

What changed, and what do people perceive to have changed? Land use transformations in peninsular Spain over the past 50 years

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Abstract

Context

Land-use and land-cover transformations are typically assessed through spatial data, yet their social recognition does not always align with the observed changes. This mismatch matters because public perceptions influence the acceptability of territorial, conservation, and land-management policies.

Objectives

We examined land transformations in peninsular Spain over the past five decades and to assess whether public perceptions reflect documented dynamics.

Methods

We characterized eight lands cover flows using national and European land cover datasets, agricultural censuses, and protected area records. Social perceptions of land change were measured through an online national survey completed by 2,071 respondents. The association between perceived change and observed transformation intensity across ages class of respondents, decades and land cover flows was assessed.

Results

Overall, 55.6% of respondents reported perceiving land transformations. Perception was positively associated with observed transformation intensity, though the strength of this relationship varied among land cover flows and weakened in recent decades. Age class and its interaction with intensity were not significant, indicating that perceptual differences were primarily temporal and process-specific. Highly visible flows—urbanization, renewable energy infrastructure, burned grasslands, protected-areas, and intensive livestock farming—showed stronger correspondence between observed and perceived changes. In contrast, agricultural intensification, irrigation, and afforestation exhibited weaker or declining perceptual sensitivity despite their territorial importance.

Conclusions

Results reveal a growing divergence between land transformation and its social recognition, likely linked to shifting environmental baselines, normalization, and differences in visual and territorial salience. Incorporating social perceptions of land change is therefore essential for anticipating policy acceptability and designing more socially responsive land-management strategies.

Introduction

Land transformation, including both conversion between land-use and land-cover (LULC) classes and internal modifications within them, has occurred at an unprecedented pace and scale, affecting approximately one-third of the Earth's land surface between 1960 and 2019 (Winkler et al. 2021). These transformations result from a complex interplay of social, cultural, political, and environmental processes, including population growth, urbanization, agricultural modernization, forest transitions and rural migration (Meyer & Turner 1992). Although these processes operate globally, their trajectories and consequences vary substantially across territories and therefore need to be examined at regional and local scale (Lambin et al. 2001).

Understanding land transformation requires not only quantifying physical changes but also examining how these changes are perceived and interpreted by society. Social perceptions of LULC transformations are not mere reflections of biophysical reality; rather, they are place-based interpretations shaped by livelihoods, values, cultural meanings, personal experiences, and access to information, which can generate contrasting narratives for the same land trajectory (Frei et al. 2020). In some contexts, such perceptions can broadly align with mapped land dynamics, as surveys have been used to corroborate perceived declines in agricultural and forest areas with trends from remote sensing data (Munthali et al. 2019). However, perceptions may also be subject to systematic biased; combining farm surveys with satellite data has revealed “over-perception” of local change consistent with motivated beliefs, and/or with intended future land conversions (Feng et al. 2022). Given these potential mismatches, several studies emphasize approaching social knowledge with data-based evidence, for instance, by combining perception interviews, observed land-use transformations, and spatial planning documents to interpret land-use dynamics and derive effective territorial, conservation, and land-management policies (Lukman et al. 2021).

In Europe, LULC transformations have historically been associated with the Industrial Revolution and, more recently, with processes of agricultural abandonment that have contributed to large-scale migration toward urban and coastal areas (Reger, Otte & Waldhardt 2007). These dynamics have contributed to the decline of traditional agricultural landscapes (MacDonald et al. 2000) and to the expansion of urban areas (Antrop 2004). By contrast, in regions with more favorable biophysical conditions for agriculture, such as Northwestern Europe, agricultural intensification has been more pronounced, whereas marginal and less productive areas have experienced stronger abandonment dynamics (Pinto-Correia & Kristensen 2013). Examining these dynamics within the European context has enable the identification of the dominant trends of change and their underlying driving forces (Feranec et al. 2010; Bürgi et al. 2017).

Within this framework of socioeconomic and territorial transformations, Spain has emerged as one of the European countries most significantly affected by LULC transformations (Jiménez-Olivencia 2021). Spain's accession to the Common Agricultural Policy (CAP) in the 1980s promoted the modernization and competitiveness of agriculture, facilitating intensification in fertile areas while accelerating abandonment in less productive territories (Perez 1990). In parallel, the expansion of irrigated agriculture, the deployment of renewable energy infrastructure, the growth of intensive livestock farming and the urban development have further reshaped the ecological landscape mosaic (Romero et al. 2012; Sánchez et al. 2018). At the same time, conservation policies have encouraged the designation and expansion of protected natural areas, together with the implementation of various reforestation programs (Ameztegui et al.

2021). These processes have not occurred uniformly across the territory and differ considerably in their spatial extent, environmental consequences, visibility, and social significance.

Despite the existing literature regarding LULC transformations in Spain (e.g., Fernandes et al. 2024), the integration of the social components associated with these processes remains limited. Existing studies have examined public perceptions in relation to specific ecological transitions or territorial conflicts (Observatorio Transición Justa 2025), but few have directly compared the magnitude of multiple objectively measured transformation processes with their retrospective social perception across several decades (Frei et al. 2020). This comparison is important because socially visible transformations may not necessarily be the most extensive or ecologically significant, while gradual or less conspicuous processes may become normalized and remain largely unnoticed. Identifying where observed and perceived change converge or diverge can therefore provide relevant evidence for territorial planning, environmental communication, and participatory decision-making (Wagner & Gobster 2007; Zurlini & Müller 2008).

To summarize the large number of possible transitions among individual LULC classes, European Environment Agency developed the land cover flows (LCFs), which interprets landscape transformations in relation to their underlying territorial processes, such as urbanization, agricultural intensification, afforestation, and renewable energy expansion (Feranec et al. 2010; ETC/ULS Report 02/2020). Concretely, our aims were: i) to analyze LULC observed changes (i.e. LCF) across the last five decades; ii) to describe the social perception and temporal variation about LCF; and iii) to examine the extent to which perceived LCF reflect observed changes, and whether this association varies across age classes of the respondents and decades. This interdisciplinary approach contributes to understanding how society perceives transformations and supports decision-makers and planners in developing coherent land-management strategies that are both socially and ecologically sustainable.

