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The analyses, opinions and findings of this paper represent the views of the authors, and not necessarily those of the Banco de Portugal or the Eurosystem.

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Socio-economic sensitivity to weather extremes: A scoping review of European research*

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Abstract

While a growing body of research has examined the economic and social consequences of extreme weather, few attempts have been made to collate this evidence into a coherent map. This scoping review addresses this gap by providing the first systematic mapping of research on the socio-economic sensitivity of European regions to short-run weather shocks. Following a PRISMA-ScR protocol, we search Scopus and Web of Science, identifying 77 eligible articles published between 2000 and 2025. We analyse how studies define and measure weather shocks and socio-economic outcomes, the data and methods they employ, the sectors and regions they cover, as well as the associated impacts across sectors and the channels they operate through. Our review finds that weather shocks are consistently associated with reduced output growth, increased heat-related mortality, rising inflationary pressures, and greater inequality, with effects varying by region, sector, and income level. However, we also identify significant gaps in spatial resolution, sectoral coverage, and methodological diversity. By mapping the existing evidence and its limitations, this review provides a structured foundation for future research on weather-related socio-economic risk in Europe.

JEL classification: Q54, Q50
Keywords: Weather shocks, Socio-economic impacts, Climate change, Europe, Scoping review

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1 Introduction

Anthropogenic greenhouse gas emissions have driven a near-linear increase in global mean surface temperature of roughly 0.2°C per decade since 1980 (Pörtner et al., 2022). Global temperature had risen to around 1.5°C above the 1850-1900 average in 2024, making it the warmest year in the instrumental record and placing global warming in the vicinity of the 1.5°C threshold commonly used in international climate policy (Sandford et al., 2025; World Meteorological Organization (WMO), 2025). A sequence of unprecedented monthly anomalies from mid-2023 through 2024, together with persistently elevated sea-surface temperatures, shows that exceptional heat is now emerging from a background climate that is itself rapidly shifting rather than from a fixed baseline (Cattiaux, Ribes, and Cariou, 2024; Sandford et al., 2025). In this global context, Europe has become one of the most rapidly warming regions, as 2024 was the hottest year on record for the continent, with seasonal anomalies above 1°C across almost all mainland areas and reaching 2-5°C in large parts of central and eastern Europe, following a succession of exceptionally warm summers since 2018 (European Environment Agency, 2024; Rantanen et al., 2025; Sandford et al., 2025). Observational and attribution studies document marked increases in the frequency and intensity of hot extremes, multi-day heatwaves, and warm nights, alongside a decline in cold spells, and model projections indicate further amplification of heat stress, especially in southern Europe and Scandinavia (Seneviratne et al., 2021). At the same time, intense rainfall and near-stationary convective systems in 2024 caused catastrophic flash floods in several European regions, consistent with long-term evidence that heavy precipitation events have strengthened across much of the continent even where mean rainfall trends remain heterogeneous (Sandford et al., 2025; Seneviratne et al., 2021). Together, these developments point to a European climate increasingly shaped by frequent, intense, and spatially compounding hot and wet extremes that interact with land use, ecosystem degradation, and social vulnerability to generate complex, cascading risks for households, firms, and public institutions.

Within the Intergovernmental Panel on Climate Change's (IPCC) vulnerability framework, sensitivity refers to "the degree to which a system or species is affected, either adversely or beneficially, by climate variability or change", with effects that may be direct or indirect (Pörtner et al., 2022). Recent assessments underscore that European socio-economic systems are already highly sensitive to weather shocks, spanning public health, labour markets, public finances, infrastructure, and financial systems (European Environment Agency, 2024). For instance, the record-hot summer of 2022 has been linked to an estimated 60,000 to 70,000 premature deaths (Ballester et al., 2023), while the droughts of 2022 and 2023 led to significant spikes in olive oil prices due to reduced harvests in key producing countries such as Spain and Italy (Kotz, Donat, et al., 2025). Recurrent droughts and floods have impaired agricultural output, disrupted energy supply and transport networks, and triggered cascading failures in essential services. At the macroeconomic level, climate extremes erode fiscal capacity through reduced tax revenue and increased expenditure, and can strain sovereign credit ratings, with recent floods in Germany (2021), Slovenia (2023), and Spain (2024) illustrating these dynamics (European Environment Agency, 2024). In this context, examining Europe's socio-economic sensitivity to weather shocks is not only essential for understanding the scale and nature of emerging risks but also for clarifying the mechanisms through which these shocks transmit across systems as this can help design effective adaptation policies under a rapidly warming climate.

To date, this sensitivity has not yet been systematically examined. There is a notable paucity of studies that seek to synthesise literature across multiple sectors, outcome domains, and climatic drivers, particularly within the European context. Tol (2024) presents the field's first attempt to map damages from weather shocks, providing a meta-analysis focused exclusively on the economic impacts of temperature fluctuations on growth. Earlier surveys adopt similarly restrictive lenses. For instance, Kousky (2014), and Botzen, Deschenes, and Sanders (2019) review the consequences of natural disasters but focus almost exclusively on direct and indirect economic losses, explicitly excluding public-health, social, and political dimensions. Sector-specific assessments exhibit the same pattern of selectivity; Allaire (2018) examines the socio-economic costs of floods and other hydro-meteorological disasters, while Venegas, Lara Schwarz, and Sabarwal (2024) assess the effects of weather extremes on education. Thus, the limited reviews that do engage with weather shocks are predominantly centred on extreme events, and are primarily concerned with aggregate economic indicators. To our knowledge, no existing synthesis brings together the diverse strands of empirical research on how weather variability and extremes affect the broader socio-economy across sectors.

The objective of this scoping review is to identify peer-reviewed studies that quantify the socio-economic effects of short-run weather shocks across Europe. We summarise the empirical literature that has examined associations between realised weather variability and key socio-economic outcomes, such as output, employment, prices, and mortality. Particular attention is given to how weather shocks are defined and measured, the outcome domains and sectors studied, and the methods used to estimate impacts. We also assess the strengths and limitations of the approaches employed, and the extent to which they capture persistence, spatial spillovers, and cross-sectoral linkages. Where reported, we extract indicative magnitudes and directions of effects to support a comparative understanding of sensitivity across European regions.

The specific research questions that guide this review are:

1. What is the distribution of the literature across disciplines, regions, and outcome domains? (*RQ1*)

2. How are weather shocks and socio-economic impacts operationalised, measured, and estimated? (*RQ2*)

3. What are the key findings regarding the magnitude, heterogeneity, and transmission of impacts? (*RQ3*)

4. What conceptual and methodological gaps remain in the evidence base? (*RQ4*)

The remainder of the paper is organised as follows. Section 2 details the review protocol, including the search strategy, eligibility criteria, and data-charting framework. Section 3 presents a descriptive overview of the mapped evidence base, directly addressing the distributional and methodological questions (*RQ1* and *RQ2*). Section 4 synthesises findings thematically across sectors and outcomes and highlights emerging gaps and priorities, answering the questions on impact magnitudes and future research directions (*RQ3* and *RQ4*). Section 5 concludes by addressing the limitations of this study and outlining directions for future research within this domain.

2 Methodology

We conduct a scoping review as the evidence on realised weather shocks and socio-economic outcomes in Europe is heterogeneous in concepts, designs, and measures, which limits the value of a narrowly framed systematic review that targets critical appraisal and pooled effects (Munn et al., 2018). Therefore, a scoping methodology allows us to map the aforementioned heterogeneity across disciplines and sectors, and to summarise the estimates or effects on the sensitivity of different sectors of the socio-economy. Our methodological approach follows the subsequent refinements of the original scoping review methodology proposed by Arksey and O'Malley (2005), that is, Levac, Colquhoun, and O'Brien (2010), Peters et al. (2015), and Bouck, Straus, and Tricco (2022). We report the review in accordance with the Preferred Reporting Items for Systematic reviews and Meta-Analyses extension for Scoping Reviews (PRISMA-ScR) (Tricco et al., 2018); the checklist for reporting items is provided in Table A.1 of the Appendix. We further use the Population–Concept–Context framework to frame the review objectives and questions in a way that fits a mapping exercise rather than a single-effect question (Bouck, Straus, and Tricco, 2022).

2.1 Article Identification and Screening

The database search was conducted on 15^{th} October, 2025 using *Scopus* and *Web of Science*, which have been identified as suitable due to their disciplinary breadth and high indexing standards (Gusenbauer and Haddaway, 2020). The search period spans from 2000 to 2025, a window selected to encompass both foundational empirical contributions and more recent development. The year 2000 serves as a natural starting point following the publication of seminal works by Nordhaus (Mendelsohn, Nordhaus, and Shaw, 1994; Nordhaus, 1991; Nordhaus and Yang, 1996) which catalysed the formalisation of climate economics and provided a conceptual foundation upon which subsequent empirical research could build. This review targeted only articles, thus excluding other publication types such as editorials, books, pre-prints, and grey literature, which are less likely to be peer-reviewed and often lack rigorous methodological disclosure (Bawack et al., 2022). The search query in Figure 1 was applied to titles, abstracts, and keywords in both databases, with minor adjustments to reflect database-specific syntax requirements. Search terms were developed iteratively through discussion among reviewers, tested for retrieval and precision, and refined until the results were deemed as adequate.

(weather* OR climate* OR temperatur* OR heat* OR rain* OR precipitation OR drought* OR flood*) W/3 (shock* OR extreme* OR variab* OR anomaly OR event*) AND ("econom*" OR "socioeconom*" OR "socio-econom*" OR "sectoral impact*" OR "macroeconom*" OR "macro-econom*") AND (Europe* OR "European Union" OR Global OR Eurozone OR EEA OR Schengen OR Austria* OR Belgium* OR Bulgaria* OR Croatia* OR Cyprus* OR "Czech Republic*" OR Denmark* OR Estonia* OR Finland* OR France* OR Germany* OR Greece* OR Hungary* OR Iceland* OR Ireland* OR Italy* OR Latvia* OR Lithuania* OR Luxembourg* OR Malta* OR Netherlands* OR Norway* OR Poland* OR Portugal* OR Romania* OR Slovakia* OR Slovenia* OR Spain* OR Sweden* OR Switzerland* OR "United Kingdom*" OR England* OR Scotland* OR Wales* OR "Turkey*" OR "North Macedonia*" OR "Serbia*" OR "Montenegro*" OR "Albania*" OR "Bosnia and Herzegovina*")

Figure 1: Search query applied to Scopus and Web of Science databases.

Article identification and screening followed the sequence in Figure 2 (PRISMA-ScR), in three phases outlined in Table 1. The database search returned 19,105 records in total, 10,948 from Scopus and 8,157 from Web of Science. An automated filtering stage removed 17,018 documents based on pre-specified eligibility parameters. To keep the corpus feasible while retaining relevance and influence, we restricted the inclusion of studies to high-impact journals within the fields of economics and environmental science, similar to prior mapping work that delimits reviews to established and influential outlets (Bawack et al., 2022). After removing 803 duplicates, 2,087 records proceeded to the title–abstract screening phase.

Table 1: Inclusion and exclusion criteria by screening phase

Phase	Inclusion criteria	Exclusion criteria
Phase 1: Database and filter stage	English language; indexed in Scopus or Web of Science; publication years 2000–2025; document type limited to journal articles; subject categories restricted to Environmental Sciences or Economics; journals classified as high-impact or influential.	Non-English publications; not indexed in Scopus or Web of Science; published outside 2000–2025; non-article document types (e.g. books, editorials, preprints, grey literature); subject categories outside Environmental Sciences or Economics; journals classified as low-impact or non-influential.
Phase 2: Title and abstract screening	Studies analysing the sensitivity of socio-economic systems to realised weather shocks or short-run weather variability; clearly defined socio-economic outcomes (e.g. prices, employment, production, sectoral activity, health service use, crime, financial market responses); weather or short-run climate variation treated as an explanatory factor; empirical analysis using European cases or an identifiable European subsample; records ambiguous on these criteria advanced to full-text screening.	Studies focused exclusively on long-run climate trends without discrete shocks; non-weather hazards (e.g. earthquakes, volcanic eruptions); greenhouse gas emissions or air pollution without an explicit weather-shock link; adaptation or policy design without realised impacts; purely theoretical or methodological contributions without empirical application; climate policy uncertainty studies; studies without a European case or subsample.
Phase 3: Full-text screening	Analysis of short-run or acute weather events (e.g. heatwaves, cold spells, storms, droughts, floods, extreme precipitation or temperature anomalies); realised socio-economic outcomes for Europe or a European subsample; weather or short-run climate variation used as an explanatory factor; sufficient methodological transparency to identify data sources and identification strategy.	No analysis of weather or climate shocks; no identifiable socio-economic outcome; geographic scope excluding Europe; exposure described without analysing differential sensitivity or impacts; adaptation or forward-looking policy focus without realised impacts; methods or frameworks proposed without empirical application; trend-based analyses without discrete shocks.

