Social media versus scientific literature: Comparing climate change discourses to support efficient communication and policy alignment in the Iberian Peninsula

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ABSTRACT

Understanding disparities between scientific priorities and public discourse is critical for improving climate change communication, fostering public engagement, and supporting evidence-based policymaking. Here we investigated thematic and spatial dynamics of climate change-related content in scientific literature and social media. We focused on the Iberian Peninsula over the 2012-2022 decade, as a test case. We compared the frequency and

geographical distribution of scientific research and Twitter posts that addressed the general topic of climate change and climate-related natural hazards (e.g., drought, wildfires, floods). We found a contrasting focus: while droughts (39%) were the most frequently mentioned hazard in scientific literature, wildfires (31%) dominated public discourse on social media. Spatially, scientific information was more concentrated in regions such as Andalusia, Catalonia, and northern Portugal, whereas Twitter activity showed broader engagement in central and northeastern Iberia. These thematic and spatial discrepancies suggest possible misalignments in the prioritization and perception of climate risks, which may undermine public understanding and engagement. Our findings underscore the need for communication strategies that are regionally adapted and aligned with public concerns and research priorities. Bridging these gaps is essential for fostering trust in climate science, enhancing collective action, and supporting the development of effective climate mitigation strategies.

Keywords: Natural language processing; Twitter; Scientific literature; Spatial analysis

1. INTRODUCTION

Ever-growing internet access has made social media platforms popular spaces for public engagement and debate on a range of environmental issues (Sultana et al., 2024). By breaking down traditional barriers of geography, language, and socioeconomic status, social media has been contributing to the rapid and widespread dissemination of information on environmental topics, including climate change (Hu et al., 2023). Social media platforms play a dual role: a) they enable rapid, widespread communication of scientific findings and policy updates to a broad, diverse audience, and b) they function as forums where individuals, organizations, and advocacy groups can share their experiences, concerns, and interpretations of climate phenomena (Hart et al., 2024). This dual function underscores the role of social media as an increasingly relevant platform for understanding and shaping public understanding and engagement with complex environmental challenges (Hu et al., 2023).

The real-time and interactive nature of social media offers unique opportunities to explore the dynamics between science-based environmental facts and people's interest and engagement towards these facts (Mavrodieva et al., 2019; León et al., 2023). Previous studies have reported a notable discrepancy between narratives presented in the scientific literature and those found on social media (Al-Rawi et al., 2021; Treen et al., 2020). For instance, Treen et al. (2020) found that climate change discussions on Twitter were frequently dominated by political polarization and misinformation, often marginalizing core scientific content. Similarly, Al-Rawi et al. (2021) identified a contrast between the systemic focus of scientific literature and the tendency of social media discourse to highlight sensational or anecdotal content, such

as extreme events or celebrity activism, thereby framing environmental issues through a more emotive and less evidence-based lens.

Differences between scientific evidence and social media narratives can be attributed to various social, psychological, or informational factors (Schäfer & Schlichting, 2018). Social and cultural differences significantly shape the perception and communication of environmental issues, as individuals tend to interpret information through the lens of their values, beliefs, and sociocultural context (Chwialkowska et al., 2020). Similarly, cognitive biases, such as confirmation bias, predispose individuals to preferentially accept information that aligns with their existing views (Frank et al., 2024). Emotion also plays a key role: content that evokes strong feelings, such as fear or outrage, is more likely to be widely shared and amplified on social media platforms, regardless of its scientific accuracy (Hosseini & Staab, 2023). Additionally, platform algorithms frequently prioritize sensational or controversial posts, which can distort public discourse by amplifying misinformation and marginalizing nuanced, scientific perspectives (Pennycook & Rand, 2019; Friggeri et al., 2014).

Identifying differences between scientific and public communication is key to mobilizing collective action, supporting public engagement, and promoting effective policy interventions (Alinejad & Van Dijck, 2023; Ivani & Dutilh Novaes, 2022). When scientific communication aligns with public concerns, it becomes easier to foster community participation, advance mitigation strategies, and develop policies that are both evidence-based and socially supported (Lopes et al., 2024). For instance, Alinejad and Van Dijck (2023) demonstrated that aligning scientific communication with public narratives can help overcome communication barriers, thereby enhancing climate change engagement, and fostering public support for policy decisions. Similarly, Ivani and Dutilh Novaes (2022) highlighted that direct public engagement in dialogues about scientific issues bridges the gap between empirical evidence and public perception, which is crucial for fostering trust, enhancing scientific literacy, and promoting collective action toward science-informed policies.

Understanding disparities between scientific and social media narratives can be particularly relevant for global-level challenges with region-specific impacts, such as climate change. The decentralized structure of social media, coupled with algorithms that favor sensationalist content, often amplifies misinformation, and distorts scientifically accurate representations of weather and climate extreme events (Vosoughi et al., 2018; González Cortés, 2014; Corner & Clarke, 2016). This misalignment between scientific knowledge and public perceptions poses significant challenges for effective climate change political decision-making and action.

When public understanding is shaped by inaccurate or distorted narratives, it can undermine trust in science, hinder the acceptance of climate policies, and weaken societal support for mitigation and adaptation strategies (Lewandowsky et al., 2017; Corner & Clarke,

2016). For instance, Lewandowsky et al. (2017) found that misinformation surrounding climate change can persist on social media platforms and undermine public understanding of climate science. Likewise, González Cortés (2014) highlighted the gap between media portrayals and the scientific consensus on climate change, where sensationalism and misrepresentation in media coverage can amplify uncertainties or controversies, distort public understanding, and undermine the broad scientific consensus. Identifying and addressing these discrepancies is therefore essential to ensure that communication strategies, risk assessments, and climate adaptation plans are not only scientifically grounded but also publicly accepted and actionable across local and national contexts (Mata et al., 2025).

In this study, we investigated the congruence between the representation of climate change-related themes in scientific literature and social media as represented on Twitter® (currently X®, henceforth Twitter). Specifically, we aimed to answer two central questions: (1) how divergent are thematic emphases on climate-related natural hazards in the scientific literature, compared to public discourse on social media, and (2) are there significant geographical discrepancies between scientific focus and social media attention on climate change and related natural hazards?

