions of Europe were used to build two case studies: one focused on land use changes (specifically land abandonment (Korevaar et al., 2019; Peeters, 2009)), and a second on land management changes (specifically stocking density change (Schils et al., 2022)). The SUPER-*G* project (www.super-g.eu) provided resources for large scale qualitative data collection, given that the same participants were involved in the quantitative survey research and the qualitive interviews. The goal was to a sufficiently large sample size in each country and for each farm intensity category (25 interviews per farm type and 75 interviews per country), in the normal range for qualitive research (Hennick and Kaiser, 2022).

1.1. Literature review

1.1.1. Behavioural decisions and tipping points in PG systems

Behavioural tipping points in PG systems across European regions can be related to changes in management intensity (e.g., the level of inputs used relative to the production level). Schils et al. (2022) note that lower PG management intensity is associated with benefits for regulating and maintenance Ecosystem Services (i.e., biodiversity, climate regulation and water purification). However, this reduces provisioning Ecosystem Services such as the production of high-quality animal fodder. Less is known about PG management changes related to (e.g.) cultural or regulatory Ecosystem Service delivery, even though recent research focusing on the supply of Ecosystem Services has demonstrated that PG can provide multiple, desirable services from both ecological and societal perspectives (Crouzat et al., 2015; Huber et al., 2022; Schirpke et al., 2016; Tindale et al., 2023; Zhao et al., 2020).

1.1.2. Land use change as a tipping point

Land use change can represent a behavioural tipping point in maintenance of beneficial PG systems (i.e., the conversion of PG to other, non-farming uses such as housing or industrial development, or other agricultural uses such as annual cropping). Land abandonment represents one of the most dominant land use changes in Europe (Keenleyside et al., 2010; Prishchepov et al., 2012; Schuh et al., 2020; Van der Zanden et al., 2017) and can be defined as situations where "[the] human control over land (e.g. agriculture, forestry) is given up and the land is left to nature" (FAO, 2006:1). Perpiña-Castillo et al. (2018) predicted that between 2015 and 2030, 11% (more than 20 million ha) of agricultural land in the EU has a high risk of abandonment, resulting from factors related to biophysical land suitability, farm structure and agricultural viability, population change and regional specifics. Such changes are exacerbated by shocks to the agrifood system that affect the balance of land use (e.g., the war in Ukraine has resulted in the conversion of PG to arable lands) (Nóia Júnior et al., 2022) and economic drivers of farmer decision-making which result from policy and market changes, or other societal factors (Pellaton et al., 2022). Statistical data on the loss of PG within Europe are fragmented. However, the available figures suggest that there has been a trend towards significant losses in the second half of the last century, which are continuing to the present time. For example, in the EU-6 countries (Belgium, Netherlands, Luxemburg, France, former West Germany, and Italy), losses have been estimated at about 30% of total PG coverage between 1967 and 2007 (Huyghe et al., 2014). Regionally, local losses may be higher, as in Upper Normandy, France, where about 50% of the PG area was lost between 1970 and 2000 (Van Den Pol-Van Dasselaar et al., 2019). In Eastern Europe, political transformations in the 1980s triggered large scale abandonment of PG, especially in marginal areas, as in Slovakia where 42% of PG was left unused (Kizeková et al., 2018). In the Czech Republic, PG represents around one third of the total agricultural area, mainly due to policy support (Ratinger et al., 2013).

1.1.3. Agricultural land abandonment

Agricultural land abandonment is a complex and multi-dimensional process, which can have both negative and positive consequences, where trade-offs depend largely on specific contexts (Hart et al., 2013; Perpiña-Castillo et al., 2018; van der Zanden et al., 2017). Where agricultural land abandonment is associated with biodiversity losses (e.g., succession of PG habitats) and cultural landscape losses (e.g., "sense of place"), land-sharing biodiversity strategies have focused on the support of extensive PG farming practices (including High Nature Value farming) and associated protection of habitats and species (Lécuyer et al., 2021). Alternatively, agricultural land abandonment can be seen as an opportunity for rewilding European landscapes. In such cases, land-sparing strategies recognise the need to reduce pressure on some ecosystems by restoring natural biodiversity dynamics and aiming for a balance of Ecosystem Services similar to "wild" landscapes (Ceauşu et al., 2015:1024), although this may be to the detriment of PG. Farmers' decisions to abandon land for agricultural use are also shaped by the context, culture and personal values associated with land use change, alongside the economic and political incentives to make such changes. Farmer and land manager decisions to change an attribute or characteristic a farming system are prompted by a critical threshold being reached within the farming system in relation to one or more decision criteria. For example, land may become impractical to graze because of adverse climatic events, climate change, or unprofitable because of rising input costs and falling output prices (e.g. see Brown et al., 2021; Soubry et al., 2020).

1.1.4. Changes in stocking rates and PG

It is important to consider the impact of agricultural intensification on the provision of multiple Ecosystem Services, and to evaluate the possible occurrence of tipping points in relation to intensification in this context (Watson et al., 2021). As most PG systems involve livestock, an important measure of the intensity of a PG system is the stocking rate or stocking density (number of animals per unit land area for a given period). Grazing management practices that aim to balance the stocking rate with the carrying capacity of the grassland can reduce damage to PG landscapes through avoidance of overgrazing and improving soil quality (Allen et al., 2011; Milazzo et al., 2023). Schils et al. (2022) identify the centrality of livestock to PG greenhouse gas budgets (see also Chang et al., 2021) and underscore the need to reduce the impact of ruminant livestock on climate change. Stocking rates can also affect botanical diversity (e.g., Fynn and Jackson, 2022; Wells et al., 2022) and animal welfare (Chabuz et al., 2019; Llonch et al., 2017). The decision of farmers to reduce (extensify) or increase (intensify) stocking rates on their PG can affect the balance of Ecosystem Services and benefits delivered from PG. As Europe is facing important decisions relating to trade-offs between food production and environmental protection (including carbon storage) within the context of legislation such as the EU Green Deal (European Commission, 2020), extensification of livestock farming in more intensive areas (principally, but not exclusively, in the Atlantic biogeographic region) could offer more opportunities to deliver multi-functionality from land and a diversity of Ecosystem Services (Daniel and Kilkenny 2009). This is important if sustainable intensification is required on more productive land (e.g., reduced or optimised intensity is required on other land remaining in agricultural production, or land use benefit from multiple ES provided by PG, including pollination services (Le Clec'h et al., 2019; Spörri et al., 2023). In grasslands, optimal agricultural intensity at European scale could result in benefits for farm businesses, biodiversity, and climate regulation, while enhancing cultural values within grassland systems. At the same time, many farmers have reached an economic tipping point, such that they are intensifying stocking rates on their PG to ensure the economic viability of their farms (Elliott et al., 2024).

