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What strategies would sheep farmers implement to respond to climate change? A cross-national comparison of sheep farming systems in the Mediterranean

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A R T I C L E I N F O

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A B S T R A C T

How livestock systems respond to climate change (CC) will shape global food security and rural livelihoods. The Mediterranean region, a climate risk hotspot, hosts diverse livestock systems, including extensive meat sheep farming, where adaptation is critical to prevent economic and social decline. However, response measures are often identified through top-down approaches that overlook local conditions and farmers' perspectives. This study conducted 216 face-to-face surveys with farmers across 11 meat sheep systems in Egypt, France, Spain, and Tunisia to examine their beliefs about CC, perceived farm impacts, and preferred strategies to cope CC. Cluster analysis identified five strategies: i) infrastructure improvement, ii) feed intensification, iii) feed optimization, iv) diversified adjustments, and v) flock management with feed intensification. These strategies were present across all countries and systems. Farmers widely recognize CC and its effects but most attribute its causes a combination of natural and human factors or to natural processes, rather than exclusively to human activity. Their primary concern is feed security, addressed through grazing, indoor feeding, or both, with increased feed purchases playing a central role. Conversely, breed substitution and reproductive management changes are rarely considered. The emphasis on farm infrastructure improvement and feed intensification suggests farmers prioritize reducing exposure to CC impacts by decoupling their farms from local environmental conditions. This aligns with a 'sustainable intensification' approach, which presents socio-economic and environmental challenges, requiring greater technical support for farmers to implement effective responses to CC.

1. Introduction

Responding to climate change (CC) in livestock systems is essential to global food security and human well-being. These systems contribute 17 % and 33 % of global kilocalorie and protein consumption, respectively (Rosegrant et al., 2009), and are the main source of livelihoods and employment for more than 1 billion people living in poverty (Rojas-Downing et al. 2017). The urgency of adaptation is accelerating because CC impacts are occurring earlier, are more widespread and have more far-reaching consequences than expected by the IPCC (Portner et al., 2023).

The Mediterranean region is a hotspot for climate risks, due to the combination of strong climate hazards and high vulnerability. Since the 1980s, the region has warmed at a higher rate than the global average (annual mean temperatures are 1.4°C above the late 19th century), and it is projected to warm at a rate about 20 % greater than the global average in the 21st century (Lionello and Scarascia, 2018). There is a high degree of certainty that extreme high-temperature events and droughts have become more frequent and intense, especially in the northern Mediterranean, and that they are likely to continue to increase

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during the 21st century (Ali et al., 2023). The exacerbation of CC in the region challenges the response capacity of coupled human-natural systems, such as livestock farming systems.

Livestock farming systems in the Mediterranean are already affected by CC, both directly and indirectly (Lacetera et al., 2013). Directly, by increasing heat stress in livestock, which can affect feed intake and utilisation efficiency, health, reproduction, and performance (Rojas-Downing et al., 2017). Indirectly, by affecting the availability and quality of feed resources and water, and by influencing the life cycle and geographical distribution of pathogens and their vectors (Pérez et al., 2023; Rojas-Downing et al., 2017).

The Mediterranean region holds an exceptional variability of livestock farming systems, which is the result of its complex topographic and ecological characteristics and its enormous socio-cultural richness (e.g. de Rancourt et al., 2006; Debolini et al., 2018). Although the strong socio-economic trends since the mid-20th century have led traditional pastoral livestock systems to a process of intensification of resource use and gradual decoupling from local feed resources (especially natural pastures and grasslands), many pastoral systems remain (Bocci et al., 2019; Pardos et al., 2022; Riedel et al., 2007; Rjili et al., 2023). Here, we understand pastoral systems as the livestock farming systems that make extensive use of local feed resources, including grasslands, rangelands, stubble, fallow, and other agricultural by-products.

Meat sheep farming systems are a paradigmatic example of the pastoral systems in the Mediterranean (Dubeuf et al., 2016; Vigan et al., 2017). Despite their historical and current importance, meat sheep farming systems are in decline in most northern Mediterranean countries for a variety of reasons and currently face significant structural and economic challenges compared to other livestock sectors (de Rancourt et al. 2006; Belanche et al., 2021). In contrast, in southern Mediterranean countries meat sheep farming systems continue to play an important economic, dietary, and socio-cultural role. In both the northern and southern Mediterranean, adapting meat sheep farming systems to CC is crucial to avoid drastic impacts on the sector, with cascading economic and social consequences, including the abandonment of family and small-scale production and the migration of farmers to urban areas (Benoit et al., 2019; Bocci et al., 2019; Thomasz et al., 2020).

To interpret the different types of on-farm responses to CC, we adopt a resilience-based framework (Darnhofer, 2014; Beitnes et al., 2022) that conceptualizes adaptation through three main capacities: buffering, adaptive, and transformative. Buffering capacity refers to the ability to absorb perturbations without changing the structure or function of the farm system. As Darnhofer (2014) notes, buffering is not rigidity but "the ability of the farm to maintain itself through a disruption." Adaptive capacity involves reconfigurations in management or resource use in response to evolving conditions, such as changes in grazing regimes, feed management, or reproductive cycles. Transformative capacity refers to deeper structural changes in the farm system, including shifts in production goals or species (e.g., transitioning from dairy to meat systems).

The literature proposed a wide range of technical and management options to support livestock farms responding to CC (Escarcha et al., 2018; Pardo and del Prado, 2020; Pérez et al., 2023; Rojas-Downing et al., 2017). These include the use of heat-tolerant genotypes (either through breeding or through breed and species substitution), adjustments in herd management (such as adjusting reproduction or providing water and shade), and changes in feeding strategies (such as selecting forage species adapted to heat and water scarcity, increasing species diversity in pastures, feed supplements or adjusting stocking rates) (Aguilera et al., 2020; Chang-Fung-Martel et al., 2017; Pardo and del Prado, 2020).

The identification and design of potential adjustments or modifications to farms structure and management practices to cope with CC have often been implemented using a top-down approach, without considering that the decisions are made at the farm level, (Ayal et al., 2018; Griffin et al., 2023; Kgosikoma et al., 2018; Kipling et al., 2019). This approach overlooks local and contextual factors as well as farmers' individual values and experiences. There is a lack of studies exploring farmers' experiential, practical knowledge and understanding of system functioning and management risks to complement the perspectives of other actors in the knowledge transfer chain, such as scientists and extension services (Concu et al., 2020; Sautier et al., 2017). Comparative studies across farming systems in different countries remain scarce (Ariom et al., 2022; Niles and Mueller, 2016; Rahut et al., 2021), and none has considered the livestock farming systems or the Mediterranean area.

This study seeks to address these research gaps by drawing on direct interactions with meat sheep farmers in four Mediterranean countries to explore: i) their beliefs about CC and perceived impacts of CC on their farms, and ii) their views on the most suited changes to farm components to cope with future CC. The analysis of the farmers' opinion would provide insights into the patterns of strategies they are inclined to consider, and how these are distributed across countries and farming systems. To the best of our knowledge, this is one of the few studies to address these issues in small ruminant systems, and the first to compare results across different types of farming systems and countries.

2. Material and methods

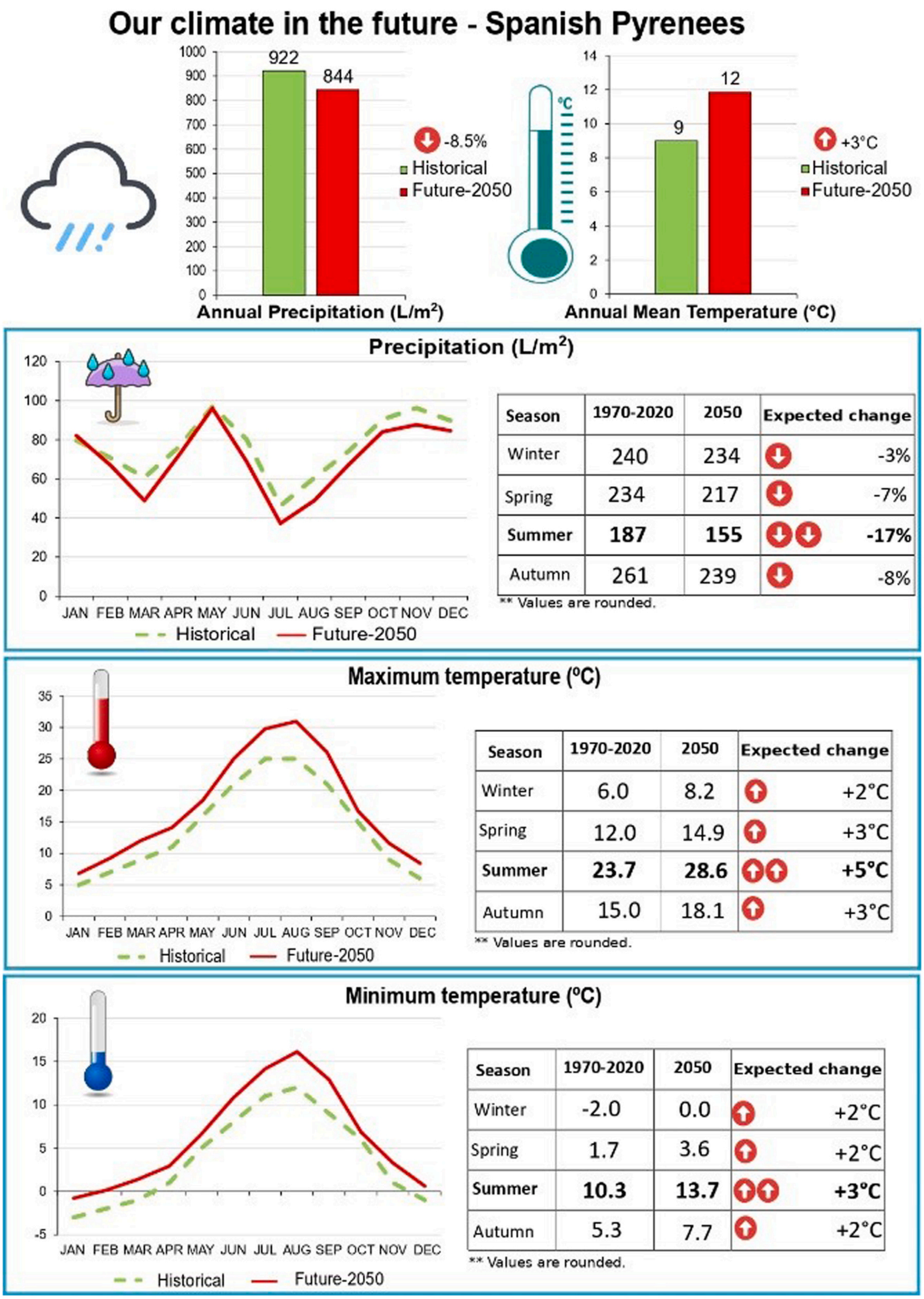
2.1. Case studies

The study was conducted on 11 meat sheep farming systems, located in four countries in the north (France and Spain) and south (Egypt and Tunisia) of the Mediterranean basin. The farming systems represent the main production systems in the study areas (Galal, 2007; Lasseur, 2005; Ripoll-Bosch et al., 2013; Mohamed-Brahmi et al., 2024). The studied systems belong to three types according to the FAO classification (Seré et al., 1996): grassland-based systems, rain-fed mixed-farming systems, and irrigated mixed-farming systems. Farming systems of the same type exhibit substantial variation between countries in terms of breeds, herd sizes, reproductive management, feeding systems, agricultural integration, irrigation levels, and climates. To account for this diversity, the systems under study are named according to country, the FAO classification, and in the case of the grassland-based systems, biogeographical indicators. The main characteristics of the farming systems are described below, with additional details provided in the Appendix A (Table A1).

In Egypt, three farming systems were considered: i) coastal rain-fed mixed-farming system (Eg_Rain.Mixed), ii) the Upper Egypt irrigated mixed-farming system (Eg_Irrig.Mixed) and iii) the desert oases irrigated mixed-farming system (Eg_Oasis.Irrig.Mixed). The Eg_Rain.Mixed system is located in the Coastal Zone of Western Desert. During the grazing season the flocks graze on natural range and barley stubble, while the rest of the time they are fed with concentrate mixture and straw. The Eg_Irr.Mixed system is located in the Upper Egypt fields are irrigated from the Nile river canals for mixed crop-livestock production. The flocks are fed indoors on cut clover in winter and maize in the summer, and crop residues during the rest of the year. Eg_Oasis_Irr.Mixed system are found in desert oases of the New Valley governorate. Fields are irrigated from groundwater springs, and animals graze clover and crop residues and supplemented with cereals and hay in the summer when pasture is not available.