To answer these questions, we focused on the regional case of the Iberian Peninsula (mainland Portugal and Spain). This region has also been identified as a climate change hotspot due to its heightened vulnerability to climate change impacts, including rising temperatures, shifting precipitation patterns, and increased frequency of climate-related natural hazards such as heatwaves and wildfires (Pereira et al., 2021; Lazoglou et al., 2024; Cos et al., 2022). The Iberian Peninsula is regarded as one of the most climate-vulnerable regions in the Mediterranean region (Ribas et al., 2020; Lazoglou et al., 2024; Cos et al., 2022). Consequently, exploring perceptions of climate change across platforms in the Iberian Peninsula can be both elucidating and important for improving public decision-making, communication, and engagement supported by scientific evidence (Pereira et al., 2021, Andrade et al., 2021). Our results deliver insights to help bridge the gap between public discourse and scientific knowledge on climate change, foster more informed dialogue, support evidence-based decision-making, and encourage collective action to address this pressing global challenge.

2. LITERATURE REVIEW

Climate change represents one of the most pressing global challenges of the 21st century, with profound ecological, social, and economic consequences. Rising temperatures, shifting precipitation patterns, and increasing frequency of extreme events such as droughts, wildfires, floods, and heatwaves are already affecting ecosystems, human health, agriculture, and urban

infrastructure (IPCC, 2022; Pereira et al., 2021). Regions such as the Iberian Peninsula are particularly vulnerable due to their Mediterranean climate, high population density in certain areas, and exposure to multiple climate-related hazards (Lazoglou et al., 2024). Understanding these risks and their potential societal impacts is therefore essential to improve mitigation strategies, adaptation measures, and sustainable environmental governance frameworks.

The rise of digital platforms has significantly revolutionized the dissemination and uptake of environmental information. Social media, mobile applications, and interactive online forums have become central channels for environmental information, enabling real-time engagement and peer-to-peer knowledge sharing (Andrachuk et al., 2019; Xie et al., 2024). Empirical studies underscore this shift: for instance, Arthur et al. (2018) analyzed Twitter conversations during major flooding events in the United Kingdom and found that public discourse was strongly event-driven and influenced by media coverage. Similarly, Zorenböhmer et al. (2025) investigated social media engagement with wildfire events in California, revealing that the virality of posts depended on their emotional framing rather than scientific accuracy. The structure and functionalities of these platforms, including algorithmic curation, virality and multimedia content, directly influence how information is framed, perceived, and shared by the public (Metzler & Garcia, 2024).

While these platforms offer unprecedented opportunities for raising awareness and fostering engagement, they also present a range of challenges. Misinformation can spread rapidly, selective exposure can create echo chambers, and viral content often prioritizes sensationalism over evidence-based information (Bakir & McStay, 2022; Vosoughi et al., 2018). For instance, studies by Elkefi and Tounsi (2024) and García et al. (2024) demonstrated that during heatwave and wildfire events, respectively, public attention tends to concentrate on immediate impacts and anecdotal experiences, rather than on the long-term systemic risks emphasized in the scientific literature. Understanding the mechanisms that shape digital climate discourse is therefore essential for designing communication strategies that enhance scientific literacy and foster informed public engagement.

Recent advances in computational and geospatial technologies have enabled more sophisticated and nuanced analyses of environmental and societal data. Advanced computational techniques such as deep learning, natural language processing, and sentiment analysis allow researchers to analyze large-scale social media data, detecting patterns in public concern, topic salience, and spatial engagement (Anderson et al., 2024; Kouloukoui et al., 2023). For instance, Gokcimen and Das (2024) used natural language processing techniques to analyze climate change discourse across multiple social media platforms and blog texts, identifying thematic clusters of concern and temporal peaks. Similarly, Yue et al. (2021) combined geotagged Twitter data with social-ecological vulnerability indicators to

assess wildfire risk across the United States. Such approaches highlight the potential of emerging technologies for informing communication strategies and supporting evidence-based interventions at local and regional scales.

Effective climate governance increasingly requires the integration of scientific knowledge, public perceptions, and adaptive policy frameworks (Munaretto et al., 2014; Biesbroek, 2021). Empirical studies on adaptative governance underscore the importance of multi-level coordination, stakeholder engagement, and iterative learning processes to enhance the capacity of policies to respond dynamically and flexibly to evolving environmental risks (Armitage et al., 2010; Djalante, 2012). Digital traces from social media offer valuable and actionable insights for participatory governance by revealing localized concerns, emerging risks, and public priorities in near real time (Segerberg & Bennett, 2011). Case studies, such as the use of social media analytics during Hurricane Harvey (Chen et al., 2020), demonstrate how integrating public-generated data can improve situational awareness, optimize resource allocation, and strengthen stakeholder engagement in disaster management.

Our review of the literature shows that, despite notable progress in the analysis of digital climate communication, several limitations persist. Existing research often treats scientific literature and social media discourse as separate domains, with few systematic efforts to compare their thematic emphases and geographical patterns. Moreover, most studies emphasize event-driven reactions or general sentiment tends, without fully considering how public discourse aligns, or misaligns, with long-term scientific priorities and regional vulnerabilities. Methodological advances in natural language processing and spatial analysis have been increasingly applied to climate change-related communication, but rarely in combination to examine both public narratives and scientific agendas. Evidence is also scarce on how digital trace data can be integrated into adaptive governance frameworks at regional scales. Addressing these gaps, our study combines text mining, spatial analysis, and cross-domain comparison of scientific and social media discourses to uncover thematic divergences and spatial misalignments in climate change communication across the Iberian Peninsula.

3. METHODS

3.1. Methodological framework

We followed a five-step methodological framework to investigate discrepancies between social media and scientific discourse on climate change. Step 1) We extracted posts related to climate change for mainland Portugal and Spain using Twitter's Application Programming Interface (API). Step 2) We identified and removed duplicates and off-topic posts. Step 3) We collected scientific literature on climate change and related phenomena for Portugal and

Spain, using the Scopus database. Step 4) We removed duplicate articles, reviewed them, and excluded those deemed irrelevant to our study, based on predefined exclusion and inclusion criteria. Step 5) Finally, we performed textual and geospatial analyses of the resulting social media and scientific literature datasets to identify overall trends and spatial patterns in the scope of climate change.