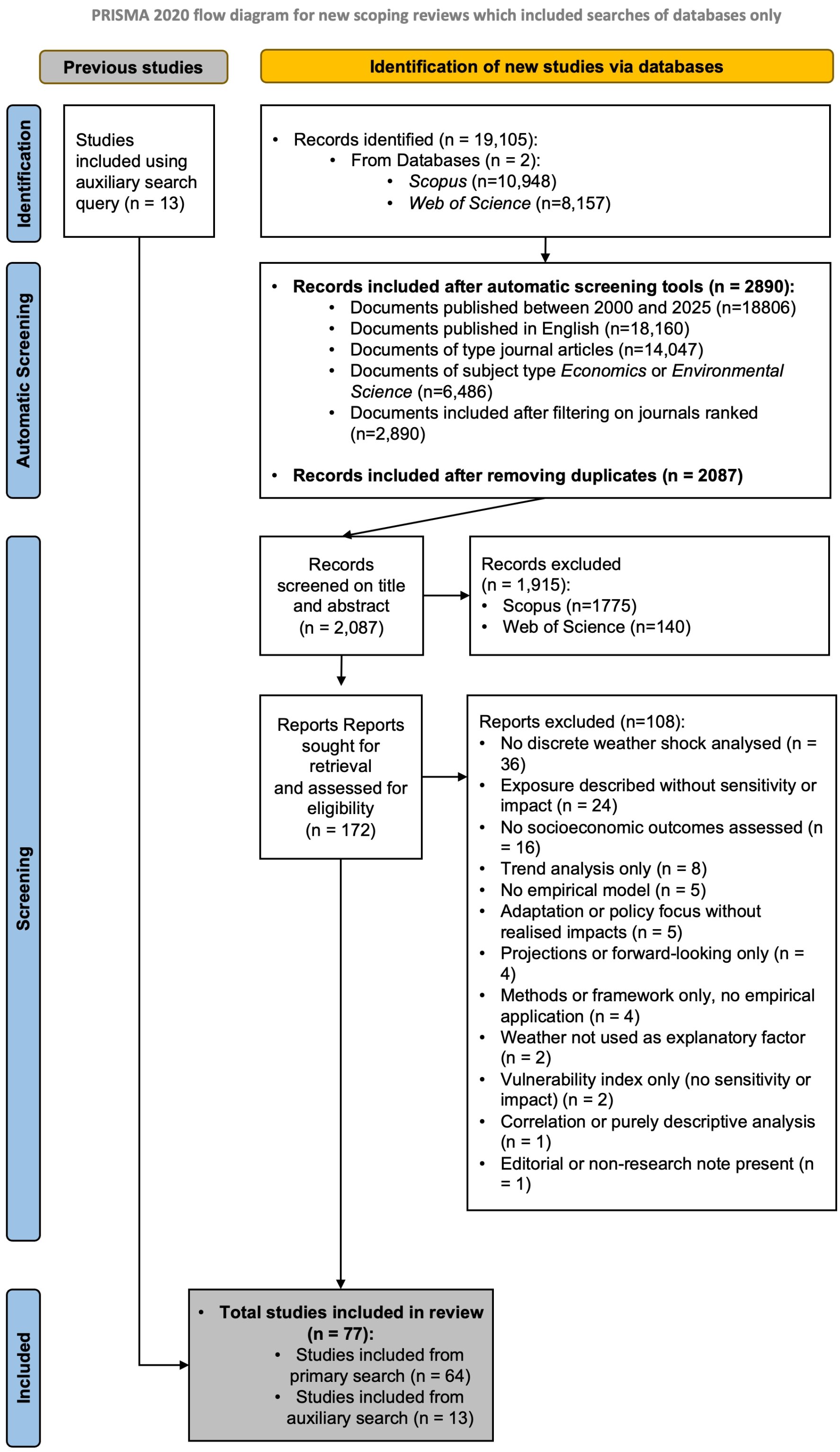

Figure 2: PRISMA-ScR flow diagram illustrating the identification, screening, eligibility assessment, and inclusion process leading to the final sample of 77 studies.

Title and abstract screening in the subsequent phase was conducted against the Population–Concept–Context criteria, with the definition of key terminologies both provided in the Appendix (Tables C.1 and C.2). Records that were unclear on scope or methods were retained for full-text screening. A total of 1,915 records were excluded at this stage, comprising 1,775 from Scopus and 140 from Web of Science. This left 172 studies for retrieval, all of which were successfully obtained.

The screening process was executed in two sequential phases following the definition of the eligibility criteria. First, all authors jointly developed and refined the inclusion and exclusion rules presented in Table 1. Using these agreed criteria, the first author screened the titles and abstracts of all retrieved records. Any uncertainties regarding eligibility were resolved through discussion with the co-authors until consensus was reached. In the second phase, the full texts of all potentially eligible studies were retrieved and screened by the same author against the refined criteria. For each excluded article, we recorded a single primary reason for exclusion; where multiple reasons applied, we selected the most immediate reason to preserve consistency in coding. Overall, 108 articles were excluded at the full-text stage, and 64 studies were retained for inclusion. The most frequent reasons for exclusion were the absence of weather or climate shocks ($n = 36$), exposure assessed without investigating sensitivity ($n = 24$), a lack of socio-economic outcomes ($n = 16$), only a trend analysis being performed ($n = 8$), and no empirical model being employed to quantify the sensitivity of a particular outcome ($n = 5$). To complement this primary identification phase, we conducted a strategic second search with minor query adjustments designed to cast a wider net. This supplementary process yielded 13 additional studies that met the eligibility criteria; details of this complementary search are provided in B.

2.2 Data charting and thematic analysis

Based on the methodology for scoping reviews, we developed a structured extraction form to chart the key characteristics of each included study in a consistent manner across heterogeneous designs (Bouck, Straus, and Tricco, 2022; Levac, Colquhoun, and O'Brien, 2010; Peters et al., 2015; Tricco et al., 2018). For every article retained after full-text screening, we recorded bibliographic information, geographical scope, the type and measurement of the weather shock, the primary socio-economic outcome, the affected sector, the spatial and temporal resolution, the source of weather data, the empirical identification strategy, and any reported direction, magnitude, or persistence of impacts. Alongside this structured charting, we wrote brief analytic notes summarising each study's aim, population, and main findings.

Thematic analysis proceeded through a hybrid inductive–deductive (*abductive*) coding process, following the approach of Fereday and Muir-Cochrane (2006). Before coding, we compiled an initial codebook that specified a priori categories for socio-economic sectors (for example, economic activity, prices and inflation, public welfare, etc.), key outcome types, and methodological features, informed by our conceptual framework and prior climate–economy literature. Each full text was then read in detail and tagged with one or more of these codes, capturing the primary outcome domain, the nature of the weather shock, and relevant design features. As coding progressed, we generated a study-by-code matrix that tabulated the tags assigned to each article. We reviewed this matrix iteratively, comparing patterns across studies and revisiting the underlying texts; where groups of papers consistently clustered together or appeared misclassified, we refined code definitions, collapsed or split sectors, and reassigned studies as needed. The final set of themes corresponds to broad socio-economic domains within which weather shocks have been analysed and provides the organising structure for the narrative synthesis in section 4.

The `bibliometrix` R package was used to summarise publication trends and to compute descriptive bibliometric indicators for the corpus (Aria and Cuccurullo, 2017). As is common in scoping reviews, a formal risk-of-bias appraisal was not undertaken, since the objective is to chart the field in a heterogeneous literature rather than to synthesise effect sizes (Bouck, Straus, and Tricco, 2022; Levac, Colquhoun, and O'Brien, 2010; Peters et al., 2015). The resulting synthesis is presented in two parts; a descriptive overview of the evidence base in section 3, followed by a thematic interpretation in section 4, where we integrate findings across sectors and outcomes to identify conceptual and empirical gaps.

3 Results

In this section, we report the descriptive characteristics of the included studies to answer the first two research questions. We first map the distribution of the literature across disciplines, regions, and outcomes (*RQ1*), and then examine how weather shocks and socio-economic impacts have been operationalised and estimated (*RQ2*).

The final dataset covers the period 2010 - 2025 and comprises 77 documents retrieved from 47 distinct sources. The average document age is just over 4 years, signalling a field that is both recent and expanding. Citations accrue quickly, as the mean of 44 citations per document is sustained by 4,491 referenced works. Authorship is markedly collaborative: only 11 papers are single-authored, the average team size is 4, and ≈ 54% of the items involve at least 2 countries.

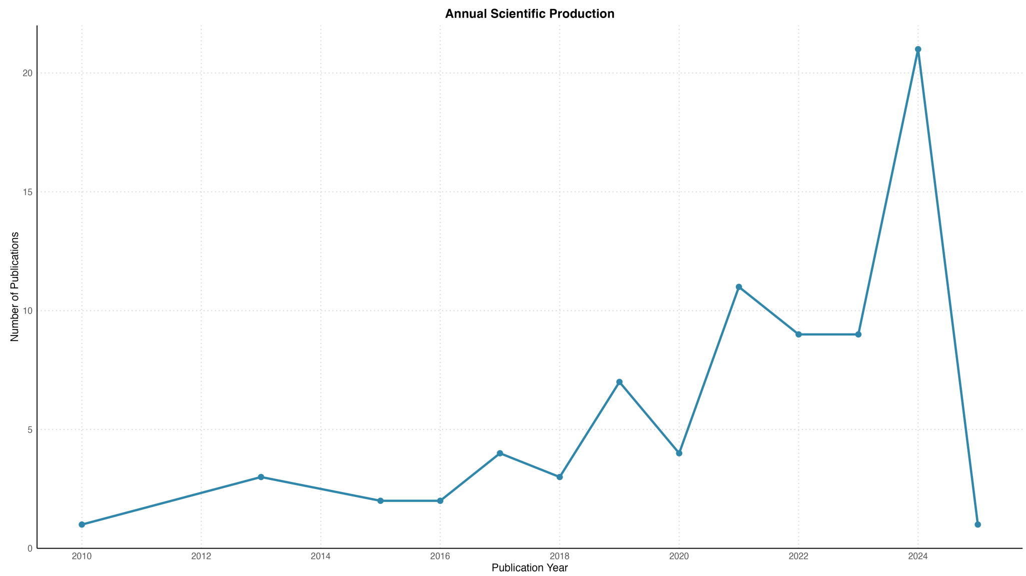

Figure 3: Annual scientific production

Figure 3 presents the annual publication trajectory of the corpus. It shows that research activity begins in 2010 and remains modest throughout the following decade. A pronounced inflection occurs in 2021 with the number of publications increasing to 11 articles. The period from 2021 to 2025 represents the field's most active phase, accounting for two-thirds of all included studies. Output peaks at 21 articles in 2024, followed by a decline in 2025 that likely reflects publication delays rather than an actual contraction in research activity.

Table 2: Thematic classification of reviewed studies by socio-economic outcome domain

Outcome studied	Publication	NP
Health	Achebak et al. (2024), Bigler and Janzen (2024), J. Chen et al. (2023), Díaz et al. (2015), Drescher and Janzen (2025), Ellena et al. (2022), Huang and Hong (2024), Karlsson and Ziebarth (2018), J. A. López-Bueno, Díaz, and Linares (2019), J. A. López-Bueno, Linares, et al. (2020), José Antonio López-Bueno et al. (2021), J. A. López-Bueno, Díaz, Sánchez-Guevara, et al. (2020), J. A. López-Bueno, Navas-Martín, et al. (2022), Marinaccio et al. (2019), Martínez-Solanas and Basagaña (2019), Otrachshenko, Popova, and Solomin (2017), Rubio-Cabañez (2024), Saucy et al. (2021), Vielma et al. (2024)	19
Economy	Blumenthal and Nyberg (2019), Boccard (2018), Donadelli, Grüning, et al. (2021), Felbermayr et al. (2022), Gupta et al. (2023), Kahn et al. (2021), Khan, Morzuch, and Brown (2017), Kotz, Wenz, et al. (2021), Kotz, Kuik, et al. (2024), Linsenmeier (2023), Mumtaz and Theophilopoulou (2024), Otrachshenko and Popova (2022), Quante et al. (2024), Russ (2020), Schleypen et al. (2022), Verschuur, Koks, and Hall (2023), Wasko, Sharma, and Pui (2021)	17
Macroeconomic outcomes	Beirne et al. (2024), Berg, Curtis, and Mark (2024), Cashin, Mohaddes, and Raissi (2017), Cevik and Gwon (2024), Ciccarelli, Kuik, and Martínez Hernández (2024), Donadelli, Jüppner, and Vergalli (2022), Letta and Tol (2019), Lis and Nickel (2010), Lucidi, Pisa, and Tancioni (2024), Middelanis et al. (2023), Miller et al. (2021), Mukherjee and Ouattara (2021)	12
Agriculture	Bastos, Straume, and Urrego (2013), Schmitt et al. (2022), Ubilava (2017), Ubilava and Abdolrahimi (2019), Zou et al. (2024)	5
Energy	Bigerna (2018), X. Chen, Fu, and Chang (2021), Colelli, Wing, and De Cian (2023), Mosquera-López, Uribe, and Joaqui-Barandica (2024), Pablo-Romero, Pozo-Barajas, and Sánchez-Rivas (2019)	5
Crime and conflict	Chambru (2020), Mannell et al. (2024), Otrachshenko, Popova, and Tavares (2021), Waldinger (2024)	4
Review	Black et al. (2013), Gössling et al. (2023), Semenova (2024), Tol (2024)	4
Financial markets	Ahmed et al. (2024), Chabot and Bertrand (2023), Peillex et al. (2021)	3
Inequality	Paglialunga, Coveri, and Zanfei (2022), Sheng et al. (2023)	2
Migration	Cai et al. (2016), Jennings and Gray (2015)	2
Politics	Crispino and Loberto (2024), Hoffmann et al. (2022)	2
Supply chains	Verschuur, Koks, and Hall (2023)	1
Tourism	Falk (2013)	1
Well-being	Möllendorff and Hirschfeld (2016)	1

Note: NP denotes the number of publications assigned to each outcome domain.