In France, two farming systems were analysed: i) the Mediterranean plain hills grassland-based system (Fr_Mediterr.Grass), and ii) the Pre-Alps grassland-based system (Fr_Mountain.Grass). Both systems are characterised by an extensive management using as much as possible natural grazed resources. The Fr_Mountain.Grass system is located in the Alps foothills and its feeding system is mainly based on dry rangelands of moorland, scrubland and grazed woods, with summer collective pasture in the mountains. The Fr_Mediterr.Grass farms are located along the Mediterranean coast and have a larger agricultural area and flock size. Its feeding system is also based on rangeland and summer collective pasture, but integrates more forage crops, grassland, and supplementation during winter with their own forage and/or concentrate.

In Spain, three farming systems were studied: i) the Ebro Valley rain-fed mixed-farming system (Sp_Rain.Mixed), ii) the Ebro Valley irrigated mixed-farming system (Sp_Irrig.Mixed), and iii) the Central Pyrenes Mountain grassland-based system (Sp_Mountain.Grass). Both Sp_Rain. Mixed and Sp_Rain.Mixed systems are located in central Ebro valley, their main difference being the irrigation. The feeding of the adult flock



Precipitation (L/m²)

Season	1970-2020	2050	Expected change
Winter	240	234	-3%
Spring	234	217	-7%
Summer	**187**	**155**	**-17%**
Autumn	261	239	-8%

** Values are rounded.

Maximum temperature (°C)

Season	1970-2020	2050	Expected change
Winter	6.0	8.2	+2°C
Spring	12.0	14.9	+3°C
Summer	**23.7**	**28.6**	**+5°C**
Autumn	15.0	18.1	+3°C

** Values are rounded.

Minimum temperature (°C)

Season	1970-2020	2050	Expected change
Winter	-2.0	0.0	+2°C
Spring	1.7	3.6	+2°C
Summer	**10.3**	**13.7**	**+3°C**
Autumn	5.3	7.7	+2°C

** Values are rounded.

Fig. 1. Example of the fact sheet describing the future climate change scenario in 2050 compared to the average climate conditions in 1970–2000 in the Spanish Pyrenees.

is based on using available grazing resources (both own and communal) as much as possible and supplemented with forage and/or concentrates when grazing resources are not available. Ewes are housed and fed with high quality forage and/or concentrate before lambing and during lactation. The Sp_Mountain.Grass has very limited cultivated area and the smallest flocks. Mountain farms use mountain, valley and intermediate pastures and shrublands. Animals are usually kept indoors during the winter when they are fed on forages and/or concentrates.

Finally, three farming systems in the semi-arid regions of Tunisia were analysed: i) the rain-fed mixed-farming system (Tn_Rain.Mixed), ii) the irrigated mixed-farming system (Tn_Irr.Mixed), and iii) the agro-silvo pastoral grassland-based system (Tn_Silvo.Grass). All these systems are located in the northern and central parts of the country. The Tn_Rain.Mixed is characterised by large farms, flocks graze year-round on natural pastures in semiarid rangelands and fodder crops, and are usually supplemented outdoors with concentrates and forages. The Tn_Irr.Mixed system is characterised by the smallest farms. The feeding system is similar to the Tn_Rain.Mixed, but they also graze irrigated forage crops. The Tn_Silvo.Grass system differs from the previous ones in that it is located more in the mountainous areas, flocks graze herbaceous vegetation and some fodder shrubs under forest trees, and in winter they are supplemented outdoors with cereals and forages.

2.2. *Survey design*

The information analysed in this study was collected through a face-to-face survey of farmers. A preliminary version of the questionnaire was developed in English language and then translated into the local languages in which the surveys were conducted (i.e. Arabic, French, and Spanish). This preliminary version was tested with 2–4 farmers in each country to assess farmers' understanding of the questions and time to complete. The survey was then shortened to reduce respondent burden, and certain questions were rephrased to improve clarity.

The final questionnaire consisted of two sections: i) farmers' perceptions on CC, and ii) their preferences for potential on-farm response actions. The full questionnaire can be found in Appendix B. The first section analysed farmers' beliefs about the causes of CC and their perceived changes in rainfall and temperature patterns over the past 20 years. This section also explored farmers' perceptions of the impact of heat stress and feed shortage, as representatives of the most important direct and indirect impacts of CC, on their farms. To ensure a common understanding, farmers were given a definition of both phenomena (see Appendix B). Farmers were then asked to individually rate the importance of such events to their farming activity when they occur on a scale of 1 ("It is not a serious problem at all") to 10 ("It is an extremely serious problem").

The second part of the survey focused on the changes that farmers would implement in their farm components to cope with future CC. Future climate scenarios for each case study region (see more details in the following section) were captured in fact sheets (Fig. 1 and Figures A1-A8 in Appendix C). These fact sheets provided a graphical and intuitive representation of the major changes in annual and seasonal temperature and precipitation expected in each region by 2050, compared to recent historical data from 1970 to 2000. Changes were presented both graphically and numerically, supplemented by a red arrow for increasing temperature and decreasing precipitation and a green arrow for decreasing temperature and increasing precipitation. Fact sheets were presented and carefully explained to farmers to ensure that they interpreted the graphs correctly.

2.2.1. *Climate change scenarios*

The climate information used to construct the future CC scenario fact sheet for each case study area was obtained from the WorldClim database. We analysed CC projections from the most recent Coupled Model Intercomparison Project (CMIP 6, Eyring et al., 2016) collection for all areas of interest, at a spatial resolution of 2.5 arc-min (equivalent to 21 km^2). These models formed the basis of the 6th Assessment Report of the IPCC (IPCC, 2023). Among the available macro-scenarios of greenhouse gas emissions and global climate models, we have chosen the Shared Socioeconomic Pathway 5–8.5 "High-reference scenario with no additional climate policy" (see more details about the Shared Socioeconomic Pathways in Riahi et al., 2017) and the Global Climate Model BCC-CSM2-MR as the worst-case scenario due to its significant variation in precipitation in most of the regions studied. For each region of interest, we obtained historical data (averages for 1970–2000) and projections to 2050 (averages for 2041–2060). The primary climate metrics included monthly precipitation, monthly maximum and minimum temperatures, annual mean temperature, and annual mean precipitation. QGIS software was used to extract the climate data. Climate data was extracted for 100 random points in each area of interest using the 'Point Sampling tool'.

Farmers were presented with future projections of precipitation and temperature, rather than with projections of potential impacts on pastures, animal health, or production, due to the complexity and uncertainty of the latter type of projections. Meta-analyses and reviews of potential impacts of CC on pastures, animal health, or performance have been conducted in the literature (Dellar et al., 2018; Dumont et al., 2015; Giorgi and Lionello, 2008; Rojas-Downing et al., 2017; Thornton et al., 2009). The specific impacts may vary considerably depending on the specific regional circumstances (Henry et al., 2018), and clear and specific projections for each study area do not exist. However, CC in the Mediterranean basin has been extensively studied and established (Cramer et al., 2018; Giorgi and Lionello, 2008; Hertig and Tramblay, 2017; Noto et al., 2023). Farmers, especially those who rely on local resources, have rich local ecological knowledge and their understanding of CC is usually consistent with observed trends (Akinyemi, 2017; Hou et al., 2012). They have first-hand experience of how changes can affect their livestock and agricultural activities (Hou et al., 2012).

2.2.2. *Farm changes to cope with climate change*

Once the CC fact sheets were presented to farmers, they were then asked a series of closed-ended questions to indicate changes they would implement on their farms to cope with to the CC scenarios considered. To determine the alternative combinations of changes, we employed a pre-defined list of farm domains and components to ensure consistency and standardisation of farmers' responses across farming systems and countries. Specifically, the survey focused on five farm management domains: pastures and forages, grazing and feeding, flock management, reproduction, and farm facilities and machinery. Within these domains, we considered 14 components (Table 1). The response options determine whether the farm components will be adjusted or modified and in what direction, without specifying its magnitude. We made this choice because we recognised that it would be very difficult for farmers to accurately quantify the magnitude of change. Therefore, the analysis focused on identifying combinations of component adjustments selected by farmers as feasible and necessary to cope with future CC scenarios, without quantifying the magnitude of these changes.

In interpreting the results, we use the terms "adjustments" and "modifications" to capture different degrees of change at the farm level. Following Darnhofer (2014) and the IPCC (2014), adjustments refer to small, often reversible changes in farm components (e.g., feeding, lambing seasons, or herd size) that do not alter system structure. Modifications, by contrast, are more structural or planned changes with longer-term implications (e.g., infrastructure and machinery, or breed changes). While not necessarily transformative, modifications involve a deeper reconfiguration than adjustments and are often linked to broader adaptation capacities. We acknowledge that the distinction between adjustments and modifications is not absolute; rather, these terms reflect a gradient of change, similar to the continuum between adaptation and transformation. Our use of both concepts aims to link this gradient of change to the theoretical distinction between adaptive and transformative responses, thereby supporting a more nuanced interpretation

Table 1
List of farm domains and components, along with alternative changes, presented to farmers as potential options for their farms to adapt to future climate change.

Farm management domains and components	Response categories
Pasture and forage	
1) Plant species or varieties	Change, no change, do not know
Grazing and feeding	
2) Extension or reduction of the grazing season	Extend, reduce, not modify, do not know
3) Extension or reduction of the area of pastures managed (as opposite to natural pastures)	Extend, reduce, not modify, do not know
4) Extension or reduction of the rangelands area used	Extend, reduce, not modify, do not know
5) Increase or decrease of amount of indoor feed	Increase, decrease, not modify, do not know
6) Increase or decrease of the amount of feed purchased	Increase, decrease, not modify, do not know
Flock management	
7) Increase or reduction of the herd size	Increase, reduce, do not know
8) Modification of the batching system	Yes, no, do not know
9) Change the breed reared	Yes, no, do not know
10) Selection of less productive but better adapted rams	Yes, no, do not know
Reproduction	
11) Change in lambing season/s	Yes, no, do not know
12) Increase or decrease in the reproductive rate	Increase, decrease, do not know
Farm facilities and machinery	
13) Improve facilities or build new ones	Yes, no, do not know
14) Introduce of new machinery	Yes, no, do not know

of the strategies identified in the study.

2.3. Survey implementation

The research team trained interviewers from all the case study countries to minimise interviewer bias and establish a common understanding of the questions. Interviewers were also taught on how to avoid leading farmers' responses and how to conduct appropriate probing. All farmers were given consensual instructions prior to the interview, which included a clear explanation of the study's purpose, the voluntary nature of participation, the anonymity of responses, and the right to withdraw at any time. Data protection regulations, including the EU General Data Protection Regulation, were compiled at all times and no personal identifying data were collected or stored.

Face-to-face surveys were conducted with 216 farmers (i.e. 47 in Egypt, 34 in France, 45 in Spain and 90 in Tunisia) between September 2020 and September 2021. The research team in each country carefully selected farms to cover the entire case study area, where each farming system is located (Fig. 2).

2.4. Data analysis

First, a descriptive analysis of farmers' beliefs about CC, their perceptions of changes in rainfall and temperature patterns, and the perceived impacts of heat stress and feed shortages on farm activity, was conducted. The findings were then compared across different farming systems and countries. Differences in perceived impacts, which were quantified on a continuous scale, were analysed using ANOVA and Tukey's HSD using R software (R Core Team, 2019).