3.2. Data collection

Data collection was conducted for the Iberian Peninsula, defined as our test region, which includes mainland Portugal and Spain. The time span of the analyzed data was 2012-2022, coinciding with a period of severe droughts, unprecedented wildfires, and extreme heatwaves in both countries (Bevacqua et al., 2024; Rodrigues et al., 2023). Throughout this study, we adhered to privacy regulations and platform terms of use at the time of data collection (January 2023), in line with best practices for ethical digital research (Di Minin et al., 2021).

3.2.1. Social media data

We retrieved online data related to climate change from the social media platform Twitter, using a list of more than 130 climate change-related keywords. These keywords included terms such as wildfires, greenhouse effect, droughts, and global warming (full list available in Tables S1, S2 and S3). We compiled this list with the help of a group of climate change specialists, supported by native speakers of Portuguese, Spanish, and English. Twitter was considered for its extensive user base, its accessibility[1] of concise, user-generated content, and its capacity to capture real-time public reactions to climate change topics (Veltr & Atanasova, 2017). Data from posts (excluding retweets) were collected using Twitter's API v2 academic research license and the open-source Python library Tweepy (https://www.tweepy.org/), from March 2006 (i.e., when Twitter was founded) to December 2022. For the subsequent analyses, only posts from 2012 to 2022 were considered. Through the Twitter API, we limited our search query to Portugal and Spain. We collected textual content of 174,674 posts in Portuguese, 1,224,504 posts in Spanish, and 372,655 posts in English. We also retrieved post metadata, including post creation dates, post locations, usernames, and user locations. Consequently, we removed duplicates, short (fewer than 6 words), and irrelevant posts (i.e., exhibiting ambiguous or metaphorical meanings; see Table 1).

[1] Currently the platform is designated as X and the accessibility policy has changed significantly.

We assessed the relevance of each post using open-source Bidirectional Encoder Representations from Transformers (BERT) models - BERTimbau for Portuguese (Souza et al., 2020), BETO for Spanish (Wu & Dredze, 2019), and BERT base for English (Devlin et al, 2019). These models have been recognized for their ease of transfer learning and strong performance in related natural language processing tasks (Varini et al., 2020; Effrosynidis et al., 2022). We manually annotated a random subsample of posts to train the models, comprising approximately 1,200 posts for Portuguese and English (42% relevant and 58% not relevant) and 3,200 posts for Spanish (47% relevant and 53% not relevant). We classified posts as 'Relevant' if their content was directly related to climate change phenomena and impacts, and 'Irrelevant' if deemed unclear or unrelated to climate change (see Table 1). As the two classes in each random subset were imbalanced, we applied an empirical balancing technique - under sampling - to mitigate bias in the models' performance. This approach involved retaining all posts in the minority class ('Relevant') and reducing the size of the majority class ('Irrelevant') to match the same number. Subsequently, 75% of the data was allocated for training, while 25% was reserved for testing. Regarding the configuration of the models (hyperparameters), we used the Adam optimizer algorithm (Kingma & Ba, 2015) and a batch size of 16 for BERTimbau, and 4 for BETO and BERT base (see supplementary material for details of all configurations). We determined the optimal number of epochs and learning rates through empirical testing. We found that the values of 20 and $2e^{-6}$ for epochs and learning rates, respectively, achieving the best performance across the three models. Lastly, we retained 10% of the training posts for validation to monitor the models' performance and adjust hyperparameters. We estimated the performance of the models (BERTimbau, BETO, and BERT base) with standard classification metrics: accuracy (ACC), precision (positive predictive value, PPV), recall (sensitivity or true positive rate, TPR), and F1-score (F_1; see Tables S6 and S7 for more details and results).

We excluded posts deemed as 'Irrelevant', yielding a final dataset of 669,730 posts: 38,419 Portuguese, 569,610 Spanish, and 61,701 English. From the set of 669,730 posts, we considered only those posts that explicitly mentioned climate change terms for subsequent analyses (55,703 posts), to enable reliable and comparable results with the scientific literature. This filtering ensured that the selected posts aligned with the scientific literature, as our search strategy for academic publications specifically targeted studies that explicitly linked climate change to each phenomenon.

Table 1. Examples of posts considered 'Relevant' and 'Irrelevant' by the models in Portuguese, Spanish and English. The posts originally in Portuguese and Spanish have been translated into English for ease of interpretation.

	Relevant	Irrelevant

Portuguese	"Guys from Lisbon, there are **floods** at Campo Grande/Sete Rios and Lumiar, be careful."	“I'm **flooded** with sleep and can't sleep.”
Spanish	“In that area, there are dozens of archipelagos and thousands of islands exposed to even more terrible **cyclones**, worsened by climate change.”	“You give heat to my heart, you cause a **cyclone** in my soul. :) #culture #womensday #literature #living”
English	“It was absolutely freezing wasn't it & that was after huge **hail** stones on Christmas day 😳”	“All **hail** to the King!”

3.2.2. Scientific literature

We retrieved scientific evidence on climate change from published peer-reviewed scientific literature accessed via Scopus (https://www.scopus.com/). To achieve this, we applied a structured search strategy using a predefined search string (available in the supplementary material) that specifically included climate change terms combined with each keyword selected for the social media data collection (e.g., 'climate change' AND 'wildfires'). This approach was adopted to obtain a manageable volume of publications and to minimize the effort and time required for manually filtering out irrelevant articles. We chose Scopus due to its comprehensive coverage of multidisciplinary journals, frequent updates on recent publications, advanced citation analysis features, and user-friendly interface that can facilitate a thorough and efficient literature review (Pranckutė, 2021). We considered only publications in English, Portuguese, and Spanish, resulting in a total of 8,707 articles. We excluded inaccessible publications and duplicates, resulting in a refined dataset of 8,604 articles. One reviewer (ASC) screened the title and abstract of each publication using the revtools R package (https://cran.r-project.org/package=revtools), to ensure each publication addressed climate change and/or associated phenomena in Portugal and/or Spain (see Table S5). This screening resulted in a final dataset of 4,481 relevant articles retained for analysis. During this process, whenever available, we collected information on the countries and their administrative regions at two levels - broader regions and smaller subregions - to facilitate a thorough analysis of the geographical distribution of research topics (Table S4). From each publication we retrieved the following information: publication type, authors, year of publication, journal, doi, keywords, title, and abstract.