The distribution of studies by outcome domain reflects a concentration of empirical attention on economic performance and public health, while areas related to inequality, mobility, and social stability remain comparatively under-explored (see Table 2). Health emerges as the most frequently analysed theme ($n = 19$), followed closely by economic activity ($n = 17$) and broader macroeconomic outcomes ($n = 12$). Fewer studies examine sectoral or social dimensions, including agriculture ($n = 5$), energy ($n = 5$), and crime and conflict ($n = 4$). A smaller number of papers investigate themes such as financial markets, inequality, migration, politics, supply chains, tourism, and well-being, each represented by one or two studies.

3.1 Geographical origin and focus of the reviewed studies

Table 3 reports the geographical distribution of research production, based on author affiliations. As this measure counts all author appearances by country, articles co-authored across institutions are attributed to each contributing country, so the total number of appearances exceeds the number of unique papers. Germany ranks as the most productive country ($n = 48$), followed by Spain and the United States ($n = 30$ each), the United Kingdom ($n = 29$), and Italy ($n = 22$). China, France, the Netherlands, Switzerland, and Austria complete the top ten. Citation performance does not mirror publication volume, as the United Kingdom achieves the highest average citations per article ($n = 95.67$), followed by Austria ($n = 111.00$) and the Netherlands ($n = 48.00$), each surpassing larger contributors such as Germany and the United States. This suggests that influence is distributed across a mix of large and smaller author bases rather than being determined solely by output.

Table 3: Number of publications by country of affiliation (top 10)

Country	NP	TC	AAC
Germany	48	275	34.38
Spain	30	317	28.82
USA	30	382	47.75
UK	29	861	95.67
Italy	22	171	34.20
China	16	35	8.80
France	8	48	16.00
Netherlands	8	48	48.00
Switzerland	8	78	39.00
Austria	5	222	111.00

Note: NP denotes the number of publications; TC denotes total citations; AAC denotes average article citations.

Turning from the location of researchers to the location of evidence, Table 4 summarises the geographical coverage of the reviewed studies. Most papers adopt a global or multi-country design, with thirty-one studies analysing cross-national panels that include European economies within wider international samples. Among single-country investigations, Spain is the most frequently studied ($n = 10$), followed by Germany ($n = 8$), Italy ($n = 7$), and France ($n = 7$). The United Kingdom ($n = 4$) and a small number of other European countries such as Switzerland, the Netherlands, and Austria are examined less often. A few studies analyse regional aggregates such as the Eurozone or OECD, while subnational and city-level analyses remain limited. Furthermore, a handful of papers explore urban impacts, including Madrid ($n = 5$), London ($n = 1$), Turin ($n = 1$), and Zurich ($n = 1$), suggesting a growing but still nascent effort to investigate weather–economy relationships below the national scale.

Table 4: Geographical coverage of reviewed studies by region and corresponding publications (top 10)

Region studied	Publications	NP
Global	Bastos, Straume, and Urrego (2013), Berg, Curtis, and Mark (2024), Cashin, Mohaddes, and Raissi (2017), J. Chen et al. (2023), X. Chen, Fu, and Chang (2021), Donadelli, Jüppner, and Vergalli (2022), Felbermayr et al. (2022), Gössling et al. (2023), Huang and Hong (2024), Kahn et al. (2021), Khan, Morzuch, and Brown (2017), Kotz, Wenz, et al. (2021), Kotz, Kuik, et al. (2024), Letta and Tol (2019), Linsenmeier (2023), Lis and Nickel (2010), Mannell et al. (2024), Middelanis et al. (2023), Miller et al. (2021), Mukherjee and Ouattara (2021), Mumtaz and Theophilopoulou (2024), Paglialunga, Coveri, and Zanfei (2022), Quante et al. (2024), Russ (2020), Semenova (2024), Tol (2024), Ubilava (2017), Ubilava and Abdolrahimi (2019), Verschuur, Koks, and Hall (2023), Wasko, Sharma, and Pui (2021), Zou et al. (2024), Black et al. (2013)	32
Spain	Achebak et al. (2024), Ciccarelli, Kuik, and Martínez Hernández (2024), Díaz et al. (2015), Gupta et al. (2023), J. A. López-Bueno, Díaz, and Linares (2019), J. A. López-Bueno, Linares, et al. (2020), José Antonio López-Bueno et al. (2021), J. A. López-Bueno, Díaz, Sánchez-Guevara, et al. (2020), J. A. López-Bueno, Navas-Martín, et al. (2022), Lucidi, Pisa, and Tancioni (2024), Martínez-Solanas and Basagaña (2019), Mosquera-López, Uribe, and Joaqui-Barandica (2024), Pablo-Romero, Pozo-Barajas, and Sánchez-Rivas (2019), Rubio-Cabañez (2024), Vielma et al. (2024)	15
Italy	Bigerna (2018), Ciccarelli, Kuik, and Martínez Hernández (2024), Crispino and Loberto (2024), Ellena et al. (2022), Gupta et al. (2023), Lucidi, Pisa, and Tancioni (2024), Marinaccio et al. (2019), Mosquera-López, Uribe, and Joaqui-Barandica (2024)	8
Germany	Bigler and Janzen (2024), Ciccarelli, Kuik, and Martínez Hernández (2024), Gupta et al. (2023), Karlsson and Ziebarth (2018), Lucidi, Pisa, and Tancioni (2024), Mosquera-López, Uribe, and Joaqui-Barandica (2024), Schmitt et al. (2022), Möllendorff and Hirschfeld (2016)	8
France	Boccard (2018), Ciccarelli, Kuik, and Martínez Hernández (2024), Gupta et al. (2023), Lucidi, Pisa, and Tancioni (2024), Mosquera-López, Uribe, and Joaqui-Barandica (2024), Peillex et al. (2021), Waldinger (2024)	7
United Kingdom	Ahmed et al. (2024), Gupta et al. (2023), Schleypen et al. (2022), Sheng et al. (2023)	4
Europe	Chabot and Bertrand (2023), Colelli, Wing, and De Cian (2023), Hoffmann et al. (2022)	3
Russia	Otrachshenko and Popova (2022), Otrachshenko, Popova, and Tavares (2021), Otrachshenko, Popova, and Solomin (2017)	3
Switzerland	Chambru (2020), Drescher and Janzen (2025), Saucy et al. (2021)	3
Eurozone	Beirne et al. (2024), Cevik and Gwon (2024)	2

Note: NP denotes the number of publications. The complete list of regions is reported in the Appendix, Table D.1.

3.2 Data resolution and sources

3.2.1 Temporal and spatial resolution of data used

Authors most often use annual data ($n = 38$), with a substantial share using daily data ($n = 21$); monthly data is less common ($n = 11$) , and hourly, quarterly, and weekly data each appear only once. This pattern suggests a split between macro-panel studies that track slow-moving aggregates and high-frequency analyses typical of health, energy, or financial outcomes. Spatially, national units dominate the literature ($n = 36$), followed by country-specific sub-national units such as provinces, counties, districts, or cantons ($n = 13$), then municipalities ($n = 7$), NUTS 3 regions ($n = 5$), cities ($n = 2$), grids ($n = 2$), and NUTS 2 regions($n = 2$), with one study using a country–basin unit ($n = 1$). Taken together, these choices indicate that impact estimation is still anchored at national and broad subnational scales, largely reflecting the availability and consistency of socio-economic indicators rather than the finer resolution at which meteorological data are often observed.

3.2.2 Weather variables and construction

Studies most often examine the impacts of temperature and precipitation. Measures of temperature appears in nearly all papers ($n = 61$), with precipitation a clear second ($n = 32$). Event-style indicators are less common, such as extreme weather events ($n = 7$), wind speed and humidity (each $n = 4$), and clouds, droughts, sea surface temperature, runoff, and floods (each $n = 2$). This distribution points to a strong emphasis on thermal and hydro-meteorological variables, while multi-hazard constructs and ancillary atmospheric conditions remain weakly explored (see Table 5).

Weather data come from a mix of national networks and global reanalyses. National meteorological agencies are the most frequent source ($n = 19$), reflecting the prevalence of single-country designs that draw on dense station networks. Among global products, the ERA5 reanalysis dataset is widely used ($n = 7$); provided by the European Centre for Medium-Range Weather Forecasts (ECMWF), it synthesises model outputs with global observational data to generate a physically consistent, high-resolution global climate record from 1940 onwards (Hersbach, Bell, Berrisford, Biavati, et al., 2018; Hersbach, Bell, Berrisford, Hirahara, et al., 2020). Studies also draw on the Climatic Research Unit (CRU) datasets provided by the University of East Anglia ($n = 5$) (I. Harris et al., 2014; Ian Harris et al., 2020), and the Terrestrial Air Temperature and Precipitation products ($n = 5$) (Matsuura and C. Willmott, 2007; Matsuura and C. J. Willmott, 2009, 2018; C. J. Willmott, 2000). National Oceanic and Atmospheric Administration products and the World Bank Climate Change Knowledge Portal each appear in four studies, where the latter compiles ERA5 and CMIP6 outputs into nationally and, in some cases, sub-nationally aggregated formats for policy use. Where event catalogues or scenarios are needed, EM-DAT and CMIP6 (Eyring et al., 2016) are used ($n = 3$ each). E-OBS and NASA products appear less often ($n = 2$ each). Detailed source counts are provided in the Appendix in Table D.2

Table 5: Weather phenomena examined across the reviewed literature (top 10)

Weather phenomenon	Publications	NP
Temperature	Achebak et al. (2024), Ahmed et al. (2024), Berg, Curtis, and Mark (2024), Bigerna (2018), Bigler and Janzen (2024), Cai et al. (2016), Cevik and Gwon (2024), Chabot and Bertrand (2023), Chambru (2020), J. Chen et al. (2023), X. Chen, Fu, and Chang (2021), Ciccarelli, Kuik, and Martínez Hernández (2024), Colelli, Wing, and De Cian (2023), Crispino and Loberto (2024), Díaz et al. (2015), Donadelli, Grüning, et al. (2021), Donadelli, Jüppner, and Vergalli (2022), Drescher and Janzen (2025), Ellena et al. (2022), Falk (2013), Felbermayr et al. (2022), Gupta et al. (2023), Hoffmann et al. (2022), Huang and Hong (2024), Jennings and Gray (2015), Kahn et al. (2021), Karlsson and Ziebarth (2018), Khan, Morzuch, and Brown (2017), Kotz, Wenz, et al. (2021), Kotz, Kuik, et al. (2024), Letta and Tol (2019), Linsenmeier (2023), J. A. López-Bueno, Díaz, and Linares (2019), J. A. López-Bueno, Linares, et al. (2020), José Antonio López-Bueno et al. (2021), J. A. López-Bueno, Díaz, Sánchez-Guevara, et al. (2020), J. A. López-Bueno, Navas-Martín, et al. (2022), Lucidi, Pisa, and Tancioni (2024), Marinaccio et al. (2019), Martínez-Solanas and Basagaña (2019), Miller et al. (2021), Mosquera-López, Uribe, and Joaqui-Barandica (2024), Mukherjee and Ouattara (2021), Mumtaz and Theophilopoulou (2024), Otrachshenko and Popova (2022), Otrachshenko, Popova, and Tavares (2021), Otrachshenko, Popova, and Solomin (2017), Pablo-Romero, Pozo-Barajas, and Sánchez-Rivas (2019), Paglialunga, Coveri, and Zanfei (2022), Peillex et al. (2021), Quante et al. (2024), Rubio-Cabañez (2024), Russ (2020), Saucy et al. (2021), Schleypen et al. (2022), Sheng et al. (2023), Verschuur, Koks, and Hall (2023), Vielma et al. (2024), Waldinger (2024), Wasko, Sharma, and Pui (2021), Zou et al. (2024)	61
Precipitation	Bastos, Straume, and Urrego (2013), Bigler and Janzen (2024), Blumenthal and Nyberg (2019), Cai et al. (2016), Chabot and Bertrand (2023), J. Chen et al. (2023), X. Chen, Fu, and Chang (2021), Drescher and Janzen (2025), Felbermayr et al. (2022), Hoffmann et al. (2022), Jennings and Gray (2015), Kahn et al. (2021), Karlsson and Ziebarth (2018), Khan, Morzuch, and Brown (2017), Kotz, Wenz, et al. (2021), Kotz, Kuik, et al. (2024), Letta and Tol (2019), Linsenmeier (2023), Miller et al. (2021), Mosquera-López, Uribe, and Joaqui-Barandica (2024), Mumtaz and Theophilopoulou (2024), Otrachshenko and Popova (2022), Otrachshenko, Popova, and Tavares (2021), Otrachshenko, Popova, and Solomin (2017), Paglialunga, Coveri, and Zanfei (2022), Quante et al. (2024), Russ (2020), Saucy et al. (2021), Schleypen et al. (2022), Waldinger (2024), Wasko, Sharma, and Pui (2021), Zou et al. (2024)	32
Extreme weather events	Beirne et al. (2024), Boccard (2018), Chabot and Bertrand (2023), Lis and Nickel (2010), Schmitt et al. (2022), Verschuur, Koks, and Hall (2023), Möllendorff and Hirschfeld (2016)	7
Wind speed	J. Chen et al. (2023), Drescher and Janzen (2025), Felbermayr et al. (2022), Mosquera-López, Uribe, and Joaqui-Barandica (2024)	4
Humidity	Achebak et al. (2024), Ahmed et al. (2024), Díaz et al. (2015), Linsenmeier (2023)	4
Clouds	Ahmed et al. (2024), Falk (2013)	2
Droughts	Mannell et al. (2024), Waldinger (2024)	2
Sea surface temperature	Ubilava (2017), Ubilava and Abdolrahimi (2019)	2
Runoff	Khan, Morzuch, and Brown (2017), Russ (2020)	2
Floods	Mannell et al. (2024), Middelanis et al. (2023)	2

