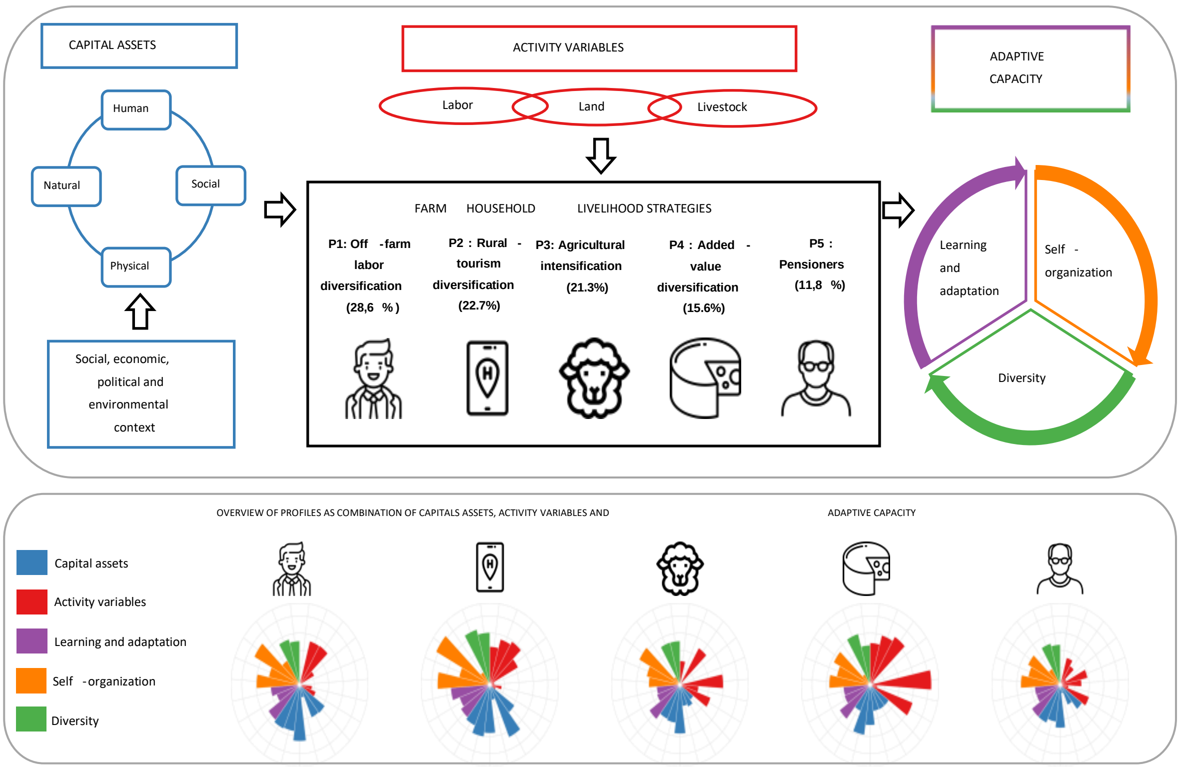
Implementing the livelihood resilience framework: An indicator-based model for assessing mountain pastoral farming systems

HIGHLIGHTS

- ✓ An indicator-based approach designed to characterize the livelihood strategies of farm households in the Spanish Pyrenees.
- ✓ Land, livestock, and on/off farm labor together with capital assets allow identifying five livelihood strategies.
- ✓ Farms intensified or pursued diversification pathways based on off-farm work, rural-tourism, or added-value productions.
- ✓ The rural tourism typology showed higher adaptive capacity (learning capacity, self-organization, and diversity).
- ✓ Policies must acknowledge farms' heterogeneity and limitations in capital assets to pursue diversification strategies.

GRAPHICAL ABSTRACT



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Abstract

CONTEXT

Ongoing decreases in family farms and livestock numbers in European mountain areas are linked to multiple interconnected challenges. The continuity of such farms concerns society at large since they also act as landscape stewards, and their management influences the provision of ecosystem services.

The livelihood resilience lens provides a means of examining how farm households respond and build their capacity to persist, to adapt to changes and shocks, and eventually transform what is understood as farming. While an increasing number of studies address livelihood resilience in different parts of the world, its link with livelihood strategies and how these enhance or erode livelihood resilience dimensions is still missing.

OBJECTIVE

We built and applied an indicator-based framework to characterize the livelihood strategies of mountain livestock farming households in the Catalan Pyrenees (Spain) considering local historical trends, to assess how these strategies contribute to their adaptive capacity.

METHODS

We combined sustainable rural livelihoods and livelihood resilience frameworks and operationalized them to: group farm households with similar livelihood strategies based on their income-generating activities; asses the influence of capital assets and context on the adoption of strategies; and relate these strategies with their performance in three dimensions of adaptive capacity, namely capacity for learning and adaptation, self-organization, and diversity. Information was gathered surveying a sample of 103 farm households.

RESULTS AND CONCLUSIONS

We identified five livelihood strategies showing different degrees of adaptive capacity. Farm households either intensified production (21.3% of the sample) or pursued various diversification pathways based on additional off-farm work (28.6%), rural-tourism activities (22.7%), or added-value production (13.3%). Pensioners (11.8%) had a low endowment of assets and presented the lowest estimates in several dimensions of adaptive capacity. In contrast, diversification into rural tourism scored higher in adaptive capacity, showing greater proactive capacity, farmer organization, and multiple income sources.

SIGNIFICANCE

We explored the multidimensional issues that influence and are influenced by the livelihood strategies and their adaptive capacity at the farm household level. Our work highlights the relevance of including income-generating activities in addition to structural, technical, and socioeconomic variables in characterizing farming systems. It demonstrates the role of farmer involvement in formal and informal social cooperation networks in the sustainability and adaptive capacity of their households. To be successful, diversification strategies may require certain prerequisites in the farms, while strategies based on off-farm activities, although they support improved financial performance of the farm household, could also contribute to the displacement of agriculture from mountain areas.

Keywords: *Livelihood strategies; Farm household typology; Diversification pathways; Adaptive capacity; Latent profile analysis; Three-step approach.*

Implementing the livelihood resilience framework: An indicator-based model for assessing mountain pastoral farming systems

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1 Introduction

Family farms represent more than 96% of the farm holdings in Europe, although this number decreased by 30% between 2005 and 2016 while the amount of land used for production remained steady (Eurostat, 2020). The deep socio-economic transformations since the second half of the 20th century have promoted demographic changes and industrialization, causing land-use polarization towards either abandonment or intensification (MacDonald et al., 2000; Verburg et al., 2010; van der Zanden et al., 2017), which was further encouraged by the Common Agricultural Policy (CAP) (Bernués et al., 2015; Navarro and López-Bao, 2018).

The CAP is one of the principal factors that can explain the developments in European livestock farming systems (Matthews et al., 2006). The CAP provides a unified agricultural policy framework at the EU level. The 2014-2020 CAP is composed of two pillars, where Pillar I supports farm revenues through direct payments subject to cross compliance, including greening payments to encourage farmers to adopt farming practices that help achieve environmental measures and climate goals, while Pillar II funds Rural Development Programs (RDP) with agro-environmental measures. The 2023-2027 CAP will introduce the legal figure of the eco-schemes that can be used to promote more targeted and tailored farming practices for addressing environmental and climate challenges (Meredith and Hart, 2019).

Mountain farming systems represent, on average, 18% of agricultural enterprises in the EU (European Comission, 2009), and livestock production is the dominant output. CAP support has been fundamental in keeping pastoral lands populated and productive, representing as much as half of pastoral revenues in the EU Mediterranean region (Euromontana, 2021). However, the CAP has also contributed to intensification of farming practices in non-disadvantaged areas, abandonment of disadvantaged mountain land, and ultimately has failed to maintain activities and halt the reduction in the number of farms (Gardner et al., 2009; Terres et al., 2015; Veysset et al., 2019; Euromontana, 2021).

The decrease in the numbers of farms and livestock (especially sheep) in mountain areas is linked to multiple interconnected challenges in the form of punctual shocks and long-term stressors that hinder the continuity of extensive livestock farming (Meuwissen et al., 2019). The continuous decline of farming revenues and the constant income gap with respect to non-disadvantaged areas (29%), are two of the main reasons behind the scarcity of successors in mountain farming (European Comission, 2009; Euromontana, 2021). The high opportunity cost of household labor for the young family members relative to more qualified jobs with higher remuneration, together with aspects such as lifestyle, job satisfaction, and working conditions, influence the generational relay and farm continuity (Davis et al., 2009; Bernués et al., 2011; Góngora et al., 2019 ; Nori and López-i-Gelats, 2020). This threatened continuity concerns not only the farm households themselves and their rural communities, but also society at large, since these farms are also landscape stewards whose management influences biodiversity conservation and the provision of a broad array of ecosystem services (ES) (Strijker, 2005; Hoffmann et al., 2014; Dean et al., 2021).

Mountain farming households have enacted adaptation strategies to cope with this situation by increasing the herd size, reducing labor dedicated to farming (García-Martínez et al., 2009) and diversifying their livelihoods, i.e. their capabilities, assets and activities that contribute to a means of living (Chambers and Conway, 1991). Livelihood diversification can occur in multiple ways, ranging from small adjustments that may imply reorganization of land, finances, or labor towards both agricultural and non-agricultural ventures on-farm, but also including off-farm, non-agricultural productive activities (López-i-Gelats et al., 2011). Diversification in farm production may promote economic security at both the farm and regional levels (Abson et al., 2013). The production of value-added products and direct-sale opportunities, especially for milk-producing farms (Toro-Mujica et al., 2015), is seen as another solution to increase revenues, especially with the increase in demand for craft cheeses (Ruiz et al., 2019). Part-time farming may be an adaptation strategy to continue with the farming activity but is related to the existence of off-farm job opportunities that are often linked to tourism development (García-Martínez et al., 2009). The extent to which the opportunities that tourism development provides will increase farm resilience by helping farms to overcome periods of low profitability in their farming activities, in line with the synergy narrative (Vik et al., 2010; Genovese et al., 2017), requires deeper investigation (Muñoz-Ulecia et al., 2021).

Although the drivers of agricultural and land-use change are described in the literature as general processes, the consideration of farm household responses and their characteristics may offer a better framework for understanding the different strategies adopted under common regional environments (Darnhofer, 2010; van Vliet et al., 2015; Muñoz-Ulecia et al., 2021). Thereby, the concept of resilience has gained momentum, providing a means of examining how farm households respond and build their capacity to persist, to adapt to changes and shocks in their systems, and eventually to transform what is understood as farming (Berkes et al., 2003; Folke et al., 2016; Tanner, 2015).

The overall objective of this study was to characterize the livelihood strategies of mountain livestock farming households in light of local historical trends, and to assess how these strategies contribute to the adaptability to the above-mentioned challenges, using a case study in the Catalan Pyrenees (Spain).

Our work elaborated upon the sustainable rural livelihoods (SRL) framework (Scoones, 1998) and the livelihood resilience (LR) framework (Speranza et al., 2014), operationalizing them through a series of quantitative and qualitative indicators adapted to extensive livestock farms. LR assessments adopt quantitative (e.g. Cabell and Oelofse, 2012; Jones and Tanner, 2017; Quandt, 2018; Awazi and Quandt, 2021) or qualitative approaches (e.g. Ashkenazy et al., 2018; Knickel et al., 2018; Jacobi et al., 2018; Nicholas-Davies et al., 2021) and may advocate for the consideration of both objective and subjective resilience indicators (Jones and Tanner, 2017; Jones et al., 2018; Jones et al., 2021). However, their link with livelihood strategies and how these enhance or erode livelihood resilience dimensions is still missing. Our work contributes to fill this gap by linking livelihood strategies with adaptive capacity of livestock farming households. Furthermore, its focus on European farmers represents a contribution to the operationalization of the SRL framework in a different context, which, to the best of our knowledge is missing in the literature.

2 Theoretical framework

This study is theoretically grounded in the conceptual frameworks of sustainable rural livelihoods (SRL) (Scoones, 1998; Ellis, 2000) and livelihood resilience (LR) (Speranza, 2013, Speranza et al., 2014, Tanner et al., 2015).