3.3. Data analysis

All computational analyses were conducted using Google Colab, a complimentary Jupyter notebook environment provided by Google Research. This cloud-based platform enables the execution of R and Python code without the need for local setup and offers free access to computational resources, including GPUs. All analyses were performed using specialized open-source platforms for natural language processing tasks. Specifically, we used Keras (https://keras.io/), TensorFlow (https://www.tensorflow.org/), spaCy (https://spacy.io/), Scikit-learn (https://scikit-learn.org/stable/), libpysal (https://pysal.org/libpysal/), ESDA (https://pysal.org/esda/), SciPy (https://scipy.org/), revtools (https://cran.r-project.org/web/packages/revtools/index.html), statsmodels (https://www.statsmodels.org/stable/index.html) and Plotly (https://plotly.com/).

3.3.1. Frequency analysis

Firstly, we addressed our main question: how divergent are thematic emphases on climate-related natural hazards in the scientific literature, compared to public discourse on social media? Our emphasis on these phenomena was driven by their growing prominence in scientific and public discourse, as immediate and visible impacts of climate change, making them particularly relevant for studying public engagement with climate change on social media platforms (Selje et al., 2024; Roxburgh et al., 2019). To do so, we started by analyzing the thematic emphasis of climate change-related discourse in each source of data (social media versus scientific literature). We selected only posts that specifically mentioned these phenomena (i.e., the terms in the 'Keyword' classification level in Table S8). This allowed a more targeted and detailed investigation of public discourse and scientific literature on the most immediate and disruptive climate-related threats. Then, we implemented different frequency functions to analyze the public and scientific attention given to climate-related natural hazards. Specifically, we used spaCy modules (Attributes, https://spacy.io/api/attributes) and classes (Matcher, https://spacy.io/api/matcher) for the three languages (Portuguese, Spanish and English) to implement frequency functions based on regular expression (regex) matching and lemmatization attributes. The regex matching function helped identify and manipulate patterns in text, ensuring thorough text pre-processing by filtering non-alphabetic characters and symbols. This produces a refined text input for analysis. Lemmatization is the process of reducing words to their base or root forms, standardizing them, and improving consistency in word usage (Srivastav et al., 2020). The combination of these regex and lemma functions minimizes textual noise and enhances the tokenization process. Tokenization involves breaking down sentences into individual words,

phrases, or symbols, known as “tokens”. This results in a more coherent and normalized dataset that allows for accurate word frequency computation (Srivastav et al., 2020).

These frequency functions were subsequently applied to both social media posts and scientific literature title, abstract, and keywords fields (whenever available). To enhance clarity and avoid repetitive visualizations, we created the figures with the broader categorization of the search keywords (i.e., the ‘Subcategory’ classification level in Table S8). Lastly, to determine whether differences in frequency proportions between social media and scientific literature were statistically significant, we performed a Two-proportion Z-test (see supplementary material for more details) using the statsmodels library (https://www.statsmodels.org/stable/index.html).

3.3.2. Spatial distribution

We focused on our second main question on whether there are significant geographical discrepancies between scientific focus and social media attention on climate change and related phenomena. To do so, we mapped and compared the geographical distribution of scientific literature and social media posts across regions of the Iberian Peninsula. We conducted separate analyses for the general topic of climate change (the entire dataset), and for the five specific climate change-related phenomena most frequently addressed in both scientific publications and Twitter posts: wildfires, drought, floods, heatwaves, and storms. We normalized social media data by dividing the raw Twitter post counts by the population size of each statistical region (https://ec.europa.eu/eurostat/databrowser/product/page/demo_r_d2jan) to mitigate potential biases arising from population density variations. To assess the statistical significance of the observed spatial distributions, we performed a Chi-Square Test using the SciPy library (https://scipy.org/). Following this, a post-hoc analysis was conducted using the statsmodels library (https://www.statsmodels.org/stable/index.html) to explore the nature of significant differences between regions (see supplementary material for more details).

Due to substantial differences in magnitude between the two datasets, we decided to standardize the frequencies. These differences arose from the prior normalization of Twitter posts. To address this issue, we implemented min-max normalization to scale both datasets. Then, we performed a spatial congruence analysis to measure alignment between the scientific literature and social media posts across regions. Specifically, we used the SciPy library (https://scipy.org/) to compute the absolute differences and Pearson correlation coefficients between the number of scientific publications and the volume of social media posts per region. To further assess spatial dependencies, we used the libpysal

(https://pysal.org/libpysal/) and ESDA (https://pysal.org/esda/) libraries to calculate Moran's I for both datasets. When significant spatial autocorrelation was detected, we implemented a Spatial Lag Model (SLM) to analyze the relationship between scientific publications and social media engagement while accounting for spatial dependencies.

Finally, we applied this methodology separately to each of the five most-discussed phenomena (wildfires, drought, floods, heatwaves, and storms). This enabled us to assess whether regional interest in particular climate change impacts was similarly reflected in both scientific literature and social media discourse.

4. RESULTS

4.1. Climate change in scientific literature versus social media posts

We found notable differences in the climate-related natural hazards between scientific and social media posts (Fig. 1; Table S9). The most frequently mentioned phenomena in both datasets were 'drought' (39% for scientific literature and 18% for posts) and 'wildfires' (19% for scientific literature and 31% for posts). The frequency of drought and wildfires was significantly different between datasets ($p < 0.001$), with drought more frequently discussed in the scientific literature, and wildfires more prominent in social media discourse. Although less noticeable, other hazards, such as 'floods' (18% for scientific literature and 13% for posts) and 'storms' (8% for scientific literature and 12% for posts), also garnered substantial attention. Floods were more frequently mentioned in scientific literature, whereas storms were more common in social media posts ($p < 0.001$). In contrast, 'heatwaves' (8% for scientific literature and 9% for posts) did not show significant differences ($p = 0.335$). Phenomena such as 'avalanches', 'dust storms', and 'downburst' were rarely addressed in both realms, with avalanches showing no significant difference between the two datasets ($p = 0.972$).