Materials and methods

Study area

Peninsular Spain refers to the Spanish territory located on the Iberian Peninsula, excluding the Balearic and Canary Islands and the Spanish territories in North Africa. It covers approximately 492,000 km², accounting for around 85% of the Iberian Peninsula. The study area encompasses two broad biogeographical contexts: Eurosiberian region, corresponding to the combination of the Atlantic and Alpine biogeographical regions, which accounts for approximately 13% of the territory, and the Mediterranean region, which covers the remaining 87% (Fig. 1A). The Eurosiberian region (northern Spain) is characterized by a wet, temperate oceanic climate that supports extensive pastures and forests and a generally dispersed rural settlement pattern. These conditions have shaped land uses dominated by grassland-based livestock systems, particularly dairy systems, and forest management, while some areas have undergone a transition from native forests to commercial plantations, such as eucalyptus and pine, to supply the timber and pulp sectors (e.g. Tomé et al. 2021). From socio-economic perspective, Atlantic region is closely linked to livestock value chains and related rural economies, where management and environmental outcomes are strongly influenced by grassland productivity and manure handling under moist-temperate conditions (Vázquez-González et al. 2023).

By contrast, the Mediterranean region (central, eastern and southern Spain) is characterized by a higher prevalence of water-limited conditions and a land-use structure in where irrigated agriculture plays a central role, particularly citrus and horticulture crops, which are overwhelmingly irrigated (Sabater et al. 2025). In emblematic areas such as Almería (southeastern Spain), where intensive greenhouse horticulture has expanded into one of Europe's most productive agricultural regions, this sector represents major economic driver but is simultaneously constrained by water scarcity and groundwater stress, motivating efficiency gains and alternative supplies (e.g., desalination, reuse; Castro et al. 2019). Mediterranean Spain is also marked by strong coastal tourism and "coastalization" pressures, with internationally concentrated tourist demand in regions such as Catalonia (northeastern Spain) and Andalusia (southern Spain) and well-documented urban sprawl along the Mediterranean coast (e.g. Hof & Blázquez-Salom 2013). These patterns intensify seasonal resource demand (especially for water) reinforcing the tight coupling between tourism, irrigated farming, and urban growth in Mediterranean basins. Some of which correspond to key transformations in land shown in Fig. 1B.

Land-use and land-cover transformation processes: land cover flows

Land-use and land-cover datasets contain numerous thematic classes, generating many possible class-to-class transitions between consecutive observation periods. We grouped these transitions into eight broader, process-oriented LCFs, following the European Environment Agency's land-accounting framework (Table 1). This framework served as the common analytical basis for integrating the observational assessment of LULC transformations with the analysis of social perceptions. The selected LCFs comprised urbanization, renewable energy expansion, agricultural intensification, irrigated arable land, afforestation, burned grasslands, protected-area expansion, and intensive livestock farming. The specific class-to-class transitions defining each flow are detailed in Table 1.

Table 1

Land cover flows (LCFs) considered to assess land-use and land-cover transformations in peninsular Spain over 50 years; adapted from European Environmental Agency (ETC/ULS Report | 02/2020). A brief description of the flow and source of data are provided.

Land cover flow	Acronymous	Description	Source
Urbanization	URB	Transformation of land to urban use	Spanish National Emissions Inventory
Renewable energy expansion	ENE	Land transformed into wind and solar farms	Spanish National Emissions Inventory
Agricultural intensification ^a	AGR	Conversion between farming systems	Spanish National Emissions Inventory
Irrigated arable land	IRR	Conversion of non-irrigated arable land into irrigated arable land	Corine Land Cover (CLC)
Afforestation ^b	AFF	The establishment and expansion of forests in previously non-agricultural landscapes, excluding cases of natural succession following agricultural abandonment	Spanish National Emissions Inventory
Burned grasslands ^c	BURN	Transitional category capturing biomass burning in woody shrublands, grazing systems, and grasslands. That burned forests retain their forest classification unless an explicit land-use change occurs	Spanish National Emissions Inventory
Protected areas	PA	Cumulative surface area of protected areas designated within each selected decade	EUROPARC Spain
Intensive livestock farming	FARM	Characterized by increased production intensity per unit area. It is here measured as the ratio between the total number of livestock heads and the number of agricultural holdings	National Statistics Institute (INE)
(a) For greater precision, this term is used here to refer to "Agricultural Internal Conversions" within the EEA framework.			
(b) As defined by IPCC guidelines, this refers to land that has not been forested for at least 50 years (e.g., long-term grasslands or croplands).			
(c) This term is used by the Spanish National Emissions Inventory to report what the IPCC defines as "biomass burning in Grassland" (IPCC, 2006, Vol. 4, Cap. 6).			

Data sources

To characterize the LULC changes in the study area, we used raster layers from the Land Use and Land-Use Change and Forestry (LULUCF) dataset at a spatial resolution of 25x25 meters. These layers were produced by the Ministry for the Ecological Transition and the Demographic Challenge (available at www.miteco.gob.es/es/cartografia-y-sig/ide/descargas/calidad-y-evaluacion-ambiental/cartografia-lulucf.html), following the guidelines established by the Intergovernmental Panel on Climate Change (IPCC) to update and adapt the cartographic information of the Spanish Inventory System and Projections of Atmospheric Emissions (IPCC 2006). The cartographic series provides data for 1970, 1990, 2000, 2006, 2009, 2012, 2015, 2018 and 2021.

The LULUCF layers are organized into two hierarchical levels with six land categories (forest, cropland, grassland, wetland, settlement and other land) and 29 classes (Supporting information Table S1). A reclassification process was performed, grouping the classes according to the LCFs considered in this study. Finally, 18 classes were considered for subsequent analyses, namely forest land, broadleaved, coniferous, mixed forest, undetermined forest, cropland, perennial woody crops, annual crops, temporary fallow land, grasslands, grassland with trees, grassland with shrubs, perennial grasses, burned grasslands, wetlands, settlements, renewable energy expansion and other lands (for a complete description see Table S1). The reclassified LULUCF classes were then used to describe the LCFs. Land transformations were identified using transition matrices based on the classification rules presented in Table 2 and following the approach proposed by Pontius et al. (2004). These matrices were estimated for five periods: 1970–1990, 1990–2000, 2000–2012, 2012–2018, and 2018–2021 to quantify the area involved in each LCF per period.

Table 2

Grouping rules to assign Land Use and Land-Use Change and Forestry intensity of change between date 1 (T) and date 2 (T + 1) into Land Cover Flows (LCF); Environmental Agency (ETC/ULS Report | 02/2020). See Table 1 for a complete description of LCFs.