The livelihood approach describes the resources that people have and the strategies they adopt to make a living. From the SRL perspective, a livelihood is sustainable when it can cope with and recover from stresses and shocks and maintain or enhance its capabilities and assets while not undermining the natural resource base (Chambers and Conway, 1991; Scoones, 1998; Carney, 1998; Carr, 2020). Livelihood assessment requires an interdisciplinary approach, considers a combination of income-generating activities and access to a range of capital assets (Chambers and Conway, 1991; Scoones, 1998; DFID, 1999). The farm household, i.e., a family or group of people sharing the same house and resources, constitutes the unit of analysis (Ellis, 2000; Jiao et al., 2017). Activities are actions taken by the households to produce outcomes, which involve the use of a single asset or set of assets (Winters et al., 2009). Capital assets are the stocks of resources (tangible) and abilities (intangible) of households to enhance their livelihood strategies (Ellis, 1998). Traditionally, they are composed of the five sources of capital: natural, physical, human, financial, and social (DFID, 1999). The multidimensionality of livelihood capital assets reflects their character as tools that allow a household to adopt a livelihood strategy (Ellis, 2000).

The specific combination of activities and capital assets defines the different livelihood strategies (Chambers and Conway, 1991; Winters et al., 2009). Accordingly, we identified livelihood strategy profiles of farming households via their combination of activity variables; then, we employed the pool of capital assets to identify and characterize the households belonging to each of these livelihood profiles (Diaz-Montenegro et al., 2018).

In this study we were interested in understanding whether the identified livelihood strategies contributed to build resilience at the household level. Resilience as a framing concept has been increasingly embraced by analyses of rural livelihoods (Sallu et al., 2005; Twine, 2013; Davies et al., 2013; Tittonell, 2014; Perez et al., 2015; Tanner et al., 2015). The concept of resilience emphasizes the intertwinedness of social and ecological processes and the way they jointly give rise to socio-ecological patterns (Folke et al., 2016; Schlüter et al., 2019). The capacity of livelihoods to buffer systemic shocks while conserving existing functions and structures (persistence) is a central property of resilience (Walker et al., 2004; Folke, 2006; Darnhofer, 2014; Speranza et al., 2014). Withstanding disturbances (i.e., buffer capacity) has been equated with the pool of livelihood capitals in previous research (Speranza, 2013; Speranza et al., 2014; Jacobi et al., 2018)

Previous studies under the SRL framework have assessed the relationship of livelihood strategies with external variables (e.g., Jansen et al., 2006; Walelign et al., 2016; Bhandari, 2013; Díaz-Montenegro et al., 2018). In a similar fashion, we examined the relationship of identified livelihood strategies with adaptive capacity, a key dimension of livelihood resilience to unveil whether the livelihood strategies pursued by farm households contribute to build adaptive capacity. Adaptive capacity is operationalized through three dimensions, namely self-organization capacity for learning and diversity, emphasizing the importance of contextualizing the indicator selection for each of these dimensions (Speranza et al., 2014). Accordingly, we adapted the indicators to the specifics of our socio-ecological context, considering general resilience, i.e., the overall capacity of farming households to adapt or transform in response to unfamiliar, unexpected events and extreme shocks (Folke et al., 2016) rather than resilience to a particular event (e.g., climate change). In this respect, our framework includes indicators that encompass both the farmer's internal capacities (those over which he/she has autonomy) and the contextual factors that lie beyond the influence of his/her own decisions. This involved expanding the framework by incorporating the diversity dimension, a cross-sectional property of resilience that enables adaptability in farm households (Darnhofer and Strauss, 2010).

The operationalization and measurement of LR is specially challenging, mainly when it comes to assessing the transformability dimension of resilience since it implies profound reconfigurations of systems (Tittonell, 2020) and the capacity to cross thresholds into new development trajectories (Folke et al., 2010). Therefore, a farm household typology derived from a survey at a single point may mask important aspects of the trajectory of livelihood transformations through time if historical trends are overlooked (Pelletier et al., 2016; Tittonell, 2014). Our work does not explicitly account for transformability and long-term development due to the limitations imposed by a one-time data collection. However, since it accounts for the changes undertaken by these households in the last 10 years (see section 3.3), this may be considered as an implicit way of encompassing transformability in our work that (partially) compensates for the lack of longitudinal data. The following section describes the main building blocks of our approach: activity variables, capital assets, and three resilience dimensions of adaptive capacity.

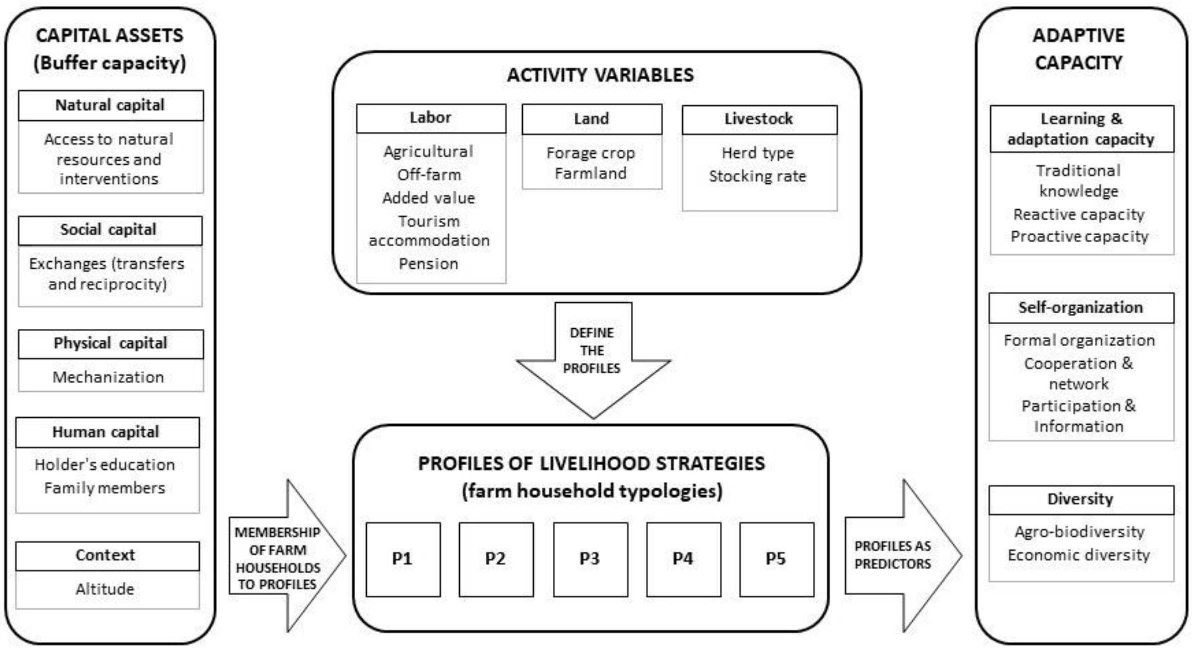

Fig. 1. The overall modelling approach followed considering the SRL and LR frameworks. We first defined the activity variables used as indicators to identify the latent livelihood strategy profiles. In the second step, the capital assets were used as covariates to predict the households' correspondence to the latent profiles. In the third step the latent livelihood profiles identified in the previous two steps acted as predictors of three resilience dimensions,

i.e., learning and adaptation, self-organization, and diversity. Source: authors' own elaboration, based on Diaz-Montenegro et al. (2018) and Speranza et al. (2014).

3. Methodological framework

We identified three core sets of variables to operationalize the SRL and LR frameworks, namely, activity variables, capital assets and adaptive capacity (**Table A1**).

3.1 Activity variables

The criteria for selecting activity variables applied in this study considered land, livestock, and labor of farm household as the main productive assets of small livestock farming households (Jansen et al., 2006), resulting in eight activity variables (**Table 1**).

Forage crop farmland comprised the proportion of land allocated to foraging crops with respect to meadows since, beyond the communal alpine lands (i.e., forest and pastures), these are the key element defining the constraints in the quantity of feedstuff available for winter feeding (López-i-Gelats et al., 2011). The stocking rate considered the availability of utilized agricultural area (UAA) (equivalent to forage surface in mountain livestock farming because of absence of cash crops) per livestock unit (LU) as a proxy for the degree of intensification of the system (Bernués et al., 2004; Riedel et al., 2007; Riveiro et al., 2013; Muñoz-Ulecia et al., 2021), whereas the herd type indicator described whether the productive orientation of the farm was either in large livestock (cattle/horses) or small ruminants (goats/sheep), according to the livestock species that held the highest value of Livestock Units (LU).

Workforce composition, i.e., family, wage workforce and activities, is a constitutive part of households (Dedieu, 2019). Furthermore, labor can be crucial in the trajectories of change of livestock farming systems (Aubron et al., 2016). Thus, we considered five labor related variables (see Table 1). Hired agricultural labor and off-farm wage labor were estimated based on the annual working unit (AWU) (i.e., the labor performed by one person in a full-time contract in one year), where the later indicates labor diversification into off-farm activities and other sources of income. The variables added-value activities and tourist accommodation indicate labor diversification on farm activities, related to farming or tourism, respectively. Finally, we also identified pension earnings since these can be the main source of income for retired farmers (Sutherland et al., 2019).

Table 1. Livelihood activity variables.

Dimension	Variable	Description	Type	Value range

Labor	Hired agricultural labor	Proportion of hired labor with respect to family labor within the farm, in AWU (%)	Continuous	0-67
	Off-farm wage labor	Proportion of non-agricultural family labor with respect to family labor, in AWU (%)	Continuous	0-80
	Added-value activities	Composite index indicating organic certification, fattening (in addition to breeding), and product-transformation facilities at the farm	Ordinal	0. Low 1. Medium 2. High
	Tourist accommodation	Indicates whether they own a rural guest house	Nominal	0. No 1. Yes
	Pension	Proportion of retirement income with respect to the total family income (%)	Continuous	0-70
Land	Forage crop farmland	Proportion of forage crops with respect to meadows, in ha (%)	Continuous	0-100
Livestock	Stocking rate	Ratio of livestock units per utilized agricultural area (LU/UAA)	Continuous	0.13-13.3
	Herd type	Dominant livestock type in the herd: either large (horse, cattle) or small (sheep, goat) species	Nominal	0. Cattle or horses 1. Sheep or goats

AWU, Annual working unit: refers to the labor performed by one person in a full-time contract in one year

UAA, Utilized agricultural area: the total area available in the farm (in ha), including meadows (both mowing and grazing as well as rainfed and irrigated) and forage crops, both owned and rented

LU, Livestock unit: herd size equivalent to adult cows weighing 380 kg that gestate and wean a calf; obtained by applying a coefficient to the number of animals according to species and age.

3.2 Capital assets and farm household context

Five variables were included, capturing four types of capital assets (**Table 2**). Natural capital comprised the goods and services that farm households obtain from the ecosystem in the forms of water, arable land, livestock pasture, forest resources, fertility, etc. (Flora et al., 2004). Natural capital was included as a composite index (ordinal variable) that reflected the benefits that the farm obtains from the ecosystems. The index was calculated by giving one point each to the existence of access to natural resources (i.e., irrigation water, alpine pastures), communal forest products (i.e., wood, firewood, mushrooms), and access to communal forest land. Physical capital represented infrastructure such as roads, buildings, waterers, etc., and production assets such as machinery, equipment, technology, and tools that support livelihoods (DFID, 1999). This variable has been used in previous studies to measure technology adoption as a proxy for farm dynamism (Riedel et al., 2007). In our case, the degree of mechanization of the farm, measured in horsepower (HP), was employed as a proxy for this dimension. Despite facilities/buildings are determinant of physical asset, the degree of mechanization of the farm, measured in HP was even more relevant as pointed out by López-i-Gelats et al., (2011) and Riveiro et al. (2013). Human capital enables the use of other capital assets in order to develop income activities, and represents the availability of labor, family involvement, abilities, skills, experience, knowledge, and health (DFID, 1999). Similarly to previous studies, we addressed it by considering both the farm owner's education level and the number of family members in the household (Martin-Collado et al., 2014; Muñoz-Ulecia et al., 2021). Social capital refers to interactions among individuals in the community network, and their relationships of trust, reciprocity, exchange, and participation that strengthen their ability to cooperate and increase their access to institutions (DFID, 1999). Social capital was assessed through a composite index capturing the degree of exchange and reciprocity of labor, equipment, and infrastructure between the household and other community members. Financial capital includes the stock of money in the form of debts, loans, or pensions (Amekawa, 2011). Financial capital indicators were not explicitly included in our estimates since access to bank loans and having credits were found to be strongly correlated to physical capital variables, and models that included them explicitly performed considerably worse in information criteria as compared to those that excluded financial capital indicators (see **Table B1-B5**).