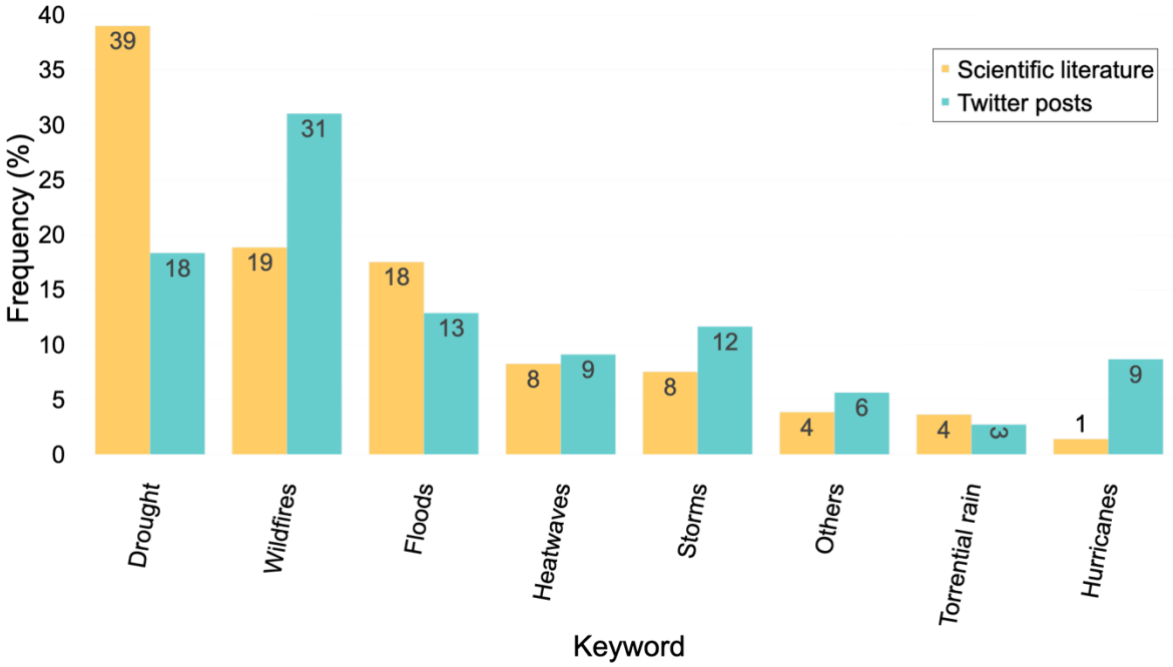

Fig. 1. Relative frequency of scientific literature and Twitter posts addressing climate-related natural hazards, considering a time window from 2012 to 2022. 'Others' refers to climate-related natural hazards that accounted for less than 1% of the total in both data sources, including landslides, frosts, cold waves, blizzards, tornadoes, avalanches, dust storms, hail, and downburst.

4.2. Spatial patterns and congruence between scientific literature and social media posts

We observed pronounced spatial discrepancies in how climate change and climate-related natural hazards are represented across scientific literature and social media, with varying degrees of congruence between the two sources (Tables S10 and S12; Figs. 2 and S2). Scientific publications showed statistically significant regional disparities ($p < 0.001$), with certain provinces, such as Andalusia and Catalonia, consistently exhibiting higher frequencies, particularly for drought (standardized residual (sr) = 2.678), floods (sr = 3.162), heatwaves and storms (sr = 2.826). Similarly, wildfire-related research was mostly concentrated in Catalonia and in the northern (sr = 4.800) and central (sr = 4.413) regions of Portugal. In contrast, social media engagement on Twitter revealed a more widespread spatial pattern, with more provinces engaging in discussions compared to scientific literature (Table S11). Peaks in public interest were observed for drought, wildfires, and heatwaves, especially in central, northern, and northeastern regions of Portugal and Spain, although these differences were not statistically significant ($p = 1.000$). Nevertheless, certain regions, such as

Madrid (sr = 0.001 for the general climate change topic) and the coastal areas of Catalonia (sr = 0.002 for heatwaves), Valencian Community (sr = 0.002 and sr = 0.004 for heatwaves and storms, respectively), and Murcia (sr = 0.003 for drought), showed particularly high engagement. Catalonia and Madrid consistently emerged as prominent regions in both scientific and public discourse. However, notable differences were also observed between the two sources; for instance, while storms received limited attention in the scientific literature for Spain but elicited higher engagement on Twitter, particularly in northern and coastal regions, the opposite was observed for Portugal, where scientific focus on storms was higher, but public interest was lower.

This mismatch was reflected in the spatial correlations between both datasets (Fig. 2). Moderate correlations were observed for general discussions on climate change ($r = 0.27$, $p = 0.168$) and drought-related content ($r = 0.41$, $p = 0.031$), with the latter being statistically significant. This suggests a partial overlap between the regions where scientific research is concentrated and where public discourse on Twitter is most active (Fig. 2a and 2b). Heatwaves exhibited the strongest spatial congruence ($r = 0.54$, $p = 0.003$), with regions such as western and central Spain showing a statistically significant alignment between the frequency of Twitter posts and scientific publications (Fig. 2e). Conversely, floods ($r = 0.16$, $p = 0.414$) and wildfires ($r = 0.08$, $p = 0.681$) displayed weaker congruence, with sporadic regions of overlap but overall limited alignment (Fig. 2d and 2c). Storms presented a negative correlation ($r = -0.17$, $p = 0.375$), indicating an inverse relationship between public discourse and scientific activity (Fig. 2f). This suggests that regions with higher public attention, such as northeastern Spain, were underrepresented in the scientific literature.