		T + 1										Set
		Forest land	Broadleaved	Coniferous	Mixed	Undetermined	Cropland	Perennial Woody crops	Annual crops	Temporary fallow land	Burned grasslands	
T	Forest land	-	-	-	-	-	-	-	-	-	BURN	URI
	Broadleaved	-	-	-	-	-	-	-	-	-	BURN	URI
	Coniferous	-	-	-	-	-	-	-	-	-	BURN	URI
	Mixed	-	-	-	-	-	-	-	-	-	BURN	URI
	Undetermined	-	-	-	-	-	-	-	-	-	BURN	URI
	Cropland	-	-	-	-	-	-	AGR	AGR	AGR	BURN	URI
	Perennial Woody crops	-	-	-	-	-	AGR	-	AGR	AGR	BURN	URI
	Annual crops	-	-	-	-	-	AGR	AGR	-	AGR	BURN	URI
	Temporary fallow land	-	-	-	-	-	AGR	AGR	AGR	-	BURN	URI
	Grasslands	AFF	AFF	AFF	AFF	AFF	-	-	-	-	BURN	URI
	Woodland	AFF	AFF	AFF	AFF	AFF	-	-	-	-	BURN	URI
	Shrubland	AFF	AFF	AFF	AFF	AFF	-	-	-	-	BURN	URI
	Perennial grasses	AFF	AFF	AFF	AFF	AFF	-	-	-	-	BURN	URI
	Burned grasslands	AFF	AFF	AFF	AFF	AFF	-	-	-	-	-	URI
	Wetlands	AFF	AFF	AFF	AFF	AFF	-	-	-	-	-	URI
	Settlements	AFF	AFF	AFF	AFF	AFF	-	-	-	-	-	-
	Renewable energies	AFF	AFF	AFF	AFF	AFF	-	-	-	-	BURN	URI
	Other land	AFF	AFF	AFF	AFF	AFF	-	-	-	-	BURN	URI

Note. Dashes (–) indicate transition processes that were outside the scope of this analysis. URB: Urbanization, ENE: Renewable energy expansion, AGR: Agr IRR: Irrigated arable land, AFF: Afforestation, BURN: Burned grasslands, PA: Protected areas, FARM: Intensive livestock farming.

Because the LULUCF layers do not distinguish between non-irrigated and irrigated arable land, IRR (conversion from non-irrigated to irrigated arable land) was estimated using the CORINE Land Cover database (CLC; raster at resolution of 100x100 meters), which differentiates between these two land classes (<https://land.copernicus.eu/en/products/corine-land-cover>). CLC layers were reclassified to quantify IRR across three periods: 1990–2000, 2000–2012, and 2012–2018 according to data availability. Data regarding the surface area of protected natural spaces (PA) were obtained from yearbooks provided by EUROPARC Spain (available for the periods 1962–1971, 1972–1981, 1992–2001, 2002–2011 and 2011–2020; <https://redeuroparc.org/publicaciones/anuarios/>). For all already described LCFs and time intervals, rate of intensity of change (S_t) was quantified, following Aldwaik and Pontius (2012) (Eq. 1).

$$S_t = \frac{\text{area of change during interval } [Y_t, Y_{t+1}] / \text{area of study region}}{\text{duration of interval } [Y_t, Y_{t+1}]} \times 100 \quad (E1)$$

For intensive livestock farming (FARM), data on livestock numbers and agricultural holdings were extracted from the agricultural census of the National Statistics Institute (INE), available for the years 1962, 1989, 1999, 2009 and 2020 (<https://ine.es>). Because FARM does not represent a physical land-cover transition, its intensity was expressed as the mean number of livestock heads per agricultural holding, and it was therefore used as a proxy for livestock production intensity and concentration. for more information about each LCF, see Supporting information S5.

Because the cartographic and statistical datasets differed in their temporal coverage and reference years, we harmonized them by assigning each dataset to the closest available period used in the social-perception survey. This harmonization enabled consistent comparisons between observed transformations and perceived changes across decades. The full temporal correspondence is presented in Supporting Information, Table S2.

Social perception on land cover flows

A questionnaire was designed to evaluate social perceptions regarding LCFs over the last decades (1960, 1970, 1980, 1990, 2000, 2010, and 2020). The questionnaire items were designed to capture perceived changes in each decade using a binary (yes/no) response format. The questionnaire (Supporting Information Table S3) was validated through a pilot test with 114 respondents (for further details see Carpio et al. 2024). The survey protocol was approved by the Research Ethics Committee of Córdoba (Spain; approval no. 5091). The instrument comprised two sections. The first section collected sociodemographic information, including gender, age, annual income, type of residence (i.e., rural, semi-rural, or urban) province, and municipality, in order to characterize the sample. The second section assessed public perceptions of local, municipality-level drivers of land transformations, using the LCF categories described in Table 1 to frame the questions.

A total of 2,071 respondents participated voluntarily after providing informed consent, providing a sample of the population of peninsular Spain. Participants were recruited via Netquest online consumer panel (www.netquest.com) using stratified sampling to ensure diversity in gender, age, urban-rural residence, and region (Supporting Information Table S4). Although online consumer panels may overrepresent more digitally engaged individuals and underrepresent some population groups (Nielsen 2011), stratified sampling can help mitigate these biases (Maas et al. 2021). The online survey was administered in 2023–2024 using the Tickstat platform (www.tickstat.com), which handled the digitization and deployment of the questionnaire. For each LCF and decade, perceived transformation was calculated as the proportion of respondents reporting that specific change relative to the total number of responses obtained for that decade. This allowed us to identify which types of transformation had the greatest relative weight in each period (Supporting information S6).

Statistical analysis

To evaluate the association between observed LCFs, change intensity and perceived transformation, we applied a Generalized Linear Mixed Model (GLMM) using the `glmmTMB` R package (Brooks et al. 2025), employing a Beta distribution and a logit link function. The perceived transformation rate was included as the response variable, whereas the $\log_{10}$ -transformed change intensity was included as the predictor. Analyses were conducted at the levels of age class, decade and LCF. Age class included six categories: 18–24, 25–34, 35–44, 45–54, 55–64 and 65–99; decade included six reference periods: 1960, 1970, 1990, 2000, 2010, and 2020; and LCF the eight transformation LCFs. Accordingly, age class and decade were initially included as main fixed effects, together with their two-way interactions with observed change intensity: age class $\times$ change intensity and decade $\times$ change intensity. LCF-specific intercepts and slopes for change intensity were specified as random effects, allowing their covariance to be estimated.

Results

Land cover flow observed dynamics

The temporal dynamics of the eight LCFs within each decade are shown in Fig. 2. URB reached its highest annual transformation intensity in the 2000s, followed by a deceleration in the 2010s and subsequent stabilization toward 2020s. A similar pattern was observed for ENE, although with a more pronounced deceleration in the last period. AGR, in turn, showed an increasing trend, with slight variations during the 2000s and 2010s, followed by a small acceleration toward 2020s. In contrast, IRR exhibited marked fluctuations between decades, with a higher intensity in 2010s. Other LCFs, such as AFF and PA, showed a similar pattern: a gradual increase in change in intensity up to a maximum in 2000s, followed by a gradual deceleration in subsequent decades. BURN accounted for a comparatively small proportion of the total area transformed but showed an overall increase in annual change intensity, reaching its highest value in the 2020s. Finally, FARM fluctuated across the earlier decades and increased sharply toward the 2020s.