2. Materials and methods

2.1. Permanent grassland (PG) definition and scope

PG is defined as land used to grow grass and herbaceous fodder for forage or energy purposes that has not been part of an arable crop rotation on a holding for 5 years or more (Eurostat, 2019). PG can be grazed by livestock, or cut and used for hay, silage, or renewable energy production. It may include areas used for intensive grazing as well as "rough grazing", i.e., permanent grazing with low yield, normally on poor soils, in mountainous areas, which are not improved by use of fertilisers, cultivation, reseeding or drainage, and which are only suitable for extensive grazing (Bengtsson et al., 2019; James Hutton Institute, 2023). PG can also include grassland no longer used for production purposes, for example grassland used primarily for biodiversity conservation (European Commission, 2021c).

2.2. Interviews with farmers

The interview sample was selected from five case study countries, each representing a biogeographic zone in Europe (Continental/Pannonian: Czech Republic, Boreal: Sweden, Mediterranean: Spain, Alpine: Switzerland, and Atlantic: UK). A map of the study areas is provided in Fig. 1 (reproduced from Tindale et al., 2023). The sample covered three farming intensity types: *High input/intensive conventional farms* (≥1.0 LU/ha); *Low input/extensive conventional farms* (<1.0 LU/ha); and *Certified organic farms.*

Farms were selected from each of the farm intensity classification levels in each country, with the aim of recruiting 25 farms within each classification level in each country. The sampling aimed to cover six main types of livestock production, i.e., beef, dairy, mixed bovines (dairy and beef), sheep/goats, mixed ruminants and other livestock (European Commission, 2018). All the selected farms had more than 5 ha of PG. Research participants were primary decision makers on their farms with more than five years of experience in farming.

The sample was recruited using networks of farmers accessible to the lead partner organisations in each country (Mendel University, University of Cordoba, Swedish University of Agricultural Sciences, ETH Zurich, ADAS UK). These covered/included agricultural professional organisations, farmer cooperatives, organic farmer production associations (Spain), the Swiss Grassland Society, (AGFF), Switzerland), *via* a farmer database managed by Statistics Sweden (Sweden), and social media (Facebook, Twitter). Farmers were recruited to reflect a geographical spread across each country (i.e., the devolved nations of the UK: Wales, Scotland and Northern Ireland), with some focus on key PG areas within countries including the 'dehesa' area of Southern Spain, which is a specialist silvo-pastural landscape (Olea and San Miguel-Ayanz, 2006) and southern Sweden, where the majority of PG farms are located (Trubins, 2013).

Compensation for participation was offered in Switzerland (a retailer voucher valued at 75 CHF), Sweden (500 SEK) and the UK (participation in a prize draw to win 500 GBP). Spanish and Czech farmers participated without financial compensation. This is in accordance with extant research practices in each country. Before conducting the interviews, a screening process took place to check the farm system, location, livestock type and farmer availability. All farmers were provided with information about the interview process and their rights as a participant prior to the interview, and their consent was sought to participate. All farmers agreed to participate voluntarily. Ethics clearance for all research was provided by Newcastle University, 20-TIN-028, August 21, 2020.

In total, 373 farm interviews were obtained. Interviews were conducted between October 2020 and October 2021. Each interview lasted 60–90 min in total (combined quantitative survey-based data collection and qualitative semi-structured interviews) and was conducted in the local language. Most interviews were carried out over the internet or *via* a phone call due to restrictions on travel and face-to-face meetings during the Covid-19 pandemic in many European countries at the time of data collection.

The interviews with farmers were recorded and transcribed in each country and translated into English (if conducted in another language). All translated data were uploaded into a central database for data collation and analysis. Most data were transferred directly as *verbatim* translated transcripts into the database. In a small number of cases, in Spain, (reflecting occasions where audio recording had been refused), interviewers recorded farmers' sentiments and uploaded slightly condensed versions of farmers' answers. This was a limitation of the data collection process.

2.3. Data analysis

2.3.1. Thematic analysis

Themes associated with the qualitative data are reported here. Illustrative quotes from the interviews are provided in Annex 2. The interview protocol is provided in the supplementary materials (1). This research aimed to understand factors influencing current and future farm management decision-making in PG systems, and to identify drivers of (positive and negative) "tipping points" related to land use and management change relevant to the case studies. Farmers were not asked directly about behavioural decisions and tipping points. Rather, evidence of this from interview discussions about decision-making in relation to land abandonment and stocking rates. The approach of thematic analysis recommended by Braun and Clarke (2006) which emphasizes the identification, analysis and reporting of patterns or themes within the data was applied, based on the researchers' judgment, and independent of the frequency of occurrence of data supporting a theme. The analysis applied an iterative process of coding the farmers' responses under different themes derived from the research objectives. Thematic analyses were conducted using NVivo software (NVivo QSR[3]). The codes were reviewed and consolidated to represent common themes and topics. Across the data set, 10% of cases were cross-checked by an additional coder for inter-coder reliability. To identify patterns in the importance of themes, we used cross-tabulations counting themes across biogeographical region, demographic characteristics and farming characteristics (farm type).

Thematic coding entailed inductively categorizing responses into themes based on content, identifying discussed changes in practice as intensification or extensification using iterative processes of checking against previous definitions, e.g., created through the SUPER-*G* PG typology (Tonn et al., 2020), triangulated against other responses given by each farmer, and verified independently by agricultural experts. Knowledge within the coding team was used to clarify uncertainties. Where classification was still uncertain, individual cases were clarified with agricultural expert advisors. Finally, 15% of the activities described (cases) were quality checked by an agricultural expert advisor to ensure consistency of coding.