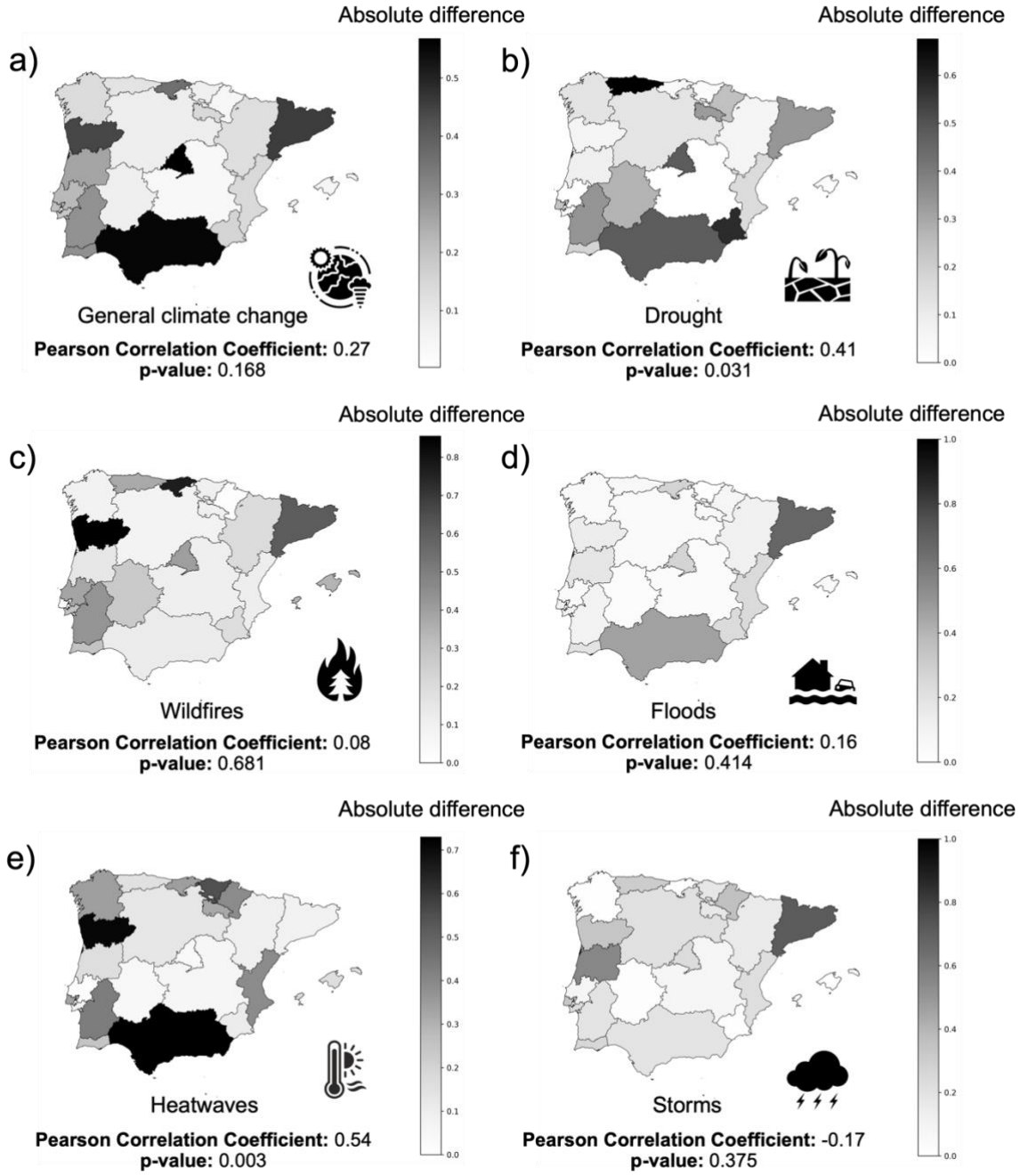

Fig. 2. Spatial congruence between scientific literature and Twitter posts related with a) general climate change topic, b) drought, c) wildfires, d) floods, e) heatwaves and f) storms. The analyses were performed considering a time window from 2012 to 2022, as well as the administrative regions of Portugal and Spain. The shading intensity represents the absolute difference between the number of scientific publications and the volume of Twitter posts for each topic, with darker shades indicating higher differences. The Pearson correlation coefficient between both variables is displayed below each map.

Spatial congruence between scientific literature and Twitter posts varied across the climate-related phenomena (Table 2). Significant spatial autocorrelation was detected in Twitter discourse for heatwaves (Moran's I = 0.391, p = 0.003) and general discussions on climate change (Moran's I = 0.513, p < 0.001), while scientific literature showed no significant clustering for these topics. Conversely, droughts exhibited significant spatial autocorrelation in scientific research outputs (Moran's I = 0.302, p = 0.019) but not in public engagement. Wildfires, floods, and storms-related content showed no significant spatial autocorrelation in either scientific literature or Twitter posts. The Spatial Lag Model indicated that for heatwaves, scientific publications had a significant positive effect on social media engagement (β = 0.361, p = 0.036). In contrast, for general climate change discussions and droughts, scientific literature had no significant influence on Twitter posts (β = 0.017, p = 0.926; β = 0.305, p = 0.178, respectively), In these cases, public engagement appeared to be primarily shaped by spatial spillover effects (W = 0.320, p = 0.104; W = 0.521, p = 0.001, respectively).

Table 2. Spatial autocorrelation (Moran's I) and Spatial Lag Model (SLM) values for scientific literature and Twitter posts related to general climate change topic, drought, wildfires, floods, heatwaves, and storms. SLM (β) represents the effect of scientific literature on Twitter engagement, while SLM (W) describes the spatial dependence of public discourse in relation to scientific research. Statistically significant results are highlighted in bold.

	Moran's I	**SLM (β)**	**SLM (W)**
Scientific literature			
General climate change topic	0.162, p = 0.168	-	-
Drought	0.302, p = **0.019**	0.305, p = 0.178	0.320, p = 0.104
Wildfires	0.224, p = 0.071	-	-
Floods	0.130, p = 0.249	-	-
Heatwaves	-0.005, p = 0.824	-	-
Storms	0.004, p = 0.779	-	-
Twitter posts			
General climate change topic	0.513, p < **0.001**	0.017, p = 0.926	0.521, p = **0.001**
Drought	0.147, p = 0.203	-	-
Wildfires	0.140, p = 0.221	-	-
Floods	-0.032, p = 0.973	-	-
Heatwaves	0.391, p = **0.003**	0.361, p = **0.036**	0.503, p = **0.003**
Storms	0.157, p = 0.180	-	-

5. DISCUSSION

In this study, we compared climate change discourses in scientific literature and social media posts from 2012 to 2022 across the Iberian Peninsula. To provide insights that can support management response to climate change, we aimed to answer two central questions: (1) how divergent are thematic emphases on climate-related natural hazards in the scientific literature, compared to public discourse on social media, and (2) are there significant geographical discrepancies between scientific focus and social media attention on climate change and related natural hazards?

Overall, our results revealed notable differences in the prominence of climate-related natural hazards (Fig. 1), with droughts and wildfires being most frequently mentioned in both datasets, though with varying emphasis. Scientific literature showed pronounced regional differences in focus, particularly for droughts, floods, and heatwaves, while public discourse on social media exhibited a broader and more widespread interest (Fig. 2). Heatwaves demonstrated the strongest spatial congruence between scientific publications and Twitter posts (Fig. 2e). We also observed different levels of spatial autocorrelation and influence between the two realms, with significant positive spatial connections for heatwaves but weaker associations for other phenomena such as wildfires and storms (Table 2).

