https://doi.org/10.1038/s44264-025-00113-w

Future heatwave exposure of the European cattle sector

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Among the many climate change impacts on the European cattle sector, heatwaves lead to some of the most profound impacts on the sector. It is therefore of utmost importance to estimate to what extent the European cattle sector can be exposed to heatwaves in the near future. Using outcomes of climate models, we analysed how cattle production systems in the wider European Union (EU) region will be exposed to changes in heatwave exposure under two scenarios. We look at both cattle systems, where animals predominantly graze on outdoor pastures, and those where they are kept indoors without access to the outdoors. We show that 6.2–13.7 million cattle livestock units (or 11.0–21.6% of current cattle in the EU and UK) will experience at least 15 additional heatwave days by 2050. This will affect 4.5–11.6% of cattle grazing outdoors compared with 18.3–+35% of cattle kept indoors without access to outdoor grazing. However, there are considerable differences between different countries in the region, with Southern European countries projected to be the most exposed. Our results therefore indicate, adaptation measures specific to different and diverse livestock system types and climatic regions across Europe are necessary for a more climate robust cattle sector in the EU.

The European Union's (EU) cattle sector is important for the income of around 1.3 million agricultural holdings that engage in rearing over 73 million cattle[1], making it one of the most important global cattle-producing regions. European cattle producing systems are however, diverse. Just over half (54%) of all cattle in the EU graze on outdoor pastures, with 3.5% grazing in low intensity seminatural areas, such as close to nature grasslands and transitional vegetation[2]. Of the remaining cattle that are reared in indoor, zero-grazing systems, 29.5% (or 13.6% of the total EU cattle) are housed in intensively managed systems with densities higher than 2 LSU/ha. While such indoor systems are highly efficient[3], they also raise concerns regarding the animal welfare of large agricultural holdings and the reliance on imported feed, often from distant places with large environmental impacts[4,5]. The EU cattle sector is a major emitter of greenhouse gases, contributing 49% of the total agricultural and around 4.9% of the total emissions in the block[6]. It is also a major nitrogen polluter, with an estimated 45% of emissions related to manure management[6]. Moreover, the cattle sector has important impacts on the EU's biodiversity[7]. All this has resulted in growing demands to lower the environmental impact of the European cattle sector[8]. At the same time, many traditional cultural European landscapes depend on cattle grazing, which maintains grassland areas, prevents abandonment and can even reduce the risk of wildfires[9–14]. The cattle sector is therefore an important part of the European culture, economy, and diets.

To maintain beef and dairy production, ensure farmer's livelihoods and decrease the environmental impact of the cattle sector, the EU has ambitious climate change mitigation goals as part of the EU's Green Deal and related policy instruments within the Farm to Fork Strategy and the Common Agricultural Policy including the target to reduce GHG emissions by at least 55% by 2030[8,15,16]. However, such goals may be difficult to achieve as the effects of climate change also present a major challenge to the EU's cattle sector, which is among the most vulnerable to climate change. This is due to both the impacts on grassland and other feed production, as well as the direct impacts on the animals due to heatwaves[17].

The cattle sector in Europe is facing numerous climate change related challenges, among them increasing occurrence of heatwaves, which have led to large rates of excess mortality as demonstrated in recent years[18–20]. Besides increased mortality, heatwaves impact the European cattle sector by threatening animal comfort and health, reducing reproductive performance and decreasing farm production, which is impacted by decreased feed intake and nutritional imbalances, leading to lower milk productivity[17,19]. Indirectly, heatwaves can lead to lower crop and grassland yields[21,22], which can reduce available feed and increase the costs for agricultural inputs for cattle farmers. The cattle sector can adapt to heatwaves by, for example, providing shade on outdoor pastures, which can help the animals maintain normal panting behaviour and respiration rates[23]. In indoor systems, adaptation can

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be more difficult, as the impacts of heatwaves can be exacerbated by higher rates of polluted air, requiring abatement with air conditioning and purification, and ideally by providing more access to outdoor areas or abandoning fully indoor systems[24]. However, in order to sufficiently plan such measures, information on the extent and spatial distribution of cattle subject to heatwaves in the near future is necessary, especially as Europe has been identified among the global regions where heat stress will most profound impact on cattle mortality and productivity[25].