Finally, we included the altitude of the farmstead as a proxy indicator of its geographical context to assess whether it affects the typological characterization of the households (Muñoz-Ulecia et al., 2021). Further, protected areas belonging to Natural and National Parks are mostly located at higher altitudes, where a higher prevalence of wild ungulates or predators such as bears has been reported. The greater influx of tourists to these areas might also cause conflicts in terms of coexistence with the livestock farming activity.

Livelihood capitals and altitude were employed in the modelling process to characterize the household belonging to each of the livelihood profiles identified according to the SRL framework.

Table 2. Variables for livelihood capital assets.

Dimension	Variable	Description	Type	Value range
Natural capital (NC)*	Access to natural resources	Access to natural resources, communal forest products, and access to communal forest land	Ordinal	0. Low 1. Medium 2. High
Social capital (SC)*	Exchanges (transfers and reciprocity)	Degree to which in-farm labor, facilities, and machinery are shared with neighbors and other farmers	Ordinal	0. Low 1. Medium 2. High
Physical capital (PC)	Mechanization	Total machine power available on the farm, measured in horsepower (HP)	Continuous	35-500

Human capital (HC)	Farmer education	Highest educational level of the head of the farm.	Ordinal	1. Primary 2. Secondary 3. University
	Members in the family	Number of members in the household	Continuous	1-6
Farm household context	Altitude	Altitude (meters above sea level) as a proxy for increased harshness, remoteness, and potential trade-offs with other land uses	Continuous	451.8-1650

* NC and SC are composite indexes calculated by adding one point according to the presence of each of the factors that comprise the index (the range of the index is thus equal to the number of factors considered).

3.3 Adaptive capacity

Three major dimensions of adaptive capacity were modeled as external variables predicted by the livelihood profiles (**Table 3**), namely capacity for learning and adaptation, self-organization, and diversity (Milestad and Darnhofer, 2003; Milestad, 2003; Speranza et al., 2014).

Capacity for learning and adaptation

Learning capacity connotes adaptive management, i.e., the ability to adjust in the face of changing external drivers (Darnhofer, 2014), drawing upon knowledge accumulated in previous experiences and incorporating it into current actions (Speranza et al., 2014; Davoudi et al., 2013; Ashkenazy et al., 2018).

Diversity in possible responses is vital to adaptability (Marten, 1988), and involves both the reactive capacity to cope with and adjust to threats and the proactive capacity to anticipate and create possibilities and opportunities from threats (Obrist et al., 2010). Reactive strategies are short-term responses to fast changes but can develop into adaptive strategies (Berkes and Jolly, 2001). We assessed the reactive capacity as an ordinal variable which considers the number of structural and managerial changes implemented over the last 10 years with regard to the location of grazing and herd mobility areas and routes, breed orientation, livestock census, territorial basis, and marketing channels. The proactive capacity involves anticipating and implementing changes to increase long-term positive farm outcomes when dealing with change (Milestad and Darnhofer, 2003; Obrist et al., 2010). Proactive capacity was addressed as an ordinal variable indicating the number of changes in farm management implemented over the last ten years to face eight different challenges: 1) unpredictability of the weather and increased drought periods; 2) reduced availability of specialized and skilled workers; 3) reduced economic viability of farms due to low perceived prices of their products; 4) coexistence with increasing numbers of ungulates and predators; 5) new tourism demands; 6) increased regulations for protected areas;

7) increased burdensome paperwork and legal requirements; 8) reduced profitability of forest products and forest management. Both reactive and proactive capacities account for the strategies put in place by the farmers to deal with contextual factors that somehow influence their activities and lie beyond the direct influence of their decisions.

In contrast, location-specific experiential knowledge alludes to the farmer's internal capacities, which are key for boosting local farmer-driven innovations that can contribute to building adaptation and hence resilience (Knickel et al., 2018). Berkes et al. (2000) refer to traditional ecological knowledge (TEK) as "a cumulative body of knowledge, practice, and belief, evolving by adaptive processes and handed down through generations by cultural transmission, about the relationship of living beings (including humans) with one another and with their environment." TEK was addressed in a dedicated section of the questionnaire containing 14 items that served to build a composite index by summing the awareness and experience of farmers on the use of traditional veterinary remedies, traditional use of plants, scavenger fauna, conservation of dry-stone walls, and preferences and customs on animal handling and feeding.

Self-organization

Self-organization encompasses the internal control of the farm household through endogenous interactions and processes that enable it to be reorganized and adapt under conditions of crisis and instability (Holling, 2001). It also reflects the ability of the farm household to build flexible networks and be involved in social, economic, and institutional decisions at different scales (Milestad, 2003), and highlights how human agency, adaptive capacities, and social interactions shape social resilience (Obrist et al., 2010; Speranza et al., 2014).

To address self-organization, we considered four ordinal variables: the membership of farmer to formal interest groups, the structure and size of farmer cooperation network, his/her participation in informal groups to access information and the reliance on own resources.

Participation in formal interest groups such as associations and cooperatives allows farmers to stay informed about new opportunities, provide resources, services, knowledge and promote cooperation, enhancing opportunities for adaptive capacity (Carpenter et al., 2001; Kangogo et al., 2020).We accounted for the number of such groups the farmer was a member of.

Cooperation networks serve as support to farmers for performing farm labour tasks, increases trust and social cohesion, and enable collaborative interactions to manage disturbances (Speranza et al., 2014). The size and structure of the cooperation network was accounted in terms of the number of people involved and their frequency in supporting farming duties.

Participation in informal groups to access information considered the leadership and active involvement of farmers within the community, the use of communication technologies tools such as emails and social media apps and their participation in seminars, workshops, and courses to acquire farm-related knowledge and skills in the last year.

The reliance on own resources reduces dependency and reflects the capacity of farm households to sustain themselves with their inputs to permit rapid reaction to change (Speranza et al., 2014). It was calculated as the inverse of the sum of the external resources used by the farm household that are listed in **Table 3**.

Diversity

According to Darnhofer (2010), diversity at the farm level encompasses biodiversity (including agro-biodiversity) as well as diversity of economic opportunities, resources, and sources of information. The former was captured by considering the variety of forage crops, animal species and breeds in the farm. The latter accounted for the number of income sources and sale channels for the farm's products.

Table 3. Livelihood adaptive capacity variables

Dimensions	Variables	Description	Value range*
Capacity for learning and adaptation	Traditional ecological knowledge	Knowledge about traditional use of the environment	3-13
	Reactive capacity	Number of structural and management changes implemented over the last 10 years	0-7
	Proactive capacity	Number of coping strategies implemented over the last 10 years to face global change and create possibilities and opportunities from threats	2-11
Self-organization	Farmer organization	Memberships in formal interest groups	1-5
	Social cooperation network	Structure and size of the social network (number of people involved)	0-8
	Participation to access information	Involvement in informal groups and use of information and communication technologies	0-7
	Reliance on own resources	Degree of self-sufficiency and independence from external inputs bought in the market, according to purchases of dung for fertilization, chemicals products, supplements, livestock feed (for reproduction and fattening), machinery rental, facilities, land, and labor	0-1
Diversity	Agro-biodiversity	Diversity of forage crops, species, and breeds on farm	3-15
	Sources of income	Diversity of income sources and marketing channels	5-7

* All variables are ordinal and higher values are perceived to contribute positively to resilience

4. Material and methods

4.1 Study area

The case study was carried out in the Mid-Eastern Pyrenees, in the counties of Pallars Sobirà (PS) and Pallars Jussà (PJ) which constitute the Pallars region (Catalonia, Spain; **Figs. 2**. **a,b**). PS is located at higher altitudes on the more mountainous northern side of the region, on the border between Spain, France, and Andorra, while PJ occupies the lower part of the valley, on the southern part of the region. The entire region extends over 2721 km^2 along the Noguera Pallaresa valley, with altitudes ranging from 421 to 3143 m.a.s.l. Pallars is home to 19,829 inhabitants, representing the lowest population density in Catalonia with 7.36 inhabitants/km^2 (Idescat, 2021). Small family livestock farms have traditionally been the base of economic activity in Pallars. Livestock management relies on the seasonal use of natural resources through herd mobility practices moving between communal alpine pastures in summer and privately owned hay meadows and forage crop lands at lower altitudes in winter (López-i-Gelats et al., 2011). Nowadays, farming is losing prominence amidst increased tourism-oriented and recreational activities that are redefining the identity of the region (Vaccaro and Beltran, 2007), in part due to the vast network of natural protected areas (**Fig. 2. c**).

Farm abandonment in marginal areas and intensification in more suitable areas are the main processes that have been shaping farming in the Pyrenees since 1950 (MacDonald et al., 2000; Mottet et al., 2006; Lasanta et al., 2017). This is also the case in Pallars, where the livestock census reflects a general decline in the number of farms (specially in PS) alongside increases in bovine and equine herd sizes and a decrease in ovine herd sizes.

The rural exodus in the region has been partially reversed in recent decades due to the arrival of migrants, shifting towards slightly positive population growth trends in both PS and PJ (**Fig. 3**). This new urban-rural migration or counter-urbanization process may be motivated by either economic reasons, such as growth expectations related to tourism-related businesses and the low cost of living, or by motivations associated with the higher quality of life close to nature, social relationships and culture (Paniagua, 2002). The coexistence of traditional residents with tourists, returnees, and neo-rural persons are considerably changing the conception of rurality in the area (López-i-Gelats et al., 2009).

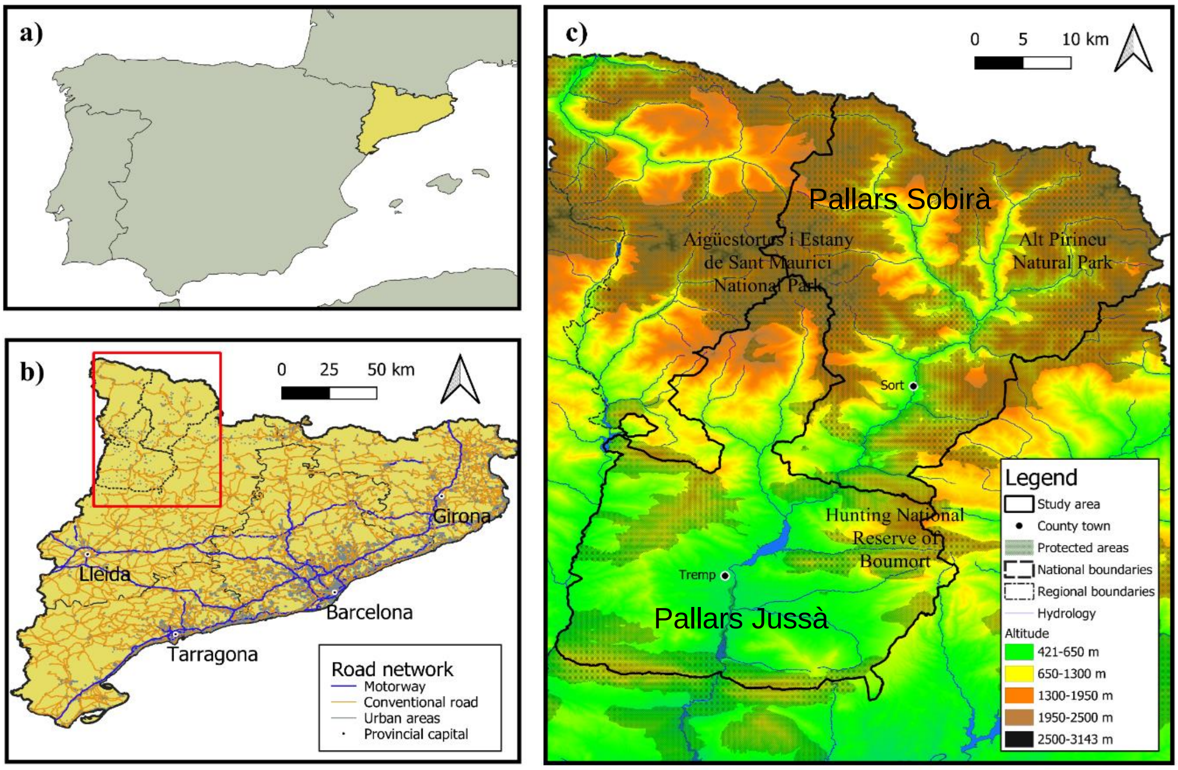

Fig. 2. a) Location of Catalonia within Spain and **b)** the Pallars region within Catalonia and **c)** its two counties, Pallars Jussà (PJ) and Pallars Sobirà.