Land use and land management changes were defined using the Intergovernmental Panel on Climate Change (2000) and Thiery et al. (2018). *Land use change* refers to changes in land cover type (e.g., trees, crops, grasses, lakes, and cities) and the activities, and inputs undertaken in a certain land cover type (a set of human actions). Examples of land use are agriculture, recreational, transport, and residential. PG is a type of agricultural land use, where land use change refers primarily to change of land cover (e.g., forest converted to PG; PG converted to crop land) and land cover sub-type (e.g., PG to temporary grassland). *Land management change* refers to change of a set of practices that aim at the conservation or intensification of existing land use. Examples of land management are irrigation, tillage, grazing, cutting and the application of fertilisers or pesticides (Thiery et al., 2018). Here, land management changes refer to starting/stopping or changing intensity, frequency, duration, or timing of specific practices (e.g., fertilisation, reseeding, cutting, grazing) within the context of elements of the social and economic purposes for which land is managed (e.g., growing grass, timber extraction or ecological conservation), and which relate to land use.

2.3.2. Participant distribution

In most countries, an even sample distribution of farms across farming systems (Organic, Extensive, and Intensive) was achieved. In

[3] QSR International Pty Ltd. (2020) NVivo (released in March 2020), https://www.qsrinternational.com/nvivo-qualitative-data-analysis-software/home.

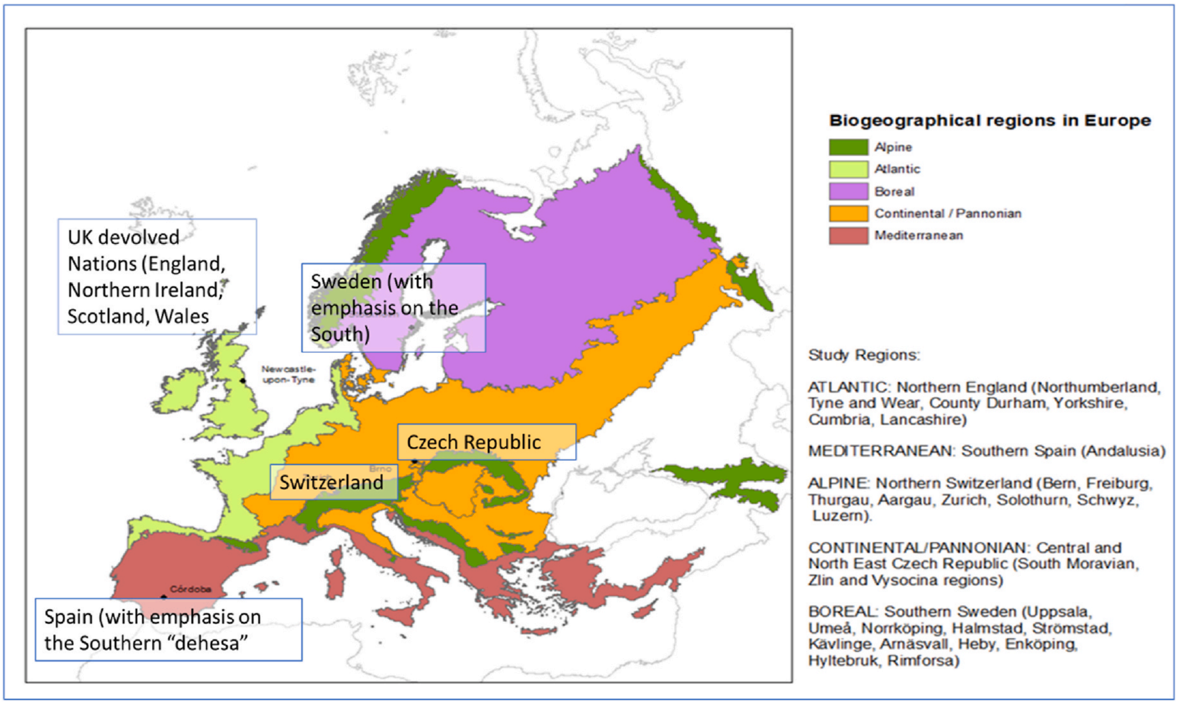

Fig. 1. Map of biogeographical regions of Europe included in the farmer survey (adapted from Tindale et al., 2023). The countries included in the research (Spain, UK, Sweden, Switzerland, and the Czech Republic) covered six biogeographic regions in Europe representing regions within each country containing a mix of grassland landscapes, as well as ecological systems associated with agronomic practices. This enabled understanding of farmers' decision-making across different farming contexts across the European region. Countries where data were collected (in in the case of Spain and Sweden the region where there is more farmed PG) are labelled.

Sweden, participants with organic farming systems were oversampled (to maintain balance across the sample), and in the UK extensive farming systems were overrepresented due to the availability of farmers. As shown in Fig. 2, beef cattle farms were the most numerous. In most countries, one or two livestock types represented most farms (e.g.) dairy farms in Switzerland; beef farms in Sweden; beef and sheep farms in the UK; sheep/goats and mixed other livestock, ruminants and pigs in Spain). Farms in the Czech Republic were associated with the most even distribution of livestock types.

Most farmers owned their land, with a smaller percentage renting land long term (≥ 5 years). Exceptionally, the majority of Czech farmers rented long term (67%), which is representative of national land rights, where 22% of land is owned by farmers. The percentage of farmers who owned land was higher in other countries (Sweden, 88%; Switzerland, 71%; Spain, 71%; UK, 72%).