Note: NP denotes the number of publications.

Additionally, given that numerous publications aggregate weather data to match economic units, we investigate the use of population weights for weather data. Generally, weather data can either be aggregated spatially, utilising administrative boundaries overlaid on gridded weather data– that is summed using the area-weighted average–or by using a set of population weights (Dell, Jones, and Olken, 2014). We find that aggregation choices vary with the target socio-economic unit. Most studies aggregate weather without population weights ($n = 51$), typically by overlaying administrative boundaries on gridded fields, while a substantial minority employ population-weighted aggregation ($n = 22$) to better reflect human exposure. The distribution of aggregation strategies is reported in Appendix Table D.3.

3.3 Identification and econometric approaches

3.3.1 Econometric approaches commonly used

Extant research widely employs a fixed effects panel regression framework to model the effects of weather shocks ($n = 27$), that absorbs unobserved heterogeneity across countries, regions, firms, or households (see Table D.2). This is followed by varying extensions and generalizations of vector autoregressive (VAR) models (Sims, 1980) ($n = 10$). Generalised linear regression models are also frequently employed ($n = 9$), alongside distributed lag non-linear models ($n = 7$) (Gasparrini, 2014) and local projections proposed by Jordá (2005) ($n = 5$). A smaller set relies on simple OLS or linear models ($n = 3$ and $n = 2$), spatial Durbin specifications to account for cross-sectional dependence ($n = 2$), and multivariate meta-regression for evidence synthesis ($n = 2$).

To control for confounding factors and isolate the effects of weather shocks, most studies implement a standard two-way fixed-effects structure that absorbs time-invariant heterogeneity with unit effects and common shocks with time effects (see Table D.2). Labels vary across papers, but the design is the same. Many specifications add unit-specific time trends, such as linear or quadratic, to flexibly capture differential growth paths, and some use higher-granularity interactions such as region–year, state–year–month, or zip-code–week effects to tighten identification to very local comparisons. Seasonality and calendar structure are typically addressed with month or week dummies, day-of-week indicators, holiday controls (such as Easter and Christmas), or smooth functions and splines of time. Trade and migration designs sometimes use country–pair and border fixed effects, with country–month or country–year interactions to handle time-varying bilateral shocks. Collectively, these controls ensure that coefficients are identified from within-unit deviations in weather, relative to units' own histories and conditional on seasonal and temporal structure.

3.3.2 Exogeneity of weather variables

An important methodological distinction across the reviewed studies concerns whether weather variables are treated as exogenous or endogenous in their econometric frameworks, when considering vector autoregression. Several studies explicitly assume the exogeneity of temperature shocks on the grounds that anthropogenic climate change operates over a much longer horizon than the macroeconomic fluctuations under investigation (Cevik and Gwon, 2024; Ciccarelli, Kuik, and Martínez Hernández, 2024; Ciccarelli and Marotta, 2024; Kim, Matthes, and Phan, 2025). In this framing, weather anomalies, such as El Niño events or short-term deviations from historical norms, are treated as external to the economic system, incapable of being influenced contemporaneously by macroeconomic variables (Cashin, Mohaddes, and Raissi, 2017). The justification rests on both theoretical and empirical grounds. Given the lagged and cumulative nature of emissions-related impacts on climate, it is deemed reasonable to model weather conditions as weakly exogenous in short-run analyses of inflation, supply chains, or consumption dynamics. By contrast, a growing strand of literature challenges the strict exogeneity assumption, particularly in models with longer temporal scopes. For instance, Mukherjee and Ouattara (2021) and Beirne et al. (2024) argue that economic activity may exert feedback effects on climatic variables, especially over multi-decade horizons. In such models, temperature or disaster indicators are placed early in the Cholesky ordering but are nevertheless allowed to respond to macroeconomic shocks. This more flexible structure acknowledges the bidirectional nature of the climate-economy nexus, particularly in the context of cumulative emissions and long-run adaptation or mitigation behaviours.

4 Discussion

In this section, we move beyond description to synthesis, addressing the remaining research questions. We summarise the key findings regarding the magnitude and transmission of impacts (*RQ3*) across the identified thematic domains, and subsequently identify the conceptual and methodological gaps that persist in the literature (*RQ4*).

4.1 Extant reviews

A small set of review articles synthesises adjacent strands of the weather–economy literature. Black et al. (2013) differentiate migration, displacement, and immobility after weather-related extremes and argue that both movers and non-movers can become trapped when adaptation fails. Gössling et al. (2023) map weather–transport linkages across modes and regions and show that extremes disrupt systems and behaviour at multiple scales with implications for planning and adaptation. Semenova (2024) frame climate change as a persistent inflationary driver and question the effectiveness of conventional monetary and growth-centred policy responses. Tol (2024) update meta-evidence on total economic impacts and weather shocks, reporting central damages that are negative on average, wide uncertainty, and greater vulnerability in poorer countries.

4.2 Public health and welfare

Across Europe, temperature–mortality relationships are non-linear and heterogeneous by place, age, and socio-economic conditions. In Spain, heat-related mortality among adults aged above 45 has weakened since the late 1980s, while cold accounts for a larger share of temperature-attributable deaths (Díaz et al., 2015). Within Madrid, maximum rather than minimum temperatures more reliably indicate heat-mortality thresholds; impacts are larger for circulatory than respiratory causes, and vulnerability is higher in lower-income areas with limited access to air conditioning, independent of their age distribution (J. A. López-Bueno, Díaz, and Linares, 2019; J. A. López-Bueno, Díaz, Sánchez-Guevara, et al., 2020). Cold waves affect more districts, operate over longer lags, and are amplified by poor housing and a lack of heating; higher deprivation is associated with greater risk to mortality, whereas recent housing rehabilitation has led to lower risks (J. A. López-Bueno, Linares, et al., 2020; J. A. López-Bueno, Navas-Martín, et al., 2022; José Antonio López-Bueno et al., 2021). At the national scale, Spain's temperature–mortality curve shifted between periods, with a marked reduction in cold-attributable mortality, little change at the hottest percentiles, and higher contributions at moderate heat in some provinces (Martínez-Solanas and Basagaña, 2019). Elsewhere, hot days increase mortality by about 4–7% in Germany, while estimated cold effects diminish once models include vapour pressure, wind speed, cloud cover, and lags of extreme-temperature indicators (Karlsson and Ziebarth, 2018). Evidence from Russia shows small but pervasive increases in all-cause and cardiovascular mortality from additional very cold and very hot days, with larger relative effects among working-age adults and implied daily economic losses in the order of millions of US dollars (Otrachshenko, Popova, and Solomin, 2017). In Switzerland, cardiovascular mortality rises with heat—especially for women and people in lower socio-economic positions—and with prolonged cold waves; heat- and cold-attributable fractions are approximately 2% and 5% (Saucy et al., 2021).

Hospital admissions exhibit similar patterns. In Spain, heat increases admissions for metabolic disorders, renal and urinary conditions, sepsis, and several infections; diurnal temperature range chiefly affects respiratory and urinary diagnoses with multi-day lags, and humidity is generally not influential (Achebak et al., 2024). In Germany, admissions rise on very hot days, but effect sizes are roughly halved when contemporaneous weather controls (vapor pressure, wind speed, cloud cover) and lags are added, while admissions fall on cold days (Karlsson and Ziebarth, 2018).

Evidence on occupational injuries is consistent with a U-shaped temperature–risk profile. Switzerland reports higher accident counts on both cold days and hot days across severities and worker subgroups, with larger cold-day effects for women and older workers (Drescher and Janzen, 2025). Italy shows elevated risks under both heat and cold, with heat risks concentrated among men, younger workers, and construction, and cold risks higher among women, older workers, and cold-exposed sectors (Marinaccio et al., 2019). Using 22.3 million cases for Spain, injury risks rise at both the 1st and 99th temperature percentiles; vulnerability has declined over time for several groups, and a higher share of tertiary-educated adults is associated with lower heat-related injury risk in meta-regression (Vielma et al., 2024).

Other health outcomes broaden the picture. Tropical nights shorten sleep duration in Germany by about 12 minutes, with little evidence of adaptation or an urban–rural divide (Bigler and Janzen, 2024). Globally, temperature variability is the dominant climatic risk factor for meningitis incidence, with stronger associations in Western Europe; precipitation appears protective, and risks are higher for young children and older adults (J. Chen et al., 2023). In Spain, extreme temperatures reduce birth weight—most strongly in the third trimester—and high energy prices approximately double these losses; effects are larger for mothers with lower education and for foreign mothers early in pregnancy (Rubio-Cabañez, 2024). Extreme events further modestly reduce life satisfaction in Germany (Möllendorff and Hirschfeld, 2016). Finally, cross-country evidence links warming to higher adult obesity when the annual mean temperature is below about 27°C, with smaller or negative effects above that threshold. Proposed channels through which these impacts propogate include income, prices, and shifts in time use and physical activity (Huang and Hong, 2024).

Taken together, the literature indicates sizeable and heterogeneous public-health burdens from temperature and rainfall extremes, mediated by housing quality, energy access, socio-economic position, and sectoral exposure. These patterns suggest that adaptation benefits—via housing rehabilitation, cooling access, and targeted protection for at-risk workers and patients—are likely to be large.

4.3 Economic activity

Presently, the balance of evidence indicates that temperature variability and extremes depress growth and productivity, with effects that are distinct from mean warming. Using annual growth data, Kotz, Wenz, et al. (2021) show that greater day-to-day variability lowers regional output growth even after conditioning on annual means. Related work reports adverse responses of productivity and total factor productivity (TFP) to intra-annual volatility in Europe and a negative, inverse-U response of activity to daily temperatures above roughly $14 - -16$°C (Donadelli, Jüppner, and Vergalli, 2022; Linsenmeier, 2023). Proxies for output corroborate these patterns as night-time lights fall after cold anomalies and heavy rainfall, with measurable spatial spillovers to neighbouring cells (Felbermayr et al., 2022). Furthermore, prolonged exposure heat depresses agricultural value added and crop quantities by much more than conventional temperature-bin models imply (Miller et al., 2021). Sectoral labour productivity within the European Union (EU) exhibits concave responses to mean temperature and strong losses under extreme heat, along with sizeable interregional spillovers (Schleypen et al., 2022).

Heterogeneity by income and climate is also a persistent feature. In particular, growth and TFP penalties from hotter conditions concentrate in poorer countries, with attenuated or offset effects at higher income levels (Letta and Tol, 2019). Additionally, water related hazards act as headwinds to growth, with unusually wet or dry years associated with lower gross domestic product (GDP) growth, especially in low income settings (Khan, Morzuch, and Brown, 2017). Evidence based on water run-off and night lights reinforces this pattern since negative run-off shocks reduce local luminosity growth and weigh on agricultural productivity, with the largest effects in middle income areas (Russ, 2020). For Russia, Otrachshenko and Popova (2022) show that consecutive hot days during heat waves reduce regional GDP per capita, consistent with short run adaptation limits. By contrast, some shocks raise activity through trade and price channels, since El-Niño events have boosted real GDP growth in several advanced economies, including Europe (Cashin, Mohaddes, and Raissi, 2017). However, decompositions of temperature variation indicate that many high income countries exhibit negative growth responses to global temperature shocks, while responses to country specific shocks vary widely (Berg, Curtis, and Mark, 2024).