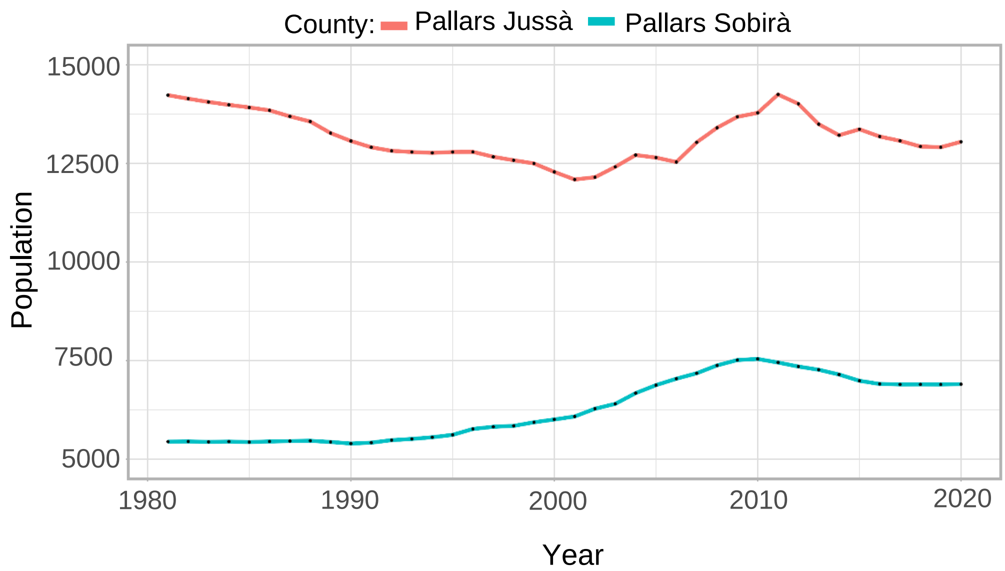

Fig. 3. Historical population in Pallars Jussà and Pallars Sobirà counties (1981–2020). Source: Idescat (2021).

4.2 Modelling approach

Latent class analysis (LCA) is a statistical tool widely applied in social studies to identify unobserved segments or subgroups (i.e., latent classes) within heterogeneous populations (Tein et al., 2013). Initially introduced by Lazarsfeld (1950), LCA differs from other segmentation techniques such as factorial analysis or cluster analysis in that the assignment of cases to segments or subgroups lies in the probabilistic definition of distance rather than in the Euclidean distance. This probability-based mixture modelling provides some advantages such as optimization of the model selection with rigorous statistical tests or measurement of errors in cluster allocation and the possibility of combining continuous and categorical (nominal and ordinal) variables (Magidson and Vermunt, 2002). When LCA modelling involves continuous variables, it is termed latent profile analysis (LPA).

The three-step approach is a variant of LCA enabling not only the determination of classes or clusters but also their relation to other external variables. These may be covariates that influence the classes (Vermunt, 2010), distal outcomes influenced by the classes (Bakk et al., 2016), or both (Nylund-Gibson et al., 2019; Vermunt and Magidson, 2020). While covariates can be used to identify characteristics that predict latent class membership by employing logistic regression, and hence explain the differences between latent classes (Collins and Lanza, 2010), distal outcomes are often considered as consequences of latent class membership, and consequently do not directly influence the class allocation of observations (Nylund-Gibson et al., 2019).

We adopted the bias-adjusted three-step approach proposed by Vermunt (2010) and Bakk et al. (2013) to build a LPA model combining a set of variables and both covariates and distal outcomes. The downward bias that may arise in estimating the association between class membership and external variables (Bolck et al., 2004; Vermunt, 2010) was overcome by adopting the direct maximum likelihood (ML) correction method for standard error (SE) estimation (Vermunt, 2010). This approach considers the following three steps developed in a single optimizing procedure: 1) building a latent profile for a set of response variables (activity variables); 2) assigning farm households to latent (livelihood) profiles based on posterior class membership probabilities; 3) examining the associations between profile membership and external variables (adaptive capacity).

Step 1: Estimating a latent profile model

The first step involves identifying the best-fitting unconditional latent profile model with covariates and saving the posterior probabilities and modal class assignment for that model. The observations, Y_i, are modelled as arising from T unobserved profiles (X):

$$P(Y_i|Z_i) = \sum_{t=1}^{T} P(X=t|Z_i) \prod_{k=1}^{K} P(Y_{ik}|X=t) \qquad (1)$$

where: $P(Y_i|Z_i)$ represents the probability of observing a particular response pattern (vector of responses), conditional on the covariate value; Z_i; $P(X=t|Z_i)$ is the probability of belonging to the latent class *t*, conditional on the covariate value; $P(Y_{ik}|X = t)$ is the probability of response pattern Y_i, conditional on belonging to profile *t*. Therefore, the model assumes that the *K* indicator variables are mutually independent within profiles given the latent variables *X* and covariates *Z*, which is known as the local independence assumption.

$P(X = t|Z_i)$ is parameterized using a multinomial logistic regression model, where α_t and β_t are the intercept and slope coefficients, respectively (Bakk et al., 2016):

$$P(X = t|Z_i) = \frac{e^{\alpha_t + \beta_t Z_i}}{1 + \sum_{t=1}^{T-1} e^{\alpha_t + \beta_t Z_i}} \qquad (2)$$

Step 2: Calculating the profile membership

In step 2, the farm households, *i*, are assigned to the latent classes based on their posterior class membership probabilities. Following Bayes' rule, the posterior probability of belonging to profile *t* is:

$$P(X_i = t|Y_i|Z_i) = \frac{P(X_i = t|Z_i)P(Y_i|X = t)}{P(Y_i|Z_i)} \quad (3)$$

This process creates a new variable, W_i, which describes the assigned profile membership of farm household *i*. Resulting classification errors from the difference between the observed latent variable (*X*) and the assigned profile membership (*W*) for each farm household i can be quantified as: P (Wi = s|X = t) (Bakk et al., 2013; Bolck et al., 2004; Vermunt, 2010). The posterior profile membership conditional on the true value can be expressed as:

$$P(W_i = s|X = t|) = \frac{\frac{1}{N}\sum_{i=1}^{N} P(X_i = t|Y_i)P(W_i = s|Y_i)}{P(X = t)} \qquad (4)$$

Step 3: Relating estimated profile membership to external variables

The third step involves specifying a new analytical model which relates the latent profiles through the indicator of class membership, *W*, with another external variable, *V*. In contrast to the external variable used in Step 1 as a covariate, Z_i, which acts as a predictor of the farm household membership to the latent profiles, this external variable, *V*, is predicted by the latent profiles:

$$P(W_i = s|V_i) = \sum_{t=1}^{T} P(X = t|V_i)P(W_i = s|X = t) \qquad (5)$$

where P (Wi = s|X = t) is fixed to the estimated values from Step 2, and P (X = t|Vi) contains the logistic parameters to be estimated. Next, just as with the simultaneous LTB approach, with the estimated values for P (X = t|Zi), the class-specific means of *Z* are calculated using Equation 6 (Bakk et al., 2016):

$$u_t = \sum_{i=1}^{N} \frac{P(X=t|V_i)}{NP(X=t)} \qquad (6)$$

4.3 Data collection and analysis

We surveyed 103 farming households in the Pallars region (47 in PJ and 56 in PS) between May and October 2018. Surveys were carried out with the head of the farm (the farm holder), conducted in the Catalan language by two experienced facilitators and lasted 1–2.5 hours. Audio was recorded with the participants' permission. The research procedure was approved by the Chair of the Ethics Committee of the Center for Agrofood Economy and Development (CREDA). Respondents were recruited by following a snowball sampling technique (Bernard, 2006). Information about the research objectives was also provided to the participants in paper and digital formats. The sample accounted for 16% of all farms in the territory assuming a sampling error of ±8.9 at 95% confidence level (INE, 2019).

We used a semi-structured questionnaire to gather information addressing the different dimensions of livelihoods and adaptive capacity. Specifically, the questionnaire encompassed eight sections: i) land and herd size, composition, and management, ii) family composition and labor dimensions, iii) farm facilities and machinery, iv) economic considerations such as commercialization of products, income sources, aid, and subsidies v) involvement in social networks, participation, organization, and trust vi) adaptive capacity to face challenges of global change, vii) TEK, and viii) opinions, perceptions, and attitudes towards regulations for protected areas, wildlife, and the future of mountain livestock farming. To design the questionnaire, five preliminary surveys were carried out in April 2018, which were used to refine and adapt the set of indicators for the particular social–ecological context of Pallars together with key stakeholders in the area (i.e., managers of protected areas, managers of the shepherds' school, foresters, veterinarians).

We conducted descriptive statistical analyses of the collected data to identify the main characteristics of farming households. We assessed whether the county (whether the farmstead is located in PS or PJ) had a significant effect on the studied variables by using either non-parametric Mann–Whitney U tests or ANOVA for normally distributed data in continuous variables, or a Chi-square test for categorical variables. Correlations between continuous variables were computed through Spearman rank correlations, while Cramer's V coefficient was employed for categorical variables to remove collinearities. The final set of variables was modeled in a latent profile analysis

Following an initial data analysis, all participants were sent a summary of the preliminary results in the format they desired (either through email or a WhatsApp message). Then, all interviewees were invited to participate in one of the two workshops held in two municipalities (one in PS and one in PJ) in July 2019 for the return and validation of the results. These workshops also provided an opportunity for in-depth discussions of the identified livelihood strategies, different challenges for mountain pastoral livestock systems, and options for improving the integration of their products into local value chains.

5 Results

Farmsteads were located at a mean altitude of 1023.9 m.a.s.l. (SD=264.0; range 451.8–1649.5). The mean age of the livestock farm holders sampled was 48.3 years (SD=13.9; range 22–79), of which women represented 13.5%. Cattle farms were the most common (48.7%), followed by sheep (39.3%), equine (10.5%), and goat (1.5%) farms, with an average of 110.7 livestock units (LU) per farm (SD=94.0; range 7.2–470.4). The utilized agricultural area (UAA) was 73.2 ha per farm (SD=99.2; range 5–500). Meadows (53.7%) dominated over forage crop lands, and the rented property regime (50.8%) was similar to the owned land. The average workload per farm was 2 annual working unit (AWU) (SD=1.0; range 0.5–6.5), of which 20% was carried out by hired workers, while 63% of family labor was invested in non-agricultural jobs.

There were some differences found in the farming households between PJ and PS (**Table A2**). Farm households in PS were located at higher altitudes, held large livestock species and more surface of irrigated meadows whereas farm households in PJ were larger both in herds and farmland, had more importance forage crops and sheep productive orientation.

5.1 Profiles of livelihood strategies

The five-profile model provided the best equilibrium between parsimony, information criteria, plausibility and explicability of results (**Table 4** and **Table A3)** and local independence assumption (**Table A4**)**.** Profile 1 (P1) comprised 29% of the sample. It involved farms based on meadows where almost half of the household's labor (42%) was allocated to off-farm activities and no external workforce was available. We labelled this profile the off-farm labor diversification strategy. Profile 2 (P2) accounted for 22.7% of the farm households and was distinguished by the feature of owning rural tourism accommodation. These households held herds of large herbivores (cattle and horses) that mainly fed on meadows and were managed by external workers while household labor focused on tourism-oriented activities. Profile 3 (P3) encompassed 21.3% of the farm households, wherein family labor was exclusively allocated on-farm to manage the largest stocking rate found amongst the five profiles (3.5 LU/ha). Profile 4 (P4) accounted for 15.5% of farm households and was characterized by their involvement in value-added production through specialization in organic farming and on-farm fattening (in addition to breeding) as well as product transformation, with land mainly allocated for forage crops (84.3%). Similarly to P2, farm labor in P4 was mainly undertaken by hired workers while household members performed added-value activities. Profile 5 (P5) covered the remaining 11.8 % of the sample, encompassing farm households where pensions were an important source of income (representing 29.3% of total income).

Table 4. Characterization of the five livelihood strategy latent profiles identified. The mean value and standard error (SE) are provided for each variable. In the case of categorical variables, the conditional probabilities are shown within the profiles for the different levels of these variables.