Comparing scientific literature and social media posts on climate change

Overall, our text mining and spatial analyses of scientific literature and social media posts highlight the dynamic and divergent ways in which climate change is discussed and represented across these two sources. We found differences in addressing certain phenomena, particularly drought and wildfires (Fig. 1). Drought was particularly prominent in the scientific literature. This focus is likely attributable to the region's vulnerability to prolonged dry periods, which pose significant challenges to water resource management, agricultural productivity, and ecosystem stability (Páscoa et al., 2017). However, drought received considerably less attention in Twitter posts (18%), indicating a potential gap in public perception or prioritization of this slow-onset phenomenon. The gradual progression of drought may be less noticeable or “newsworthy” for social media users, who are often drawn to immediate and visually striking events (Stieglitz et al., 2018). Conversely, wildfires had more attention on Twitter compared to scientific literature. This discrepancy is likely influenced by the immediate and visible impacts of wildfires on communities and landscapes in the Iberian Peninsula, where such hazards are recurrent (Senande-Rivera et al., 2025; Carmo et al., 2021). Additionally, wildfires tend to have high visibility in media coverage, which can further amplify public attention (Paveglio et al., 2015). These differences highlight important challenges for regional environmental governance, emphasizing the potential necessity of integrating empirical scientific knowledge with public perceptions to design adaptive

management strategies that address both ecological dynamics and community priorities (Avilés Irahola et al., 2022).

Floods, heatwaves, and storms, in contrast, showed more comparable levels of attention across scientific and public domains (Fig. 1). The focus on floods likely reflects their substantial socio-economic impacts in the Iberian Peninsula, especially in highly vulnerable low-lying and coastal regions (Sánchez-García & Schulte et al., 2023). Heatwaves and storms also garnered moderate attention, with slightly higher visibility on Twitter, possibly due to their immediate effects on daily life and health (Lorenzo et al., 2021; Gonçalves et al., 2020). Phenomena such as avalanches, dust storms, and downbursts were rarely addressed in either scientific literature or social media discourse. The lower prominence of these hazards in the Iberian Peninsula may explain this limited emphasis. Nonetheless, this underrepresentation, especially on social media, may signal a need to enhance awareness in regions where these hazards have the potential to cause significant localized impacts.

Spatial patterns in scientific literature vs. social media posts on climate change

The spatial distribution of scientific literature and social media posts across Portugal and Spain revealed important divergences between academic focus and public engagement on climate change and related phenomena (Figs. 2 and S2). In scientific research, the prominence of regions such as Catalonia, Andalusia, and northern and central Portugal reflects a well-documented emphasis on areas historically exposed to climate risks (Calheiros et al., 2021; Páscoa et al., 2017; Lorenzo et al., 2021). This concentration is likely influenced by factors such as data availability, population density, global trends, funding opportunities, and resource allocation (Eggleton & Winfield, 2020; Ebadi & Schiffauerova, 2016). Research efforts often align with larger consortia or funding priorities, which can limit or drive the focus to certain regions and phenomena, potentially overshadowing more localized or emerging events (Petersen, 2021). Conversely, Twitter engagement shows broader and more diffuse public interest that may be shaped by immediate, event-driven responses amplified by media coverage and local impacts (Kirilenko et al., 2015). Coastal regions and urban centers, for instance, showed heightened Twitter activity in response to floods and storms, despite these areas being underrepresented in scientific research. This discrepancy underscores the reactive nature of social media, which captures public attention during or after extreme events (Silver & Andrey, 2019), while academic focus tends to prioritize persistent climate risks in well-documented areas (Ford et al., 2018).

Wildfires illustrate both convergence and divergence. Spatial congruence analysis did not reveal any significant spatial autocorrelation in either scientific literature or social media posts (Fig. 2c, Table 2). These findings may reflect the contrasting temporal and spatial dynamics

between long-term research outputs and real-time public engagement. While northern and central Portugal and Catalonia likely attract significant research attention due to their historical wildfire susceptibility (Oliveira et al., 2021; Alcasena et al., 2019), regions like Extremadura and Andalusia, while experiencing significant wildfire activity, show less concentrated research outputs. This suggests that factors beyond ecological vulnerability, such as resource allocation, regional priorities, and research capacity, may also influence the distribution of academic attention (de Diego et al., 2023). Public interest, however, is more geographically dispersed, with social media engagement spreading to regions like central and coastal Spain, likely driven by media coverage. Scientific efforts may focus on persistent wildfire hotspots and long-term wildfire risks. However, public concern appears to be predominantly event-driven, responding to immediate threats or widely publicized events (McCaffrey, 2015; Momin et al., 2024).

Moderate positive correlations for general climate change discussions and drought suggest some degree of alignment between scientific research and social media discourse (Fig. 2a and 2b). For the general climate change topic, the spatial autocorrelation analysis revealed significant clustering in social media posts (Table 2), which suggests that public interest is highly localized. Regional mismatches were observed in areas such as northern Portugal and southern Spain, where scientific research is more prominent. This may reflect a focus on systemic climate issues that are particularly acute in these regions, such as wildfires, desertification, and water scarcity (Oliveira et al., 2021; Hervás-Gámez & Delgado-Ramos, 2019). Conversely, in central Spain, public discourse predominates, likely driven by locally resonant issues, high-profile events such as the Conference of the Parties (COP25) held in Madrid, or public concern over climate change and its local consequences (Polaino et al., 2024). For droughts, scientific literature showed significant spatial autocorrelation but not public engagement (Table 2). The research on this phenomenon is geographically clustered in the southern and eastern parts of Spain, possibly due to their chronic exposure to drought (Hervás-Gámez & Delgado-Ramos, 2019), while Twitter discourse did not exhibit the same localized pattern. This discrepancy suggests that public attention may be event-driven, with spikes during specific drought episodes rather than consistent interest that reflects the long-term severity of this issue (Matei et al., 2021). Moreover, populations living in drought-prone regions may become familiarized with such hazards, leading to reduced sensitivity to changes in drought patterns and a gradual decline in public concern over time (Panda, 2016). This gap highlights the need for more effective communication strategies to raise awareness on the long-term severity of slow-onset phenomena like droughts.