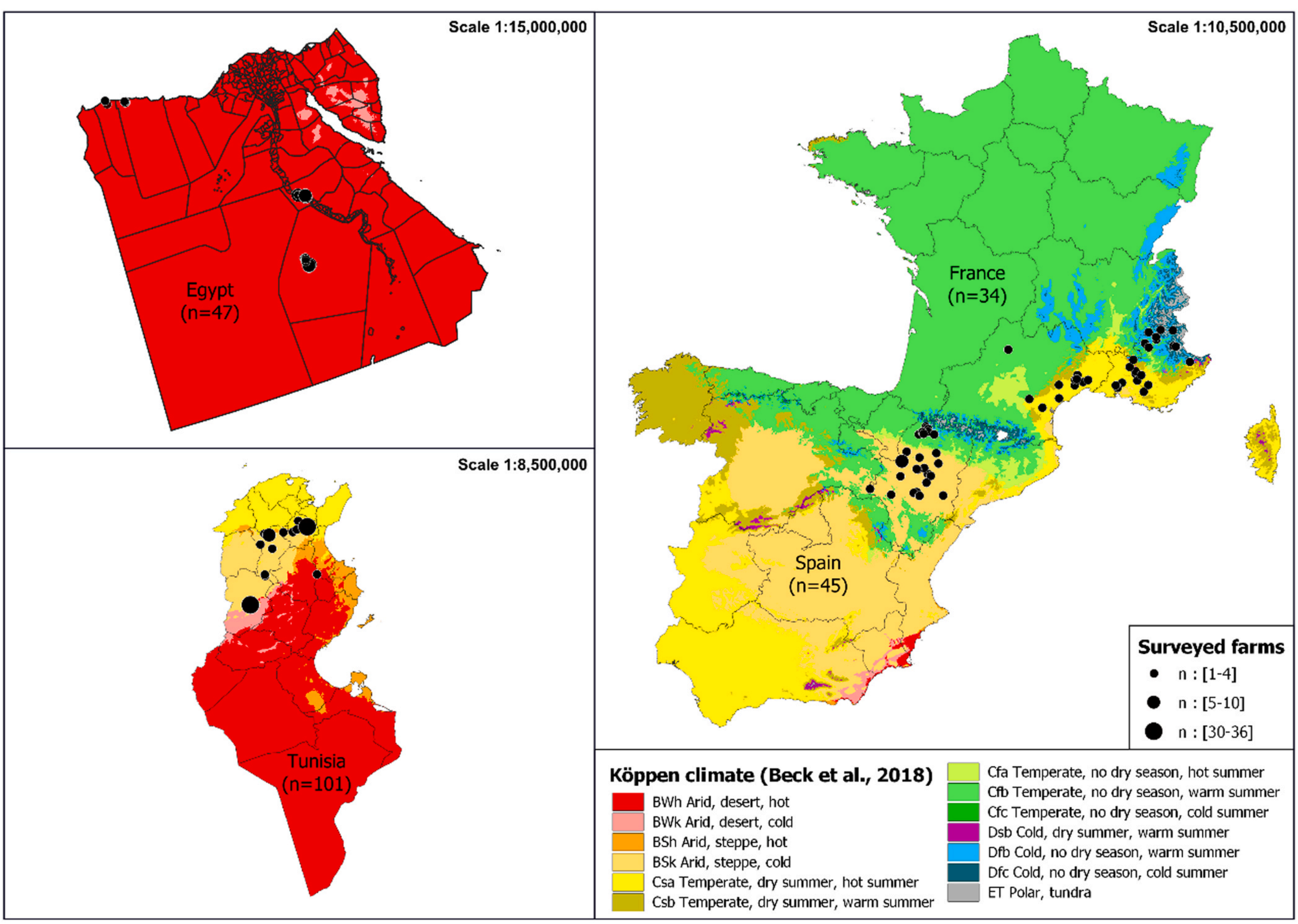


Fig. 2. Location of surveyed farms in Köppen climate regions in Egypt, France, Spain and Tunisia.

Farmers' preferences for potential on-farm changes were then examined. The 14 questions asked to farmers about the potential adjustments of farm components were converted into categorical variables that were used in subsequent analyses. These variables indicated whether farm components would be adjusted and the direction of the adjustments (see Table 1). We define response strategies as the alternative combinations of adjustments to farm components. Following this definition strategies were identified using cluster analysis approaches.

The clustering process began with the cleaning and preparation of the dataset. Observations (i.e. farms) were eliminated from the dataset with more than four variables (out of the 14 variables that defining components adjustments) that had 'do not know' responses, as we were not interested in analysing such responses. This left 208 observations for use in the cluster analysis, consisting of 46 from Egypt, 33 from France, 45 from Spain, and 81 from Tunisia. However, 88 observations in this subset still had "do not know" responses. Specifically, 41 observations had one "do not know" response, 29 held two, 10 had three, and 8 had four. Since it was not of interest to analyse the "do not know" responses, they were treated as missing values. Clustering algorithms are unable to utilise observations with missing values, so we chose to impute the missing values to avoid loss of information from the remaining variables. Given the categorical nature of the variables, missing values were imputed using a non-parametric technique based on chained random forest imputation as described in (Wright and Ziegler, 2017).

The k-modes algorithm (Huang, 1997) implemented in the R package klaR (version 1.7–2), which is an extension of the k-means algorithm developed by (MacQueen, 1967), was used. The k-modes method aims to partition the observations into k groups such that the distance of objects to the assigned cluster modes is minimised. The simple matching distance, which is calculated by counting the number of mismatches in all variables, was used to determine the dissimilarity of two objects. The appropriate number of clusters was selected using Ward (1963) approach, which is based on the intra-cluster sum of squares loss at each cluster partition. The final number of clusters was determined by selecting the partition with the highest inertia loss. To ensure the consistency and robustness of the clustering solution, after determining the number of clusters, 100 runs of the clustering algorithm were performed. The solution with the lowest intra-cluster sum of squares was chosen. The validity of the chosen number of clusters was confirmed by an interpretative analysis of the results (Dossa et al., 2011; Emtage et al., 2006).

3. Results

3.1. Farmers' perceptions on climate change

Most farmers in France, Spain and Tunisia, believed that CC was occurring. However, between 50–100 % of them, depending on the country and farming system, thought that CC was either a natural process or due to both natural and human factors (Fig. 3). In Egypt, many farmers believed that there was no evidence of CC, or that it was not happening. In terms of perceived changes in temperature patterns over the last 20 years, there was a consensus in all countries that temperatures had increased and/or become more extreme (Fig. 4).

Perceived changes in rainfall patterns were more variable across farming systems and countries than perceived changes in temperature (Fig. 5). Most Tunisian farmers thought rainfall had decreased, although about a quarter of them thought it had either increased or remained the same. In Egypt, farmers' perceptions varied across different farming systems, ranging from no change (Eg_Oasis.Irrig.Mixed) to a decrease (Eg_Irrig.Mixed) or either a decrease or more erratic rainfall (Eg_Rain. Mixed). In Spain, SP_Mountain.Grass farmers thought that rainfall had become more erratic or decreased, while the four options were similarly frequent for both Sp_Rain.Mixed and Sp_Irrig.Mixed farmers. Most French farmers, regardless of the farming system, thought rainfall had become more erratic and about a quarter thought it had decreased.

3.2. Farmers' perceptions of the impact of heat stress and feed shortages

There were significant differences between farmers in different countries in their perception of the impact of feed shortage and heat stress on their farm activity (Table 2). Statistical differences between farming systems within countries were found in Egypt for both feed shortage and heat stress, and in Tunisia for the impact of heat stress.

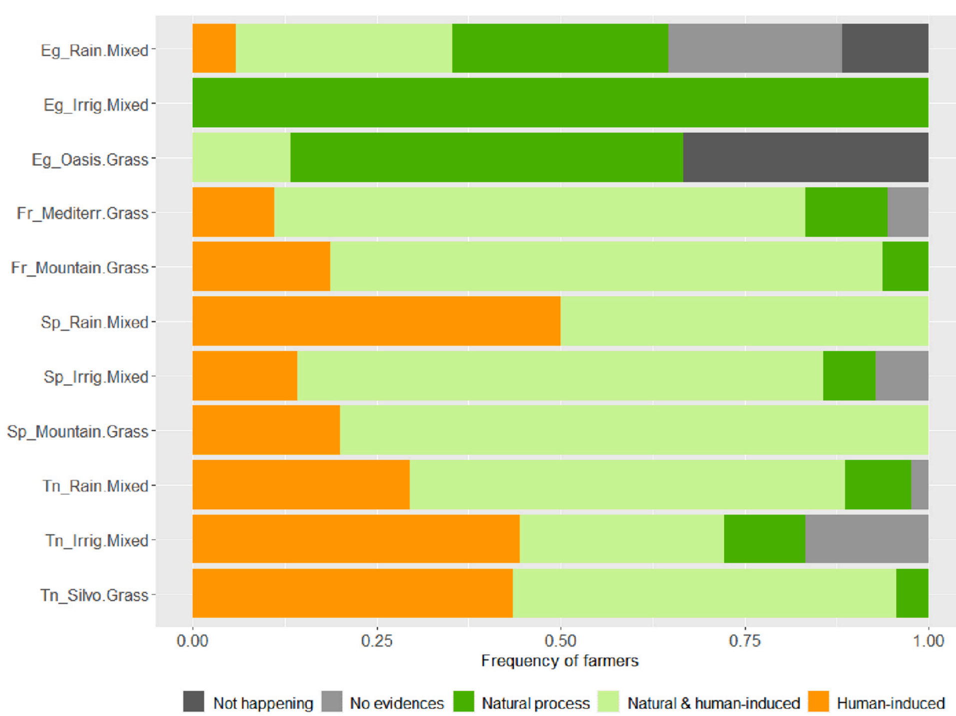


Fig. 3. Farmers' belief in climate change and its causes.

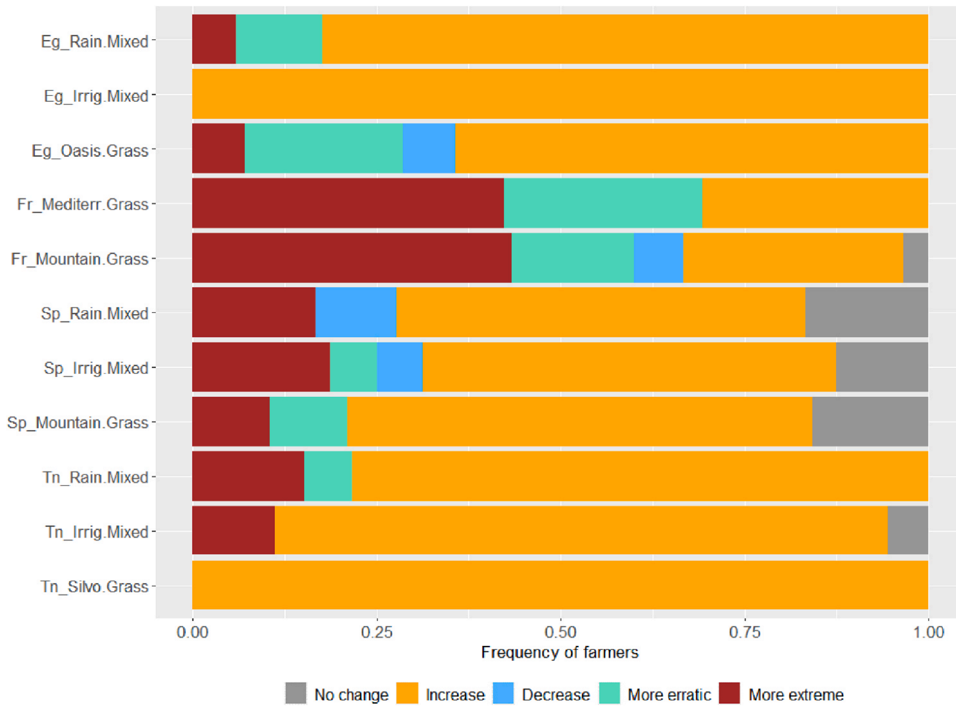


Fig. 4. Farmers' perceptions of changes in temperature patterns over the past 20 years.

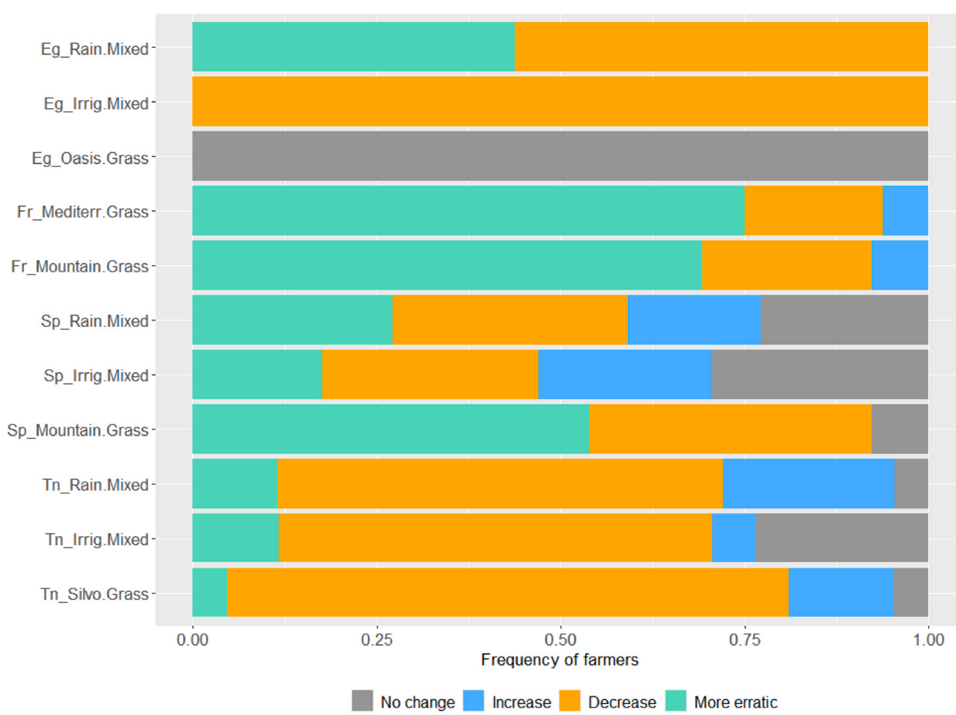


Fig. 5. Farmers' perceptions of changes in rainfall patterns over the past 20 years.