Most farmers were aged over 40 years old, with a higher percentage of younger farmers (under 40 years old) in Switzerland (33%), and the lowest in the UK (12%). Over 50% of farmers had a higher education (college or university) qualification. Farmers with a higher education qualification were more represented in the UK (95%) and Spain (72%),

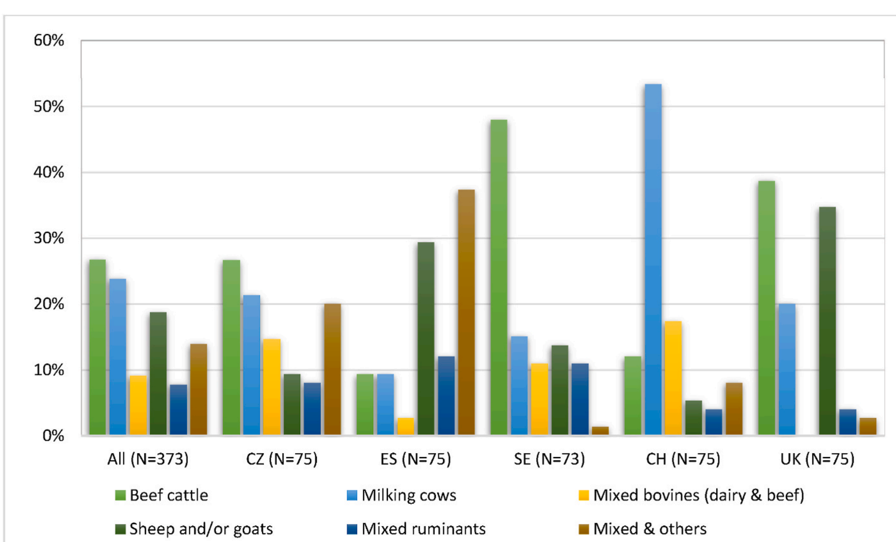

Fig. 2. Livestock types of survey participants' farms (CZ = Czech Republic, ES = Spain, SE = Sweden, CH = Switzerland, UK = United Kingdom). The graph illustrates the distribution of Livestock species across each country (which are found in different biogeographic zones).

with the lowest (8%) in Switzerland. Over 50% of farmers had received full agricultural training, with the highest percentage in Switzerland (87%) and the lowest (13%) in Spain.

3. Results

Thematic codes are presented in Annex 1. ,Table 1, (a and b) provides details thematic codes reflecting farmers 'decision making in relation to land abandonment. Table 2, (a to e) summarise factors influencing farmer decisions in relation to stocking rates.

3.1. *Farmers' perceptions of PG on their farms*

Across all countries, farmers described PG as being often located on difficult terrain described as "steep sloping", or "rocky land". Land used as PG was more often associated with poor soil quality or less productive land. Farmers described PG on their farms as having an important role in the farming system; as being "central"; as "the most important thing"; as "having a high value"; or as "the basis for the farm" primarily in relation to production value in relation to feed, but also in relation to environmental or cultural values. The main purpose of PG in the farming systems was reported to be grazing, with rotational grazing identified as the predominant type of grazing practice. Sowing, or planting seeds, were referenced as an important activity associated with PG, linked to the production of forage, hay, or fodder. PG was noted as having significant use in livestock feed production. Environmental drivers contributed to the reasons for farmers having or maintaining PG. Farmers reported that they wanted to maintain or improve biodiversity, usually because the land was seen to hold some biodiversity value that needed to be maintained, protected, or improved, for conservation, for plant diversity in fodder, the landlord's requirements, special designation of land in relation to the environment, and because this enabled participation in Agri-Environment Schemes. Landscape quality maintenance was mentioned by farmers as an important function of PG land, including mitigation of landslides or erosion. Weather/climate was perceived as a negative driver or reason for having PG on farms. Some farmers mentioned that droughts resulted in inability to repurpose or convert PG to other land uses. Profitability was identified as a reason for introducing and maintaining PG, and many farmers used PG for feed production and grazing, which represented an important source of income. Some farmers described a perceived lack of ability to do anything else with PG due to the poor quality of soil or restrictive topography, or because it would be unprofitable if it was repurposed.

3.2. *Tipping points for future change in PG*

3.2.1. *Case study: land abandonment*

Farmers were asked under what circumstances they would consider land abandonment in their PG Farmers (around 25 % of the total sample) indicated that they would not abandon their PG under any circumstances [1]. This is relevant for understanding the circumstances in which tipping points towards land abandonment are resisted or avoided, particularly where land abandonment is perceived as a negative decision. Many farmers discussed a link to their values, passion, identity and well-being that would prevent them from abandoning PG land [2]. Some farmers talked about having a "passion" for farming, with some expressing negative emotions associated with enforced land abandonment: their emotional links to livestock farming represented a way of life that they were not willing to give up. Farm-related factors were associated with the preservation of land due to its links to livestock grazing, and landscape conservation [3]. Some farmers considered that there would be no need for land abandonment as they already had extensive systems and biodiversity on the farm [4]. Certain activities associated with PG were seen to have benefits that some farmers did not want to lose, e.g., grazing which reduces the risk of fires [5]. We identified both "pull" and "push" factors in the analysis. Pull factors were considered to be factors which attracted or incentivised a farmer to engage in a particular activity, whereas push factors were considered as forces that drive farmers away from a (perceived) negative situation (Verkerk et al., 2018). Where farmers would consider abandoning PG, "push" factors towards the tipping point (i.e., mainly negative reasons that would necessitate abandonment) predominated over "pull" factors (i.e., factors which incentivise abandonment). Economic and regulatory issues were identified as push factors that may trigger the tipping points of abandonment of land. These encompassed general economic concerns, as well as farmers considering PG abandonment if they could no longer make a living from farming it, or if products were not worth the cost of production [6].

In relation to regulation, agricultural policy or direct payment collapse (including changes to the Common Agricultural Policy (CAP)), or regulations that were impossible to follow, were perceived to force some farmers to consider abandonment [7].In addition, farmer-related characteristics such as health issues or lack of a successor were reported to play a role in the decision to "give up" the land [8]. Land management issues (e.g., inability to continue to farm steep topography), predators (e.g., wild boars or wolves) and land rent issues (e.g., lease periods or prices) were also identified by farmers as tipping points for land abandonment [9].Conversely, economic reasons relating to payments for steep areas or less productive land, or higher direct payments were identified as the most important pull factors for land abandonment [10]. Environmental concerns in relation to promoting biodiversity, saving endangered species, or ensuring drinking water supply or quality, and preventing erosion also represented pull factors. Swiss farmers reported considering land abandonment linked most frequently to farmer-related factors. In contrast to other countries, Swiss farmers identified more pull factors when it came to land abandonment, particularly environmental factors [11]. Similar reference was made to pull factors in the UK, predominantly related to payments [12]. Czech farmers referred more to push factors, relating to farm issues (such as land quality and outside threats) and financial reasons (e.g., if the land is no longer profitable) [13].