Several studies address persistence and macroeconomic transmission. Long run growth declines when temperatures persistently deviate from historical norms, with larger losses when warming increases climate volatility (Kahn et al., 2021). Moreover, estimates indicate that the median path of GDP per capita remains below baseline for several years after temperature shocks (Mumtaz and Theophilopoulou, 2024). In addition, higher temperatures reduce research and development (R&D) expenditure growth and patenting, with knock on effects on investment and GDP (Donadelli, Grüning, et al., 2021). Climate risk also helps predict periods of stagnation in advanced economies, with the volatility of global temperature anomalies raising the probability of slowdowns for several European countries and the United Kingdom (Gupta et al., 2023). Large scale events widen budget deficits, especially in younger democracies and in countries nearer the equator (Lis and Nickel, 2010). For France, administrative data indicate no measurable effect of individual disasters on employment or GDP, and a modest aggregate insurance burden (Boccard, 2018). Elsewhere, higher local temperature are linked to larger catastrophe losses at the extreme tail, and city level analyses show that short duration rainfall intensity explains flood related insurance damages (Blumenthal and Nyberg, 2019; Wasko, Sharma, and Pui, 2021).

Finally, losses are also shown propagate through economic networks, within and across borders. In the EU, climate–productivity shocks in one region spill over to others (Schleypen et al., 2022), and global input–output models show that consumption losses from extremes rise sharply when the economy is under stress (Middelanis et al., 2023). Weather-induced production disruptions travel along supply chains, with lower-income households facing larger consumption risks and unequal transmission across country groups (Quante et al., 2024). Maritime port downtime creates systemic cross-border vulnerabilities in trade and sectoral output (Verschuur, Koks, and Hall, 2023), while broader supply-chain pressure responds positively to temperature deviations, albeit with imprecise estimates in some samples (Cevik and Gwon, 2024). Collectively, the balance of evidence indicates nontrivial activity costs that are unevenly distributed across countries, sectors, and income groups.

4.4 Prices, inflation and fiscal policy

The evidence indicates statistically significant but heterogeneous effects on consumer price inflation (CPI) from weather shocks. For the euro area, headline CPI rises by about 0.2 percentage points in the month after a weather-related disaster, with fading within a quarter and smaller responses for core items (Beirne et al., 2024). Cross-country panels show that a one percent increase in monthly mean temperature is associated with roughly 2–3% higher CPI in emerging economies and around 2.4% in advanced economies, though persistence varies (Mukherjee and Ouattara, 2021). El Niño episodes add upward pressure to prices in most countries; estimated increases are modest in advanced regions, about 0.12 percentage points in the United States and 0.07 percentage points in Europe (Cashin, Mohaddes, and Raissi, 2017). Average warming also lifts unprocessed-food inflation by 0.1–0.2 percentage points within a year, especially in Spain and Italy, while processed food and most core items show muted reactions (Ciccarelli, Kuik, and Martínez Hernández, 2024; Kotz, Kuik, et al., 2024). Energy prices move with heating and cooling demand and can even dampen inflation during milder winters that reduce gas consumption (Lucidi, Pisa, and Tancioni, 2024). Hotter summers tend to raise prices across latitudes, winter warming is mildly disinflationary in northern Europe, and the differences in impacts observed across countries reflect their exposure to supply chains and reconstruction demand after disasters (Cevik and Gwon, 2024; Kotz, Kuik, et al., 2024). Overall, climate-related shocks have moved European inflation by only a few basis points to date, with direction and duration shaped by season, region, and energy mix.

But what are the channels through which the impacts are themselves transmitted? A review of the evidence suggests three inter-linked transmission routes by which climate and weather anomalies feed through to inflation: 1) agricultural supply shocks, 2) energy-related demand-supply shifts, and 3) propagation through trade and production networks. Each operates with its own timing, seasonality and regional specificity.

First, agricultural supply shocks reduce yields and shift up farm-gate and wholesale prices, which pass through to food CPI with short lags; this "first-round" channel is most visible in food-import-dependent economies and in the euro-area unprocessed-food component (Ciccarelli, Kuik, and Martínez Hernández, 2024; Mukherjee and Ouattara, 2021). Second, energy demand and supply respond to weather. Higher cooling demand in summer and, for now, lower heating needs in mild winters exert offsetting pressures, while heat or hydrological stress can impair thermal and hydro output and raise electricity price sensitivity where renewables are prominent (Cevik and Gwon, 2024; Ciccarelli, Kuik, and Martínez Hernández, 2024; Lucidi, Pisa, and Tancioni, 2024). Third, shocks propagate through trade and production networks. Disrupted logistics and weather-related production shortfalls raise intermediate costs and delivery times, which feed into producer and then consumer prices; in some episodes, reconstruction activity offsets output losses and helps sustain price pressure (Beirne et al., 2024; Cevik and Gwon, 2024).

Thus, as weather shocks intensify with climate change, these channels are likely to strengthen and interact more frequently, complicating inflation dynamics and policy responses.

4.5 Inequality

Weather shocks affect inequality through income, prices, and assets, with larger impacts in poorer, rural, and hotter settings. Paglialunga, Coveri, and Zanfei (2022) find that for more than 150 countries over 2003–2017, a 1% temperature increase is associated with an increase of 0.5 Gini points, while an extreme heat event or increasing precipitation anomalies add roughly 0.2 and 0.1 points. Effects are larger where rural population shares and agricultural employment are higher, and in predominantly urban countries larger precipitation anomalies are linked to rises in inequality through flood exposure, infrastructure damage, and food price pressures. In the United Kingdom, Sheng et al. (2023) show that shocks to temperature growth and volatility raise wealth inequality in the medium to long run, with the 80–50 and 90–50 ratios increasing more than the 50–20 and 50–10 ratios, so gaps widen between the top and the middle, while short-run effects near the bottom are mixed. Globally, Mumtaz and Theophilopoulou (2024) report that an adverse climate shock lifts the Gini coefficient by about 0.62% over one year, with effects concentrated in low-income, hot, and high-inequality countries, and stronger where agriculture's share is higher.

A separate strand does not model inequality as the primary outcome but estimates heterogeneous effects across groups, revealing distributional pressures. In Russia, Otrachshenko and Popova (2022) find that single hot days can raise the income share of poorer groups and lower the top share, yet sequences of hot or very wet days increase poverty and unemployment, and prices rise in poor regions. Cross-country analyses show larger productivity and growth losses from temperature and hydrological extremes in poorer economies (Khan, Morzuch, and Brown, 2017; Letta and Tol, 2019). Agricultural channels amplify this asymmetry, since yield and TFP losses from heat, rainfall extremes, and day-to-day variability are larger in low-income regions (Ubilava and Abdolrahimi, 2019; Zou et al., 2024). Finally, Quante et al. (2024) argue that low-income households face higher climate-driven consumption risk because necessities dominate their baskets and market dynamics can crowd them out. Across these strands, temperature shocks tend to raise inequality in rural and hot economies, while extreme precipitation raises inequality in urban settings, and price and asset channels can widen gaps over time.

4.6 Agriculture

Agricultural impacts are sharpest when hydro-meteorological shocks hit sensitive growth stages and short-run adaptation is limited. Using municipality data for Germany, Schmitt et al. (2022) show that summer drought during flowering, fruit formation, and ripening depresses revenues for winter wheat, winter barley, and grain maize. Average losses are about €7–8 per hectare for wheat and maize, and waterlogging around shooting and flowering also reduces returns, particularly in the south. Accounting for within-place variability, a one-standard-deviation intensification of summer drought cuts revenues by about €17 per hectare for wheat and €38 per hectare for maize, narrowing gross margins in hard-hit municipalities by four per cent or more.

Large-scale variability is also shown to matter. A +1°C El Niño sea-surface-temperature anomaly reduces maize yields by 11–21% in strongly teleconnected countries[1], with larger losses in lower-income economies; La Niña deviations also depress yields, so ENSO cycles

[1] Countries that are strongly teleconnected to the ENSO are those where the correlation between local climate variables and ENSO indices is statistically significant and substantial. This means that in these countries, ENSO events have a pronounced impact on local weather patterns, which in turn affect agricultural outcomes such as crop yields.

are on average yield-reducing where teleconnections are strong (Ubilava and Abdolrahimi, 2019). In addition, monthly mean temperature and day-to-day temperature variability have independent effects on agricultural TFP, as higher intra-month variability moderates marginal damages from high monthly temperatures, yet amplifies harm from extreme wet days. Each additional day above the 95th–99th precipitation percentile lowers TFP by roughly 0.9–1.5%, with the largest impacts in low- and lower-middle-income regions (Zou et al., 2024).

Markets and policy transmit and partly buffer these shocks. In international wheat markets, La Niña raises prices and El Niño lowers them, with peak effects of about 2 to 6% after 6 to 10 months and more persistence under La Niña, consistent with low inventories (Ubilava, 2017). On the policy side, rainfall shortfalls tend to be followed by lower agricultural import tariffs, whereas unusually wet years are associated with higher tariffs, consistent with counter-cyclical border adjustments when weather strains domestic supply (Bastos, Straume, and Urrego, 2013).

4.7 Energy

Energy outcomes adjust through demand and supply, with clear heterogeneity by climate, technology, and market structure. Wholesale prices rise once temperatures cross country-specific thresholds; in colder systems the pressure comes from heating, while in Italy and Spain both heating and cooling matter, and effects are largely contemporaneous. Precipitation lowers prices where hydropower is widely used, especially in Norway, with effects appearing after several days as reservoirs respond with a lag. Wind in the $7 - 20ms^{-1}$ range and higher solar irradiance depress prices in markets with sizeable wind and solar, most clearly Spain and Italy, with weaker effects in markets where penetration is lower (Mosquera-López, Uribe, and Joaqui-Barandica, 2024). In Italy's day-ahead market, temperature is a statistically significant determinant of wholesale prices after standard controls, with marginal effects near 1 percentage point per degree; cooling-degree hours carry larger coefficients than heating-degree hours, and island systems show stronger heating responses (Bigerna, 2018). Additionally, electricity use in Spain's hospitality sector rises with cooling-degree days and with heating-degree days, although the latter can become non-significant under low base temperatures, plausibly due to deterred tourism or fuel switching (Pablo-Romero, Pozo-Barajas, and Sánchez-Rivas, 2019). Peak demand exhibits a U-shape with respect to maximum temperatures. Long-run exposure to cold raises peaks in northern Europe, while warming amplifies summer peaks in the south, implying higher capacity needs despite milder winters (Colelli, Wing, and De Cian, 2023). Investment responses differ on the contrary, as extreme temperatures and weather events reduce solar and wind investment where these markets are already large, while geothermal energy is inhibited in lower-investment countries but less affected where deployment is established. In OECD economies extreme heat is associated with higher geothermal investment, and higher greenhouse gases correlate with more solar and geothermal (X. Chen, Fu, and Chang, 2021).

4.8 Distributional and social outcomes

4.8.1 Crime and conflict

Limited evidence suggests that weather extremes can exacerbate violent behaviour and social unrest. In Russia, extreme heat has been shown to significantly elevate violent mortality, particularly during days exceeding 25°C, while cold temperatures appear to have no measurable effect; absolute risks are higher for males, but relative increases are often greater for females, and weekend exposure amplifies risks for both sexes (Otrachshenko, Popova, and Tavares, 2021). Mannell et al. (2024) suggest a positive association between hydro-meteorological shocks and intimate partner violence, whereas droughts, wildfires, and extreme temperatures show no robust link in that specification (Mannell et al., 2024). Historical studies provide additional insight into how weather-induced economic hardship can translate into social unrest. In late eighteenth-century France, growing-season drought interacting with warm anomalies raised the incidence of peasant revolts and increased the number of demands for institutional change, particularly where lean-season scarcity and anxiety about the harvest were most acute (Waldinger, 2024). Evidence from Savoy shows that temperature shocks can move violent and property crime in opposite directions, with downturns reducing violent crime through lower alcohol consumption, yet higher staple prices increasing property crime as economic stress intensifies (Chambru, 2020).

4.8.2 Migration

Evidence on migration is thin but informative. Across countries, temperature increases raise outmigration only where livelihoods are agriculture dependent: a 1 °C rise is linked to about a five per cent increase from the most agricultural origins, and an extra 100 growing-season hours above 30 °C adds roughly five percentage points, attenuating to 3.5 after income controls, with multi-year lags (Cai et al., 2016). By contrast, historical data from the Netherlands indicate that warmer three-year means reduce the odds of both short and international moves, and higher multi-year rainfall similarly lowers international migration; more hot days are associated with fewer long-distance moves, while more cold days slightly raise international moves. Riverine and coastal flooding are insignificant, and temperature effects on short moves vanish once agricultural conditions are controlled (Jennings and Gray, 2015).