Spanish and Tunisian farmers reported the highest impact of feed shortage and heat stress, and Egyptian farmers the lowest. Within Egypt, Eg_Irrig.Mixed farmers reported the lowest impact of feed shortage and Eg_Oasis.Irrig.Mixed farmers reported the highest impact of heat stress.

3.3. Farm strategies to cope with climate change

The cluster analysis resulted in five clusters that defined different strategies (Table 3). None of the strategies would include modifications in the selection of rams adapted to harsh conditions or adjustments in reproductive rates as part of their central adaptation actions. Both actions were only chosen by a minority of farmers spread across the five strategies. Table 4 shows the relative importance of the farm strategies across countries and farming systems. Below, we describe in detail the five strategies, and their relevance in the different countries.

3.3.1. Strategy 1. Improvement of infrastructures

Farmers following this strategy were characterised by putting the

Table 2
Farmers' perceptions of the impact of heat stress and feed shortages on farm activity.

Country and farming system	n	Feed shortage impact*	Heat stress impact*
Egypt	**46**	**3,4 ^{A}±1,1**	**3,0 ^{A}±0,9**
Eg_Rain.Mixed	17	3,6^{a}±0,8	2,5^{b}±0,7
Eg_Irrig.Mixed	15	2,5^{b}±0,5	2,9^{b}±0,5
Eg_Oasis.Irrig.Mixed	14	4,1^{a}±1,0	3,7^{a}±1,2
France	**33**	**5,7^{B}±1,8**	**6,2^{B}±2,1**
Fr_Mediterr.Grass	17	6,0 ± 1,6	6,4 ± 2,4
Fr_Mountain.Grass	16	5,5 ± 2,0	5,9 ± 1,7
Spain	**45**	**7,3 ^{C}±1,9**	**6,9^{BC}±1,7**
Sp_Rain.Mixed	15	8,0 ± 1,4	7,4 ± 1,7
Sp_Irrig.Mixed	15	7,2 ± 2,4	6,7 ± 1,7
Sp_Mountain.Grass	15	6,8 ± 1,6	6,3 ± 2,9
Tunisia	**81**	**7,5 ^{C}±1,8**	**7,4 ^{C}±1,8**
Tn_Irrig.Mixed	17	7,4 ± 2,1	6,2^{a}±1,7
Tn_Rain.Mixed	41	7,6 ± 1,8	7,7^{ab}±1,9
Tn_Silvo.Grass	23	7,7 ± 1,5	8,1^{b}±0,9

Different capital letters indicate differences ($P < 0.01$) in perceived impact among farmers of different countries according to Tukey's HSD test.
Different lower-case letters indicate differences ($P < 0.01$) in perceived farming systems within each country according to Tukey's HSD test. Absence of letter indicate that no statistical differences were found
* Farmer perceived impact of heat stress and feed shortage events for their farming activity is measured on a scale of 1 ("It is not a serious problem at all") to 10 ("It is an extremely serious problem").

focus on improving farm facilities and machinery, and usually not adjusting any other farm component. This strategy would be adopted by around 40 % of the sampled farms in Egypt, France, and Spain and 10 % of the farms in Tunisia.

3.3.2. Strategy 2. Feed Intensification

This strategy was characterised by increasing the diets provided indoors and the amount of feed purchased and decreasing the grazing season and flock size. New machinery would be introduced. This strategy would be followed by 26 % of the sampled farms; 35 % of the farms in Egypt, 12 % in France, 27 % in Spain and 26 % in Tunisia.

3.3.3. Strategy 3. Feed optimization

This strategy would maximise the use of all available feed resources. As with the previous strategy, the diet provided to the animals indoors and the amount of purchased feed would be increased. However, in this strategy, the farmer would also extend the grazing season and increase the grazing area. The flock size would be reduced, and new machinery would be introduced. This strategy would be followed by 21 % of the farms; 24 % in Egypt, 15 % in France, 18 % in Spain and 23 % in Tunisia.

3.3.4. Strategy 4. Diversified adjustments

Farmers following the diversified adjustment strategy maximise all feed alternatives including both grazing and purchased feed resources, but they would also modify the plant species and varieties grown in managed pastures and crops, adjust the batching systems and improve farm facilities and machinery. This strategy is chosen by 14 % of the farms in the total sample; 12 % in France, 16 % in Spain, 22 % in Tunisia and absent in Egypt.

3.3.5. Strategy 5. Flock management and feed extensification

This strategy involves adjusting nearly every farm domain, excluding facilities, machinery, indoor diets, and the reproductive rate of the flock. It is the only strategy where farmers would change the lambing season and select rams better adapted to harsh conditions. This strategy is particularly relevant for farmers in France (18 %) and Tunisia (19 %), have almost no importance in Egypt (2 %) and is absent in Spain.

3.3.6. Farming system strategies in each country

In Egypt, Eg_Irrig.Mixed and Eg_Oasis_Irrig.Mixed farms preferred mostly *Improvement of infrastructures* or *Feed intensification* strategies. Eg_Rain.Mixed farmers mostly chose the *Feed optimization* strategy, followed by *Improvement of infrastructure* and *Feed Intensification* strategies.

In France, regardless of the system, farmers mainly chose the *Improvement of Infrastructures* strategy, but there were some differences in the next most preferred strategies. In the Fr_Mountain_Grass system, farmers equally opted in the second place for the *Feed Intensification* and *Flock management* strategies. In the Fr_Mediterr_Grass system, farmers chose *the Feed optimization* strategy in the second place, followed by both the *Diversified adjustments* and the *Flock management and feed extensification* strategies with equal importance.

In Spain, farmers of Sp_Irrig.Mixed and Sp_Rain.Mixed systems primarily chose the *Improvement of Infrastructures* strategy for both systems followed by the *Feed Intensification* strategy in the second place. Sp_Mountain_Grass equally opted in first place for farmers, the *Improvement of Infrastructures* and *Diversified adjustments* strategies followed by *Feed optimization* in the second place.

In Tunisia, regardless of their farming system, in contrast to other countries, only a small proportion of farmers chose the *Improvement of infrastructures* strategy. Farmers from Tn_Silvo_Grass systems distributed their choices equally among *Feed Intensification*, *Feed optimization* and *Diversified adjustments* strategies. Farmers within the Tn_Irrig.Mixed system predominantly selected the *Feed intensification* strategy, followed by the *Feed optimization* in the second place. Conversely, farmer within the Tn_Rain.Mixed systems primarily opted for the *Flock management and feed extensification* strategy, followed by the *Diversified adjustments*, the *Feed optimization* strategies, with *Feed intensification* strategies being the less selected strategy.

4. Discussion

There is a lack of cross-country studies that examine farmers' perspectives on CC, particularly their beliefs, their perceived impacts, and their views on the changes needed at farm level to face cope with it. Our study addresses this research gap by analysing 11 sheep farming systems in four Mediterranean countries. The face-to-face survey provided insights into the specific farm components farmers would consider adjusting or modifying to cope with future climate conditions. Based on this responses, we identified five distinct farm-level strategies and explore how these are distributed across countries and types of farming systems.

The impact of CC on farming systems vary depending on their structure and resource dependencies (Nardone et al., 2010). It is generally accepted that highly intensive livestock systems are less vulnerable to changes in local climatic conditions, as they rely on externally sourced feed resources can control the production environment to a greater or lesser extent (Bezner Kerr et al., 2023). In contrast, they remain vulnerable to the volatility and crises of agricultural commodity markets, water resources and energy. In contrast, extensive systems are more dependent on local feed availability and climatic stability, making them more exposed to CC impacts on local feed resources and heat stress in livestock. However, they often well adapted to the temporal and spatial variability of feed resources (Joly et al., 2022).

Our study complicate this binary classification showing that Mediterranean pastoral meat sheep systems do not fit neatly into either category. Instead, they combine characteristics of both intensive and extensive systems. This implies a dual vulnerability to the impacts of CC on both local feed resources and agricultural commodity prices. At the same time, it offer flexibility as farmers can strategically balance the use of local and imported feed resources to counteract specific climate-related pressures.

Table 3
Description of farm strategies according to changes that farmers would implement in different components of the farming system to respond to climate change. The percentage and bar in each cell represent the proportion of farmers within each strategy that would apply each modification to the components of the farming system.

Farm components (Modification of…)		Response strategies: Improvement of infrastructures (n=58)	Feed intensification (53)	Feed optimization (43)	Diversified adjustments (29)	Flock management and feed extensification (22)
Cultivation	Plant species* and varieties					
	Change	21%	29%	29%	79%	53%
	No change	79%	71%	71%	21%	47%
Grazing	Grazing season					
	Extend	19%	30%	58%	68%	45%
	Reduce	19%	46%	9%	18%	27%
	No change	62%	24%	33%	14%	27%
	Managed grazing area					
	Extend	11%	4%	86%	95%	77%
	Reduce	13%	16%	0%	5%	5%
	No change	75%	80%	14%	0%	18%
	Natural rangeland area					
	Extend	13%	2%	88%	79%	75%
	Reduce	15%	18%	7%	7%	10%
	No change	71%	80%	5%	14%	15%
Feed supplementation	Indoor feeding					
	Increase	14%	71%	65%	79%	23%
	Decrease	2%	4%	9%	3%	14%
	No change	84%	24%	26%	17%	64%
	Amount of food purchased					
	Increase	19%	64%	90%	74%	71%
	Decrease	2%	14%	6%	12%	11%
	No change	79%	23%	4%	14%	18%
Flock management	Flock size					
	Increase	7%	17%	7%	25%	19%
	Decrease	14%	56%	65%	21%	71%
	No change	79%	27%	28%	54%	10%
	Batching system					
	Modify	9%	20%	13%	70%	80%
	No change	91%	80%	87%	30%	20%
Breeds and rams	Breeds raised					
	Change	12%	23%	12%	7%	40%
	No change	88%	77%	88%	93%	60%
	Selection of more adapted rams**					
	Select	21%	26%	14%	31%	76%
	No change	79%	74%	86%	69%	24%
Reproductive management	Lambing season					
	Modify	9%	8%	19%	21%	86%
	No change	91%	92%	81%	79%	14%
	Reproductive rate					
	Increase	2%	0%	7%	14%	20%
	Decrease	2%	10%	19%	7%	5%
	No change	96%	90%	74%	79%	75%
Infrastructures	Improve/build facilities					
	Improve	68%	25%	19%	88%	7%
	No change	32%	75%	81%	12%	93%
	Introduce new machinery					
	Introduce	90%	76%	78%	77%	18%
	No change	10%	24%	22%	23%	82%

The coloured bar cells indicate the most frequent change in each farm component of the farms grouped in each strategy. The green bars refer to farm changes that involve extending or increasing measures, the red bars indicate reductions or decreases, the blue bars indicate modifications that do not affect the quantity, and the grey bars indicate no changes.
*Modification of plant species and varieties either in managed pastures or in feed crops.
**Rams more adapted to harsh environmental condition which are usually less productive.

Table 4
Relative importance of strategies across countries and farming systems.

Countries and farming systems	Response strategies: Improvement infrastructures (n=58)	Feed intensification (53)	Feed optimization (43)	Diversified adjustments (29)	Flock management and feed extensification (22)
Egypt (n= 46)	39%	35%	24%	0%	2%
Eg_Rain.Mixed (17)	24%	24%	47%	0%	6%
Eg_Irrig.Mixed (n=15)	47%	53%	0%	0%	0%
Eg_Oasis_Irrig.Mixed (14)	50%	29%	21%	0%	0%
France (33)	42%	12%	15%	12%	18%
Fr_Mediterr_Grass (17)	35%	6%	24%	18%	18%
Fr_Mountain_Grass (16)	50%	19%	6%	6%	19%
Spain (45)	40%	27%	18%	16%	0%
Sp_Irrig.Mixed(15)	47%	33%	20%	0%	0%
Sp_Rain.Mixed (15)	40%	33%	13%	13%	0%
Sp_Mountain_Grass (15)	33%	13%	20%	33%	0%
Tunisia (81)	10%	26%	23%	22%	19%
Tn_Irrig.Mixed (17)	6%	47%	24%	6%	18%
Tn_Rain.Mixed (41)	12%	17%	20%	22%	29%
Tn_Silvo_Grass (23)	9%	26%	30%	35%	0%

The numbers and bars in every box indicate the proportion of sampled farms that would implement each strategy for each country and farming system.