3.2.2. *Case study: stocking rate changes*

Farmers discussed the circumstances in which they would consider decreasing stocking rates. Some claimed they would never decrease it [14]. Trigger factors described by farmers that influenced their decisions about stocking rates related to the need to adapt to the capacity of the land, resources available, climate, season and economic and regulatory conditions (agricultural policies) [15]. Farmers described different reasons for considering different stocking density choices, which were often linked to farmer-related, and farm-related issues and financial justification. Farmer-related factors included those relating to never considering the decreasing of stocking rates (e.g., the farmer had found a balance of stocking rates on the farm, or because they employ workers to help with livestock and do not want to lose them), as well as continuing with the same stocking rates (no reason for change or change was not possible). These were linked to the practicalities of managing the farm, rather than characteristics of the farmers themselves. When considering the circumstances in which farmers would increase stocking rates, farm-related reasons (improved infrastructure, grassland quality and grazing methods) were described, as well as concerns about policy and farm income requirements [16]. In relation to decreasing stocking rates, lack of resource, poor grass quality, and poor livestock health were described as justification for decisions [17]. Environmental concerns and climate triggers were also identified in relation to decreasing stocking rates (drought, damage to pasture), and as reasons against increasing stocking (damage to pasture) [18].

When the farming intensity type was considered, existing extensive farmers recognised the potential to increase stocking rates in some circumstances, with intensive farmers recognising that there could be problems associated with increasing stocking rates above the carrying capacity of the land [19.20].

Spanish farmers, in particular extensive farmers, were often against changing stocking rates. Swedish farmers from all farm types made most reference to circumstances in which they would consider increasing stocking rates. Farmers from all farm types in the UK (apart from organic farmers), Sweden and the Czech Republic made more reference to increasing, compared to decreasing, stocking rates. Spanish and Swiss famers made more reference to decreasing stocking rates. Together, this may indicate opportunities for positive tipping points to be reached if policy takes account of the drivers of extensification and intensification, and the optimal balance between these in terms of Ecosystem Service delivery from PG.

3.3. Conditions and feedbacks for positive tipping points

The need for PG to be managed sustainably to maximise the potential for a multi-functional landscape that promotes social well-being and environmental sustainability has been recognised in research (Le Clec'h et al. 2019; Huber et al., 2022). Both land use change (maintaining PG, preventing negative land abandonment), and land management change (de-intensification of practices for optimisation of stocking rates in relation to ecosystem delivery) are to be encouraged (Allan et al. 2015; Schils et al., 2022). In order for positive tipping points towards transformation of the system to be reached, interventions, reinforcing feedbacks and supportive conditions need to be in place (see Food and Land Use Coalition, 2021). In interviews, farmers could identify the supporting systems needed for them to be able to deliver improved environmental benefits from their PG (one way in which the positive system change can be conceptualised). These related to changes needed to overcome perceived barriers to managing or maintaining their PG more sustainably, and therefore to avoid reaching negative tipping points. Most, but not all, farmers could specify changes that would be helpful to PG maintenance or management. However, some stated that there was already sufficient support in relation to PG management.

3.3.1. Financial interventions, feedbacks and conditions

Across all countries, the main form of support that would enable farmers to deliver environmental benefits and to retain PG was financial support. This was generally discussed by participants in relation to subsidies and grants, particularly regarding financial compensation and payment for Ecosystem Services and public goods. Farmers expressed a desire for payments and subsidies for added benefits and services (soil health, water quality, carbon storage, biodiversity) they provided (or could provide with incentives) through their PG, particularly highlighting the need for adequate compensation of income lost *in addition* to costs associated with activities to maintain benefits [21].

Some farmers commented on the need for financial support to be flexible and adaptable to circumstances, including those related to weather and climate. This was thought to be particularly important at times of extreme events such as drought or flood, in relation to extra support being available, and in flexibility of restrictions (e.g., cutting date) to facilitate different trade-offs under changing conditions [22].

Adaptation of support conditions to the location was also identified as being important, whether that was the region, or individual farm, some farmers felt financial support should take into account what is possible and beneficial on their land (with advice and guidance). Others stipulated that there was a need to finance exploratory work involved in setting up new measures or technologies and indicated that this need was not often recognised. Specific financial support for organic farmers or intensive farmers was identified as important, including that targeted at certain grassland management activities (e.g., grazing). Institutional and administrative support to enable the financial support systems to be effective was also mentioned as being important. A small number of farmers indicated that such support did not always have to be from government but could originate in the private sector. Several farmers reflected that the quality of products produced, and the costs associated with additional benefits from the land, needed to be better represented in the price of products, and felt this was the way in which their farm systems could remain financially viable [23].

3.3.2. Advice, guidance and educational support

Advice, guidance and educational support were frequently discussed; often as a general need; but sometimes specifying particular needs (e.g. advice on optimising field performance; building farm plans; for small farmers; in relation to understanding environmental and societal benefits from PG; technical support; connections with academics; independent expert advice; and information on access to funding). Training was perceived to be needed specifically in relation to pasture management and ecological management. There was emphasis on the need for peer-to-peer learning networks and demonstrations as effective learning mechanisms [24].

Education was perceived to be needed to communicate the value of PG to the public, to demonstrate the work that was being done by farmers (to value their efforts and role), to explain why the work was done, and demonstrate the ecological benefits of PG to the public. There was a perceived need to encourage consumers to value PG products, as well as "encourage people to respect PG" (e.g., reduce litter when visiting), and to "educate the next generation about how to manage PG". The attitude of the public was seen to be important by farmers, in relation to respecting and understanding what farmers do; supporting farmers, both in terms of accepting management actions (e.g., spreading slurry) and in relation to their awareness of the origin of products and production methods that may inform consumer choices and justify (higher) product prices [25].

3.3.3. Policy structures and advisory support systems

In relation to specific policy support, farmers focused on how strict regulations of environmental schemes can often make them very inaccessible for farmers. Some farmers requested that free consultations by professionals be provided by the government/state to ensure that the farm's potential to produce while providing environmental services is maximised [26]. Other policy support priorities of farmers related to grazing and livestock management, new technologies and pasture care. Many farmers commented on the need for changes, flexibility and adaptation in Agri-Environment Schemes or subsidies, giving farmers more freedom to interpret the regulations, particularly in line with unpredictable circumstances such as droughts, floods or market shocks [27,28].