Social perception assessment

Of the 2,071 respondents, 55.6% reported perceiving changes in LCFs. Overall, perception patterns were broadly consistent across age classes, although some differences were observed for specific transformation processes (Fig. 3).

All age classes highlighted processes such as ENE and BURN as consistently increasing transformation processes, reaching their highest perceived proportion in recent decades (2020). URB showed a more heterogeneous pattern, peaking between 1990 and 2000, followed by a subsequent deceleration toward 2020, whereas the youngest group (18–24) showed a sustained and increasing trend, differing from the rest of the age class. In contrast, AGR showed a moderate and consistent decline across all age classes throughout the study period, equivalent to the observed pattern to IRR. AFF mostly fluctuated across decades and age classes but generally showed lower perceived proportions in the most recent period. PA remained comparatively stable over time, with moderate variation among age class and a slight increase in some groups during the 2000s and 2020s). FARM also remained relatively stable, although perceived proportions tended to decline slightly in several age classes before increasing modestly in the 2020s. Other processes (not included in the studied LCFs) showed a higher proportion of perceived changes in the 1960s, followed by a continuous decline until 2020 consistently across age-classes.

Relationship between perceived and observed land transformation dynamics

The mixed-effects model showed high explanatory power (conditional $R^2c = 0.99$; marginal $R^2m = 0.16$). Age class and its interaction with change intensity were not retained in the final model according to significance and AIC value. The model revealed a significant positive association between perceived transformation and actual intensity of change ($p < 0.05$; see Table 3). However, the strength of this association varied across decades and among LCFs, with weaker associations in more recent decades (Fig. 4).

Table 3
Summary of the Generalized Linear Mixed Model (GLMM) with Beta family (logit-link) for perceived social perception as a function of land-use change intensity (LCI) and decade and its interaction; including land cover flows (LCF) specific intercepts and slopes for change intensity as random effects.

Groups	Name	Variance	Std.Dev.	Corr
LCF	Intercept	1.03	1.01	
	Land-use change intensity (LCI)	0.30	0.55	0.06
Conditional model	Estimate	Std.error	Z value	P-value
Intercept	-0.86	0.40	-2.12	*
LCI	0.53	0.25	2.11	*
Decade (1970)	-0.61	0.24	-2.51	*
Decade (1990)	-0.95	0.20	-4.76	***
Decade (2000)	-0.97	0.18	-5.43	***
Decade (2010)	-1.14	0.20	-5.65	***
Decade (2020)	-1.46	0.28	-5.28	***
LCI:Decade (1970)	-0.004	0.15	-0.02	ns
LCI:Decade (1990)	-0.18	0.13	-1.40	ns
LCI:Decade (2000)	-0.07	0.10	-0.74	ns
LCI:Decade (2010)	-0.28	0.12	-2.40	*
LCI:Decade (2020)	-0.44	0.15	-2.87	*
P-values: <0.001 '***'; <0.01 '**'; <0.05 '*'; and > 0.05 'ns'				

Discussion

Land cover flows provided a consistent framework for characterizing major LULC transformations over recent decades, while survey data captured how these processes were socially perceived across peninsular Spain. The integration of both sources enabled the examination of the relationship between the actual magnitude of land transformations and their social interpretation, thereby facilitating the analysis of contrasting territorial change scenarios across the peninsular Spain. Our results show that this relationship is not homogeneous but varies according to both historical context and the specific LCF involved.

There were no significant differences in LCFs perception among age class of the respondents, aligning with evidence that social identity, and territorial context shape environmental views more than age (Landwehr et al. 2023; Sales et al. 2024). Instead, the relationship between observed change intensity and perceived transformation was strongly modulated by decade. This association was stronger for changes occurring in the 1960s and 1970s than for those occurring in recent decades, particularly in 2010s and. This pattern suggests a temporal weakening in the correspondence between land transformation and social recognition, consistent with shifting environmental baselines and the gradual normalization of environmental change over time (Soga et al. 2024).

Our results indicate that the relationship between land-use change intensity and social perception also varies markedly across LCFs. Urbanization expanded most intensely during the 2000s, mirroring the housing bubble and its high rate of land consumption (Burriel 2016); the collapse of this cycle led to a sharp contraction in construction activity (Serrano-Martínez et al. 2017), revealing the institutional unsustainability of the underlying growth model (Romero et al. 2012). This trajectory is reflected in public perception, clustered around the 1990s and 2000s, with 2010–2020 the least identified—except among 18–24-year-olds, who perceived urbanization as a sustained trend, likely due to the lack of a long-term baseline for contextualizing recent changes, in line with "personalized ecology" (Gaston et al. 2023). Although the urbanization boom was highly visible at its peak, it is no longer widely interpreted as an active process—except among younger respondents, for whom its salience may persist given ongoing concerns about housing accessibility during the transition to residential independence, particularly amid the European housing crisis (e.g., Arampatzi et al. 2026). Even so, the consistent positive structural relationship across the full intensity range indicates that intense urban transformation tends to be socially recognized, and its material legacy—built-up and sealed surfaces—continues to shape collective memory, especially where traditional landscapes are culturally valued (Gil 2009). Overall, our findings support the view that landscape perception is mediated not only by the magnitude of physical change but also by cultural, historical, and territorial factors (Priego et al. 2008).

A similar pattern was observed for the development of renewable energy expansion. Transformation peaked between 2000, when Spain's energy transition was supported by favorable regulation, and later slowed following the suspension of incentives and the shift toward repowering existing sites (Doukas et al. 2022). The positive relationship between observed change intensity and social perception reveals a high perceptual sensitivity. Nonetheless, perception remained high even during years of lower expansion, suggesting that beyond current rates of expansion, the cumulative visual and symbolic effects of these infrastructures continue to sustain their social recognition as an active process of territorial transformation. Renewable energy development is therefore perceived not only as a technical process of decarbonization, but also as a visible expression of territorial restructuring and rural landscape change.