4.1. Farmers' perceptions of climate change

Regardless of country or farming system, most farmers in our study acknowledge that CC is happening and that there have been recent changes in temperature and rainfall patterns, indicating that farmers accept the reality of CC, as other studies have shown (Amamou et al., 2018; Liu et al., 2014; Niles and Mueller, 2016; Yang et al., 2021). However, our research also indicates that there is still a significant level of scepticism regarding its causes. Only a minority of respondents believe that CC is a human-induced process, with many attributing it to a combination of human and natural causes or solely to natural causes (particularly in Egypt), which is consistent with previous findings (Muñoz-Ulecia et al., 2025; Campbell et al. 2019). The mistrust narrative in the sheep farmer communities studied does not focus on denying CC but on its causes. This type of scepticism has been linked to social trust and political ideologies (Muñoz-Ulecia et al., 2025; Martin-Collado et al., 2024; Running et al., 2017). Our findings confirm that climate mistrust has permeated these farmer communities (e.g. Davidson et al., 2019; Doll et al., 2017; Kuehne, 2014), mirroring broader patterns in Western societies in general (Falkenberg et al., 2022; McCright and Dunlap, 2011; Poortinga et al., 2019). It is important to note that scepticism about the causes of CC has not prevented farmers from implementing changes to farm components in response to its impacts in the past (Doll et al., 2017; Davidson et al., 2019).

Some of the differences in farmers' perceptions between countries seem to be related to actual climate realities at the regional level. In Egypt, where the climate is already extreme, a substantial proportion of farmers said that either CC is not happening or there is no evidence that it is happening. Farmers located in Egypt desert oases (Eg_Oasis.Grass) mostly believe that rainfall patterns have remained unchanged, an observation that aligns with climatic conditions in the region, where rainfall is extremely limited and shows little interannual variability. Conversely Egyptian farmers located in more favourable areas, near the northern coast or in the Nile Valley, believe that temperatures have increased, and rainfall has decreased or become more erratic.

Differences in farmers' perceptions of the impact of heat stress and feed shortages may be influenced by both their expectations regarding livestock performance and the degree of intensification of their farms. In Egypt, for example, farmers may not perceive heat stress and feed shortages as having a major impact because their production expectations are generally low and their systems are well adapted arid environments through the use of groundwater, Nile irrigation canals and oases-based resources. In contrast, sheep farming systems in Spain and Tunisia have undergone significant intensification in recent decades through increased use of feed supplementation (e.g. Olaizola et al., 2015; Rjili et al., 2023). This trend, although not always economically justified (Ripoll-Bosch et al., 2014), may have raised animal and farm performance expectations. This increased concern may not only stem from rising performance expectations but also from the structural characteristics of these systems, which—combining intensive and extensive elements—are simultaneously exposed to both local climate risks and external input dependencies.

4.2. General trends in farm strategies to cope with climate change

We identified two key insights from our findings on farmer perspectives on the best the strategies to cope with CC. First, that adjusting or modifying feeding practices is central to all strategies. Second, that both breed substitution and adjustments in reproductive management are noticeably overlooked by farmers; only a small proportion of farmers considered changes in breeds, breeding stock selection criteria, or adjustments in lambing season, and reproductive rate.

We acknowledge that the relative importance farmers give to each inferred strategy in our study should be interpreted with caution. The proportions reported reflect preferences stated by farmers within a relevant but limited number of case studies and are subject to methodological sampling constraints. As such, they are not statistically representative of the broader Mediterranean meat sheep sector. However, given the diversity of countries, farming systems, and the authors' in-depth knowledge of the sector, we consider these patterns to be meaningful within the scope of this study. Further research is needed to assess the relative importance of these strategies in other regions and production systems, where different response logics or new strategies may emerge.

The fact that farmers place securing animal feed, whether through grazing, indoor feeding, or both, at the heart of farms responses to CC is not surprising, as feeding is the basis of livestock performance and represents the main expenditure of farms (e.g. Benoit et al., 2019; Perrin et al., 2020). In their response, the farmers considered are fully aware that future climate scenarios will negatively affect grassland and crop production and water availability (Lacetera et al., 2013), challenging the viability of their farms. Maintaining viable livestock systems in the face of CC is particularly challenging in the Mediterranean region where rangeland and pasture productivity is highly variable between seasons and years (Dumont et al., 2015; Jouven et al., 2010). Projected CC impacts are expected to further exacerbate these challenges, particularly for feed production (Ali et al., 2023; Lionello and Scarascia, 2018). As discussed in more detail below, most farmers in our study anticipate the need to increase indoor feeding and rely more heavily on feed purchased off-farm, presumably as a way to reduce their exposure to the impacts of CC on local feed availability.

The fact that farmers did not consider breed substitution a relevant option to cope with CC was an expected result. All farming systems studied raise local breeds that are already well adapted to local conditions, which is usually the case for meat sheep farming systems in the Mediterranean (Cloete et al., 2023; Lauvie et al., 2022; Pérez et al., 2023). In contrast, in other livestock sectors, such as beef cattle, dairy cattle or dairy sheep, breed substitution is more commonly proposed as a relevant option (Henry et al., 2018; McIntosh et al., 2023). However, the question remains whether the current adaptation of local breeds will be sufficient to withstand the conditions expected under CC, or whether further selection for traits linked to rusticity will be needed, as suggested by some authors (Brito et al., 2021; Casey, 2023). A key practical challenge driving farmers' use of genetic selection to adapt to CC is the genetic trade-off between selecting for rusticity and selecting for productivity. Some studies suggest that farmers may be unwilling to sacrifice production gains to select for more climate-resilient traits (e.g. Martin-Collado et al., 2024). Nevertheless, some recent studies in beef suggest that this negative genetic trade-off may be more pronounced in more intensive systems such as dairy production than in meat systems (Bradford et al., 2016).

Farmers' lack of intention to adjust their reproductive management practices to adapt to CC might be related to the fact that the seasonal reproductive patterns of small ruminants in temperate areas are coupled with optimal pasture availability to feed offspring (late winter and spring) (Simões et al., 2021). The farmers surveyed seem to be unaware that CC will potentially lead to a mismatch between pasture nutrient availability and increased animal demand for reproductive activities. This will be exacerbated by the negative effects of heat stress on reproduction performance (van Wettere et al., 2021). These negative effects can be overcome either by the induction of 'off-season' oestrous cycles (Simões et al., 2021), selection for more heat-tolerant animals, strategic supplementation during periods of increased demand, or shifting the mating season to coincide with peak feed availability and more moderate temperatures (Henry et al., 2018). Of these options, only feed supplementation was considered by farmers in our study, as discussed below.

4.3. Improvement of farm infrastructure and feed intensification strategies

Improving farm infrastructure and intensifying feed use were the most widely supported among the consulted farmers across countries and farming system. Both strategies indicate the importance farmers place reducing exposure to the impact of CC on both animal performance and local feed production, as shown by other studies (Amamou et al., 2018). These findings are consistent with strategies reported in the literature for adapting to short-term impacts of extreme climate events, when farmers seek to partially decouple their farm from local conditions making only incremental adaptations of their farming practices, rather than pursuing transformative changes in farming systems (Beitnes et al., 2022; Griffin et al., 2023). However, these strategies also reflect a progressive artificialization of the production environment, and they may represent early steps on a transformative pathway, which could eventually lead to more intensive production models, including shifts in species as seen in other contexts such as Egypt (Bonnet et al., 2014). This interpretation underscores the importance of framing on-farm adjustments within a continuum of change: while initially adaptative, such adjustments may cumulatively drive structural modifications of Mediterranean meat sheep systems, potentially eroding their extensive character.

Infrastructure improvements will depend on the state and opportunities of farms in the studied regions. In developed farming systems, improvements may refer to technological innovations such as fans and sprinklers to reduce heat stress, while in other systems, improvements are likely to refer to enhancing shading and improving building ventilation. In any case, these farmers appear to approach the long-term impacts of CC in the same way they deal with the short-term impacts of extreme climate events, by reducing exposure and trying to continue with business as usual (Beitnes et al., 2022; Griffin et al., 2023). Interestingly, there is little variation between farming systems in the importance that farmers give to this strategy. Although this finding should be taken with caution, as discussed below, it may reflect two factors that warrant further investigation: a) during informal conversations with farmers during the surveys, many expressed a preference for abandoning farming rather than implementing costly and/or labour-intensive adjustments and modifications to multiple farm components, particularly in a context of significant socioeconomic and climatic uncertainty; b) some farming systems, such as mountain or rainfed systems, may have limited capacity to adjust other farm components because they are finely tuned to highly constrained natural and socioeconomic contexts (e.g. Lamarque et al., 2013).

Increasing purchases of feed to supplement animal diets appears to be a critical component of most strategies. The utilisation of off-farm feed resources has increased greatly in recent decades, with different rates of growth occurring in different countries, livestock species and farming systems (e.g. Riedel et al., 2007; Rjili et al., 2023). This trend exemplifies the transformative trajectory from extensive to more intensive systems discussed above. While this trend is often associated with broader patterns of global agricultural development, it remains unclear to what extent it is also being driven by farmers' responses to CC.

The broad support among farmers in our sample for improving infrastructure and adopting feed intensification strategies suggests that most farmers consider it to be also the optimal solution for adapting to the effects of CC. However, this perspective reflects the specific farming systems included in this study and should not be generalized across the entire Mediterranean region, where climatic conditions and production systems vary widely. While this strategy may be reasonable at the individual farm level and at specific times, it presents significant challenges for the long-term sustainability of viable meat sheep livestock farming systems. On the one hand, small family farms without the economic power to increase purchased feed will not be able to compete with those that can intensify (Godber et al., 2016; Ripoll-Bosch et al., 2014). On the other hand, the remaining farms will become highly dependent on the fluctuations of global agricultural commodity markets, which may undermine food security in the region (Lacirignola et al., 2015). In some countries, where there are no public structures or programs to support farmers during market crises, their dependence on commodity markets has made them extremely vulnerable. There are examples in some southern Mediterranean countries where economic instability and social crises have recently been attributed to this dependence (Behnassi and El Haiba, 2022; Jayasuriya et al., 2012; Mittal, 2009). These problems are likely to be exacerbated in the context of CC (Vesco et al., 2021). However, some authors argue that the potential downsides of intensification can be mitigated through sustainable intensification of livestock production (e.g. Aguilera et al., 2020; Rudel et al., 2015; Singh et al., 2023).

4.4. Feed optimization

We found that, despite the general importance given by the studied farmers to feed intensification, a notable proportion, particularly those in systems with access to local feed resources (i.e. Eg_Irr.Mixed, Fr_Mediterr.Grass, Sp_Mountain.Grass, SP_Irr.Mixed, Tn_Silvo.Grass), would try to optimise those resources by extending the grazing areas and the grazing season in order to compensate for the likely reduction in pastures productivity due to CC. Nonetheless, most of these farmers still consider the purchase of off-farm feed as part of the broader sets of feed adjustments they would use. This suggest that even committed to maximize local feed resources acknowledge the need to combine this with external inputs as part of the pool of adjustments needed to respond to CC.

4.5. Diversified adjustments and flock management and feed extensification strategies

In France, Tunisia, and in the Spanish mountain farming systems (Sp_Mountain.Grass), around one-third of the farms considered strategies involving adjustments across multiple farm components rather than solutions focusing on individual components such as feed management and farm infrastructures. Under these strategies, farmers respond to CC systematically, considering simultaneous adjustments in batching systems, flock sizes, lambing seasons, and forage productivity together with feeding systems and infrastructures. These strategies align with scholars' call for multidimensional and integrative approaches to address the complex impact of CC on livestock systems (e.g. Henry et al., 2018; Pardo and del Prado, 2020; Rojas-Downing et al., 2017) and also with agroecological approaches (Alary et al., 2017; Nozières-Petit et al., 2021; Ripoll-Bosch et al., 2012). Their rationale is to exploit the synergies of the many components of farming systems, gradually balancing them to adapt in time to the local context resulting from the process of CC. For example, this may involve aligning herd and reproduction management with spatial and temporal availability of feed resources, and even finding complementarities with mitigation strategies (Pardo and del Prado, 2020). As a result, the specifics adjustments required will vary depending on the farming systems, the socio-environmental context, and the local impacts of CC.

4.6. Methodological considerations

While the standardized survey-based approach used in this study ensured the comparability across countries and systems, it also introduced certain methodological constraints that need to be acknowledged to properly interpret the results of the study.

First, the climate scenarios presented to farmers described mean temperature and precipitation for 2050 but did not incorporate inter-annual variability or extreme events. This is a limitation in pastoral systems, where management flexibility, such as adjusting flock size and the use of external feed resource from year to year, is a key mechanism to cope with climatic variability (e.g. Gillin, 2021; Ntombela et al., 2024). This simplification reflects both data limitations and methodological constraints. On the one hand, the climate scenarios were based in WorldClim projections which provides long term climatic averages but does not project year-to-year fluctuations or local-scale extremes (Fick and Hijmans, 2017). On the other hand, including inter-annual variability in the scenarios would have introduced considerable complexity and likely overburdened respondents. Given the standardized and close-ended format of the survey, this simplification was a deliberate trade-off, acknowledging that such instruments have limitations to eliciting systemic reasoning under conditions of high uncertainty.