Heatwaves showed the strongest spatial alignment, between scientific research and social media discourses, particularly in western and central Spain (Fig. 2e). As with the general climate change topic, we found notable clustering in social media posts (Table 2), which

indicates that public interest regarding heatwaves is concentrated in specific areas. Moreover, scientific publications seem to have a significant effect on social media engagement (Table 2). This suggests that public responses are shaped not only by local research but also by the neighboring regions. Such congruence likely stems from the immediate and highly visible impacts of heatwaves, which tend to dominate both public attention and research agendas due to their direct consequences on human health, infrastructure, and ecosystems (Klingelhöfer et al., 2023; Grasso et al., 2017).

In contrast, floods exhibited more pronounced regional mismatches, with a weak correlation and no significant spatial autocorrelation in both scientific literature and social media posts (Fig. 2d, Table 2). These disparities may arise from floods' localized impacts and the nature of public attention, which often focuses on high-profile events or urban areas particularly affected by flash floods (Hale et al., 2018). On the other hand, scientific research may aim to understand broader flood risk patterns, such as floodplain dynamics and long-term adaptation strategies, which may attract less public interest (Grigg, 2024; Ceola et al., 2022). These results underscore the need for more effective science communication strategies to improve public understanding of flood risks.

Lastly, storms exhibited a negative correlation between scientific and social media attention across regions (Fig. 2f). Moreover, there was no significant clustering in either scientific literature or social media posts (Table 2), with northern Spain showing moderate Twitter activity while remaining underrepresented in scientific research. This mismatch may arise from the scientific focus on broader systemic storm analysis, while public discourse tends to be driven by large-scale and more frequent storm events that resonate locally (Torricelli et al., 2023). Additionally, limited research funding or infrastructure in certain areas may constrain scientific efforts, which may further contribute to the discrepancies observed (Aagaard et al., 2021).

Limitations, opportunities, and the way forward

We focused exclusively on articles that directly address climate change. Consequently, our review may have overlooked several potentially relevant studies. For instance, research on biodiversity impacts, renewable energy, pollution, extreme weather events (such as droughts, hurricanes, and wildfires), or ocean acidification may not explicitly include the term 'climate change' but is still crucial to understand broader climate dynamics (Mahecha et al., 2022; Cho, 2021). This could lead to the underrepresentation of important contributions. Additionally, restricting our search to specific phrases focused directly on climate change as a phenomenon, rather than including studies that address its impacts, consequences, or mitigation strategies under alternative terminologies, may have led to the omission of relevant

works (Schuldt et al., 2011; Pathak et al., 2024). For instance, articles that explore sustainability, adaptation, resilience, or environmental policy may discuss climate change indirectly but use alternative frameworks (Selje et al., 2024). Consequently, such articles may have been excluded, reducing the diversity of perspectives and disciplines in our dataset.

Our analyses assume equal access to social media across regions. However, there are regional differences in internet penetration, with rural and less populated areas sometimes experiencing lower connectivity compared to urban centers (Feurich et al., 2024). This is the case for Spain, where the overall internet penetration rate is 94.0% (DataReportal, 2022a), and for Portugal, where it is 85.0% (DataReportal, 2022b). In both countries, rural areas tend to have lower connectivity levels than urban centers. This may lead to lower levels of online engagement in these areas, despite potentially experiencing frequent or severe climate-related natural hazards like wildfires and heatwaves. Social media use is also skewed by age and socioeconomic status (Yates et al., 2015). Younger populations and urban dwellers are more active on online platforms, while older generations and lower-income groups may rely more on traditional media. This demographic disparity can lead to biases in social media-based analysis, where certain voices and concerns are overrepresented or underrepresented. Additionally, our analysis did not explicitly account for the role of traditional media. Traditional media can exert an indirect influence on social media patterns and lead to a misrepresentation of public concern in certain regions. It should also be noted that geographic data associated with Twitter posts may not always be precise or available. Many users choose not to share their exact locations, and geotagging is limited to those who explicitly enable it. Consequently, the geographic distribution of social media posts may not reliably represent the areas most affected by these phenomena, which can lead to possible gaps or inaccuracies in social media data. Moreover, hotspots in public engagement, as measured by post frequency, may coincide with high-profile events (e.g., major wildfires, extreme heatwaves), but might not sustain throughout the entire period (Noviello et al., 2023). Future research could incorporate survey data, media content analysis, and participatory mapping to support a more holistic understanding of public engagement across platforms and scales, thereby providing a more robust and multidimensional understanding of societal responses to environmental challenges (Revez et al., 2022).

Nonetheless, our study revealed key insights on the divergence between scientific research and social media discourse on climate change and climate-related natural hazards in the Iberian Peninsula. We adopted an interdisciplinary approach that integrates insights from environmental science, communication studies, and spatial analysis to enable a more holistic understanding of climate change dynamics. This allowed us to evaluate not only the informational content of public and scientific narratives but also how they intersect with context-specific vulnerabilities, institutional responses, and governance mechanisms (Donald

et al., 2022). Our comparative analysis underscores the importance of improving public communication about the urgency of long-term environmental risks, whose far-reaching consequences are often less immediately apparent. A key insight potentially emerging from our results is the critical need for improved public engagement, particularly regarding issues that may not receive immediate media attention, such as drought and floods. Scientific literature often focuses on long-term trends and systemic vulnerabilities, while public discourse may be more influenced by acute, event-driven content that captures immediate attention (Torricelli et al., 2023; Weber, 2010). Specifically, targeted social media campaigns and educational outreach initiatives can raise awareness regarding the long-term risks of climate change-related phenomena, especially in regions that recurrently experience these events (Segerberg, 2017). Furthermore, the spatial and thematic disparities between public and scientific focus suggest an opportunity to foster greater interaction between research, policy, and social media. By aligning research agendas with local public concerns and leveraging both traditional media and social media platforms to communicate key findings, the scientific community can help bridge the gap between academic research and public awareness. Such an approach would not only enhance the effectiveness of climate change adaptation strategies but also foster a more informed and engaged public capable of responding to climate risks more effectively (Hügel & Davies, 2020; Segerberg, 2017). In particular, the alignment observed in discussions around heatwaves may serve as a useful model for other climate-related hazards. The strong spatial congruence and shared focus between scientific research and public discourse suggest that immediate and visible impacts can act as focal points for synchronized climate communication and action (Chang et al., 2022). Expanding this alignment to other climate-related phenomena can foster more coherent regional climate governance (Attanasio, 2018).

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