4.8.3 Politics

The evidence on political responses is similarly limited but consistent. Across Europe, recent exposure to positive temperature anomalies, heat days and drought months increases environmental concern and support for Green parties; a one standard deviation positive anomaly lifts concern by about 0.18 standard deviations and Green voting by about 0.12, with stronger effects in temperate and cold regions, weaker or absent in the Mediterranean, and smaller where mean GDP is lower (Hoffmann et al., 2022). In Italy, extreme events and meteorological anomalies raise online attention to climate and weather; effects are larger when clean non-event weeks are used as controls, heat anomalies shift climate discourse, cold anomalies shift weather discussion, and attention shows short-lived persistence (Crispino and Loberto, 2024). Historically, drought and storm damage in pre-revolutionary France were followed by longer grievance lists that demanded broader representation and civil liberties, especially where heat combined with low precipitation (Waldinger, 2024). Overall, realised heat and dryness heighten attention and can translate into voting shifts and, in earlier periods, institutional demands.

4.9 Financial markets

Finally, recent studies show that weather shocks affect financial markets and institutions. In the United Kingdom, extreme combinations of temperature, humidity, cloud cover and visibility move daily stock index returns, consistent with mood and attention effects

(Ahmed et al., 2024). In France, trading volumes fall by 4 to 10% on days above 30°C even after controlling for holidays and seasonality, likely reflecting heat related fatigue and impaired cognition (Peillex et al., 2021). These results point to rapid transmission through sentiment, liquidity and price discovery. Moreover, chronic temperature anomalies and acute events such as heatwaves, droughts and storms worsen bank Z scores and raise default probabilities (Chabot and Bertrand, 2023). At the aggregate level, financial conditions tighten and volatility rises, suggesting amplification through interbank linkages and asset price feedback. There is also early evidence of adaptation, including portfolio shifts away from temperature exposed sectors and greater use of weather derivatives (Ahmed et al., 2024). Whether these adjustments can offset projected increases in climate extremes remains an open research question.

5 Limitations, conclusion and future directions

This scoping review provides a structured map of empirical research on the socio-economic sensitivity of European systems to short-run weather shocks, but several limitations of the review itself should be noted. First, the review is confined to peer-reviewed journal articles indexed in Scopus and Web of Science and, by design, excludes working papers, policy reports, and other grey literature. This choice improves transparency and replicability but may omit relevant evidence, particularly in fast-moving areas such as macro-finance and disaster economics where influential findings often circulate as working papers before journal publication. Second, we restricted the corpus to high-impact journals within economics and environmental science to keep the evidence base tractable and methodologically comparable, and the review feasible. This may have excluded pertinent contributions from adjacent fields that publish outside these. Third, although eligibility rules were developed jointly and applied systematically, scoping reviews necessarily involve judgment when classifying heterogeneous studies by outcomes, sectors, and shock definitions. Some misclassification risk remains, especially where papers examine multiple outcomes or where exposure definitions blur "variability" and "extremes." Fourth, the objective of this review is mapping rather than effect-size synthesis; we therefore do not undertake formal critical appraisal, risk-of-bias assessment, or quantitative pooling, and the synthesis should not be interpreted as establishing comparative causal magnitudes across sectors.

Within these boundaries, the review addresses four research questions. Regarding *RQ1*, the mapped evidence base is recent and expanding, but unevenly distributed across outcome domains and geographic settings. Research attention is concentrated on health, economic activity, and macroeconomic outcomes, with substantially less coverage of distributional, behavioural, and institutional dimensions. Regarding *RQ2*, most studies operationalise shocks through temperature and precipitation anomalies or extremes, and estimate impacts using panel fixed-effects frameworks, complemented by methods such as VARs, local projections, and distributed lag non-linear models. Identification is typically derived from within-unit deviations in weather conditional on fixed effects and seasonal structure, but comparability is hindered by differences in exposure construction, non-linear functional forms, lag structures, and the handling of concurrent meteorological conditions. Regarding *RQ3*, the balance of findings is consistent with economically and socially meaningful sensitivity to weather shocks, as temperature variability and heat extremes are repeatedly linked to reductions in output growth and productivity, health burdens increase non-linearly with heat and cold extremes, and price responses indicate inflationary pressure operating mainly through food and, in some contexts, energy and supply-chain channels. Effects vary by region, sector, and income level, and the literature increasingly points to propagation through interregional linkages and economic networks. Finally, for *RQ4*, the mapped evidence highlights that the central challenge is no longer documenting whether weather shocks matter, but characterising how impacts propagate across space, sectors, and time, and who bears the burden within countries.

These patterns motivate three priority directions for future research. First, there is a clear need for more sub-national and high-frequency evidence that can capture the heterogeneity of exposure and adaptive capacity within countries. Designs that integrate locally measured shocks with municipal- or neighbourhood-scale socio-economic outcomes would improve inference on thresholds, lags, and compound sequences of extremes. Second, future studies should more explicitly model spillovers and transmission mechanisms. Europe's integration implies that local shocks can generate cross-border and interregional effects through trade, migration, supply chains, shared infrastructure, and fiscal linkages, yet explicit spatial and network-based modelling remains limited relative to the plausibility of these channels. Third, the evidence base would be strengthened by expanding coverage of under-studied outcome domains and under-studied European regions. Priority outcomes include within-country inequality and distributional incidence, housing and energy markets, labour-market adjustments beyond aggregate employment, social stability endpoints, and fiscal and financial-system stress. Geographically, Scandinavia and Eastern Europe could benefit from more focused inquiry, given their distinct climatic baseline and lack of representation in the current literature. Progress on these fronts would not only close persistent gaps identified in this review but also improve the capacity of European research to inform adaptation policy in a climate regime where extremes are becoming more frequent, and societally consequential.

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Appendix

A PRISMA-ScR Checklist

Table A.1: PRISMA-ScR checklist

Section	Item	PRISMA-ScR Checklist Item	Reported on page(s)
Title			
Title	1	Identify the report as a scoping review.	1
Abstract			
Structured summary	2	Provide a structured summary that includes (as applicable): background, objectives, eligibility criteria, sources of evidence, charting methods, results, and conclusions that relate to the review questions and objectives.	1
Introduction			
Rationale	3	Describe the rationale for the review in the context of what is already known. Explain why the review questions/objectives lend themselves to a scoping review approach.	3-5
Objectives	4	Provide an explicit statement of the questions and objectives being addressed with reference to their key elements (e.g., population or participants, concepts, and context) or other relevant key elements used to conceptualize the review questions and/or objectives.	5
Methods			
Protocol and registration	5	Indicate whether a review protocol exists; state if and where it can be accessed (e.g., a Web address); and if available, provide registration information, including the registration number.	N/A
Eligibility criteria	6	Specify characteristics of the sources of evidence used as eligibility criteria (e.g., years considered, language, and publication status), and provide a rationale.	6-12
Information sources	7	Describe all information sources in the search (e.g., databases with dates of coverage and contact with authors to identify additional sources), as well as the date the most recent search was executed.	6-12
Search	8	Present the full electronic search strategy for at least 1 database, including any limits used, such that it could be repeated.	7
Selection of sources of evidence	9	State the process for selecting sources of evidence (i.e., screening and eligibility) included in the scoping review.	6-12
Data charting process	10	Describe the methods of charting data from the included sources of evidence (e.g., calibrated forms or forms that have been tested by the team before their use, and whether data charting was done independently or in duplicate) and any processes for obtaining and confirming data from investigators.	12-13

Continued on next page

Table A.1: PRISMA-ScR checklist (Continued)

Section	Item	PRISMA-ScR Checklist Item	Reported on page(s)
Data items	11	List and define all variables for which data were sought and any assumptions and simplifications made.	12-13
Critical appraisal of individual sources of evidence	12	If done, provide a rationale for conducting a critical appraisal of included sources of evidence; describe the methods used and how this information was used in any data synthesis (if appropriate).	13
Synthesis of results	13	Describe the methods of handling and summarizing the data that were charted.	12-13
Results			
Selection of sources of evidence	14	Give numbers of sources of evidence screened, assessed for eligibility, and included in the review, with reasons for exclusions at each stage, ideally using a flow diagram.	13
Characteristics of sources of evidence	15	For each source of evidence, present characteristics for which data were charted and provide the citations.	Appendix
Critical appraisal within sources of evidence	16	If done, present data on critical appraisal of included sources of evidence (see item 12).	N/A
Results of individual sources of evidence	17	For each included source of evidence, present the relevant data that were charted that relate to the review questions and objectives.	Appendix
Synthesis of results	18	Summarize and/or present the charting results as they relate to the review questions and objectives.	14-24
Discussion			
Summary of evidence	19	Summarize the main results (including an overview of concepts, themes, and types of evidence available), link to the review questions and objectives, and consider the relevance to key groups.	25-41
Limitations	20	Discuss the limitations of the scoping review process.	42-43
Conclusions	21	Provide a general interpretation of the results with respect to the review questions and objectives, as well as potential implications and/or next steps.	42
Funding			
Funding	22	Describe sources of funding for the included sources of evidence, as well as sources of funding for the scoping review. Describe the role of the funders of the scoping review.	43

B Auxiliary search

To ensure the robustness of our evidence base, we conducted a supplementary search using an alternative query specification. This secondary search was designed to capture relevant studies that might have been overlooked by the primary search string due to variations in terminology or indexing. All records identified through this complementary process were screened against the same inclusion and exclusion criteria outlined in the main protocol. This strategic addition resulted in the identification of 13 further studies that met all eligibility requirements and were integrated into the final corpus. The search query used in this supplementary phase is shown in Figure B.1.

(”weather” OR ”climate” OR ”rain*” OR ”precipitation” OR ”temperature”) AND
(”shock*” OR ”extreme” OR ”variability”) AND
(”economic*” OR ”socio-economy*” OR ”sectoral impact*” OR ”macroeconomy*” OR ”inflation*”) AND
(”Europe*” OR ”Eurozone” OR ”Austria*” OR ”Belgium*” OR ”Bulgaria*” OR ”Croatia*” OR ”Cyprus*” OR ”Czech Republic*” OR ”Denmark*” OR ”Estonia*” OR ”Finland*” OR ”France*” OR ”Germany*” OR ”Greece*” OR ”Hungary*” OR ”Iceland*” OR ”Ireland*” OR ”Italy*” OR ”Latvia*” OR ”Lithuania*” OR ”Luxembourg*” OR ”Malta*” OR ”Netherlands*” OR ”Norway*” OR ”Poland*” OR ”Portugal*” OR ”Romania*” OR ”Slovakia*” OR ”Slovenia*” OR ”Spain*” OR ”Sweden*” OR ”Switzerland*” OR ”United Kingdom*” OR ”England*” OR ”Scotland*” OR ”Wales*” OR ”Northern Ireland*”)

Figure B.1: Auxiliary search query applied to Scopus and Web of Science databases.

C Scoping review framework

C.1 Population-Concept-Context

Table C.1: Population–Concept–Context (PCC) criteria for this review

PCC element	Definition
Population	Economic agents and systems in Europe, including households, workers, firms, sectors, municipalities, regions, and countries. Studies with or without comparator groups are eligible; comparators may be temporal (e.g. before–after designs, anomalies) or cross-sectional (e.g. treated versus control areas).
Concept	Sensitivity of socio-economic systems to realised weather shocks or short-run weather variability, with weather treated as an explanatory factor for socio-economic outcomes. Eligible study types include empirical primary studies (quantitative or mixed-methods) that estimate or describe realised impacts; both multi-country panels and single-country studies are eligible. Systematic reviews are included as primary evidence when the studies they synthesise meet the inclusion criteria. Socio-economic outcomes include, among others, prices and inflation, employment and unemployment, productivity and output, sectoral activity (e.g. agriculture, energy, transport, tourism), health service utilisation, crime, and financial market responses. Ineligible concepts include exposure-only assessments without sensitivity or realised impacts; adaptation or forward-looking policy analyses without realised impacts; long-run climate trend analyses without discrete shocks; non-weather hazards (e.g. earthquakes, volcanic eruptions); methodological or framework papers without empirical application; and greenhouse gas or air pollution studies without an explicit weather-shock link.
Context	European settings, including European Union member states, the EEA, the Schengen area, the United Kingdom, and candidate or associated states; Russia and Turkey are included. Global or multi-region studies are eligible when a European subsample or identifiable European estimates are available. Weather shocks or hazards are operationalised as short-run extremes or anomalies, such as heatwaves, cold spells, storms, droughts, floods, extreme precipitation, and temperature anomalies, typically defined relative to local historical distributions (e.g. tail thresholds such as the 10th or 90th percentiles) or via discrete event classifications.