In this study, we estimate the potential extent of cattle subject to increases in heatwaves in the near future. We achieved this by mapping changes in days with health-related heatwaves across the current spatial distribution of cattle in the EU. We considered two scenarios, covering a wide spectrum in terms of greenhouse gas emissions in the future and expected climate change impacts (RCP4.5 and RCP8.5) for the period 2041 to 2060, and compared the results with the current climate (see the Methods for more details). We then analysed the exposure of European cattle to heatwaves for different systems, depending on the prevalence of cattle grazing outdoors, or without access to outdoor pastures, and summarized the findings for individual EU Member States and the United Kingdom.

Results

Differences in exposure between European countries

We find that 6.2 to 13.7 million cattle (expressed in livestock units - LSUs) in the studied countries in Europe, or 11.0 to 21.6% of total current cattle, are expected to be subject to 15 or more additional days of heatwaves in the near future under the two scenarios. When looking at exposure greater than 5 additional heatwave days, we observe that 70 to 92% of all European cattle is projected to experience such increases (Figs. S1–S6). Exposure varies considerably across individual Member States and European climatic regions (Figs. 1 and 2), where most of the cattle impacted are found in indoor, zero grazing systems located in southern European, Mediterranean Member States, such as Italy, Greece, Slovenia, Croatia and Spain – 27.2 to 46.4% of all cattle in Mediterranean Member States of the EU are projected to experience profound increases to heat stress. Worryingly, many high-density commercial cattle producing areas, such as the Po valley in northern Italy and Catalonia, where many so called megastable holdings are located (holdings with over 500 cattle LSU)[4] will experience more than 15 additional heatwave days compared to today (Fig. 1). We observe similar increases in heatwaves also for medium cattle density (1 to 2 LSU/ha) areas such as those around the Central Massif in France and in the eastern Alps (Austria and Slovenia).

Differences in exposure between indoor and grazing systems

Besides differences in exposure between different countries, we also found that indoor cattle are projected to have greater exposure to future increases in heat stress. Although 4.5 to 11.6% of all cattle with access to outdoor grazing will be impacted by more than 15 additional heatwave days, this is substantially higher when considering cattle kept in indoor systems without access to the outdoors. Under the RCP4.5 scenario, 18.2% of permanently indoor cattle are projected to experience more than 15 additional days with extreme temperatures, with this share increasing to 35.0% under the RCP8.5 scenario.

Differences in exposure between European climatic zones

Accounting for climatic characteristics across Europe, we see that there are considerable differences in projected exposure to future heatwaves between climatic zones of the region (Table 1, Tables S1–S7). Most of the cattle in Atlantic, and Boreal, Nemoral and Alpine North regions of Europe will experience between up to 5 additional days of heatwaves under RCP4.5. Under the more extreme scenario, less than 15% of grazing cattle will experience less than 5 days of additional days with heatwaves in these regions, and up to 37% of indoor cattle in these regions. In the Continental and Lusitanian zone, most of the cattle is projected to be exposed to 5 to 15 additional days with heat stress. Cattle populations in the Alpine South, Pannonian and the Mediterranean regions are projected to be particularly exposed to increases in heatwave (Table 1). More than 75% under RCP4.5 and nearly all cattle under 8.5 are projected to experience more than 15 additional heatwave days in these regions.