Second, farmers were asked to evaluate possible changes to 14 farm components individually. While this allowed for a structured and manageable survey experience, it carried the risk of limiting opportunities for farmers to express a more systemic thinking. As such, the strategies inferred from responses are not to be interpreted as actual planned strategies, but as emergent typologies that reflect common combinations of farmers stated changes. Their value lies in revealing underlying patterns of thinking rather than quantifying thoughtfully developed strategies that farmer have already conceived for the future. That said, it is likely that in most cases farmers' responses drew from their internal systemic understanding of farm functioning. Empirical studies show that farmers often develop adaptive mental models of their systems, linking farm components, constraints, and goals (Eckert and Bell, 2005; Vanwindekens et al. 2014), meaning that even responses to isolated components may reflect underlying systemic logic. Moreover, the survey protocol explicitly invited farmers to adopt a comprehensive perspective before answering questions on possible changes aiming to foster thoughtful and integrative reflection, even if responses were collected component by component (Appendix B).

Third, the "Do not know" responses were handled as missing values and imputed using a non-parametric random forest technique suited for categorical variables. While this preserved the sample size, it assumes that these responses are missing at random, an assumption that may not always hold. These responses may reflect epistemic uncertainty or discomfort with the questioning format. Although we cannot dismiss low levels of respondent discomfort, based on our field experience during interviews, we did not observe this as a widespread issue. Future studies could benefit from treating such responses as analytically meaningful in their own right.

Fourth, the scope of the survey was limited to core elements of sheep production. We excluded other potential farm-level changes beyond this domain, such as modification of livestock species, initiating product transformation, or placing stronger emphasis on crop production. These are undeniably relevant, but beyond the study's focus on internal components of sheep systems.

In sum, while our survey design imposed structural drawbacks, it generated valuable insights into farmers' current reasoning and adaptive preferences. These insights can inform targeted interventions and be complemented with other participatory approaches such as scenario-building workshops (e.g. Galang et al., 2025), serious games (e.g. Martin, 2015) and structure stakeholder dialogues (e.g. Sautier et al., 2017) to fully capture the systemic nature of farm responses to CC.

5. Conclusions

This study contributes to addressing the lack of cross-national evidence on how sheep farmers perceive and anticipate responding to it at the farm level. By analysing 216 interviews across 11 farming systems in four Mediterranean countries, we identified patterns in farmers' beliefs about CC and their preferences for specific adjustments and modification of farm components.

Our findings challenge the binary view of extensive vs. intensive systems by showing that Mediterranean meat sheep systems often combine characteristics of both. This duality creates both risks—e.g. exposure to local feed variability and market volatility—and opportunities, such as flexibility to combine local and external inputs.

Farmers across all systems acknowledges the existence of CC and are aware of its impacts. However, many farmers remain sceptical about the anthropogenic nature of CC, often attributing it to natural causes or a mix of natural and human factors. This is relevant because it suggests that while farmers are willing to respond to climate-related challenges, their support for mitigation policies may be limited by their beliefs about its causes.

Five distinct response strategies were identified reflecting different degrees of adjustment and modification across farm components. All of them appeared in all farming systems and countries, which suggests that there are no optimal strategies specific to agroclimatic conditions.

Farmers prioritise securing animal feed, whether through grazing, indoor feeding, or a combination of both. This is unsurprising as feeding is fundamental to livestock performance and represents the primary expense for farms. Particularly, increasing purchases of feed to supplement animal diets appears to be a critical component of most strategies. However, farmers commonly overlook breed substitution and changes in reproductive management.

The most common strategies in the studied cases where those aimed at reducing livestock and feed exposure to CC impact by decoupling their farms from the local environmental conditions through improving farm infrastructure and feed intensification strategies. Nevertheless, a smaller number of farmers also proposed more integrated or systemic response. In practice these approaches also imply that farmers would need to engage in a continuous process of fine-tuning their farm management and structure, which can be extremely challenging to manage and requires a considerable workload and sustained motivation over the long term. This is particularly difficult in the Mediterranean region, where farmers must work under harsh environmental conditions, which are expected to worsen due to CC.

Future research should build on these findings by integrating complementary methods that foster a more systemic understanding of farmers' responses, beyond what survey-based approaches alone can provide. Doing so will help capture the complexity of farmers' adaptive reasoning and support more inclusive and context-sensitive policy design.

CRediT authorship contribution statement

M. Joy: Writing – review & editing, Writing – original draft, Resources, Project administration, Funding acquisition, Conceptualization. **F. Stark:** Writing – review & editing, Resources, Investigation. **A. Lurette:** Writing – review & editing, Investigation, Funding acquisition. **A. Mohamed-Brahmi:** Writing – review & editing, Resources, Investigation. **M. Ameur:** Writing – review & editing, Resources, Investigation. **A. Aboulnaga:** Writing – review & editing, Resources, Investigation. **M. Elshafie:** Writing – review & editing, Resources, Investigation. **S. Lobón:** Writing – review & editing, Writing – original draft, Supervision, Resources, Project administration, Investigation, Conceptualization. **Martín Collado Daniel:** Writing – review & editing, Writing – original draft, Visualization, Validation, Supervision, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **A. Tenza-Peral:** Writing – review & editing, Writing – original draft, Resources, Investigation, Conceptualization. **I. Casasús:** Writing – review & editing, Writing – original draft, Resources, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the author(s) used the online AI-based tools DeepL and ChatCPT 4.0 to improve readability and language. After using these tools, the authors reviewed and edited the content as needed and takes full responsibility for the content of the publication. The authors have not stated any conflicts of interest.

Declaration of Competing Interest

None.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.smallrumres.2025.107576.

References

Aguilera, E., Díaz-Gaona, C., García-Laureano, R., Reyes-Palomo, C., Guzmán, G.I., Ortolani, L., Sánchez-Rodríguez, M., Rodríguez-Estévez, V., 2020. Agroecology for adaptation to climate change and resource depletion in the Mediterranean region. A review. Agric. Syst. 181, 102809. https://doi.org/10.1016/J.AGSY.2020.102809.

Akinyemi, F.O., 2017. Climate change and variability in semiarid Palapye, Eastern Botswana: an assessment from smallholder farmers' perspective. Weather Clim. Soc. 9, 349–365. https://doi.org/10.1175/WCAS-D-16-0040.s1.

Alary, V., Moulin, C.-H., Lasseur, J., Aboulnaga, A.M., Sraïri, M.T., 2017. The future of Mediterranean livestock farming systems: opportunity and efficiency of crops – livestock integration. Final Rep. Climed. S. l. 60.

Ali, E., Cramer, W., Carnicer, J., Georgopoulou, E., Hilmi, N.J.M., Le Cozannet, G., Lionello, P., 2023. Mediterranean Region. in: Climate Change 2022 – Impacts, Adaptation and Vulnerability. Cambridge University Press, pp. 2233–2272. https://doi.org/10.1017/9781009325844.021.

Amamou, H., Sassi, M.Ben, Aouadi, H., Khemiri, H., Mahouachi, M., Beckers, Y., Hammami, H., 2018. Climate change-related risks and adaptation strategies as perceived in dairy cattle farming systems in Tunisia. Clim. Risk Manag. 20, 38–49. https://doi.org/10.1016/j.crm.2018.03.004.

Ariom, T.O., Dimon, E., Nambeye, E., Diouf, N.S., Adelusi, O.O., Boudalia, S., 2022. Climate-smart agriculture in African Countries: a review of strategies and impacts on smallholder farmers. Sustainability 14, 11370. https://doi.org/10.3390/su141811370.

Ayal, D.Y., Radeny, M., Desta, S., Gebru, G., 2018. Climate variability, perceptions of pastoralists and their adaptation strategies: Implications for livestock system and diseases in Borana zone. Int J. Clim. Chang. Strateg. Manag. 10, 596–615. https://doi.org/10.1108/IJCCSM-06-2017-0143.

Behnassi, M., El Haiba, M., 2022. Implications of the Russia–Ukraine war for global food security. Nat. Hum. Behav. 6, 754–755. https://doi.org/10.1038/s41562-022-01391-x.

Beitnes, S.S., Kopainsky, B., Potthoff, K., 2022. Climate change adaptation processes seen through a resilience lens: Norwegian farmers' handling of the dry summer of 2018. Environ. Sci. Policy 133, 146–154. https://doi.org/10.1016/j.envsci.2022.03.019.

Belanche, A., Martín-Collado, D., Rose, G., Yáñez-Ruiz, D.R., 2021. A multi-stakeholder participatory study identifies the priorities for the sustainability of the small ruminants farming sector in Europe. Animal 15, 100131. https://doi.org/10.1016/j.animal.2020.100131.

Benoit, M., Sabatier, R., Lasseur, J., Creighton, P., Dumont, B., 2019. Optimising economic and environmental performances of sheep-meat farms does not fully fit with the meat industry demands. Agron. Sustain Dev. 39, 40. https://doi.org/10.1007/s13593-019-0588-9.

Bezner Kerr, R., Hasegawa, T., Lasco, R., Bhatt, I., Deryng, D., Farrell, A., Gurney-Smith, H., Ju, H., Lluch-Cota, S., Meza, F., Nelson, G., Neufeldt, H., Thornton, P., 2023. Food, fibre and other ecosystem products. in: (IPCC), I.P. on C.C. (Ed.), Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, pp. 713–906. https://doi.org/10.1017/9781009325844.007.

Bocci, M., Smanis, T., Gaaloul, N., 2019. Assessment of the impacts of climate change on the agriculture sector in the southern Mediterranean: foreseen developments and policy measures. Union for the Mediterranean, European Union: Barcelona, Spain.

Bonnet, P., Alary, V., Daoud, I., Abdel-Kader, F., Aboulnaga, A., Abdelzaher, O., Tourrand, J.F., Moselhy, N., Bastianelli, D., Hassan, F., Salama, O., Boutonnet, J.P., Hosni, T., Martin, V., 2014. Atlas of changes in livestock farming systems, livelihoods and landscapes of the north west costs of Egypt. Retrieved on 11 July 2025 from ⟨https://elvulmed.cirad.fr/FichiersComplementaires/Atlas_Egypt_Ver-8.pdf⟩.

Bradford, H.L., Fragomeni, B.O., Bertrand, J.K., Lourenco, D.A.L., Misztal, I., 2016. Genetic evaluations for growth heat tolerance in Angus cattle1. J. Anim. Sci. 94, 4143–4150. https://doi.org/10.2527/jas.2016-0707.

Brito, L.F., Bedere, N., Douhard, F., Oliveira, H.R., Arnal, M., Peñagaricano, F., Schinckel, A.P., Baes, C.F., Miglior, F., 2021. Review: genetic selection of high-yielding dairy cattle toward sustainable farming systems in a rapidly changing world. Animal 15, 100292. https://doi.org/10.1016/j.animal.2021.100292.

Campbell, A., Becerra, T.A., Middendorf, G., Tomlinson, P., 2019. Climate change beliefs, concerns, and attitudes of beef cattle producers in the Southern Great Plains. Clim. Change 152, 35–46. https://doi.org/10.1007/s10584-018-2344-6.

Casey, N.H., 2023. Livestock adaptation to climate. Anim. Front. 13, 3–5. https://doi.org/10.1093/af/vfad048.

Chang-Fung-Martel, J., Harrison, M.T., Rawnsley, R., Smith, A.P., Meinke, H., 2017. The impact of extreme climatic events on pasture-based dairy systems: a review. Crop Pasture Sci. 68, 1158–1169.

Cloete, S.W.P., Greeff, J.C., Nel, C.L., Scholtz, A.J., 2023. Breeds and lines of sheep suitable for production in challenging environments. Anim. Front. 13, 33–42. https://doi.org/10.1093/af/vfad053.

Concu, G.B., Atzeni, G., Meleddu, M., Vannini, M., 2020. Policy design for climate change mitigation and adaptation in sheep farming: insights from a study of the knowledge transfer chain. Environ. Sci. Policy 107, 99–113. https://doi.org/10.1016/J.ENVSCI.2020.02.014.

Cramer, W., Guiot, J., Fader, M., Garrabou, J., Gattuso, J.-P., Iglesias, A., Lange, M.A., Lionello, P., Llasat, M.C., Paz, S., Peñuelas, J., Snoussi, M., Toreti, A., Tsimplis, M.N., Xoplaki, E., 2018. Climate change and interconnected risks to sustainable development in the Mediterranean. Nat. Clim. Chang 8, 972–980. https://doi.org/10.1038/s41558-018-0299-2.

Darnhofer, I., 2014. Resilience and why it matters for farm management. Eur. Rev. Agric. Econ. 41 (3), 461–484. https://doi.org/10.1093/erae/jbu012.

Davidson, D.J., Rollins, C., Lefsrud, L., Anders, S., Hamann, A., 2019. Just don't call it climate change: climate-skeptic farmer adoption of climate-mitigative practices. Environ. Res. Lett. 14, 034015. https://doi.org/10.1088/1748-9326/aafa30.

Debolini, M., Marraccini, E., Dubeuf, J.P., Geijzendorffer, I.R., Guerra, C., Simon, M., Targetti, S., Napoléone, C., 2018. Land and farming system dynamics and their drivers in the Mediterranean Basin. Land Use Policy 75, 702–710. https://doi.org/10.1016/J.LANDUSEPOL.2017.07.010.