	Profile 1 Off-farm labor diversification strategy	**Profile 2** Rural-tourism diversification strategy	**Profile 3** Agricultural intensification strategy	**Profile 4** Added-value diversification strategy	**Profile 5** Pensioners		
Profile Size (%)	28.6	22.7	21.3	15.6	11.8		
Activity variables	**Mean (SE)**	**Mean (SE)**	**Mean (SE)**	**Mean (SE)**	**Mean (SE)**	**p-value** [a]	**R^2**
Hired agricultural labor	0 (0.003) ***	0.30 (0.045) ***	0.19 (0.037)	0.33 (0.055) ***	0 (0.008) ***	0.000	0.447
Off-farm labor	0.420 (0.044) **	0.439 (0.044) ***	0 (0.005) ***	0.477 (0.029) ***	0.261 (0.071)	0.000	0.483
Added-value activities	1.062 (0.110)	1.176 (0.120)	1.001 (0.128)	1.309 (0.145) ***	0.514 (0.160) ***	0.009	0.123
0. Low	0.148 (0.055)	0.095 (0.046)	0.185 (0.069)	0.066 (0.041)	0.517 (0.137)		
1. Medium	0.643 (0.052)	0.633 (0.060)	0.630 (0.053)	0.559 (0.081)	0.452 (0.115)		
2. High	0.210 (0.066)	0.271 (0.083)	0.185 (0.070)	0.375 (0.110)	0.031 (0.026)		
Tourist accommodation						0.085	0.145
0. No	0.772 (0.076)	0.562 (0.100)	0.960 (0.039)	0.936 (0.060)	0.904 (0.086)		
1. Yes	0.228 (0.076)	0.438 (0.100) ***	0.040 (0.039)	0.064 (0.060)	0.096 (0.086)		
Pension	0.952 (0.416) ***	4.620 (1.270)	2.641 (0.886) ***	1.875 (0.929)	26.896 (6.832) ***	0.000	0.443
Forage crop farmland	3.686 (1.372) ***	6.738 (1.876) ***	59.776 (8.843) ***	84.346 (5.126) ***	29.292 (8.192)	0.000	0.654
Stocking rate	2.430 (0.318)	2.334 (0.263)	3.539 (0.657) **	1.475 (0.280) ***	1.652 (0.278)	0.002	0.124
Herd type						0.047	0.148
0. Cattle or horses	0.763 (0.078)	0.911 (0.059) **	0.552 (0.107)	0.379 (0.120)	0.578 (0,142)		
1. Sheep or goats	0.237 (0.078)	0.089 (0.059)	0.449 (0.107)	0.621 (0,120) ***	0.422 (0,142)		

[a] Associated with overall Wald test. *** z-value >2.575; ** z-value >1.960; * z-value >1.645

5.2 Capital asset variables for prediction of profile membership

The second step in the model involved assessing the influence of capital assets and altitude as predictors of belonging to the livelihood strategies. **Table 5** shows the β coefficients of these variables in each profile (mean values can be found in **Table A5** and **Fig. A1**). Physical capital (mechanization) and social capital (exchanges) were, by far, the most influential variables in predicting correspondence to the profiles, while the remaining variables significantly discriminated at least one profile. Farm households with more access to physical capital were more likely to belong to P3 or P4. The higher the score in social capital (exchanges), the more likely that household was to belong to P2, while the opposite was true for P3. A higher level of education of the farmer predicted association with P1 while the opposite applied for P4. The households with smaller families were more likely to fit P3. Higher scores in natural capital (access to natural resources) were inversely correlated with classification as P3. Finally, farms located at higher altitudes were more likely to be found in P1.

Table 5. Influence of capital assets and farm household context variables on livelihood strategy classification (β Coefficients).

	Profile 1	Profile 2	Profile 3	Profile 4	Profile 5	
Capital asset and context variables	Off-farm labor diversification strategy	Rural-tourism diversification strategy	Agricultural intensification strategy	Added-value diversification strategy	Pensioners	**p-value [a]**
Access to natural resources (NC)	0.167	0.099	-0.595 **	-0.006	0.335	0.380
Exchanges (transfers and reciprocity) (SC)	0.070	1.322 ***	-0.797**	-0.268	-0.327	0.021
Mechanization (PC)	-0.003	-0.002	0.007 ***	0.007 ***	-0.009 **	0.002
Farmer education (HC)	0.969 **	0.210	0.225	-1.093 *	-0.310	0.140
Members in the family (HC)	0.222	0.338	-0.446 **	0.101	-0.214	0.160
Altitude	0.002 **	0.000	0.000	-0.002 **	0.000	0.160

[a] Associated with overall Wald test; *** z > 2.575; ** z > 1.96; *z > 1.645

5.3 Prediction of adaptive capacity variables by latent livelihood profiles

In the last step, the adaptive capacity variables were modelled as external variables determined by the different livelihood profiles (**Table 6; Table A6**)[1]. The off-farm labor diversification strategy (P1) positively and significantly influenced the reliance on own resources, giving the highest estimates for this indicator amongst the profiles. The rural-tourism diversification strategy (P2) displayed positive and significant values for proactive capacity, farmer organization, participation to access information, sources of income, and agro-biodiversity. The agricultural intensification strategy (P3) gave significant and positive scores, although still lower than those for the other profiles, for farmer organization and reliance on own resources. The added-value diversification strategy (P4) did not significantly contribute to determining any adaptive capacity dimensions. The pensioners profile (P5) retrieves significant and negative values in participation to access information, scoring also the lowest on this dimension.

[1] We also estimated an overall adaptive capacity indicator and modelled it as an external variable (see **Appendix A, sections 8 and 9**, **Table A7-A10**).

Table 6. Mean estimates of adaptive capacity variables predicted by livelihood strategy profiles (SE).

Adaptive capacity dimensions	Variables	Profile 1 Off-farm labor diversification strategy	Profile 2 Rural-tourism diversification strategy	Profile 3 Agricultural intensification strategy	Profile 4 Added-value diversification strategy	Profile 5 Pensioners	p-value [a]
Capacity for learning and adaptation	Traditional ecological knowledge (TEK)	8.268 (0.332)	7.871 (0.426)	8.159 (8.159)	8.125 (0.564)	7.806 (0.656)	0.95
	Reactive capacity	2.353 (0.283)	3.085 (0.464)	2.354 (0.325)	2.625 (0.404)	2.446 (0.419)	0.65
	Proactive capacity	5.597 (0.274)	6.844 (0.391) ***	4.900 (0.442)	5.317 (0.473)	5.180 (0.488)	0.11
Self-organization	Farmer organization	3.384 (0.194)	3.880 (0.178) ***	2.721 (0.167) ***	3.252 (0.312)	3.181 (0.354)	0.0027
	Social cooperation network	3.473 (0.342)	3.437 (0.330)	3.749 (0.390)	3.748 (0.228)	3.608 (0.380)	0.92
	Participation to access information	4.933 (0.294)	5.826 (0.216) ***	4.429 (0.378)	3.948 (0.503)	3.517 (0.624) ***	0.00078
	Reliance on own resources	0.404 (0.053) ***	0.264 (0.019)	0.208 (0.011) ***	0.238 (0.028)	0.035 (0.060)	0.0035
Diversity	Sources of income	11.574 (0.459)	12.994 (0.369) ***	11.123 (0.614)	12.369 (0.623)	10.970 (0.767)	0.032
	Agro-biodiversity	9.100 (0.393)	10.273 (0.361) ***	9.098 (0.371)	8.507 (0.591)	8.586 (0.573)	0.036

[a] Associated with overall Wald test; *** z > 2.575; ** z > 1.96; *z > 1.645

6. Discussion

In this study, we identified five mountain livestock farming patterns characterized by distinct combinations of income-generating activities and capital assets that led to different estimates of adaptive capacity. Although previous typological studies captured the variability of livestock farms by focusing on technical, structural, and economic aspects (Olaizola et al., 2008; Gaspar et al., 2008; Toro-Mujica et al., 2012;) and socio-economic characteristics (Martin-Collado et al., 2014), few studies had explicitly considered the influence of these factors and the integration of agricultural and non-agricultural activities on farm livelihood strategies (van der Ploeg et al., 2009; Guarín et al., 2020; Olaizola et al., 2015).

Livelihood strategies

Labor diversification took place in 68% of the sampled households following different strategies. In P1 it involved economic diversification into off-farm activities. On-farm diversification was important either separately from farming in the form of tourist accommodation (P2) or by expanding the range of products linked to the farming activity through innovation (P4). Diversification of labor beyond on-farm agricultural activities is a common practice within rural livelihoods to attain better remuneration (Ellis, 1998; Kinsella et al., 2000; Ripoll-Bosch et al., 2014). However, it also imposes significant effort on households to manage the workload and may actually erode resilience (Darnhofer and Strauss, 2010).

Diversification cannot be achieved without sufficient capital in the form of a mixture of human and structural factors such as labor availability, location (i.e., access to marketing channels), or social networks (Darnhofer et al., 2013; Lamine et al., 2015; Knickel et al., 2018). The households wherein the head of the farm had a higher level of education often pursued off-farm non-agricultural labor diversification pathways, most likely because they had access to higher-paying job opportunities (Corcoran and Dent, 1994; Martin-Collado et al., 2014). These pluriactive households were located at higher altitudes, where the harsh natural conditions together with increased touristic activities potentially augmented the opportunity cost of the farmer's own labor (Morgan-Davies et al., 2012). These factors may explain the decrease in farming activities (Lasanta et al., 2007).

Physical and social capital were the most significant predictors of household allocation to a livelihood strategy. Increased market integration (as in P4) often requires investments in farm machinery (Fredriksson et al., 2017), and intensification is eased by increased mechanization (as in P3). In contrast, farm households in P2 seemed to compensate for the low availability of machinery with labor and equipment exchanges with the community, highlighting the key role played by social capital in the diversification performance of such households.

P4 households held sheep and goat herds and showed the lowest stocking rate and the highest share of land devoted to forage crops. Their focus on either on-farm fattening or dairy products with on-farm processing, added value to their production and can be a strategy for enhancing livelihood resilience (Ashkenazy et al., 2018). These households were located in lowlands where access costs to markets are lower (Fredriksson et al., 2017), while those in more remote areas were more likely to follow an off-farm labor diversification strategy.

Building adaptive capacity

Households in P2 contributed the most out of the profiles to building adaptive capacity in different dimensions, while engaging in rural tourism activities and adopting new practices in the face of change (Folke et al., 2002; Knickel et al., 2018). Shucksmith and Rønningen (2011) pointed out that non-conventional farms might retain populations in areas from which they would surely have been lost if farm amalgamation had proceeded. These households managed hay meadows and had the highest proportion of large livestock species, which translated to less labor requirements. They also hired employees and presented the highest levels of social capital, highlighting its importance in coping with and recovering from changes (Kerr, 2018). Households belonging to the intensification profile, P3, gave significant and low values in farmer organization and reliance on own resources, which is aligned with the higher vulnerability of specialized farms to changing markets (de Roest et al., 2018).

The profile of pensioners (P5) had a low endowment of assets and presented the lowest estimates in several dimensions of adaptive capacity, reflecting not only the low chances of continuity but also their vulnerable condition. Muñoz-Ulecia et al. (2021) identified a similar group of farm households in Spanish Central Pyrenees with low continuity prospects. Our study indicated a smaller representation by this type of farm household (12% in our case study compared to 40% in their sample), which may indicate greater dynamism in our target region. The nature of farming in this group may well represent their household identities (Hebinck et al., 2018; Carr, 2020). This may be one of the reasons underpinning the persistence of livestock farming practices among pensioners and even in the profiles P1 and P2, wherein livelihood strategies imply a balance between material needs and a desire to preserve existing systems of meaning (Carr, 2020).

Policy implications

For farming systems in Europe, the relationship between the progressive abandonment of disadvantaged mountain areas and the trend towards concentration of production in more-favorable areas threatens the multiple ES provided by mountain livestock farming systems (Bernués et al., 2014; Dean et al., 2021).

European mountain livestock farming systems are highly dependent on subsidies, and the CAP is key for explaining their evolution (Muñoz-Ulecia et al., 2021). There is an ongoing debate about the imbalances produced by the CAP, which is failing to achieve its cohesion and convergence objectives (Bonfiglio et al., 2017). Moreover, the Rural Development Programs (RDP) in some European countries are unable to correct disparities between rich and disadvantaged rural areas, sometimes even increasing these gaps, as pointed out by Kiryluk-Dryjska et al. (2020).