Agricultural intensification showed a comparatively weak association between observed change intensity and social perception, suggesting that this process may become socially recognizable only when it produces sufficiently visible territorial changes. The observed intensity was relatively high during the 1990s and increased again in the most recent period. These dynamics are consistent with long-term processes of land consolidation, mechanization, and CAP reforms that encouraged production concentration while contributing to the decline of traditional farming systems in marginal areas (Lasanta et al. 2017). Although agricultural intensification has supported food production, it has also generated substantial environmental pressures and may be difficult to reverse once established (Deguines et al. 2014). Social perception of this process was mostly pronounced in the 1970s but weakened in the following decades. This decline can be explained by the limited visual salience of many intensification processes, which often preserve the apparent visual coherence of rural landscapes despite profound ecological and productive reorganization (Cloquell-Ballester et al. 2012). Such transformations may therefore become normalized over time, particularly when they occur gradually and are incorporated into prevailing ideas of agricultural modernization. This interpretation is compatible with shifting environmental baselines and with local learning processes shaped by imitation and peer influence (Pauly 1995; Albizua et al. 2020). Agricultural intensification may thus be perceived less as environmental degradation than as an established and socially legitimized production model.

Similarly, irrigated arable land also exhibits low perceptual sensitivity, despite representing one of the most intensive expressions of agricultural modernization in Spain. Change intensity accelerated markedly during the 2010s, particularly in the Mediterranean basin and in the southern peninsular Spain, where it has been closely associated with olive groves (Debolini et al. 2018). In the context of increasing water scarcity, such systems should be oriented toward sustainable production efficiency (Pretty & Bharucha 2014). However, irrigation expansion has largely continued as a strategy to maximize productivity, often with limited consideration of its environmental consequences (Rosegrant, 2009; Guerrero-Casado et al. 2021). Respondents do not perceive this process as a primary driver of change. Our findings suggest that, although this transformation is physically visible in the study area, it is rapidly normalized because it unfolds gradually, continuously, and in a spatially dispersed manner. Irrigation expansion rarely appears as a disruptive process in public perception. Yet its long-term effects may be profound, altering the structure, functioning, and symbolic meaning of traditional agricultural landscapes and undermining the vitality of cultural landscapes that sustain territorial identity (Antrop 2005). Low perceptual sensitivity, therefore, should not be interpreted as evidence of low impact, but rather as an indication of social normalization.

Afforestation showed a completely different pattern. Change intensity progressively increased from 1970 onwards, peaking in the 2000s, initially driven by forest and hydrological restoration policies and later by CAP subsidies promoting afforestation of agricultural land for conservation purposes (Martín-Rodríguez et al. 2026). Conversely, new afforestation declined during 2010–2020, likely due to financial constraints, administrative complexity, and competing land management priorities (Thomas et al. 2010). Despite these fluctuations, the relationship between physical change and perceived intensity remained weak and practically flat, with social perception showing a decreasing, relatively homogeneous trend across age class. This weak correspondence suggests that afforestation is less readily recognized as an active landscape transformation, particularly when forest expansion is gradual or interpreted as ecological restoration rather than land transformation. Although afforestation is often viewed positively for its contribution to ecosystem services and environmental restoration (Frei et al. 2020), its social valuation is not uniform. Urban and non-resident populations may value forest expansion mainly for its ecological benefits, whereas local communities may associate denser forest landscapes with rural depopulation, reduced accessibility, and the erosion of traditional cultural landscapes (Lasanta & Pascual 2015). Social acceptance is thus likely greater when afforestation is multifunctional, locally adapted, and integrated into existing rural systems rather than implemented as isolated or large-scale interventions (Schirmer 2007).

On the other hand, burned areas showed an increasing trend in change intensity that corresponds to the same trend in perception, albeit it supposed a smaller percentage of overall transformation in comparison with other LCF. In Mediterranean systems, fire recurrence is strongly influenced by climatic conditions, land-use conflicts, management changes, and human behavior (Viedma et al. 2015). However, the burned category captures only shrubland and grassland affected by fire, while burned forest areas retain their wooded status unless a land-use change occurs. Since direct transitions between forest classes and burned areas are scarce, respondents are likely to react to fire as a general landscape disturbance rather than to the specific cartographic category. This could explain the strong relationship observed between change intensity and perception. In this case, perception displayed a clearly increasing trend in recent decades, escalating alongside the growing intensity of fires and their cumulative visual and emotional impacts. Furthermore, media coverage acts as an amplifier of this trend, reinforcing this effect by framing wildfires as catastrophic events and elevating their territorial salience (Crespo & Briales 2015; Hase et al. 2021).

Protected areas showed a strong association between landscape transformation and social perception. Although their territorial expansion slowed after the 2000s boom, the consolidation of the Natura 2000 network reinforced their territorial and institutional visibility. This protection framework has nonetheless functioned passively in reducing land pressures, so its long-term effectiveness depends not only on the protection decree but also on adaptive management and each region's ecological context (García-Llamas et al. 2026). The observed association may not reflect direct recognition of legal protection status itself, but rather its visible consequences—changes in land-use restrictions, management, access, or development pressure around protected-area boundaries—together with edge effects displacing pressures to adjacent areas (González-García et al. 2022). Protected areas are commonly associated with biodiversity conservation rather than land transformation, in line with generally positive attitudes toward conservation (Allendorf 2020). However, such perceptions are far from homogeneous: some stakeholders value protected areas mainly for their aesthetic, recreational, and ecosystem service benefits (García-Llorente et al. 2012), while others experience conservation designations as externally imposed restrictions on traditional livelihoods (Quintas-Soriano et al. 2015), depending on whether policies are perceived as facilitators or constraints to local needs (Bragagnolo et al. 2016). This underscores the importance of participation and co-management to align conservation with local expectations.

Finally, intensive livestock farming also showed a positive association with social perception, though the estimated relationship was comparatively uncertain. Despite profound intensification—livestock heads per agricultural holding rising from 8.9 in the 1960s to 957.5 in the 2020s—perceptions remained relatively stable or declined across several age class before a modest increase in the 2020s, suggesting that, in this case, productive concentration does not translate into an equally visible land transformation. This process was driven by agrarian reforms that restructured rural territories (Domínguez 2001) and by the transition to highly industrialized production models (Ruano 2022), which benefited much of the sector but also generated growing social opposition and

accelerated the decline of extensive systems, already weakened by the lack of generational renewal, land abandonment, and eroding rural livelihoods (Bernués et al. 2005). Intensive livestock farming therefore represents a socially contested process whose perception likely depends on proximity and direct exposure, reflecting a perceptual disconnection at the local scale: populations beyond production hubs rarely experience the associated externalities directly. In line with the NIMBY (Not In My Back Yard) effect, opposition intensifies when impacts are perceived in the immediate environment (Dear 1992), while spatial discounting suggests perceived relevance decreases with distance (Hannon 1994). As many impacts remain spatially concentrated and partially hidden within enclosed facilities, public perception is likely to stay strongly localized and shaped by direct exposure.