Dellar, M., Topp, C.F.E., Banos, G., Wall, E., 2018. A meta-analysis on the effects of climate change on the yield and quality of European pastures. Agric. Ecosyst. Environ. 265, 413–420. https://doi.org/10.1016/J.AGEE.2018.06.029.

Doll, J.E., Petersen, B., Bode, C., 2017. Skeptical but adapting: what Midwestern farmers say about Climate Change. Weather Clim. Soc. 9, 739–751. https://doi.org/10.1175/WCAS-D-16-0110.1.

Dossa, L.H., Abdulkadir, A., Amadou, H., Sangare, S., Schlecht, E., 2011. Exploring the diversity of urban and peri-urban agricultural systems in Sudano-Sahelian West Africa: an attempt towards a regional typology. Land. Urban Plan 102, 197–206. https://doi.org/10.1016/j.landurbplan.2011.04.005.

Dubeuf, Jean-Pierre, AW, H., Chentouf, M., Dubeuf, Jean-Paul, Mena, Y., Pacheco, F., Boutonnet, J.-P., 2016. The Mediterranean sheep and goat sectors between constants and changes over the last decade Future Challenges and Prospects. Options Méditerranéennes 115, 53–60.

Dumont, B., Andueza, D., Niderkorn, V., Lüscher, A., Porqueddu, C., Picon-Cochard, C., 2015. A meta-analysis of climate change effects on forage quality in grasslands: specificities of mountain and Mediterranean areas. Grass Forage Sci. 70, 239–254. https://doi.org/10.1111/gfs.12169.

Eckert, E., Bell, A., 2005. Invisible force: farmers' mental models and how they influence learning and actions. J. Ext. 43 (3), 3.

Emtage, N., Herbohn, J., Harrison, S., 2006. Landholder typologies used in the development of natural resource management programs in Australia—A review. Australas. J. Environ. Manag. 13, 79–94. https://doi.org/10.1080/14486563.2006.10648675.

Escarcha, J.F., Lassa, J.A., Zander, K.K., 2018. Livestock under climate change: A systematic review of impacts and adaptation. Climate. https://doi.org/10.3390/cli6030054.

Eyring, V., Bony, S., Meehl, G.A., Senior, C.A., Stevens, B., Stouffer, R.J., Taylor, K.E., 2016. Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) experimental design and organization. Geosci. Model Dev. 9, 1937–1958. https://doi.org/10.5194/gmd-9-1937-2016.

Falkenberg, M., Galeazzi, A., Torricelli, M., Di Marco, N., Larosa, F., Sas, M., Mekacher, A., Pearce, W., Zollo, F., Quattrociocchi, W., Baronchelli, A., 2022. Growing polarization around climate change on social media. Nat. Clim. Chang 12, 1114–1121. https://doi.org/10.1038/s41558-022-01527-x.

Fick, S.E., Hijmans, R.J., 2017. WorldClim 2: new 1-km spatial resolution climate surfaces for global land areas. Int J. Clim. 37, 4302–4315. https://doi.org/10.1002/joc.5086.

Galal, S., 2007. Farm animal genetic resources in Egypt: factsheet. Egypt J. Anim. Prod. 44, 1–23.

Galang, E.I.N.E., Bennett, E.M., Hickey, G.M., Baird, J., Harvey, B., Sherren, K., 2025. Participatory scenario planning: a social learning approach to build systems thinking and trust for sustainable environmental governance. Environ. Sci. Policy 164, 103997. https://doi.org/10.1016/j.envsci.2025.103997.

Gillin, K., 2021. Variability is not uncertainty; mobility is not flexibility: clarifying concepts in pastoralism studies with evidence from Tajikistan. Pastoralism 11, 13. https://doi.org/10.1186/s13570-021-00203-7.

Giorgi, F., Lionello, P., 2008. Climate change projections for the Mediterranean region. Glob. Planet. Change 63 (2–3), 90–104. https://doi.org/10.1016/j.gloplacha.2007.09.005.

Godber, O., Laroussi, B., Chentouf, M., Wall, R., 2016. Intensification of Mediterranean goat Production Systems: A Case Study in Northern Morocco. Agriculture 6, 16. https://doi.org/10.3390/agriculture6020016.

Griffin, C., Wreford, A., Cradock-Henry, N.A., 2023. As a farmer you've just got to learn to cope': understanding dairy farmers' perceptions of climate change and adaptation decisions in the lower South Island of Aotearoa-New Zealand. J. Rural Stud. 98, 147–158. https://doi.org/10.1016/J.JRURSTUD.2023.02.001.

Henry, B.K., Eckard, R.J., Beauchemin, K.A., 2018. Review: adaptation of ruminant livestock production systems to climate changes. Animal. https://doi.org/10.1017/S1751731118001301.

Hertig, E., Tramblay, Y., 2017. Regional downscaling of Mediterranean droughts under past and future climatic conditions. Glob. Planet Change 151, 36–48. https://doi.org/10.1016/J.GLOPLACHA.2016.10.015.

Hou, X.-Y., Han, Y., Li, F.Y., 2012. The perception and adaptation of herdsmen to climate change and climate variability in the desert steppe region of northern China. Rangel. J. 34, 349–357.

Huang, Z., 1997. A Fast clustering algorithm to cluster very large categorical data sets in data mining. Workshop on Research Issues on Data Mining and Knowledge Discovery.

IPCC, 2014. In: Field, C.B., Barros, V.R., Dokken, D.J., Mach, K.J., Mastrandrea, M.D., Bilir, T.E., Chatterjee, M., Ebi, K.L., Estrada, Y.O., Genova, R.C., Girma, B., Kissel, E. S., Levy, A.N., MacCracken, S., Mastrandrea, P.R., White, L.L. (Eds.), Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects, Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK, New York, USA.

IPCC, I.P. on C.C., 2023. Climate Change 2022 – Impacts, Adaptation and Vulnerability: Working Group II Contribution to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge. https://doi.org/10.1017/9781009325844.

Jayasuriya, S., Mudbhary, P., Broca, S.S., 2012. Food price spikes, increasing volatility and global economic shocks: coping with challenges to food security in Asia. RAP Publication, Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific, Bangkok, Thailand.

Joly, F., Sabatier, R., Tatin, L., Mosnier, C., Ahearn, A., Benoit, M., Hubert, B., Deffuant, G., 2022. Adaptive decision-making on stocking rates improves the resilience of a livestock system exposed to climate shocks. Ecol. Model. 464, 109799. https://doi.org/10.1016/J.ECOLMODEL.2021.109799.

Jouven, M., Lapeyronie, P., Moulin, C.H., Bocquier, F., 2010. Rangeland utilization in Mediterranean farming systems. Animal 4, 1746–1757. https://doi.org/10.1017/S1751731110000996.

Kgosikoma, K.R., Lekota, P.C., Kgosikoma, O.E., 2018. Agro-pastoralists' determinants of adaptation to climate change. Int J. Clim. Chang. Strateg. Manag. 10, 488–500. https://doi.org/10.1108/IJCCSM-02-2017-0039.

Kipling, R.P., Topp, C.F.E., Bannink, A., Bartley, D.J., Blanco-Penedo, I., Cortignani, R., del Prado, A., Dono, G., Faverdin, P., Graux, A.-I., Hutchings, N.J., Lauwers, L., Özkan Gülzari, Ş., Reidsma, P., Rolinski, S., Ruiz-Ramos, M., Sandars, D.L., Sándor, R., Schönhart, M., Seddaiu, G., van Middelkoop, J., Shrestha, S., Weindl, I., Eory, V., 2019. To what extent is climate change adaptation a novel challenge for agricultural modellers. Environ. Model. Softw. 120, 104492. https://doi.org/10.1016/j.envsoft.2019.104492.

Kuehne, G., 2014. How do farmers' climate change beliefs affect adaptation to climate change? Soc. Nat. Resour. 27, 492–506. https://doi.org/10.1080/08941920.2013.861565.

Lacetera, N., Segnalini, M., Bernabucci, U., Ronchi, B., Vitali, A., Tran, A., Guis, H., Caminade, C., Calvete, C., Morse, A., Baylis, M., Nardone, A., 2013. Climate Induced Effects on Livestock Population and Productivity in the Mediterranean Area. In: Navarra, A., Tubiana, L. (Eds.), Regional Assessment of Climate Change in the Mediterranean: Volume 2: Agriculture, Forests and Ecosystem Services and People. Springer Netherlands, Dordrecht, pp. 135–156. https://doi.org/10.1007/978-94-007-5772-1_7.

Lacirignola, C., Adinolfi, F., Capitanio, F., 2015. Food security in the Mediterranean countries. N. Medit. 14, 2–10.

Lamarque, P., Artaux, A., Barnaud, C., Dobremez, L., Nettier, B., Lavorel, S., 2013. Taking into account farmers' decision making to map fine-scale land management adaptation to climate and socio-economic scenarios. Land. Urban Plan 119, 147–157. https://doi.org/10.1016/j.landurbplan.2013.07.012.

Lasseur, J., 2005. Sheep farming systems and nature management of rangeland in French Mediterranean mountain areas. Livest. Prod. Sci. 96, 87–95. https://doi.org/10.1016/J.LIVPRODSCI.2005.05.017.

Lauvie, A., Couix, N., Sorba, J.-M., 2022. Farmers using local livestock biodiversity share more than animal genetic resources: indications from a workshop with farmers who use local breeds. Genet. Resour. 3, 15–21. https://doi.org/10.46265/genresj.HJEH3830.

Lionello, P., Scarascia, L., 2018. The relation between climate change in the Mediterranean region and global warming. Reg. Environ. Change 18, 1481–1493. https://doi.org/10.1007/s10113-018-1290-1.

Liu, Z., Smith, W.J., Safi, A.S., 2014. Rancher and farmer perceptions of climate change in Nevada, USA. Clim. Change 122, 313–327. https://doi.org/10.1007/s10584-013-0979-x.

MacQueen, J., 1967. Some methods for classification and analysis of multivariate observations. in: The Fifth Berkeley Symposium on Mathematical Statistics and Probability. University of California Press, pp. 281–297.

Martin, G., 2015. A conceptual framework to support adaptation of farming systems–Development and application with Forage Rummy. Agric. Syst. 132, 52–61. https://doi.org/10.1016/j.agsy.2014.08.013.

Martin-Collado, D., Diaz, C., Ramón, M., Iglesias, A., Milán, M.J., Sánchez-Rodríguez, M., Carabaño, M.J., 2024. Are farmers motivated to select for heat tolerance? Linking attitudinal factors, perceived climate change impacts, and social trust to farmers' breeding desires. J. Dairy Sci. 107, 2156–2174. https://doi.org/10.3168/jds.2023-23722.

McCright, A.M., Dunlap, R.E., 2011. The politicization of climate change and polarization in the American public's views of global warming, 2001–2010. Socio Q 52, 155–194. https://doi.org/10.1111/j.1533-8525.2011.01198.x.