4. Discussion

Tipping points for PG in relation to both land use and land management changes were explored using an interview methodology, and were considered using two case studies, *land abandonment* and *changes in stocking rate*.

4.1. Tipping points for land use change: risks and opportunities of land abandonment

Land abandonment is an important consideration for future change to PG landscapes, particularly in light of current trajectories of agricultural and environmental policy that encourage taking some land out of production to improve the delivery of environmental Ecosystem Services of landscapes, e.g., for habitat improvement and species diversity, carbon storage, water quality and flood control (Grass et al., 2019). This aligns with policy goals aimed at reducing the carbon impact of farming (e.g. European Environment Agency, 2020; UK Government, 2021), increasing tree planting (or succession into forest/woodland) (e.g. European Commission, 2021b), and re-wilding (European Commission, 2020). These positive goals of land abandonment for environmental Ecosystem Services are often considered in land sparing/sharing debates relating to land policy that aims at utilising the most productive land for food production and the least productive land for environmental

Ecosystem Services (Phalan, 2018; Balmford, 2021) However, land abandonment can also cause concern as unmanaged landscapes can become sources of pests, weeds, disease, viruses or predators for adjacent agricultural land (Lambert and Dudley, 2014; Marini et al., 2011; Stoate et al., 2009), as well as signifying failing financial viability of farming and collapse of agricultural systems (Subedi et al., 2022), together with the loss of cultural elements and social functions of landscapes (Leal Filho et al., 2017; Quintas-Soriano et al., 2022). Farmers considered land abandonment to be associated with negative "push" factors more frequently than more positive 'pull' factors (e.g., promotion of biodiversity and other environmental ES *via* subsidy payments). Triggers for tipping points were associated with farmers' choices to abandon land for negative reasons (e.g., lack of ability to make a living, subsidy collapse, lack of resources, pests, land rent issues, health issues, or lack of farm succession). Around a third of farmers indicated that they would never consider abandoning land, partly because land abandonment militates against their identity as farmers (Jin et al. in press; Burton et al., 2020).

The majority of farmers indicated that they would consider giving up their land for economic reasons, including in relation to ensuring livelihoods, the cost of inputs, and rent costs or lease expiry. Land tenure security in particular could be a key concern in relation to land abandonment (Krčílková and Janovská, 2016). Land issues were also seen as tipping points for abandonment, including contexts where soil quality, or access including topography (Pawlewicz and Pawlewicz, 2023), prevented the land from supporting livestock, or if pests and predators caused too many unmanageable problems. These perceived issues may be linked to external threats including changes in climatic conditions, or land degradation caused by previous management choices. Health issues, age, workload and a lack of a successor were key tipping points for abandonment. These are of significant concern, given the older age of farmers across Europe and concerns surrounding generational renewal (e.g., European Commission, 2021a; May et al., 2019).

The perceived collapse or withdrawal of subsidy support under CAP reform, or national equivalents, was key for driving land abandonment (particularly payment for steep areas), as well as perceived inability to implement regulations, and changes that threatened activities as livestock farmers. Many farmers expressed concern about regulations and policies (e.g., Agri-Environment Schemes) in relation to a lack of adaptation to regional circumstances or difficulty of implementation, which may indicate a significant risk of increased abandonment if difficulties continue. Acknowledging such concerns has resulted in adaptive approaches to schemes being widely trialled, and there is continued interest in outcome-based, or results-based, schemes that are less prescriptive (Elliott and Image, 2018; Wuepper and Huber, 2022). Under hypothetical scenarios, results-based schemes can be seen as acceptable including in relation to grassland (Birge and Herzon, 2019), although effective uptake is only likely where scheme designs acknowledge farmers' motivations, differences in nature values, provide adequate support and advice (Birge and Herzon, 2019), where administrative burdens are reduced, and costs and benefits are communicated (Massfeller et al., 2022). Very few results-based schemes are currently in place across Europe, and there continues to be uncertainty for farmers. Moreover, points of transition in policy (e.g., CAP reform or UK policy change post EU-exit) may heighten farmers' perception of the uncertainty around Agri-Environment Schemes and the perception that withdrawal of financial support would present significant challenges, potentially leading to abandonment.

In the UK and Switzerland, some farmers discussed triggers that would "pull" them towards abandonment, including promotion and protection of biodiversity, water supply protection, erosion prevention, when combined with payments for abandoning land. However, there may be differences in interpretation of land abandonment amongst farmers in different countries, particularly in relation to differing policy contexts and narratives. In the UK, this may be related to recent discussions of payment for Ecosystem Services *via* Landscape Recovery schemes in England and equivalent schemes still under development in the devolved nations of the UK post EU-exit, as well as discourses of rewilding, tree planting and carbon capture. In Switzerland, land is considered abandoned if farmers no longer farm the area, not if they remove management from that land in return for payments from Agri-Environment Schemes.

Discourse in the UK may more often associate land abandonment with schemes such as rewilding, which can offer financial payment for land owners and farmers e.g., government funded nature recovery grants (DEFRA, 2022). As the UK and Switzerland are not part of the EU, they are less impacted by EU agricultural policies. The complexity of the Common Agricultural Policy (CAP), and its current state of reformation, means the issues are affected in different ways by different measures, sometimes with competing outcomes. However, the most recent reform of the CAP (2021–2027) may offer opportunity to address some competing complexities through new voluntary ecological measures in Pillar 1 and the introduction of a comprehensive planning process across all measures (Zavalloni et al., 2021).

Triggers for tipping points may also be affected by policy changes to regulatory limits on reduction in PG area. Currently, in EU legislation, PG area (as a proportion of Utilised Agricultural Area) must not be reduced by more than 5% at national (and sometimes regional) level (Schuh et al., 2020), with proposals to increase this to more than 5%. This change could prevent some farmers abandoning PG, but would need to be balanced against drivers for farmers wanting to make reductions in the PG area on their farm (e.g., threats to their livelihood at multiple scales) and counteract negative impacts through other mechanisms within the wider agri-food system, including change induced by system shocks that increases demand for alternative land uses, for example in relation to increased demand for wheat linked to the war in Ukraine (Júnior et al., 2022).