In our study, it was seen that mountain livestock farming households implemented both labor- and market-based diversification strategies. These strategies, simultaneously focused on diversification and economies of scope, can stimulate more resilient development pathways (de Roest et al., 2018). While diversification is encouraged by the current RDP in Catalonia (DARP, 2021), these regional policies must acknowledge the limitations that farmers face in pursuing these strategies. In order to be successful, this pathway may require certain prerequisites, as shown in our results for profile P4. Finally, while strategies based on off-farm activities, as in P1, certainly allow for improving financial performance of the farm household (Olaizola et al., 2015), those could also contribute to the displacement of agriculture from mountain areas (Muñoz-Ulecia et al., 2021).

Policy can also strengthen resilience of mountain farming households by supporting collective initiatives and cooperation toward co-innovation processes for local capacity building (Knickel et al., 2018) fostering resilience to sustain desirable conditions and change course from undesirable trajectories when opportunities appear (Folke et al., 2016). In this respect, although crises are seen within a resilience context as opportunities for transformation and "bouncing forward" (Darnhofer, 2014), reducing stresses on the livelihoods can produce opportunities for the farmers to identify transformation pathways without instrumentalized interventions (Carr, 2020).

Limitations of the study and future prospects

A limitation of our approach is that it captured the situation of the farms at a single point in time, addressing adaptive capacity from a static approach (Thulstrup, 2015), and thus may not adequately capture the continuous processes that strengthen or erode it (Darnhofer, 2014). As such, our work does not explicitly account for the transformability dimension of resilience that implies profound changes of the system. It may require a longitudinal focus (e.g., Muñoz-Ulecia et al., 2021) that can incorporate the long-term development of farming households, although data availability is a major constraint in adopting such a perspective. Furthermore, an assessment of financial and physical capital considering additional variables may contribute to better inform these dimensions. Future assessments can also incorporate additional proxy indicators, such as distance to slaughterhouses or counselling centers or other environmental variables. Furthermore, incorporating the views of different household members may also improve the assessment (Quandt, 2019). Our study can eventually be expanded towards a stronger focus on co-production, allowing for other types of outcomes that inspire collective action such as reframing narratives and building institutions (Chambers et al., 2021).

7. Conclusions

Extensive mountain livestock farming households have implemented a variety of strategies to guarantee their livelihood in the face of changing conditions. Drawing upon the conceptual framework of livelihood resilience in farming systems, we explored the multidimensional issues that influence and are influenced by the livelihood strategies and their adaptive capacity at the farm household level. The conceptual and methodological approaches adopted in this study are flexible and applicable to other livelihood groups with specific contexts. In our case study, we identified five livelihood strategy profiles, with one based on intensification of production, another differentiated by external sources of income from pensions, and three involving different diversification paths, among which labor allocation was a key differentiating factor. Physical and social capital were the most important assets for predicting classification into these livelihood profiles. In this sense, our study highlights the relevance of including income-generating activities in addition to other structural, technical, and socioeconomic variables in studying farming systems, since they may be crucial for maintaining farming activities.

We also observed the vital roles played by farmers' proactive capacities to face changes and their involvement in formal and informal social cooperation networks with regard to the sustainability and adaptive capacity of their households, and thus these factors may be integrated into policy and research agendas. The results of this study could be used to design and implement targeted actions and policies to build long-term livelihood resilience in order to meet agricultural and rural development needs.

Future research should focus on integrating longitudinal data and complex contextual variables in the typology identification process to support the design of more-suitable targeted policies.

Acknowledgments

This research is framed within the PACTORES project (Pastoral ACTORs, Ecosystem services and Society as key elements of agro-pastoral systems in the Mediterranean) funded by MINECO (PCIN2017-051) and the project: "Silvopastoralism as an adaptation strategy for integrated rural development in the Mediterranean" (RTA2017-00036-C01/02) which has received funding from Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA), Spain. A. Lecegui was supported by grant PRE2018-084779 co-funded by the European Social Fund (ESF) and the Spanish Ministry of Science, Innovation and Universities (MCIU). This article is part of his PhD dissertation. We also acknowledge the support of Berta Vidal-Monés and Mathias Brummer in the collection of survey data. The authors wish to thank all interviewees who participated in the study for sharing their time and insights on livestock farming. Finally, we are thankful to the editor and two anonymous reviewers for their constructive comments that significantly helped to improve the manuscript.

8. References

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• Appendix A

1. Indicators employed and their link with previous works

Table A1 compiles from literature the 22 indicators to assess the resilience of livelihoods farming systems used in this study differentiated according to the three main dimensions for its operationalization: activity variables, capital assets and adaptive capacity.

Table A1. Overview of variables employed for assessing livelihood resilience in mountain pastoral farming systems and their link with previous works.

	Dimension	Variable	Description	Reference
Activity variables	Labor	Hired agricultural labor	Proportion of hired labor with respect to family labor within the farm, in AWU (%)	Diaz-Montenegro et al., 2018; Olaizola et al., 2015
		Off-farm wage labor	Proportion of non-agricultural family labor with respect to the amount family labor in AWU (%)	Diaz-Montenegro et al., 2018; Olaizola et al., 2015
		Added-value activities	Composite index indicating organic certification, fattening (in addition to breeding), and product-transformation facilities at the farm	Milestad and Hadatsch, 2003; Milestad and Darnhofer, 2003; López-i-Gelats et al., 2011; Gökdai et al., 2020
		Tourist accommodation	Indicates whether they own a rural guest house	López-i-Gelats et al., 2011; Gökdai et al., 2020
		Pension	Proportion of retirement income with respect to the total family income (%)	López-i-Gelats et al., 2011; Sutherland et al., 2019
	Land	Forage crop farmland	Proportion of forage crops with respect to meadows, in ha (%)	Diaz-Montenegro et al., 2018
	Livestock	Stocking rate	Ratio of livestock units per utilized agricultural area (LU/UAA)	Riedel et al., 2007; Riveiro et al., 2013; Muñoz-Ulecia et al., 2021
		Herd type	Dominant livestock type in the herd: either large (horse, cattle) or small (sheep, goat) species	López-i-Gelats et al., 2011 ; Mekuyie et al., 2018
Capital assets	Natural capital (NC)	Access to natural resources	Access to natural resources, communal forest products, and existence of communal forest management plan	Speranza, 2013; Speranza et al., 2014; Quandt, 2018
	Social capital (SC)	Exchanges (transfers and reciprocity)	Degree to which in-farm labor, facilities, and machinery are shared with neighbors and other farmers	Speranza et al., 2014; Milestad and Darnhofer, 2003
	Physical-capital (PC)	Mechanization	Total machinery power measured in HP available on the farm	Riveiro et al., 2013; Speranza, 2013; Speranza et al., 2014; López-i-Gelats et al., 2011;
	Human capital (HC)	Farmer education	Highest educational level of the head of the farm (primary, secondary and university)	Speranza et al., 2014; Martin-Collado et al., 2014
		Members in the family	Number of members in the household	Speranza et al., 2014; Muñoz-Ulecia et al., 2021
	Farm context	Altitude	Altitude (meters above sea level) as a proxy for increased harshness, remoteness, and potential trade-offs with other land uses	Nielsen et al., 2013; Jansen et al., 2006

Table A1 (Cont.). Overview of variables employed for assessing livelihood resilience in mountain pastoral farming systems and their link with previous works.

	Dimension	Variable	Description	Reference
Adaptive capacity	Capacity for learning and adaptation	Traditional ecological knowledge	Knowledge about traditional use of the environment	van Oudenhoven et al., 2011; Cabel and Oelofse, 2012; Panpakdee and Limnirankul, 2018; Jacobi et al., 2015
		Reactive capacity	Number of structural and management changes implemented over the last 10 years	Speranza et al., 2014; Milestad and Darnhofer, 2003; Riedel et al., 2007
		Proactive capacity	Coping strategies to face global change and create options and opportunities from threats	Speranza et al., 2014; Milestad and Darnhofer, 2003; Marschke and Berkes, 2006; Jacobi et al., 2018
	Self-organization	Farmer organization	Memberships in formal interest groups	Speranza et al., 2014; Milestad and Darnhofer, 2003; Cabel and Oelofse, 2012
		Social cooperation and network	Structure and size of the social network (number of people involved)	Speranza et al., 2014; Milestad and Darnhofer, 2003
		Participation to access information	Involvement in informal groups and use of information and communication technologies	Speranza et al., 2014; Cabel and Oelofse, 2012; Jacobi et al., 2018
		Reliance on own resources	Degree of market independence of the household according to the purchases of external inputs in the form of dung to fertilise, chemicals products, supplements, feed for livestock (reproduction and fattering) rent of machinery, facilities, land, and labor	Speranza et al., 2014; Lopez-i-Gelats, 2015; Ripoll-Bosch et al., 2012
	Diversity	Agro-biodiversity	Diversity of crops, species, and breeds on farm	Milestad and Darnhofer, 2003; Cabel and Oelofse, 2012; Mekuyie et al., 2018; Dardonville et al., 2020
		Sources of income	Diversity of income sources and marketing channels	Milestad and Darnhofer, 2003; Panpakdee and Limnirankul, 2018

2. Characteristics of the sampled farm households

Table A2. Summary characteristics of the sampled farm households in Pallars Jussà and Pallars Sobirà counties Mean (standard error).

	Pallars Jussà (n=46)	Pallars Sobirà (n=57)	Significance
Altitude of farmstead (m.a.s.l.)	905.01 (293.43)	1119.93 (191.95)	***
Age of holder (years)	50.33 (13.41)	46.75 (14.33)	n.s.
Women (%)	13.03	14.04	n.s.
Herd size (LU)	135.6 (109.2)	90.7 (75.0)	**
Cattle (LU)	44.85 (64.35)	61.26 (60.89)	*
Sheep (LU)	79.48 (104.41)	14.43 (50.90)	***
Horse (LU)	9.10 (33.10)	13.55 (40.10)	**
Goat (LU)	2.12(4.91)	1.43 (4.70)	n.s.
Land size (UAA)	96.43 (110.69)	54.45 (85.41)	***
Rainfed meadows (ha)	38.62 (67.78)	24.24 (31.48)	***
Irrigated meadows (ha)	4.34 (8.13)	12.16 (16.09)	n.s.
Forage crop (ha)	53.47 (85.68)	18.05 (71.19)	***
Owned land (%)	46.17 (28.57)	54.59 (26.16)	n.s.
Workload per farm (AWU)	2.23 (1.18)	1.80 (0.79)	*
Hired labor (AWU)	0.60 (0.65)	0.25 (0.45)	**
Agricultural family labor (AWU)	1.64 (0.79)	1.55 (0.70)	n.s,
Non-agricultural family labor (AWU)	0.68 (0.72)	1.10 (0.82)	**

Mann–Whitney U tests or ANOVA: *** $p< 0.01$; ** $p< 0.05$; * $p< 0.1$; n.s.: not statistically significant.
AWU, Annual working unit, refers to the labor performed by one person in a full-time contract in one year UAA, Utilized agricultural area, the total area available in the farm in hectares (ha). Meadows include both mowing and grazing as well as owned and rented while forage crops include owned and rented. LU: Livestock unit, herd size equivalent to adult cows weighing 380 kg that gestate and wean a calf; obtained by applying a coefficient to the number of animals according to species and age.

3. Information criteria

We estimated LPA models ranging from one to seven profiles using the eight activity variables as indicators and the six capital assets variables as covariates in order to determine the best number of segments (**Table A3**). The selection of the best-fitting model lied on a balance between plausibility of outcomes and parsimony of information criteria such as Log-likelihood (LL), Bayesian Information Criterion (BIC), Akaike's Information Criterion. (AIC, AIC3), and classification error while considering a minimum class size of 10% of the sample. The five-profile model provided the best fit based on AIC3 information criterion. In the context of mixture models such as LCA, some researchers (Andrews and Currim, 2003; Fonseca and Cardoso, 2007; Yang and Yang, 2007) have signaled the preference for AIC3 as a superior performance indicator.

Table A3. Summary statistics for models from 1 to 7 latent profiles for selecting the best fit number of profiles: Log-likelihood (LL), Bayesian Information Criterion (BIC), Akaike's Information Criterion (AIC), number of parameters (Npar) and classification errors (Class.ERR.).