Concluding remarks

Understanding the historical trajectory of the land is essential for interpreting how territorial systems function and how societies respond to transformation. Land dynamics are shaped not only by the intensity of change, but also by its visibility, historical context, and incorporation into everyday experience. Highly visible or socially prominent transformations, such as urbanization, renewable energy expansion, and wildfires, were more readily recognized as drivers of land change. Intensive livestock farming may also become socially salient at the local scale, particularly where communities are directly exposed to its impacts. Likewise, even administrative designations, such as protected areas, may be perceived as agents of change because of the territorial effects they generate and the social meanings they acquire. By contrast, gradual and spatially diffuse processes, including agricultural intensification, irrigation expansion, and afforestation, were less closely aligned with social perception despite their substantial ecological consequences. Their progressive incorporation into everyday lands may contribute to their normalization, reducing their recognition as active transformations. This divergence highlights the need to monitor not only the most visible transformations, but also those gradual processes that may remain socially unnoticed. Such monitoring is essential for designing territorial policies that are not only responsive to visible conflicts, but also capable of anticipating slower, less perceptible forms of land change.

CRedit authorship contribution statement

Conceptualisation: BMA, PA; Methodology: BMA, AJC, PA; Formal Analysis and Writing – original draft: BMA, PA; Data Curation: BMA, RPR, AJC; Formal Analysis and Writing – Review & editing: BMA, RPR, AJC, AAS, PA; Supervision: PA; Project administration: PA; Funding acquisition: PA.

Declarations

Author Contribution

Conceptualisation: B.M-A, P.A; Methodology: B.M-A, A.J.C, P.A; Formal Analysis and Writing – original draft: B.M-A, P.A; Data Curation: B.M-A, R.P-R, A.J.C; Formal Analysis and Writing – Review & editing: B.M-A, R.P-R, A.J.C, A.A-S, P.A; Supervision: P.A; Project administration: P.A; Funding acquisition: P.A.

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Data Availability

Data used for statistical models are available in the zenodo repository at the following URL: <https://zenodo.org/records/22095355?preview=1&token=eyJhbGciOiJIUzUxMiJ9.eyJpZCI6IjNIMDk1ZTViLTE5YzItNGQ2MC1hMzQwLWFiODBmM2UxMDM0MSIsImRhdiGEiOnt9LCJyYW5kb20iOiJkN>. The raw survey information has restrictions according to the Ethics Committee; the raw data is only available upon request and with the permission of the University of Cordoba.

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Figures

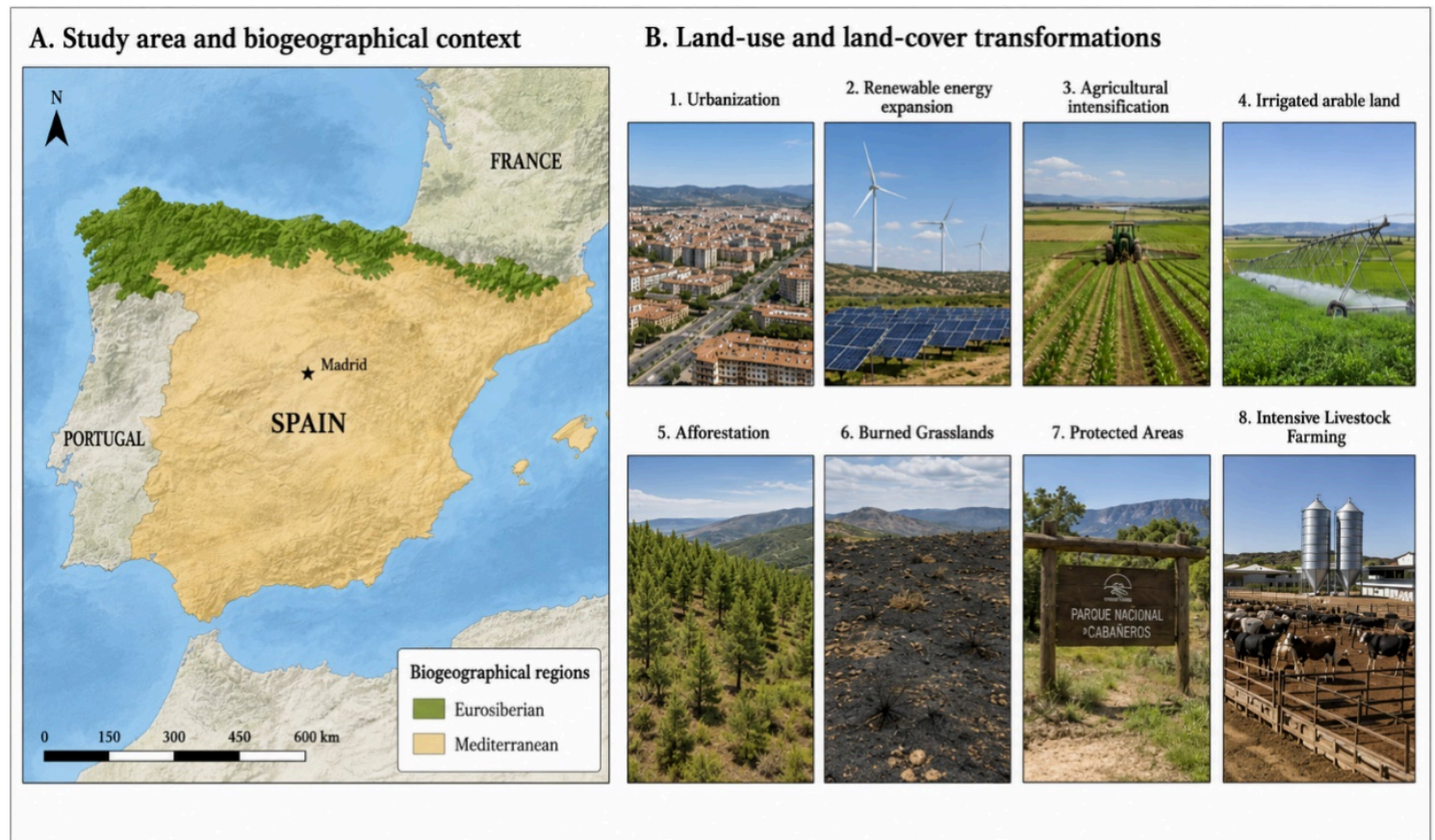


Figure 1

A) Study area and biogeographical contexts, showing the Eurosiberian and the Mediterranean regions. (B) Representation of land-use and land-cover transformations analyzed in this study.