Discussion

Timely and adequate adaptation to heatwaves can ensure the stability and socio-economic and environmental sustainability of the European cattle sector. By analysing the exposure of European cattle to future heat stress, we have identified the hotspots and the scale of climate adaptation needs in one of the most important European agricultural sectors. Numerous studies provide evidence on potential increases in exposure of European cattle to heat stress and its impact on cattle productivity[26,27], mortality[18,20,24], and welfare and comfort[19,23]. Despite these advancements in estimating heat stress impacts on cattle, continental-scale spatially explicit hotspots of future change throughout the whole European cattle sector remained understudied. A recent study that examined the impact of heat stress on cattle globally[28], used data with a coarser spatial and thematic distribution of cattle [29,30]. In our study, we went beyond changes to average temperatures and focused on the direct exposure to extreme temperatures such as in the case of heatwaves. This makes our results more suitable for Europe, also due to the high diversity of cattle production systems at relatively detailed scales in the region. Our study, presents a novel approach by separating cattle systems into those where outdoor grazing dominates, and those where cattle are kept inside, thereby accounting for the diversity in European cattle rearing systems. When comparing our results to other studies, we also found that cattle systems of Southern, Mediterranean Europe will experience most heat stress in the future, with Boreal and Atlantic parts of the region being subject to less heat stress[25,28]. In addition, other studies corroborate our findings that high-yielding systems in Europe are particularly vulnerable to heat stress[31].

The potential impacts of increasing heatwaves on the European cattle sector will clearly require measures tailored to the characteristics of individual countries and climatic regions (particularly the Mediterranean, the Alps, and other European mountain regions) and to the type of cattle rearing system (mostly indoor systems without access to grazing). Moreover, impacts related to potential losses in production and the economic impact on the livestock sector should be investigated further to estimate the costs to cattle farmers and financial needs for adaptation. However, it is clear from our results, that the holdings with cattle without access to outdoor grazing will be most exposed to future heat stress, presenting an opportunity to transform them to cattle rearing systems with more access to outdoors, which can, besides climate change adaptation, also lead to synergies in animal welfare, landscape preservation and improved sustainability of the cattle sector[32]. Nevertheless, such systems might have different economic outcomes[33,34], and could lead to less feed provided by grasslands due to trampling of animals[35,36]. In addition, lower density outdoor grazing can have higher emissions per unit of meat or dairy compared to more intensive outdoor and indoor systems[37,38]. However, while high exposure could potentially lead to decreases in cattle numbers due to decreased productivity, if planned properly, it can present an opportunity for emission reduction goals with simultaneous reductions in exposure to heat stress. Future research should therefore explore potential synergies in climate change adaptation through cattle rearing systems change and a decrease in cattle numbers.

Our results indicate that many of the intensive, large agricultural holdings in the European south will need to invest in climate-proof housing, with changes to water and temperature management of barns, and in some cases, even reductions in cattle numbers[39]. Adaptation in such systems can, however, be difficult, as heatwaves can lead to lower productivity, and consequently negatively impact the adaptive capacity of agricultural holdings due to decreased income[40]. Potential impacts of increased heatwaves might be exacerbated due to the fact that many of the areas most impacted - such as the Mediterranean, Alpine, and other mountainous regions - are dominated by old and ageing farmer populations[4], which could also be less likely to adapt by changing their farming system.