Profile model	LL	BIC(LL)	AIC(LL)	AIC3(LL)	SABIC(LL)	Npar	Class.ERR.
1	-1312.564	2773.438	2689.127	2721.127	2672.356	32	0.000
2	-1133.740	2536.295	2383.481	2441.481	2353.083	58	0.006
3	-1050.643	2490.603	2269.286	2353.286	2225.262	84	0.007
4	-996.143	2502.105	2212.285	2322.285	2154.635	110	0.005
5	-943.529	2517.382	2159.059	2295.059	2087.782	136	0.008
6	-916.067	2582.960	2156.134	2318.134	2071.230	162	0.008
7	-879.847	2631.023	2135.694	2323.694	2037.164	188	0.010

4. Bivariate residuals for the model reported

The assumption of local independence was verified by checking that all bivariate residuals (BVR) were mutually independent with values lower than 3.84. When local independence could not be assumed between two pairwise variables, we relaxed local dependencies by introducing direct effects among these variables (Vermunt, 2010). Local independence for the five-class model was assumed since both indicators and covariates had non-correlative BVR after relaxing local dependencies by introducing direct effects among variables when required (Vermunt, 2010; **Table A4**).

Table A4. Bivariate Residuals (BVR) in the five-profile solution model with covariates for checking the assumption of local independence.

Activity variables (indicators)	**Agricultural labor**	**Off-farm wage labor**	**Added-value activities**	**Tourist accommodation**	**Pension income**	**Farmland**	**Stocking rate**	**Herd type**
Hired agricultural labor	.							
Off-farm wage labor	0	.						
Added-value activities	0.031	0.011	.					
Tourist accommodation	0.003	0.298	0.059	.				
Pension income	0.696	0	0	1.902	.			
Forage crop farmland	0	0.153	0.798	2.569	0	.		
Stocking rate	0.548	0	0.010	1.071	0	0.912	.	
Herd type	0.037	0.017	0	0	0.342	0.773	0.215	.
Capital assets (covariates)	**Agricultural labor**	**Off-farm wage labor**	**Added-value activities**	**Tourist accommodation**	**Pension income**	**Farmland**	**Stocking rate**	**Herd type**
Access to natural resources (NC)	0.003	0.220	0.090	0	0.011	0.055	0	0.262
Exchanges (SC)	0	0.004	0.175	0.103	0.237	0	0.448	0.001
Mechanization (PC)	0.059	0.006	0.005	0.579	0.263	0.213	0	0.026
Farmer education (HC)	0.033	0.021	0.007	0.126	1.291	0.001	0	0.007
Members in the family (HC)	0	0.003	0.002	1.548	0.584	0.118	2.021	0.220
Altitude	0.095	0	0	0	0.040	0	0	0

NC: Natural Capital; PC: Physical Capital; HC: Human Capital.

5. Mean values of covariates for the model reported

Table A5.¡Error! No se encuentra el origen de la referencia. provides the mean values of covariates for each profile reported in **Table 5** in the manuscript.

Table A5. Capital assets and farm household context variables influence on livelihood strategies membership. Mean values.

Capital assets (covariates)	Profile 1 Off-farm labor diversification strategy	Profile 2 Rural-tourism diversification strategy	Profile 3 Agricultural intensification strategy	Profile 4 Added-value diversification strategy	Profile 5 Pensioners	p-value
Access to natural resources (NC)	1.275	1.249	0.677**	0.938	1.096	0.380
Exchanges (transfers and reciprocity) (SC)	1.829	2.330***	1.557**	1.626	1.508	0.021
Mechanization (PC)	151.796	180.614	253.479***	311.688***	105.236**	0.002
Farmer education (HC)	2.309 **	2.123	2.137	1.938*	2.001	0.140
Members in the family (HC)	3.722	4.044	3.235**	3.937	3.172	0.160
Altitude	1118.202**	1070.823	971.569	850.862**	1027.728	0.160

*** z > 2.575; ** z > 1.96; *z > 1.645. NC: Natural Capital; PC: Physical Capital; HC: Human Capital.

6. Beta coefficients of external variables

Beta effects of adaptive capacity variables entered as external variables in the step 3 of the LCA that complements the mean values of **Table 6** in the manuscript, are presented in **Table A6.**

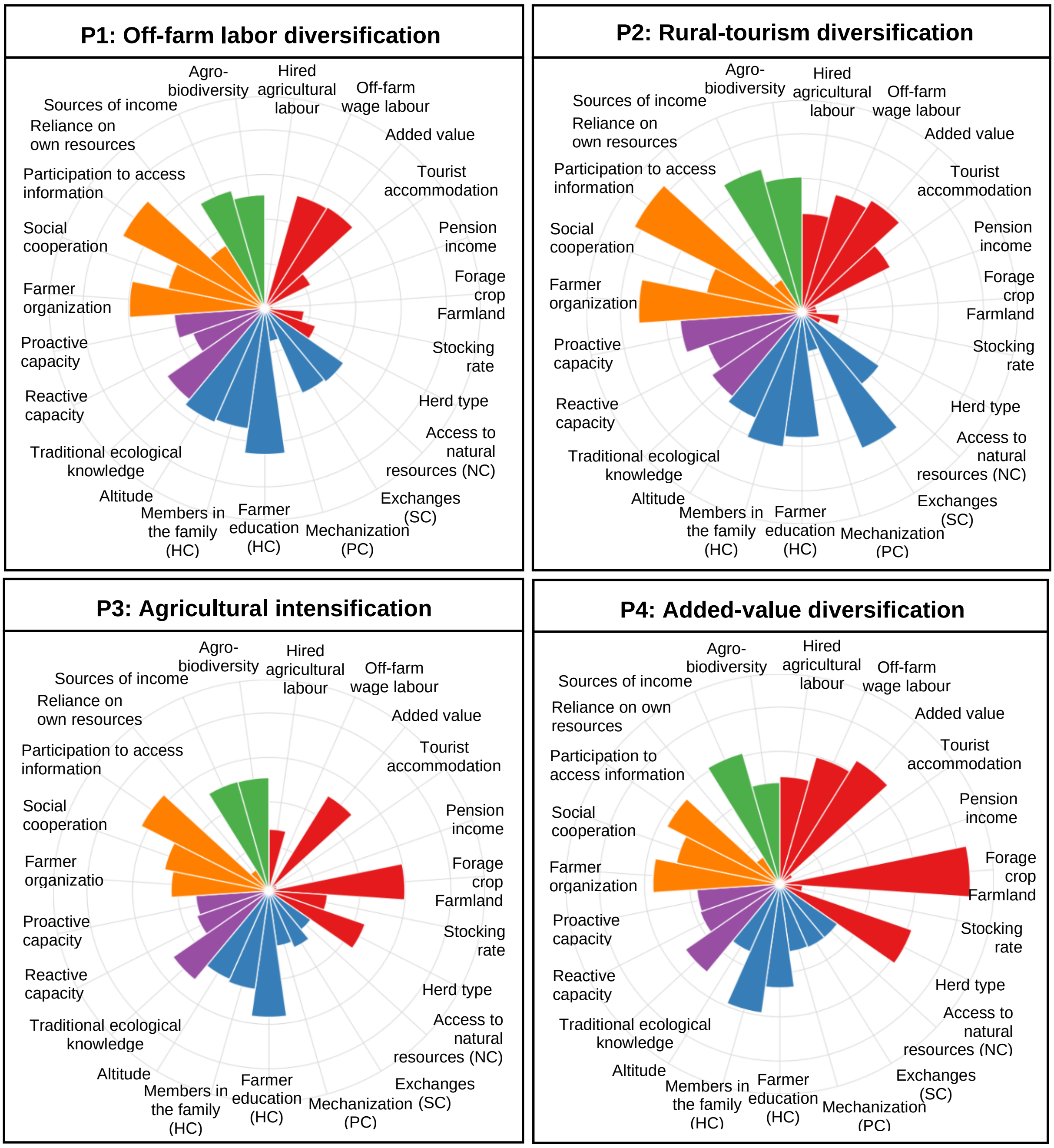
Table A6. Adaptive capacity variables for learning capacity and adaptation, self-organization, and diversity, predicted by the livelihood strategy profiles (β Coefficients).

Adaptive capacity variables	Off-farm labor diversification strategy	Rural-tourism diversification strategy	Agricultural intensification strategy	Added-value diversification strategy	Pensioners	p-value [a]
Traditional ecological knowledge	0.044	-0.035	0.022	0.016	-0.047	0.95
Reactive capacity	-0.074	0.165	-0.073	0.022	-0.040	0.65
Proactive capacity	0.016	0.410 ***	-0.224	-0.078	-0.125	0.11
Farmer organization	0.089	0.578 ***	-0.533 ***	-0.034	-0.100	0.0027
Social cooperation network	-0.049	-0.064	0.056	0.055	0.003	0.92
Participation to access information	0.103	0.495***	-0.061	-0.205	-0.333 ***	0.00078
Reliance on own resources	4.398 ***	1.098	-7.050 ***	-1.102	2.656	0.0035
Sources of income	-0.041	0.201 ***	-0.113	0.090	-0.137	0.032
Agro-biodiversity	-0.005	0.299 ***	-0.006	-0.154	-0.134	0.036

[a] Associated with overall Wald test; *** z > 2.575; ** z > 1.96; *z > 1.645

7. Profile plots for the model reported

Fig A1 shows the profile plot rescaled between 0-1 for activity variables, capital assets and adaptive capacity of the three-step LCA. The 0- 1 means are obtained from the conditional probabilities for the nominal variables and means by subtracting the minimum observed value and dividing by the range within each profile (Vermunt and Magidson, 2005a).



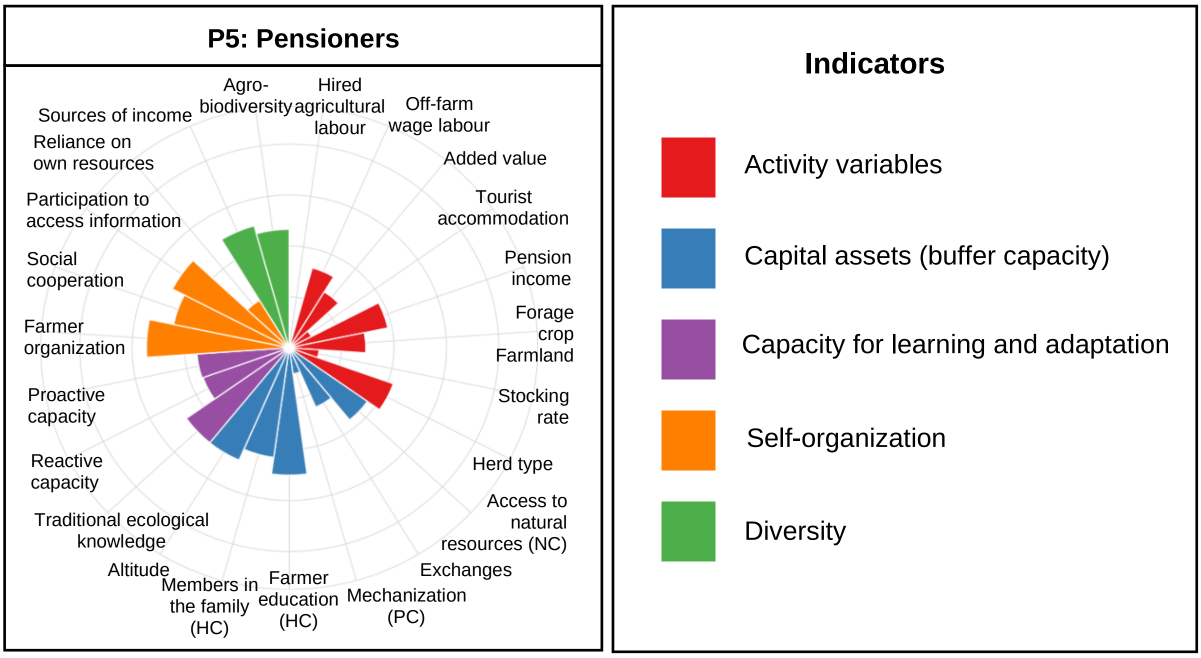


Fig A1. Rose chart showing the mean conditional probability (0-1) for activity variables, capital assets, Capacity for learning and adaptation, self-organization, and diversity indicators within the five profiles of farm identified in the study through the three-step latent profile model.