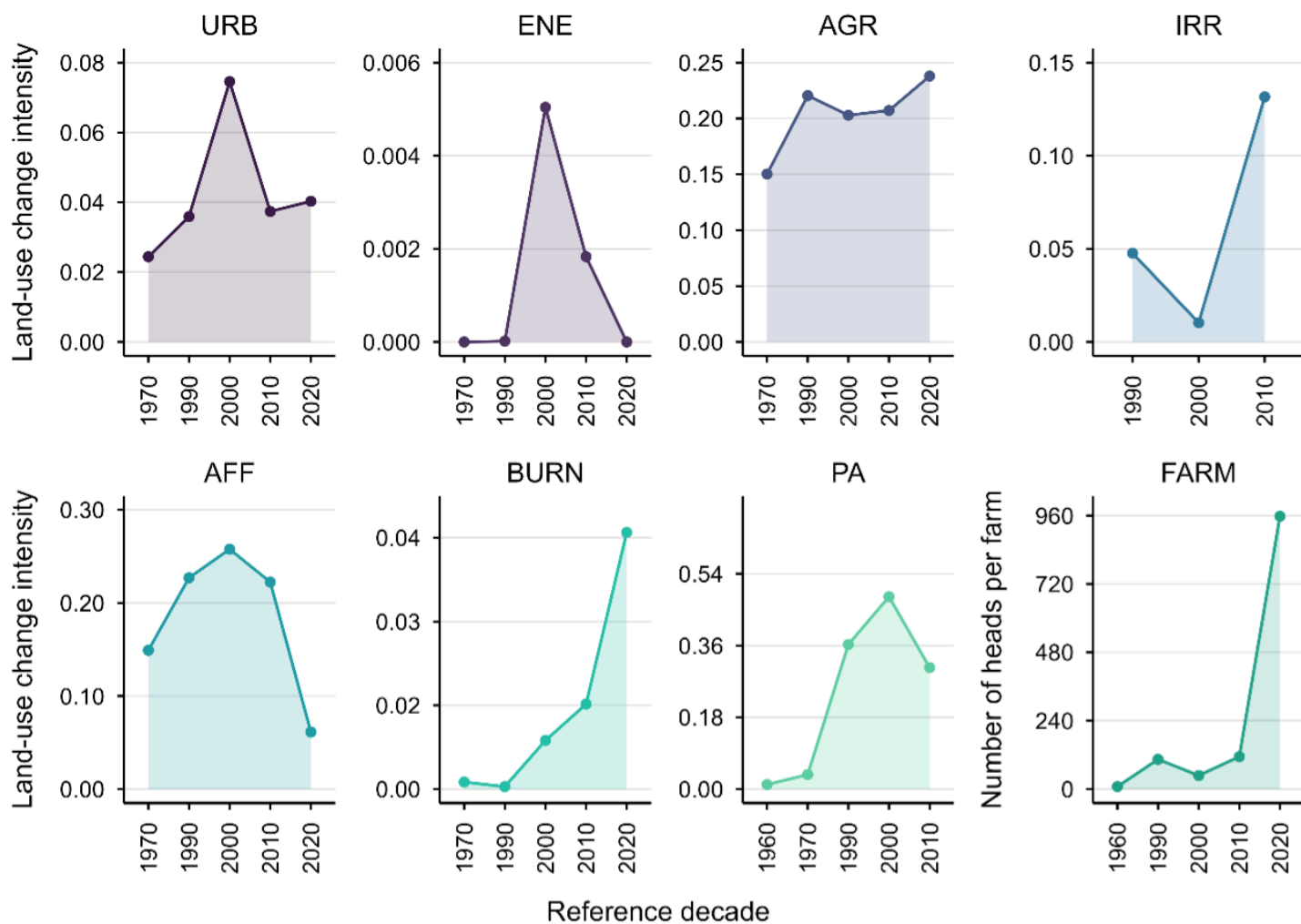


Figure 2

Evolution of transformation intensity by land cover flow category. The Y-axis represents the change intensity; excepting for FARM that reflects the mean number of heads per farm. The X-axis represents the reference decade; please note that only for PA and FARM information was available for 1960s and IRR was only available for 1990s, 2000s, and 2010s because of limitations in the historical data series. URB: Urbanization, ENE: Renewable energy expansion, AGR: Agriculture intensification, IRR: Irrigated arable land, AFF: Afforestation, BURN: Burned grasslands, PA: Protected areas, FARM: Intensive livestock farming.