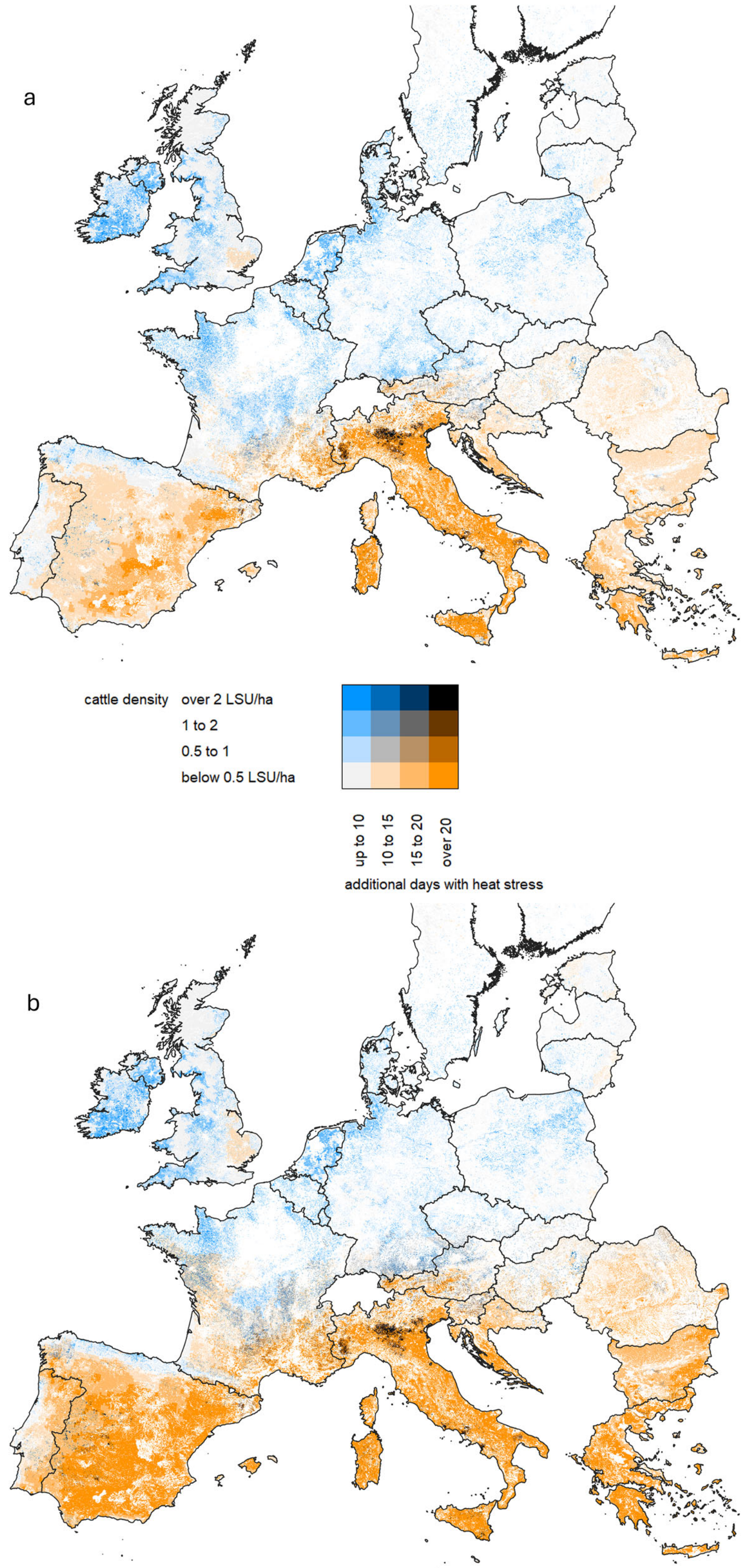

Fig. 1 | Spatial distribution of cattle exposed to heatwaves. Bivariate map showing the additional days with heatwaves and cattle densities for **a** RCP4.5 scenario, and **b** RCP8.5 scenario. High resolution versions, and maps split per system are provided in the Supplementary Materials (Figs. S7–S10).

Methods

Spatial distribution of cattle

We used a recent spatial distribution of cattle for the European Union and the United Kingdom, which maps cattle density and type of system at a 100 m spatial resolution[2]. Cattle in the data are split into those that spend a considerable amount of time on outdoor pastures in the vegetation period, those that do not have access to outdoor grazing (defined as indoor in this study), and those grazing on seminatural habitats in low densities, such as seminatural pastures, transitional vegetation, and other open areas covered with shrubs and individual trees. We combined cattle grazing in seminatural areas with grazing cattle, as the former represents a small share of cattle in Europe and most individual countries. We refer to both types together as grazing cattle.