4.2. Tipping points for land management change: opportunities for creating multi-functional PG

One element of extensification for PG farmers is a reduction in stocking density, where appropriate. A small proportion of farmers were against decreasing stocking density. These farmers were mainly located in Spain and Switzerland and perceived that they had a good balance in relation to current stocking practices. In this case the system was perceived to be stable and resilient. Farmers considering reducing stocking density identified triggers for tipping points related to age and health restrictions, the desire to reduce workload, and improving quality of life. Some acknowledged that it would not be a voluntary choice (driven by agronomic- or policy-related factors), or that they would need to have other income in place. Farmers also stated that the inability of the land to support existing livestock would cause them to reduce stocking density. This included water availability, soil health, and changes of livestock type with different requirements (which may be influenced by a change of product demand). Animal ill-health was also a concern as were economic drivers related to changes in product prices, lack of market or high input costs.

Most farmers focused on the negative drivers of reduced stocking density with only a handful of farmers mentioning tipping points associated with "pull" factors (e.g., if there were incentives to optimise stocking rates or plant trees). Farmers may have most focus on the productivity and profitability of their farm system, implying that supplying non-provisioning Ecosystem Services does not motivate reduced stocking rates, potentially because non-market value Ecosystem Services are not monetised effectively in the current regulations (CAP or national support). If future PG land management is to accommodate multifunctional landscapes and trade-offs at the regional or national scale between food production and environmental Ecosystem Services, non-market Ecosystem Services should be more clearly incentivised through policy support to allow extensive systems to be viable.

4.3. Positive tipping points for PG systems

Farmers required policy support to trigger increased provision of Ecosystem Services, which represents the feedbacks and conditions for positive tipping points in the system (e.g., see Food and Land Use Coalition, 2021). This could include financial compensation and/or payment for Ecosystem Services and public goods, potentially entailing public and private support. At the same time, the market for Ecosystem Services such as those linked to carbon, biodiversity or nutrient credits is not well developed, with payments based on income forgone and costs. Policies should be flexible and adaptable to circumstances (including extreme conditions and events) and location, including biogeographical variation in landscapes which may act as a barrier or facilitator of change. The quality and cost of products could also be better represented in prices, although evidence is needed to indicate that consumers recognise the value of products produced from PG and are willing to pay a premium (see Ammann et al., 2024). Equally, exploration is needed in relation to the extent to which the environmental value can be included in product prices, and how it is likely (or not) to affect the supply of Ecosystem Services.

Communicating the value of PG (and products) to the public may increase positive evaluation of farmers' efforts and justify higher prices, representing a reinforcing feedback in the system. In terms of policies, changes, flexibility and adaptation in Agri-Environment Schemes or subsidies could potentially give farmers more flexibility in delivering Ecosystem Services, particularly in line with unpredictable circumstances such as droughts, floods or market shocks. This could represent the conditions necessary for systemic tipping points by giving farmers capacity to adapt. Easier access to agronomic, soil science and ecological expertise, including, for example, support to buy and use new equipment and machinery, new technology, including satellite data use, as well as expert support on seed mixes and mitigation of environmental damage will be helpful and could be provided through extension or consultancy services.

Financial compensation for Ecosystem Service delivery was seen to be one of the most significant support mechanisms needed for PG to deliver more goods and services. Current payment systems do not align with the understanding of many farmers that PG management should be delivering (more) environmental Ecosystem Services. The analysis of tipping points indicates that few farmers are against making changes to optimise their practices for environmental Ecosystem Service delivery, but perceive that negative circumstances drive them to make changes, with very few farmers acknowledging the role of "pull" factors to deliver more environmental Ecosystem Services. If there was an improved payment system for delivery of public goods such as soil quality, water quality and biodiversity, then farmers may be more likely to carry out activities associated with delivery of multiple Ecosystem Services.

There are many emerging policy initiatives which aim to create the goals and vision for a desired state of agricultural ecosystems, including in the EU Green Deal (European Commission, 2020), and non-EU policies which are implemented in a complex policy environment with multiple overlapping and competing aims. For example, policies focused on food production (e.g., The National Food Strategy in England (The National Food Strategy, 2021) and Scotland's Food and Drink Strategy (Scotland Food and Drink Partnership, 2023)) may compete in complex and as yet unforeseen ways, with climate change policies focused on carbon emissions reductions such as the Paris Agreement (United Nations Climate Change, 2015) enacted through EU policies such as the Green Deal, and non-member-state legislation, regulation and targets such as UK Net Zero targets (UK Government, 2021) Environmental Land Management Schemes e.g. In England,[4] the Environmental Land Management Scheme, ELMS, which aims to incentivise sustainable farming, while at the same time promoting local nature and landscape recovery (DEFRA, 2021), and the Swiss CO^2 Act and Climate and Innovation Act (Swiss Government, 2021, 2023). Given that Ecosystem Service delivery may be considered a "transboundary" issue, there may be opportunities for PG to be more carefully considered as part of this "policy nexus", given the consequences of PG management for significant parts of the food system, linking Ecosystem Service delivery to animal welfare, food policies, climate change goals and social wellbeing ambitions.

Key questions remain around the trade-offs needed between production systems that focus on delivering for food security, particularly induced by times of crisis, and likely future unknown changes in climate leading to acute extreme events, or longer-term vulnerabilities and threats to PG management and maintenance, and extensive (or optimised) systems that can both maintain a livelihood for farmers and deliver multiple environmental benefits. The value of PG for both food production and environmental and cultural Ecosystem Services in each biogeographic region should be better understood, and optimal management promoted in regional policies, contributing to pan-European multi-functionality of PG.

4.4. Limitations of this research and further analysis

This research sampled farmers across the five case study countries, and although the sample represents a split of farm types, some farm categories and associated activities and perspectives were represented more frequently than others. Recruitment of farmers took account of regional differences in most countries, but in some cases, farmers were sampled from the PG representative ecosystem for the biogeographical region (e.g., the Spanish dehesa system in Andalusia). The results therefore demonstrate a range of opinions that may not be representative of the country as a whole. Further, non-agricultural land managers were not included in the interviews given the overall focus of the paper, which was on livestock management in the context of PG and agricultural land -use. Further research might address non-agricultural use of PG in terms of Ecosystem Service delivery (e.g. see Nitsch et al., 2012).