8. Estimation of an overall adaptive capacity factor

Following previous studies that estimated a resilience indicator composed of several individual indicators (i.e. FAO, 2016; Quandt, 2018), we estimated a latent class discrete factor model (LC DFactor) to capture the overall adaptive capacity in a single variable. DFactor models are restricted LC cluster models where ordinarily restrictions are imposed in each DFactor (Vermunt and Magidson, 2005a; Magidson and Vermunt, 2001). Each DFactor may have two or more levels that are assumed to be ordered (Vermunt and Magidson, 2005a). The general form of a two-DFactor model for three nominal indicators would show the following probability structure (Vermunt and Magidson, 2005b):

$$P(y_{i1} = m_1, y_{i2} = m_2, y_{i3} = m_3) = \sum_{x=1}^{K} P(x_1, x_2) \prod_{t=1}^{3} P(y_{it} = m_t | x_1, x_2) \quad (1)$$

The DFactor model considered adaptive capacity as a latent discrete factor where a three-level model achieved the best fit according to the information criteria BIC, AIC and AIC3 (**Table A7**). All indicators were mutually independent (**Table A8**) and contributed significantly to building the adaptive capacity latent factor (**Table A9**). Farmer organization scored the most for the factor of overall resilience (1.946), followed by proactive capacity (1.307) and sources of income (1.201). Conversely, traditional ecological knowledge (0.654) and reactive capacity (0.642) were the least contributors to the adaptive capacity factor. Sources of income were the best predictor variable since it obtained the highest R^2.

Table A7. Statistical fit for discrete one-factor models involving 1 to 8 levels.

Number of levels	LL	BIC(LL)	AIC(LL)	AIC3(LL)	Npar	L^2	df	p-value	Class.Err.
2-level	-1552.659	3457.556	3257.317	3333.317	76	2150.563	27	4.8e-439	0.074
3-level	-1546.978	3450.830	3247.956	3324.956	77	2139.202	26	1.4e-437	0.165
4-level	-1547.254	3456.016	3250.507	3328.507	78	2139.753	25	1.2e-438	0.320
5-level	-1546.977	3460.098	3251.955	3330.955	79	2139.201	24	1.6e-439	0.314
6-level	-1547.012	3464.803	3254.024	3334.024	80	2139.270	23	1.6e-440	0.407
7-level	-1546.987	3469.388	3255.975	3336.975	81	2139.221	22	1.6e-441	0.417
8-level	-1546.995	3474.038	3257.991	3339.991	82	2139.236	21	1.6e-442	0.478

Table A8. Bivariate Residuals (BVR) of adaptive capacity variables for one-factor and three level solution model.

Adaptive capacity variables	Traditional knowledge	Reactive capacity	Proactive capacity	Farmer organization	Cooperation and network	Participation	Agro-biodiversity
Traditional ecological knowledge	.						
Reactive capacity	0.933	.					
Proactive capacity	1.534	0.306	.				
Farmer organization	0.629	0.456	0.162	.			
Cooperation network	1.962	1.464	0.252	0.074	.		
Participation	0.396	0.422	0.101	0.685	0.443	.	
Agro-biodiversity	0.279	0.012	1.256	1.391	0.015	0.224	.
Sources of income	0.200	0.134	0.101	0.000	0.101	0.137	0.132

Table A9. Composition of the adaptive capacity factor according to its variables.

Adaptive capacity variables	**DFactor1 (Coefficients)**	**p-value** [a]	**R^2**
Farmer organization	1.946 ***	0,008	0.307
Proactive capacity	1.307 ***	0,000	0.345
Sources of income	1.201 ***	0,000	0.436
Participation to access information	0.987 ***	0,001	0.267
Social cooperation network	0.706 ***	0,004	0.132
Agro-biodiversity	0.696 ***	0,001	0.182
Traditional ecological knowledge	0.654 ***	0,001	0.196
Reactive capacity	0.642 ***	0,009	0.128

[a] Associated with overall Wald test; *** z > 2.575; ** z > 1.96; *z > 1.645

9. Test of the adaptive capacity factor as external variable of the model

The adaptive capacity factor was modelled as an external variable, i.e., as determined by the different livelihood profiles in the Step 3 of our model, showing significant differences among the livelihood strategies profiles (overall Wald test with p < 0,05; **¡Error! No se encuentra el origen de la referencia. A10**). The rural-tourism diversification strategy (P2) displayed the highest overall adaptive capacity. Next, Off-farm labor diversification strategy (P1), diversification with an added value strategy (P4) and agricultural intensification strategy (P3) do not significantly contribute to determining adaptive capacity. Conversely, pensioners (P5) reported the lowest levels of adaptive capacity.

Table A10. Estimates of mean adaptive capacity indicator predicted factor by livelihood strategy profile (SE).

External variable	**Profile 1** Off-farm labor diversification strategy	**Profile 2** Rural-tourism diversification strategy	**Profile 3** Agricultural intensification strategy	**Profile 4** Added-value diversification strategy	**Profile 5** Pensioners	**p-value** [a]
Adaptive capacity	2.087 (0.130)	2.534 (0.122) ***	1.811 (0.153)	1.939 (0.164)	1.760 (0.173) *	0.009

[a] Associated with overall Wald test; *** z > 2.575; ** z > 1.96; *z > 1.645

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• Appendix B

This appendix contains the results of an additional model considering the financial capital. Despite our model solution included income-generating activities and pensions as a form of financial capital (Amekawa, 2011), this asset dimension was not explicitly included in the preferred model to explain the livelihood strategies of livestock farmers in Pallars. In order to test the explanatory capacity of the financial capital variable and to capture the portfolio of five livelihood capital assets, we estimated an additional model (model 2) where access to credit was added as financial capital variable. Goodness-of-fit statistics between each pair of variables based on BVR enabled to assume the local independence of this model after applying direct effects (**Table B1¡Error! No se encuentra el origen de la referencia.**). Access to credit performed quite well to predict the profile membership of the farm households to the latent profiles, showing significance in profiles 3 and 5, with the same direction as the variable of mechanization power **(Table B2** and **Table B3**). Fit statistics reported in **Table B4** suggested that this model underperformed the selected model reported in the manuscript.

Table B1. Bivariate Residuals (BVR) in model 2.

Activity variables (indicators)	**Agricultural labor**	**Off-farm wage labor**	**Added-value activities**	**Tourist accommodation**	**Pension income**	**Farmland**	**Stocking rate**	**Herd type**
Hired agricultural labor	.							
Off-farm wage labor	0	.						
Added-value activities	0.001	0.055	.					
Tourist accommodation	0.017	0.272	0.183	.				
Pension income	0.075	0	0.032	1.347	.			
Forage crop farmland	0.203	0.426	0.516	0.661	0	.		
Stocking rate	1.688	0	0.001	1.274	0	0.716	.	
Herd type	0.012	0.707	0	0	0.618	0.892	0.584	.
Capital assets (covariates)	**Agricultural labor**	**Off-farm wage labor**	**Added-value activities**	**Tourist accommodation**	**Pension income**	**Farmland**	**Stocking rate**	**Herd type**
Access to natural resources (NC)	0.014	0.013	0.328	0	0.077	0.054	0	0.016
Exchanges (SC)	0.016	0.690	0.100	0.263	0.171	0.531	0.122	0.068
Mechanization (PC)	0.000	0.035	0.010	1.463	0.091	0.143	0.612	0.050

Farmer education (HC)	0.008	0.424	0.000	0.245	0.107	0.012	0	0.005
Members in the family (HC)	0.008	0.480	0.009	0.557	0.923	0.835	0.593	0.031
Access to credit (FC)	0.030	0	0.630	0.549	0.940	0.027	0.063	0.029
Altitude	0.004	0.069	0	0	0.140	0	0.096	0

NC: Natural Capital; PC: Physical Capital; HC: Human Capital; FC: Financial Capital.

Table B3. Five latent profiles of livelihood strategies identified in model 2. The mean value and standard error (SE) are provided for each indicator. In the case of categorical indicators. the conditional probabilities are shown within profiles for the different levels of these indicators.

	Profile 1 Off-farm labor diversification strategy	**Profile 2** Rural-tourism diversification strategy	**Profile 3** Pensioners	**Profile 4** Added-value diversification strategy	**Profile 5** Agricultural intensification strategy		
Profile Size (%)	26.67 (3.93)	21.6 (3.53)	18.5 (3.35)	18.27 (2.84)	14.91 (2.97)		
Activity variables (indicators)	**Mean (SE)**	**Mean (SE)**	**Mean (SE)**	**Mean (SE)**	**Mean (SE)**	**p-value [a]**	**R^2**
Hired agricultural labor	0 (0.003) ***	0.340 (0.044) ***	0 (0.005) ***	0.225 (0.049)	0.290 (0.042) ***	0.000	0.517
Off-farm labor	0.424 (0.048) ***	0.476 (0.040)	0.192 (0.053) ***	0.337 (0.052)	0.077 (0.044) ***	0.000	0.309
Added-value activities						0.035	0.062
1.low	0.171 (0.060)	0.106 (0.049)	0.346 (0.099) ***	0.121 (0.057)	0.137 (0.068)		
2.medium	0.623 (0.051)	0.608 (0.059)	0.569 (0.069)	0.600 (0.058)	0.598 (0.058)		
3.high	0.206 (0.067)	0.287 (0.086)	0.085 (0.046)	0.279 (0.090) *	0.264 (0.097)		
Tourist accommodation						0.420	0.070
1.No	0.755 (0.081)	0.668 (0.099)	0.797 (0.092)	0.951 (0.048)	0.931 (0.065)		
2.Yes	0.245 (0.081)	0.332 (0.099) ***	0.203 (0.092)	0.049 (0.048)	0.070 (0.065)		
Pension	0.850 (0.419) ***	3.267 (1.128) ***	19.877 (5.065) ***	2.898 (0.895)	1.304 (0.938) ***	0.000	0.326
Forage crop farmland	0.424 (0.048) ***	0.476 (0.040) ***	0.192 (0.053)	0.337 (0.052) ***	0.077 (0.044)	0.000	0.705
Stocking rate	2.148 (0.286)	2.516 (0.312)	1.611 (0.188) ***	1.995 (0.300) *	4.198 (0.884) ***	0.008	0.170
Herd type						0.051	0.146
1.Cattle + horses	0.747 (0.083)	0.863 (0.073) *	0.681 (0.107)	0.317 (0.108)	0.666 (0.121)		
2.Sheep + goats	0.253 (0.083)	0.137 (0.073)	0.320 (0.107)	0.683 (0.108) ***	0.334 (0.121)		

[a] Associated with overall Wald test. *** z-value >2.575; ** z-value >1.960; * z-value >1.645 NC: Natural Capital; PC: Physical Capital; HC: Human Capital; FC: Financial Capital.

Table B4. Capital assets and farm context variables influence on livelihood strategies membership in model 2 (β Coefficients).

Capital assets (covariates)	Profile 1 Off-farm labor diversification strategy	Profile 2 Rural-tourism diversification strategy	Profile 3 Pensioners	Profile 4 Added-value diversification strategy	Profile 5 Agricultural intensification strategy	p-value [a]
Access to natural resources (NC)	0.195	0.233	0.128	0.570	-1.127 **	0.190
Exchanges (transfers and reciprocity) (SC)	-0.161	1.623 ***	-0.321	-0.526	-0.615	0.017
Mechanization (PC)	-0.007 **	-0.003	-0.007 *	0.008 ***	0.009 ***	0.004
Farmer education (HC)	1.170 **	0.451	0.029	-2.837 ***	1.187 *	0.041
Members in the family (HC)	0.247	0.504	-0.467 *	0.224	-0.509 *	0.052
Access to credit (FC)						0.052
No	0.106	0.260	0.704 **	-1.055	-0.016	
yes	-0.106	-0.260	-0.704	1.055 ***	0.016	
Altitude	0.003 **	-0.002	0.003 ***	-0.005 ***	0.001	0.006

[a] Associated with overall Wald test; *** z > 2.575; ** z > 1.96; *z > 1.645. NC: Natural Capital; PC: Physical Capital; HC: Human Capital; FC: Financial Capital.

Table B5. Summary statistics to compare the fit of the selected latent profile model with model 2 that includes a variable for physical capital: Log-likelihood (LL), Bayesian Information Criterion (BIC), Akaike's Information Criterion (AIC), number of parameters (Npar) and classification errors (Class.ERR.).

Model	LL	BIC(LL)	AIC(LL)	AIC3(LL)	Npar	Class.ERR.	Entropy R^2
Selected	-943.102	2516.527	2158.203	2294.203	136	2.569	0.010
Model 2	-976.439	2569.298	2218.879	2351.879	133	1.688	0.012