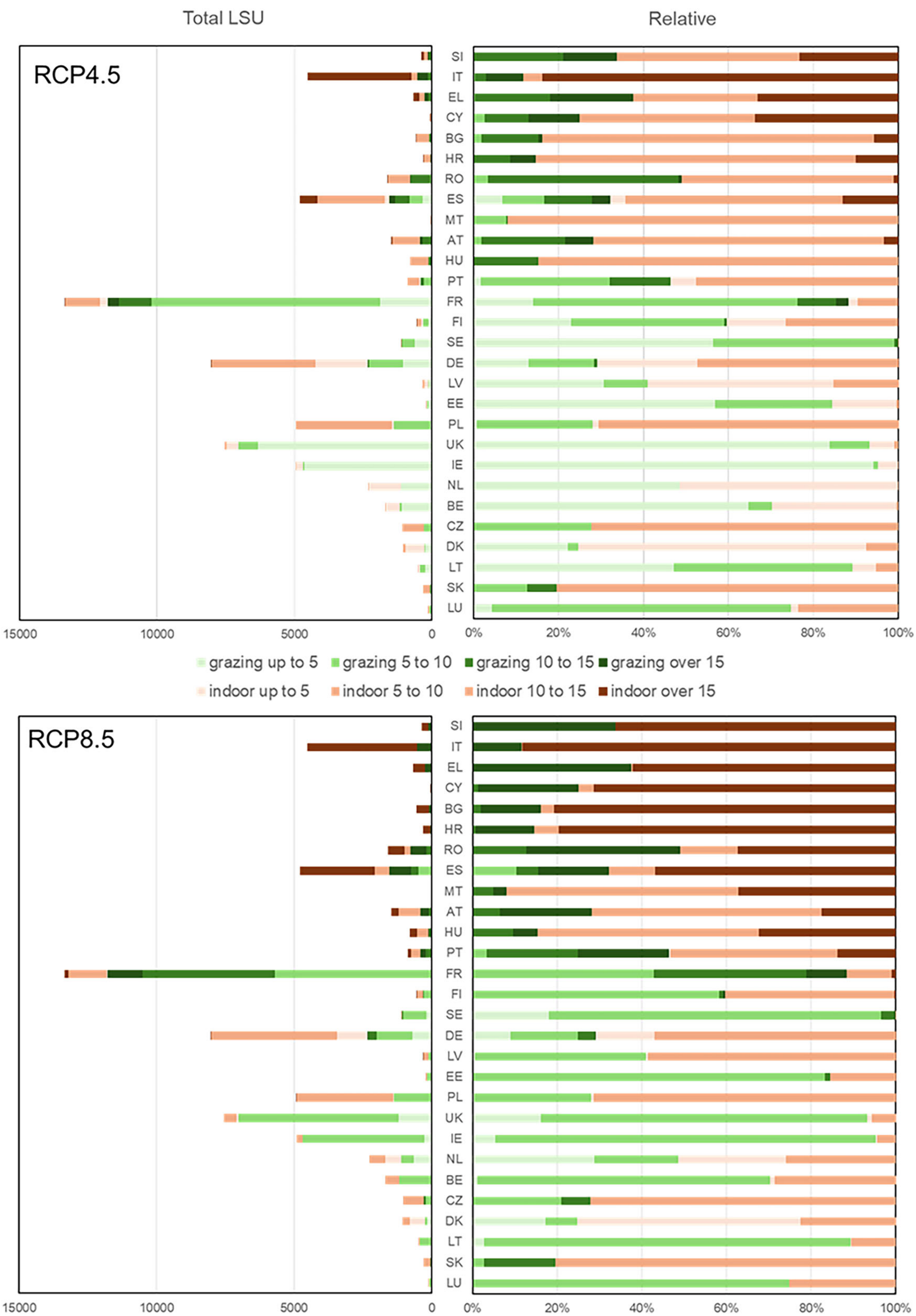

Fig. 2 | Exposed cattle in livestock units (left, in thousand LSU) and relative share of total cattle per European Union Member State and the United Kingdom under both scenarios. Countries are sorted by share of cattle exposed to 15 or more additional days with heatwaves by 2050. More detailed figures can be in the Supplementary material (Figs. S1–S6), where we also explain the abbreviations for European Union Member States (Table S1).