Although a range of farmer and land manager networks known to the authors were used to recruit participants, together with the use of social media to recruit those members of our target group not included on these networks, we acknowledge that some "hard to reach" farmers and land managers could have been excluded. This was exacerbated by lockdowns during covid, which meant that "in person" contact at remote farms could not be initiated at some times and in some countries.

The interviews did not explicitly explore participant responses between maintenance of agricultural activity or its reduction in favour of environmental management. Given that there is a difference between funding to Less Favoured Areas to actively farm versus Agri-environment type payments to reduce livestock numbers, this is an important issue and should be considered in further research.

The translation of interviews into English (although translated and back-translated) also means that some nuances of opinion and perspectives expressed uniquely in native languages will have been lost, where language does not directly translate. This is restrictive on the interpretation of meaning. The involvement of multiple researchers, including many native language speakers from each country within the research team has aimed to reduce (as far as possible) misinterpretation, and strike a balance between understanding cultural nuance and meaning and the ability to compare internationally.

Further consideration of differences in farmers age in relation to their decisions to engage in land use change is warranted. This is relevant because 1). Farmers are more likely to be older in European countries where smallholding is more common (Sutherland et al., 2012; Zagata and Sutherland, 2015), and 2). Farmer age, and farm succession plans, are linked to generational renewal as well as cultural, economic and policy drivers of decision-making (Coopmans et al., 2021; Zorn and

[4] It is important to note that, post Brexit, the developed nations within the UK have, as a consequence of policy freedom in agriculture, diverged (e.g. in relation to retaining some elements of basic payment; Greer and Grant, 2023), although this policy divergence was not in place at the time of data collection.

Zimmert, 2022). In addition, a comparative analysis in relation to perceived policy support for PG introduction and maintenance between different farmers involved in different types of production systems (e.g., organic *versus* conventional) is relevant, given that PG famers and land managers may be differentiated in terms of their farming identity, for example in relation to environmental or protectionist values (Jin et al., accepted). These issues will be the focus of future analysis.

It should be noted that PG covers a broad range of land use categories, from intensively managed improved land to extensively managed rough grazing (e,g see Milazzo, 2023; Tonn et al., 2020). Thus productivity in terms of (e.g.) stocking densities is also influenced by a range of management practices such as use of fertilisers (Francksen et al., 2022) and sward management practices such as overseeding (Mack et al., 2024). Farmer decision-making in relation to these practices could be further considered in relation to these results, as they could have impacts on Ecosystem service delivery.

5. Conclusion

The maintenance and management of sustainable PG systems is important for creating multi-functional landscapes that offer significant socio-environmental benefits. In the face of threats to PG landscapes, consideration of how to create positive tipping points to facilitate critical transitions in grassland systems, as well as the avoidance of negative tipping points, were considered in the context of farmer decision-making. Farmer interviews across five European case study countries have indicated the perceived factors which lead to behaviours driving tipping points in PG systems. This was considered in the context of two case studies, both of which could affect the multifunctionality of landscapes: land abandonment and changes in livestock stocking rates towards intensification or extensification.

The results suggest that farmers tend to perceive that they are "pushed" towards making decisions which result in reduced ecosystem service delivery, rather than being "pulled" towards it by policy changes. Greater perceptions of "pull" could be developed within policy. For example, specific payments for delivery of public goods such as soil quality, water quality and biodiversity might result in farmer prioritisation of "pull" factors and bring about improved Ecosystem Service delivery on their farms. Financial incentives and technical guidance, embedded in policy, may to trigger behaviours which lead to positive tipping points. This could include financial compensation and/or payment for Ecosystem Services and public goods, which are dependent on markets for Ecosystem Services linked to carbon, biodiversity or nutrient credits being better developed. However, bespoke guidance is required in relation to specific agronomic situations to ensure farmers can access such incentives. From the demand side of the system, the extent to which the environmental value can be included in product prices, and how it is likely (or not) to affect the supply of Ecosystem Services, should be considered in the context of increasing positive evaluation of the products of PG on the part of the public. This may reinforce farmers' perceptions of their identity as providers of a range of ecosystem services in addition to food production, but is contingent on interventions being introduced which increase the sustainability of consumers decisions in relation to the products of PG.

Key changes might include land management change towards adoption of more extensive systems, where appropriate, and land use change balancing the benefits, and avoiding the harms, of context specific land abandonment. E However, although the broad goals for the desired state of the system exist in policy and are shared by many farmers, changes to the design and implementation of Agri-Environment Schemes and subsidy programmes are needed to deliver more Ecosystem Services from PG. This will potentially give farmers more freedom to interpret management prescriptions, particularly in line with unpredictable circumstances such as droughts, floods or market shocks. Financial compensation for Ecosystem Service delivery was seen to be one of the most significant support mechanisms needed for maintaining PG that delivers more goods and services. Other factors, including personal values, (perceived) agronomic and topographical barriers, and consumer demand, were also drivers of farmer decision-making. Such considerations are important for transformational change in PG systems.

Declarations of interest

None

CRediT authorship contribution statement

Sophie Tindale: Writing – original draft, Methodology, Investigation, Formal analysis, Conceptualization. **Yiying Cao:** Formal analysis, Conceptualization. **Shan Jin:** Writing – review & editing, Writing – original draft, Formal analysis. **Olivia Green:** Formal analysis. **Michael Burd:** Formal analysis. **Victoria Vicario-Modrono:** Writing – review & editing, Writing – original draft, Methodology, Formal analysis, Conceptualization. **Natasha Alonso:** Formal analysis. **Sydney Clingo:** Formal analysis. **Rosa Gallardo-Cobos:** Supervision, Conceptualization. **Pedro Sanchez-Zamora:** Supervision, Conceptualization. **Erik Hunter:** Methodology, Conceptualization. **Simona Miskolci:** Methodology, Formal analysis, Conceptualization. **Gabriele Mack:** Supervision, Conceptualization. **Nadja El Benni:** Writing – review & editing. **Martina Spoerri:** Writing – review & editing, Formal analysis. **Samantha Outhwaite:** Conceptualization. **John Elliott:** Conceptualization. **Paul Newell- Price:** Writing – review & editing, Supervision, Funding acquisition, Conceptualization. **Lynn J. Frewer:** Writing – review & editing, Writing – original draft, Validation, Supervision, Methodology, Investigation, Funding acquisition, Data curation, Conceptualization.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

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