C.2 Key terms used

Table C.2: Concepts and working definitions used in screening and charting

Concept	Definition
Socio-economic outcome	A measurable effect on economic or social well-being, including but not limited to income, prices, employment, productivity, sectoral activity, health service use, crime, and financial market responses.
Sensitivity	The degree to which a system is affected, adversely or beneficially, by weather variability or extremes through direct or indirect pathways.
Exposure	The presence of people, livelihoods, assets, or infrastructure in locations that could be affected by weather or climate events.
Vulnerability	The propensity to be adversely affected as a function of exposure, sensitivity, and adaptive capacity. In this review, sensitivity and realised impacts are mapped rather than constructing composite vulnerability indices.
Europe	European Union member states, the EEA, the Schengen area, the United Kingdom, and candidate or associated states; Russia and Turkey are included. Global or multi-region studies are eligible when European estimates are identifiable.
Weather shock	A short-run extreme or unusual realisation of weather or climate relative to local historical conditions, often operationalised using threshold-based definitions (e.g. values beyond the 10th or 90th percentiles) or discrete hazard events whose rarity and intensity vary by location and season.

C.3 Journal selection criteria

To identify the most impactful and rigorous research within the broad search results, we applied a quality filter based on journal rankings. Specifically, we restricted inclusion to journals ranked in the first quartile (Q1) of the Scimago Journal Rankings (SJR) in their year of publication. If a ranking was unavailable for the specific publication year, the ranking from the nearest available year was used. This criterion ensures that the review captures studies that have met high standards of peer review and disciplinary impact, while also serving as a practical heuristic to manage the volume of records returned by the broad search string. The SJR data were retrieved from `https://www.scimagojr.com/journalrank.php`.

D Supplementary Tables

Table D.1: Summary of study characteristics: publication, region, sector, and data granularity

Publication	Region	EU region	Sector	Outcome studied	Temp. period.	Spatial res.
Achebak et al. (2024)	Spain	Spain	Health	Hospitalisation	Daily	Province
Ahmed et al. (2024)	London	United Kingdom	Financial markets	Stock returns (FTSE 100)	Daily	–
Bastos, Straume, and Urrego (2013)	Global	Global	Agriculture	Macroeconomic and agricultural outcomes	Annual	Country
Beirne et al. (2024)	Eurozone	Eurozone	Macroeconomy	Inflation	Monthly	Country
Berg, Curtis, and Mark (2024)	Global	Global	Macroeconomy	GDP per capita	Annual	Country
Bigerna (2018)	Italy	Italy	Energy	Electricity prices	Hourly	–
Bigler and Janzen (2024)	Germany	Germany	Health	Sleep	Daily	NUTS 3
Black et al. (2013)	Global	Global	Review	–	–	–
Blumenthal and Nyberg (2019)	Sweden	Sweden	Economy	Insurance and flood damage	Daily	–
Boccard (2018)	France	France	Economy	Economic losses and insurance	Annual	Country
Cai et al. (2016)	OECD	OECD	Migration	Migration, agriculture, GDP	Annual	Country
Cashin, Mohaddes, and Raissi (2017)	Global	Global	Macroeconomy	Inflation, GDP, exchange rates	Quarterly	Country
Cevik and Gwon (2024)	Multiple	Eurozone	Macroeconomy	Inflation and supply chains	Monthly	Country
Chabot and Bertrand (2023)	Europe	Europe	Financial markets	Financial stability, GDP	Monthly	Country
Chambru (2020)	Switzerland	Switzerland	Crime and conflict	Crime, prices, migration	Annual	Region
J. Chen et al. (2023)	Global	Global	Health	Meningitis	Annual	Country
X. Chen, Fu, and Chang (2021)	Global	Global	Energy	Energy outcomes	Annual	Country
Ciccarelli, Kuik, and Martínez Hernández (2024)	Multiple	Multiple	Macroeconomy	Inflation	Monthly	Country
Colelli, Wing, and De Cian (2023)	Europe, India	Europe	Energy	Electricity load	Monthly	Country
Crispino and Loberto (2024)	Italy	Italy	Politics	Climate awareness	Weekly	NUTS 3
Díaz et al. (2015)	Madrid	Spain	Health	Mortality	Daily	City
Donadelli, Grüning, et al. (2021)	G7, OECD	G7, OECD	Economy	R&D activity	Annual	Country
Donadelli, Jüppner, and Vergalli (2022)	Global	Global	Macroeconomy	GDP, productivity, capital	Daily	Country
Drescher and Janzen (2025)	Switzerland	Switzerland	Health	Occupational injuries	Annual	Canton
Ellena et al. (2022)	Turin	Italy	Health	Mortality	Daily	–
Falk (2013)	Austria	Austria	Tourism	Tourist stays	Annual	–
Felbermayr et al. (2022)	Global	Global	Economy	Economic activity	Annual	Grid
Gössling et al. (2023)	Global	Global	Review	–	–	–
Gupta et al. (2023)	Multiple	Multiple	Economy	Real GDP	Annual	Country
Hoffmann et al. (2022)	Europe	Europe	Politics	Voting behaviour	Annual	NUTS 3
Huang and Hong (2024)	Global	Global	Health	Obesity, inequality	Annual	Country
Jennings and Gray (2015)	Netherlands	Netherlands	Migration	Human migration	Annual	Municipality
Kahn et al. (2021)	Global	Global	Economy	GDP per capita	Annual	Country
Karlsson and Ziebarth (2018)	Germany	Germany	Health	Mortality	Daily	County
Khan, Morzuch, and Brown (2017)	Global	Global	Economy	GDP growth, inequality	Annual	Country–basin
Kotz, Wenz, et al. (2021)	Global	Global	Economy	Gross regional product	Annual	Subnational
Kotz, Kuik, et al. (2024)	Global	Global	Economy	Inflation	Monthly	Country
Letta and Tol (2019)	Global	Global	Macroeconomy	TFP and inequality	Annual	Country
Linsenmeier (2023)	Global	Global	Economy	Economic activity	Daily	Country
Lis and Nickel (2010)	Global	Global	Macroeconomy	Fiscal outcomes	Annual	Country
J. A. López-Bueno, Díaz, and Linares (2019)	Madrid	Spain	Health	Mortality	Daily	City

Table D.1 (Cont.): Summary of study characteristics: publication, region, sector, and data granularity

Publication	Region	EU region	Sector	Outcome studied	Temp. period.	Spatial res.
J. A. López-Bueno, Linares, et al. (2020)	Madrid	Spain	Health	Mortality	Daily	District
José Antonio López-Bueno et al. (2021)	Madrid	Spain	Health	Mortality	Daily	Municipality
J. A. López-Bueno, Díaz, Sánchez-Guevara, et al. (2020)	Madrid	Spain	Health	Mortality	Daily	District
J. A. López-Bueno, Navas-Martín, et al. (2022)	Spain	Spain	Health	Mortality rate	Monthly	Municipality
Lucidi, Pisa, and Tancioni (2024)	Multiple	Multiple	Macroeconomy	Inflation and prices	Monthly	NUTS 2
Mannell et al. (2024)	Global	Global	Crime and conflict	Violence	Annual	Country
Marinaccio et al. (2019)	Italy	Italy	Health	Occupational injuries	Daily	Municipality
Martínez-Solanas and Basagaña (2019)	Spain	Spain	Health	Mortality	Daily	Province
Middelanis et al. (2023)	Global	Global	Macroeconomy	Prices and consumption	Daily	Country
Miller et al. (2021)	Global	Global	Macroeconomy	GDP and agriculture	Annual	Country
Mosquera-López, Uribe, and Joaqui-Barandica (2024)	Multiple	Multiple	Energy	Energy and electricity	Daily	Country
Mukherjee and Ouattara (2021)	Global	Global	Macroeconomy	Inflation and policy variables	Annual	Country
Mumtaz and Theophilopoulou (2024)	Global	Global	Economy	GDP and inequality	Annual	Country
Otrachshenko and Popova (2022)	Russia	Russia	Economy	Income and inequality	Annual	Regional
Otrachshenko, Popova, and Tavares (2021)	Russia	Russia	Crime and conflict	Violence	Annual	Regional
Otrachshenko, Popova, and Solomin (2017)	Russia	Russia	Health	Mortality	Annual	Regional
Pablo-Romero, Pozo-Barajas, and Sánchez-Rivas (2019)	Spain	Spain	Energy	Electricity and tourism	Annual	Province
Paglialunga, Coveri, and Zanfei (2022)	Global	Global	Inequality	Gini index	Annual	Municipality
Peillex et al. (2021)	France	France	Financial markets	Stock market outcomes	Daily	Country
Quante et al. (2024)	Global	Global	Economy	Income and consumption	Daily	Country
Rubio-Cabañez (2024)	Spain	Spain	Health	Birth weights	Monthly	Municipality
Russ (2020)	Global	Global	Economy	Agricultural productivity	Annual	Country
Saucy et al. (2021)	Zurich	Switzerland	Health	Mortality	Daily	Grid
Schleypen et al. (2022)	EU, UK	EU, UK	Economy	Productivity	Annual	NUTS 2
Schmitt et al. (2022)	Germany	Germany	Agriculture	Crop yields	Annual	Municipality
Semenova (2024)	Global	Global	Review	–	–	–
Sheng et al. (2023)	United Kingdom	United Kingdom	Inequality	Wealth inequality	Monthly	Country
Tol (2024)	Global	Global	Review	–	–	–
Ubilava (2017)	Global	Global	Agriculture	Wheat prices	Monthly	Country
Ubilava and Abdolrahimi (2019)	Global	Global	Agriculture	Crop yields	Annual	Country
Verschuur, Koks, and Hall (2023)	Global	Global	Supply chains	Ports and shipping	Annual	Country
Vielma et al. (2024)	Spain	Spain	Health	Occupational injuries	Daily	NUTS 3
Möllendorff and Hirschfeld (2016)	Germany	Germany	Well-being	Life satisfaction	Annual	NUTS 3
Waldinger (2024)	France	France	Crime and conflict	Conflict and politics	Annual	Canton
Wasko, Sharma, and Pui (2021)	Global	Global	Economy	Insurance losses	Annual	Country
Zou et al. (2024)	Global	Global	Agriculture	Agricultural TFP	Annual	Country

Table D.2: Weather variables, methodologies, and data features of studies included in the review

Publication	Weather studied	Weather measure	Methodology	Weighted	Weather data source	Controls used
Achebak et al. (2024)	Temperature, humidity	Cross-basis function of temperature	Quasi-Poisson GLM; DLNM; multilevel meta-analysis	No	E-OBS	Day of week; day of season; year squared
Ahmed et al. (2024)	Temperature, humidity, clouds, visibility	Moving averages and standard deviations; above-/below-average extremes	GARCH; logit; OLS	No	Visual Crossing Weather	Day of week
Bastos, Straume, and Urrego (2013)	Precipitation	Annual precipitation	FE panel regression; Tobit RE	Yes	Terrestrial Air Temperature and Precipitation	Industry FE; country FE; year FE
Beirne et al. (2024)	Extreme weather events	Extreme weather events	Panel structural VAR	No	EM-DAT	–
Berg, Curtis, and Mark (2024)	Temperature	Population-weighted temperature; two-factor decomposition; cold/hot/normal days	Local projections	No	Terrestrial Air Temperature and Precipitation; Berkeley Earth	–
Bigerna (2018)	Temperature	Hourly temperature; CDH; HDH	VAR	Yes	Italian Military Airforce (Meteorology Office)	–
Bigler and Janzen (2024)	Temperature, precipitation, cloud cover	Discretised bins of minimum daily temperature	FE panel regression	No	ERA5	District FE; state-year-month FE; day-of-week FE; holiday FE
Black et al. (2013)	–	–	–	–	–	–
Blumenthal and Nyberg (2019)	Precipitation	Precipitation	Linear regression	No	State Meteorological Agency	–
Boccard (2018)	Extreme weather events	Floods; droughts; heatwaves	FE panel regression	No	CATNAT	–
Cai et al. (2016)	Temperature, precipitation	Annual mean precipitation; annual mean temperature	FE panel regression	Yes	NASA	Country-pair FE; origin-specific trend; destination-specific trend
Cashin, Mohaddes, and Raissi (2017)	ENSO	SOI anomaly	Local projections; VARX; global VAR	No	NOAA	–
Cevik and Gwon (2024)	Temperature	Temperature anomaly	Structural VAR; local projections	No	World Bank CCKP	–
Chabot and Bertrand (2023)	Temperature, precipitation, extreme events	Temperature anomaly; counts of floods, heatwaves, droughts, coldwaves	FE panel regression	Yes	State Meteorological Agency	–
Chambru (2020)	Temperature	Temperature and precipitation anomalies; seasonal means	FE panel regression	No	European Seasonal Temperature and Precipitation Reconstruction	Province FE; time FE
J. Chen et al. (2023)	Temperature, precipitation, wind speed	Max temperature; average precipitation; temperature variability	GLM	No	CMIP6; TerraClimate	–
X. Chen, Fu, and Chang (2021)	Temperature, precipitation	Extreme temperature events; droughts; floods	FE panel quantile regression	No	International disasters database	Cross-specific FE
Ciccarelli, Kuik, and Martínez Hernández (2024)	Temperature	Temperature anomaly (historical mean)	Bayesian VAR	Yes	ERA5	Seasonal dummies