Climate data processing and heat stress estimation

We then processed heatwave data for Europe, derived from climate projections provided by the Copernicus Climate Change Service[41]. We used data following the definition for health-related heatwave days[42], where heatwaves are defined as days in which the maximum apparent temperature (Tappmax) exceeds the 90th percentile of the respective month, and the minimum temperature (Tmin) is greater than the 90th percentile of Tmin of the respective month for at least two days for the

Table 1 | Distribution of cattle exposed to up to 5 additional days and more than 15 additional days with heatwaves until 2050 across European environmental zones, in %, for the RCP4.5/RCP8.5 scenario

Environmental zone	Grazing cattle		Indoor cattle	
	Up to 5 additional days	More than 15 additional days	Up to 5 additional days	More than 15 additional days
Alpine South	0.3/0.0	21.9/57.9	0.2/0.0	18.8/52.2
Atlantic	71.9/13.9	0.0/0.1	80.6/37.0	0.0/0.1
Boreal, Nemoral and Alpine North	58.4/10.5	0.0/0.3	38.3/0.5	0.1/0.3
Continental	14.3/1.7	0.0/8.3	2.9/1.0	0.2/6.9
Lusitanian	11.1/0.1	0.0/5.2	17.9/0.4	0.0/13.8
Mediterranean mountains	0.6/0.0	37.5/83.3	0.3/0.0	76.5/95.9
Mediterranean	0.4/0.0	28.5/77.5	0.1/0.0	55.9/95.9
Pannonian	0.0/0.0	3.0/74.6	0.0/0.0	1.9/63.8

Full exposure statistics are available in Tables S2–S7.

period between June to August. This way, the data capture summer heatwaves only, and not also unusually warm days in the winter, spring, and autumn periods. We used the data on the ensemble members' average, which contains bias-adjusted outputs of 8 model combinations of EURO-CORDEX model outputs for Europe, available for the RCP4.5 and RCP8.5 scenarios. Representative Concentration Pathways (RCPs) are the most recent climate scenarios developed and used in global climate and environmental research, as well as policy support. This allows comparison with other potential studies and studying the context of global climate change impact research. The two studied RCPs are relevant, as they present a spectrum for two different emission levels. RCP4.5 is a future scenario, where greenhouse gas emissions and radiative forcing stabilize by 2100, thereby presenting a scenario with climate change mitigation[43]. The second scenario, RCP8.5, is characterized by high greenhouse gas emissions due to a lack of climate change mitigation policies[44]. The two scenarios therefore, present contrasting climate change impacts in terms of type, intensity, and the spatial extent of impacts. This combination of scenarios is useful to study a wider range of potential impacts of heat stress on European cattle that can also be described as medium (RCP4.5) and high or extreme (RCP8.5).

We first calculated the average number of heatwave days per year for the current climate, represented by the period 1986-2010 (as these are years based on observed days of heatwaves). We then calculated the average number of heatwave days per year for the period 2041 to 2060 for both scenarios, roughly corresponding to the period around the year 2050. We then overlaid the processed data with the cattle distribution data and calculated differences between the current climate and the two future scenarios. We performed our analysis on the scale of whole of the whole region, individual Member States and the United Kingdom, and individual European climatic zones, using the typology for European climatic stratification[45] (Fig. S11). This way, we were also able to estimate the impacts in different climatic regions. The resulting maps indicate the number of additional days with heat stress. All processing was performed using QGIS[46].

Data availability

All the data used are freely accessible. The cattle distribution data are accessible at https://zenodo.org/records/13734518. Current and projected heatwave data are accessible at https://cds.climate.copernicus.eu/datasets/sis-heat-and-cold-spells?tab=overview.

Code availability

No additional code was generated, and standard operations available in geographic information systems software were used.

Received: 11 February 2025; Accepted: 2 December 2025;
Published online: 12 January 2026

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Acknowledgements

This research has received funding by the Slovenian Research and Innovation Agency (grant J4-50224 “Land-based climate change mitigation and adaptation”), and by the European Union’s Horizon Europe Research and Innovation programme (grant 101060423 “LAnd use and MAnagement modelling for SUStainable governance”).

Author contributions

Ž.M. designed the research, processed and analysed the data, wrote the main manuscript text, and prepared the figures. L.S. designed the research and wrote the main manuscript text. Both authors have read and approved the manuscript.

Competing interests

Ž.M. is a member of the Editorial Board of this journal. Ž.M. did not handle the manuscript and did not have any role in the review process of the paper.

Additional information

Supplementary information The online version contains supplementary material available at https://doi.org/10.1038/s44264-025-00113-w.

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