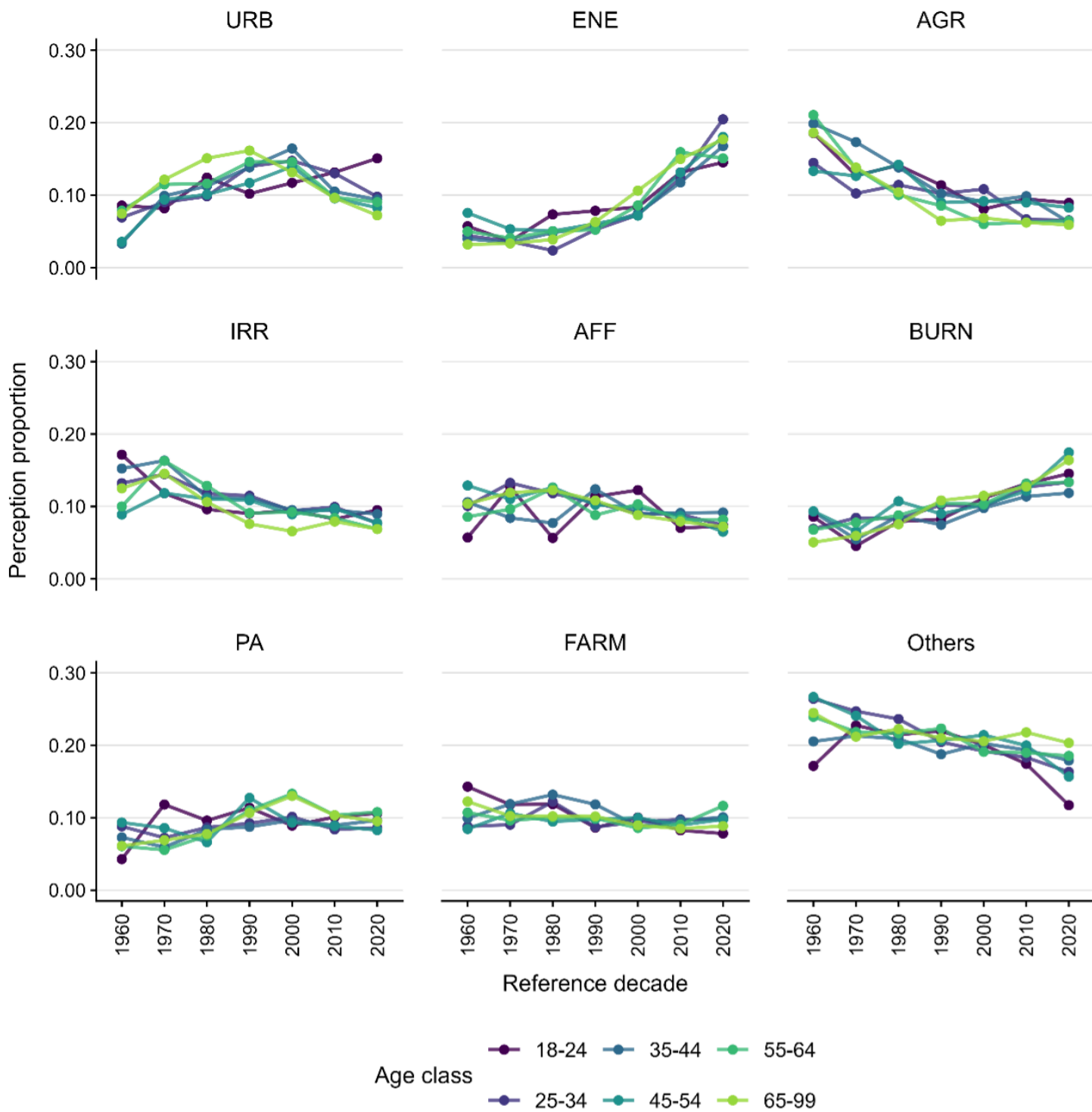


Figure 3

Social perception of land cover flows by age class and decades. Perceived transformations are expressed as the proportion of respondents reporting that specific change relative to the total number of responses obtained for that decade. URB: Urbanization, ENE: Renewable energy expansion, AGR: Agriculture intensification, IRR: Irrigated arable land, AFF: Afforestation, BURN: Burned grasslands, PA: Protected areas, FARM: Intensive livestock farming and Others.

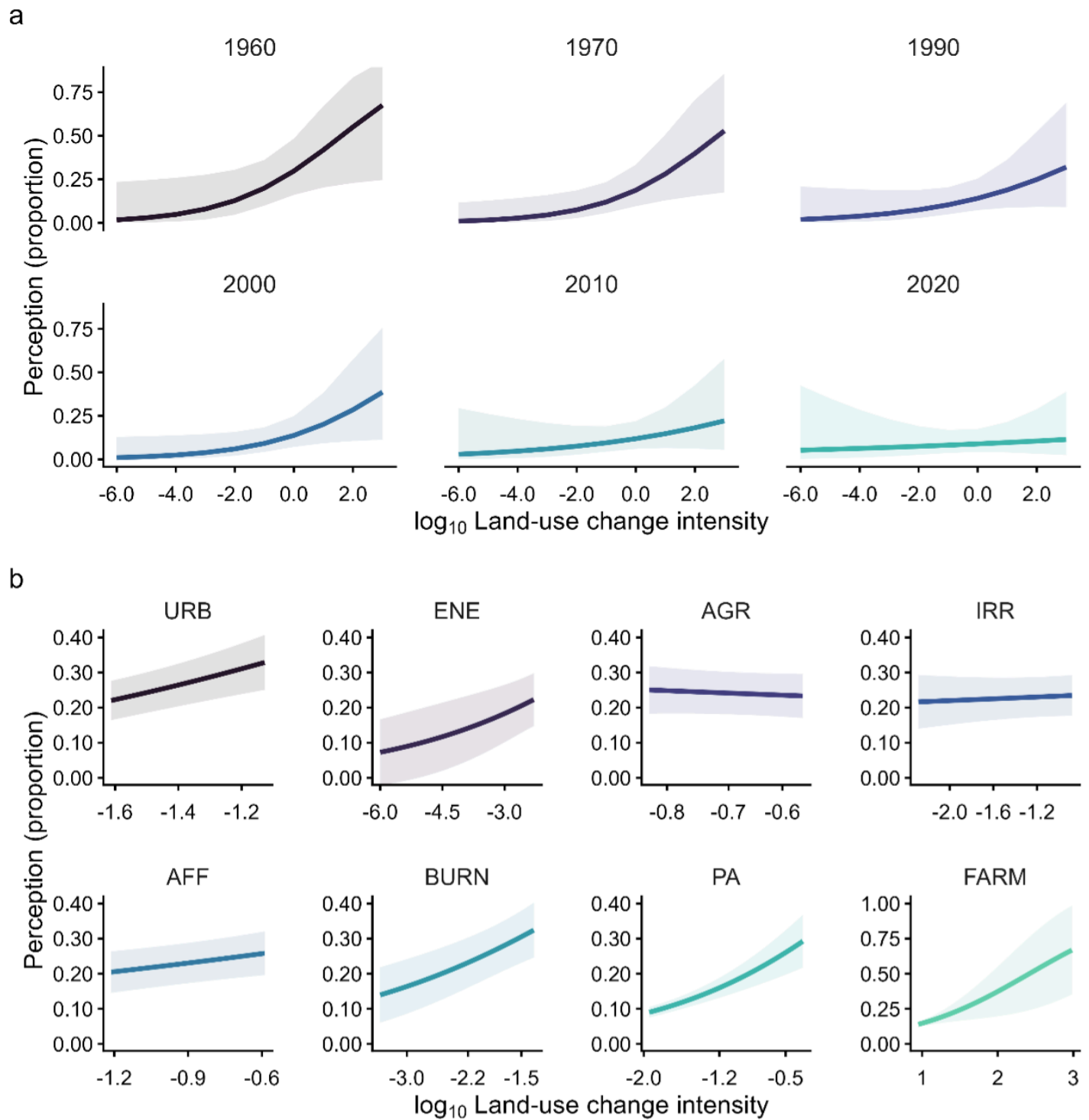


Figure 4

Association between the mean expected proportion of the social perception and land-use change intensity ($\log_{10}$) according to model summarized in Table 3. Variability across decades (panel a) and land cover flows (panel b) were represented. Shaded bands indicate a 95% confidence interval. URB: Urbanization, ENE: Renewable energy expansion, AGR: Agriculture intensification, IRR: Irrigated to arable land, AFF: Afforestation, BURN: Burned grasslands, PA: Protected areas, FARM: Intensive livestock farming.

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