McIntosh, M.M., Spiegal, S.A., McIntosh, S.Z., Castaño Sanchez, J., Estell, R.E., Steele, C. M., Elias, E.H., Bailey, D.W., Brown, J.R., Cibils, A.F., 2023. Matching beef cattle

breeds to the environment for desired outcomes in a changing climate: a systematic review. J. Arid Environ. 211, 104905. https://doi.org/10.1016/j.jaridenv.2022.104905.
Mittal, A., 2009. The 2008 food price crisis: rethinking food security policies. In: G-24 Discussion Paper No, 56. United Nations Publication, New York, NY, USA and Geneva, Switzerland.
Mohamed-Brahmi, A., Ameur, M., Mekki, I., Tenza-Peral, A., Nasraoui, M., Yagoubi, Y., Smeti, S., Ben Saïd, S., Atti, N., Lobón, S., Mahouachi, M., 2024. Analysis of management practices and breeders' perceptions of climate change's impact to enhance the resilience of sheep production systems: a case study in the Tunisian Semi-Arid Zone. Animals 14, 885. https://doi.org/10.3390/ani14060885.
Muñoz-Ulecia, E., Bernués, A., Carabaño, M.J., Joy, M., Martín-Collado, D., 2025. The importance of the messenger in climate change communication to farmers. Ital. J. Anim. Sci. 24, 1336–1344. https://doi.org/10.1080/1828051X.2025.2515264.
Nardone, A., Ronchi, B., Lacetera, N., Ranieri, M.S., Bernabucci, U., 2010. Effects of climate changes on animal production and sustainability of livestock systems. Livest. Sci. 130, 57–69. https://doi.org/10.1016/j.livsci.2010.02.011.
Niles, M.T., Mueller, N.D., 2016. Farmer perceptions of climate change: associations with observed temperature and precipitation trends, irrigation, and climate beliefs. Glob. Environ. Change 39, 133–142. https://doi.org/10.1016/j.gloenvcha.2016.05.002.
Noto, L.V., Cipolla, G., Francipane, A., Pumo, D., 2023. Climate change in the Mediterranean Basin (Part I): induced alterations on climate forcings and hydrological processes. Water Resour. Manag 37, 2287–2305. https://doi.org/10.1007/s11269-022-03400-0.
Nozières-Petit, M.-O., Etienne, L., Launay, F., Moulin, C.H., 2021. Editorial: 5 ans de travaux au sein de l'UMT Elevages Pastoraux en territoires méditerranéens. Fourrages 245, 1–3.
Ntombela, K.P., Angula, M., Samuels, I., Cupido, C., Swarts, M., Menjono-Katjizeu, E., Inman, E., Nakanyala, J., 2024. Pastoral coping and adaptive management strategies to climate change in communal areas in Namibia and South Africa. Pastor Res. Policy Pr. 14, 13548. https://doi.org/10.3389/past.2024.13548.
Olaizola, A.M., Ameen, F., Manrique, E., 2015. Potential strategies of adaptation of mixed sheep-crop systems to changes in the economic environment in a Mediterranean mountain area. Livest. Sci. 176, 166–180. https://doi.org/10.1016/J.LIVSCI.2015.03.012.
Pardo, G., del Prado, A., 2020. Guidelines for small ruminant production systems under climate emergency in Europe. Small Rumin. Res. 193, 106261. https://doi.org/10.1016/J.SMALLRUMRES.2020.106261.
Pardos, L., Lahoz, B., Bernués, A., Alabart, J.L., Fantova, E., 2022. Integrated sustainability assessment of sheep meat production in Aragon. ITEA. Inf. Tec. Econ. Agrar. 118, 594–612. https://doi.org/10.12706/itea.2022.003.
Pérez, S., Calvo, J.H., Calvete, C., Joy, M., Lobón, S., 2023. Mitigation and animal response to water stress in small ruminants. Anim. Front. 13, 81–88. https://doi.org/10.1093/af/vfad049.
Perrin, A., Milestad, R., Martin, G., 2020. Resilience applied to farming: organic farmers' perspectives. Ecol. Soc. 25 art5. https://doi.org/10.5751/ES-11897-250405.
Poortinga, W., Whitmarsh, L., Steg, L., Böhm, G., Fisher, S., 2019. Climate change perceptions and their individual-level determinants: a cross-European analysis. Glob. Environ. Change 55, 25–35. https://doi.org/10.1016/J.GLOENVCHA.2019.01.007.
Portner, H., Roberts, D.C., Adams, H., Adelekan, I., Adler, C., Adrian, R., Aldunce, P., Ali, E., Ara Begum, R., Bednar- Friedl, B., Bezner Kerr, R., Biesbroek, R., Birkmann, J., Bowen, K., Caretta, M.A., Carnicer, J., Castellanos, E., Cheong, T.S., Chow, W., Cisse, G., Clayton, S., Constable, A., Cooley, S.R., Costello, M.J., Craig, M., Cramer, W., Dawson, R., Dodman, D., Efitre, J., Garschagen, M., Gilmore, E.A., Glavovic, B.C., Gutzler, D., Haasnoot, M., Harper, S., Hasegawa, T., Hayward, B., Hicke, J.A., Hirabayashi, Y., Huang, C., Kalaba, K., Kiessling, W., Kitoh, A., Lasco, R., Lawrence, J., Lemos, M.F., Lempert, R., Lennard, C., Ley, D., Lissner, T., Liu, Q., Liwenga, E., Lluch-Cota, S., Loschke, S., Lucatello, S., Luo, Y., Mackey, B., Mintenbeck, K., Mirzabaev, A., Moller, V., Moncassim Vale, M., Morecroft, M.D., Mortsch, L., Mukherji, A., Mustonen, T., Mycoo, M., Nalau, J., New, M., Okem, A., Ometto, J.P., O'Neill, B., Pandey, R., Parmesan, C., Pelling, M., Pinho, P.F., Pinnegar, J., Poloczanska, E.S., Prakash, A., Preston, B., Racault, M.F., Reckien, D., Revi, A., Rose, S.K., Schipper, E.L.F., Schmidt, D.N., Schoeman, D., Shaw, D., Simpson, N.P., Singh, C., Solecki, W., Stringer, L., Totin, E., Trisos, C.H., Trisurat, Y., van Aalst, M., Viner, D., Wairiu, M., Warren, R., Wester, P., Wrathall, D., Zaiton Ibrahim, Z., 2023. Technical Summary. In: Climate Change 2022 – Impacts, Adaptation and Vulnerability. Cambridge University Press, pp. 37–118. https://doi.org/10.1017/9781009325844.002.
R Core Team, 2019. R: A Language and Environment for Statistical Computing. R Core Team. 2019. R Foundation for Statistical Computing, Vienna, Austria. ⟨https://www.R-project.org/⟩.
Rahut, D.B., Aryal, J.P., Marenya, P., 2021. Understanding climate-risk coping strategies among farm households: evidence from five countries in Eastern and Southern Africa. Sci. Total Environ. 769, 145236. https://doi.org/10.1016/j.scitotenv.2021.145236.
de Rancourt, M., Fois, N., Lavín, M.P., Tchakérian, E., Vallerand, F., 2006. Mediterranean sheep and goats production: an uncertain future. Small Rumin. Res. 62, 167–179. https://doi.org/10.1016/j.smallrumres.2005.08.012.
Riahi, K., van Vuuren, D.P., Kriegler, E., Edmonds, J., O'Neill, B.C., Fujimori, S., Bauer, N., Calvin, K., Dellink, R., Fricko, O., Lutz, W., Popp, A., Cuaresma, J.C., KC, S., Leimbach, M., Jiang, L., Kram, T., Rao, S., Emmerling, J., Ebi, K., Hasegawa, T., Havlik, P., Humpenöder, F., Da Silva, L.A., Smith, S., Stehfest, E., Bosetti, V., Eom, J., Gernaat, D., Masui, T., Rogelj, J., Strefler, J., Drouet, L., Krey, V., Luderer, G., Harmsen, M., Takahashi, K., Baumstark, L., Doelman, J.C., Kainuma, M., Klimont, Z., Marangoni, G., Lotze-Campen, H., Obersteiner, M., Tabeau, A., Tavoni, M., 2017. The Shared socioeconomic pathways and their energy, land use, and greenhouse gas emissions implications: an overview. Glob. Environ. Change 42, 153–168. https://doi.org/10.1016/j.gloenvcha.2016.05.009.
Riedel, J.L., Casasús, I., Bernués, A., 2007. Sheep farming intensification and utilization of natural resources in a Mediterranean pastoral agro-ecosystem. Livest. Sci. 111, 153–163. https://doi.org/10.1016/j.livsci.2006.12.013.
Ripoll-Bosch, R., de Boer, I.J.M., Bernués, A., Vellinga, T.V., 2013. Accounting for multi-functionality of sheep farming in the carbon footprint of lamb: a comparison of three contrasting Mediterranean systems. Agric. Syst. 116, 60–68. https://doi.org/10.1016/j.agsy.2012.11.002.
Ripoll-Bosch, R., Díez-Unquera, B., Ruiz, R., Villalba, D., Molina, E., Joy, M., Olaizola, A., Bernués, A., 2012. An integrated sustainability assessment of mediterranean sheep farms with different degrees of intensification. Agric. Syst. 105, 46–56. https://doi.org/10.1016/j.agsy.2011.10.003.
Ripoll-Bosch, R., Joy, M., Sanz, A., Blasco, I., Ripoll, G., Álvarez-Rodríguez, J., 2014. Effect of concentrate supplementation and prolificacy on the productive and economic performance of autochthonous sheep breeds fed forage-based diets. Span. J. Agric. Res. 12, 1099–1104. https://doi.org/10.5424/sjar/2014124-6321.
Rjili, H., Muñoz-Ulecia, E., Bernués, A., Jaouad, M., Martin-Collado, D., 2023. Evolution of pastoral livestock farming on arid rangelands in the last 15 years. Animal 17, 100748. https://doi.org/10.1016/j.animal.2023.100748.
Rojas-Downing, M.M., Nejadhashemi, A.P., Harrigan, T., Woznicki, S.A., 2017. Climate change and livestock: Impacts, adaptation, and mitigation. Clim. Risk Manag 16, 145–163. https://doi.org/10.1016/J.CRM.2017.02.001.
Rosegrant, M.W., Fernández, M., Sinha, A., Alder, J., Ahammad, H., Fraiture, C. de, Eickhout, B., Fonseca, J., Huang, J., Koyama, O., Omezzine, A.M., Pingali, P.L., Ramírez, R., Ringler, C., Robinson, S., Thornton, P.K., Vuuren, D.P. van, Yana-Shapiro, H., 2009. Looking into the future for agriculture and AKST. In: McIntyre, B. D., Herren, H.R., Wakhungu, J., Watson, R.T. (Eds.), International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD): Agriculture at a Crossroads, Global Report. Island Press, Washington, DC, USA, pp. 307–376.
Rudel, T.K., Paul, B., White, D., Rao, I.M., Van Der Hoek, R., Castro, A., Boval, M., Lerner, A., Schneider, L., Peters, M., 2015. LivestockPlus: forages, sustainable intensification, and food security in the tropics. Ambio 44, 685–693. https://doi.org/10.1007/s13280-015-0676-2.
Running, K., Burke, J., Shipley, K., 2017. Perceptions of environmental change and climate concern among Idaho's farmers. Soc. Nat. Resour. 30, 659–673. https://doi.org/10.1080/08941920.2016.1239151.
Sautier, M., Piquet, M., Duru, M., Martin-Clouaire, R., 2017. Exploring adaptations to climate change with stakeholders: a participatory method to design grassland-based farming systems. J. Environ. Manag. 193, 541–550. https://doi.org/10.1016/j.jenvman.2017.02.050.
Seré, C., Steinfeld, H., Groenewold, J., 1996. World Livestock Production Systems. Food and Agriculture Organization of the United Nations.
Simões, J., Abecia, J.A., Cannas, A., Delgadillo, J.A., Lacasta, D., Voigt, K., Chemineau, P., 2021. Review: managing sheep and goats for sustainable high yield production. Animal 15, 100293. https://doi.org/10.1016/j.animal.2021.100293.
Singh, R., Maiti, S., Garai, S., Rachna, 2023. Sustainable intensification – Reaching towards climate resilience livestock production system – A Review. Ann. Anim. Sci. 23, 1037–1047. https://doi.org/10.2478/aoas-2023-0027.
Thomasz, E., Pérez-Franco, I., García-García, A., 2020. The economic impact of climate risk on extensive livestock: the case of lamb production in Extremadura, Spain. Sustain. (Switz.) 12, 1–19. https://doi.org/10.3390/su12187254.
Thornton, P.K., van de Steeg, J., Notenbaert, A., Herrero, M., 2009. The impacts of climate change on livestock and livestock systems in developing countries: a review of what we know and what we need to know. Agric. Syst. 101, 113–127. https://doi.org/10.1016/j.agsy.2009.05.002.
Vanwindekens, F.M., Baret, P.V., Stilmant, D., 2014. A new approach for comparing and categorizing farmers' systems of practice based on cognitive mapping and graph theory indicators. Ecol. Model 274, 1–11. https://doi.org/10.1016/j.ecolmodel.2013.11.026.
Vesco, P., Kovacic, M., Mistry, M., Croicu, M., 2021. Climate variability, crop and conflict: Exploring the impacts of spatial concentration in agricultural production. J. Peace Res. 58, 98–113. https://doi.org/10.1177/0022343320971020.
Vigan, A., Lasseur, J., Benoit, M., Mouillot, F., Eugène, M., Mansard, L., Vigne, M., Lecomte, P., Dutilly, C., 2017. Evaluating livestock mobility as a strategy for climate change mitigation: combining models to address the specificities of pastoral systems. Agric. Ecosyst. Environ. 242, 89–101. https://doi.org/10.1016/J.AGEE.2017.03.020.
Ward, J.H., 1963. Hierarchical grouping to optimize an objective function. J. Am. Stat. Assoc. 58, 236–244. https://doi.org/10.1080/01621459.1963.10500845.
van Wettere, W.H.E.J., Kind, K.L., Gatford, K.L., Swinbourne, A.M., Leu, S.T., Hayman, P. T., Kelly, J.M., Weaver, A.C., Kleemann, D.O., Walker, S.K., 2021. Review of the impact of heat stress on reproductive performance of sheep. J. Anim. Sci. Biotechnol. 12, 26. https://doi.org/10.1186/s40104-020-00537-z.
Yang, S., Yu, L., Leng, G., Qiu, H., 2021. Livestock farmers' perception and adaptation to climate change: panel evidence from pastoral areas in China. Clim. Change 164, 21. https://doi.org/10.1007/s10584-021-02992-7.