Table D.2 (Cont.): Weather variables, methodologies, and data features of studies included in the review

Publication	Weather studied	Weather measure	Methodology	Weighted	Weather data source	Controls used
Colelli, Wing, and De Cian (2023)	Temperature	30-year moving average of daily $T_{\max}$; anomaly; bins	FE panel regression	Yes	ERA5	Time FE; region FE; day-of-year FE; weekly, monthly, yearly FE
Crispino and Loberto (2024)	Temperature	Temperature anomaly	FE Poisson panel	No	E-OBS; European Severe Weather Dataset	Region FE; week-year FE
Díaz et al. (2015)	Temperature, pressure, humidity	Cold waves; mean pressure; mean humidity; daily min/max temperature	Poisson regression	No	State Meteorological Agency	–
Donadelli, Grüning, et al. (2021)	Temperature	Global annual temperature; mean annual temperature	Panel VAR; stochastic endogenous growth model	No	World Bank CCKP; CRU	Country FE
Donadelli, Jüppner, and Vergalli (2022)	Temperature	Annual temperature volatility	Panel VAR	No	World Bank CCKP	Country FE
Drescher and Janzen (2025)	Temperature, precipitation, solar radiation, wind speed	Temperature bins	Poisson FE	No	State Meteorological Agency	ZIP-week FE; region-year-month FE; day of week; holiday
Ellena et al. (2022)	Temperature	Daily mean temperature	Quasi-Poisson GLM; DLNM	No	UERRA regional reanalysis	Day of week
Falk (2013)	Temperature, clouds, snow depth, clear skies	Monthly mean temperature; max snow depth; clear-sky days; cloud cover	Panel error-correction model	No	ZAMG (Austria)	–
Felbermayr et al. (2022)	Temperature, precipitation, wind speed	Precipitation anomalies; SPEI; cold spells; storms	Spatial Durbin model; FE panel regression	No	CRU	Cell FE
Gössling et al. (2023)	–	–	–	–	–	–
Gupta et al. (2023)	Temperature	Global temperature anomaly	Probit	No	NOAA	–
Hoffmann et al. (2022)	Temperature, precipitation, evapotranspiration, UTCI	Anomalies; heat/cold spells; hot/cold days; dry/wet spells	FE panel regression	No	ERA5	Region FE; period FE; season FE
Huang and Hong (2024)	Temperature	Annual mean; bins; seasonal means; anomaly; shocks	FE panel regression	Yes	CRU; CMIP6; World Bank CCKP	Country FE; country trends; year squared
Jennings and Gray (2015)	Temperature, flooding, precipitation	Mean annual temperature; tropical/cold days; flooding; annual precipitation	Multinomial logit	No	State Meteorological Agency	Province FE; quadratic time trend
Kahn et al. (2021)	Temperature, precipitation	Mean levels and anomalies	Panel ARDL	Yes	Terrestrial Air Temperature and Precipitation	Country FE; time FE
Karlsson and Ziebarth (2018)	Temperature, precipitation	Hot/cold days; temperature bins	FE panel regression; RE Poisson	Yes	State Meteorological Agency	Country FE; week FE; year-month FE; splines of date
Khan, Morzuch, and Brown (2017)	Temperature, precipitation, runoff	Standardised weighted anomalies; means; squared mean temperature	FE panel regression	No	ERA-Interim; MacPDM	Country-basin FE; year FE

Table D.2 (Cont.): Weather variables, methodologies, and data features of studies included in the review

Publication	Weather studied	Weather measure	Methodology	Weighted	Weather data source	Controls used
Kotz, Wenz, et al. (2021)	Temperature, precipitation	Intra-monthly SD of daily temperature	FE panel regression	No	ERA5	Region FE; year FE; time trend
Kotz, Kuik, et al. (2024)	Temperature, precipitation	Mean temperature; SD; 99th pct rainfall; SPEI	FE panel regression	Yes	ERA5	Country FE; time FE; country-month FE
Letta and Tol (2019)	Temperature, precipitation	Annual changes and squared change	FE panel regression	Yes	Terrestrial Air Temperature and Precipitation	Country FE; region-year FE
Linsenmeier (2023)	Temperature, precipitation, humidity, radiation	Means and variability (daily, seasonal, interannual); totals	Spatial first differences	No	ERA5	Country FE; border-pair FE
Lis and Nickel (2010)	Extreme weather events	Extreme weather events	FE panel regression	No	EM-DAT	Time FE; country FE
J. A. López-Bueno, Díaz, and Linares (2019)	Temperature	Cold waves	GLMs	No	State Meteorological Agency	Seasonality; month-year; time trend
J. A. López-Bueno, Linares, et al. (2020)	Temperature	Cold wave	GLMs	No	State Meteorological Agency	–
José Antonio López-Bueno et al. (2021)	Temperature	Cold wave	GLMs	No	State Meteorological Agency	Time trend; month-year; seasonality
J. A. López-Bueno, Díaz, Sánchez-Guevara, et al. (2020)	Temperature	Heatwaves	GLMs	No	State Meteorological Agency	–
J. A. López-Bueno, Navas-Martín, et al. (2022)	Temperature	Minimum daily temperature	Mixed GLM	No	State Meteorological Agency	Seasonality
Lucidi, Pisa, and Tancioni (2024)	Temperature	Temperature anomaly	Local projections	Yes	–	Country FE; country-specific trends
Mannell et al. (2024)	Extreme events	Count of shock indicators	SEM; exploratory factor analysis	No	EM-DAT	–
Marinaccio et al. (2019)	Temperature	Daily mean temperature	Poisson GLM; DLNM; meta-regression	No	NASA	Municipality FE; year FE; month; day of week; holiday
Martínez-Solanas and Basagaña (2019)	Temperature	Daily $T_{\max}$; heatwaves	DLNM; meta-regression	No	ECA&D	–
Middelanis et al. (2023)	Heat stress, floods, cyclones	–	Global agent-based loss propagation model	No	CMIP5	–
Miller et al. (2021)	Temperature, precipitation	Annual precipitation; mean temperature; heatwaves	FE panel regression	Yes	Climate Prediction Center	Country FE; year FE; linear and quadratic country trends
Mosquera-López, Uribe, and Joaqui-Barandica (2024)	Temperature, wind, precipitation, irradiance	Daily values	DLNM	No	Bloomberg	–
Mukherjee and Ouattara (2021)	Temperature	Temperature change	Panel VAR	Yes	UN Climate Database	Country FE; year FE
Mumtaz and Theophilopoulou (2024)	Temperature, precipitation	Annual means	Bayesian panel VAR	No	CRU	Country FE; region FE; time FE
Otrachshenko and Popova (2022)	Temperature, precipitation	Bins	FE panel regression	Yes	State Meteorological Agency	Regional FE; time FE; time trend; region trends

Table D.2 (Cont.): Weather variables, methodologies, and data features of studies included in the review

Publication	Weather studied	Weather measure	Methodology	Weighted	Weather data source	Controls used
Otrachshenko, Popova, and Tavares (2021)	Temperature, precipitation	Bins	FE panel regression	Yes	State Meteorological Agency	Regional FE; time FE; time trend; region trends
Otrachshenko, Popova, and Solomin (2017)	Temperature, precipitation	Bins	FE panel regression	Yes	State Meteorological Agency	Regional FE; time FE; time trend; region trends
Pablo-Romero, Pozo-Barajas, and Sánchez-Rivas (2019)	Temperature	CDD/HDD and squared terms	FE panel regression	No	State Meteorological Agency	Province FE; time FE
Paglialunga, Coveri, and Zanfei (2022)	Temperature, precipitation	Monthly mean temperature; heatwave dummy; SPI; anomalies	FE panel regression	No	CRU	Country FE; time FE
Peillex et al. (2021)	Temperature	Hot days; bins	OLS	No	Infoclimate	Month; day of week; year
Quante et al. (2024)	Temperature, precipitation	Temperature anomaly; extreme rainfall; wet days; thresholds	Acclimate	Yes	CMIP6	–
Rubio-Cabañez (2024)	Temperature	Daily mean; extreme hot/cold days; season indicators	FE DiD	Yes	State Meteorological Agency	Municipality FE; time FE
Russ (2020)	Runoff, temperature, precipitation	Runoff shocks; annual temperature and precipitation shocks	FE panel regression	No	GWAM; Terrestrial Air Temperature and Precipitation	Grid FE; year FE; country trends
Saucy et al. (2021)	Temperature, precipitation	Daily temperatures and precipitation	DLNM	Yes	State Meteorological Agency	Country FE
Schleypen et al. (2022)	Temperature, precipitation	Means; totals; shocks; spell indices	Non-linear panel; spatial Durbin model	Yes	GLDAS	Region FE; time FE
Schmitt et al. (2022)	Soil moisture, extreme events	Drought; waterlogging; black frost; chill; heat	FE panel regression	No	State Meteorological Agency	Farm FE; year FE
Semenova (2024)	–	–	–	–	–	–
Sheng et al. (2023)	Temperature	YoY growth; volatility	Local projections	No	State Meteorological Agency	–
Tol (2024)	–	–	–	–	–	–
Ubilava (2017)	Sea surface temperature	Niño index; SST anomaly	Vector smooth transition AR	No	NOAA	–
Ubilava and Abdolrahimi (2019)	Sea surface temperature	SST anomaly	FE panel regression	No	NOAA	Country FE; quadratic trend
Verschuur, Koks, and Hall (2023)	Temperature, extreme events	–	OLS	No	–	–
Vielma et al. (2024)	Temperature	Cross-basis function of temperature	Quasi-Poisson GLM; DLNM	Yes	E-OBS (ECA&D)	Smooth time; day of week; holidays; Easter; Christmas; August; March 11
Möllendorff and Hirschfeld (2016)	Extreme weather events	Extreme weather events	FE panel regression	No	–	Individual FE; time FE
Waldinger (2024)	Temperature, precipitation, droughts	Deviations from long-run means	FE panel regression	No	–	Region FE
Wasko, Sharma, and Pui (2021)	Precipitation, temperature	Drought	Linear regression	No	Sigma	–
Zou et al. (2024)	Temperature, precipitation	Day-to-day variability; wet days; extreme rainfall deviations	RE panel regression	No	20CRv3-W5E5	Region RE; time RE

Note: "Weighted" indicates whether exposure measures are population-weighted or otherwise explicitly weighted, as reported by each study.

Table D.3: Publications by use of population weighting for aggregation of weather data

Category	Publications	NP
Do not use population-weighted weather data	Achebak et al. (2024), Ahmed et al. (2024), Beirne et al. (2024), Berg, Curtis, and Mark (2024), Bigler and Janzen (2024), Blumenthal and Nyberg (2019), Boccard (2018), Cashin, Mohaddes, and Raissi (2017), Cevik and Gwon (2024), Chambru (2020), J. Chen et al. (2023), X. Chen, Fu, and Chang (2021), Crispino and Loberto (2024), Díaz et al. (2015), Donadelli, Grüning, et al. (2021), Donadelli, Jüppner, and Vergalli (2022), Drescher and Janzen (2025), Ellena et al. (2022), Falk (2013), Felbermayr et al. (2022), Gupta et al. (2023), Hoffmann et al. (2022), Jennings and Gray (2015), Khan, Morzuch, and Brown (2017), Kotz, Wenz, et al. (2021), Linsenmeier (2023), Lis and Nickel (2010), J. A. López-Bueno, Díaz, and Linares (2019), J. A. López-Bueno, Linares, et al. (2020), José Antonio López-Bueno et al. (2021), J. A. López-Bueno, Díaz, Sánchez-Guevara, et al. (2020), J. A. López-Bueno, Navas-Martín, et al. (2022), Mannell et al. (2024), Marinaccio et al. (2019), Martínez-Solanas and Basagaña (2019), Middelanis et al. (2023), Mosquera-López, Uribe, and Joaqui-Barandica (2024), Mumtaz and Theophilopoulou (2024), Pablo-Romero, Pozo-Barajas, and Sánchez-Rivas (2019), Paglialunga, Coveri, and Zanfei (2022), Peillex et al. (2021), Russ (2020), Schmitt et al. (2022), Sheng et al. (2023), Ubilava (2017), Ubilava and Abdolrahimi (2019), Verschuur, Koks, and Hall (2023), Möllendorff and Hirschfeld (2016), Waldinger (2024), Wasko, Sharma, and Pui (2021), Zou et al. (2024)	51
Use population-weighted weather data	Bastos, Straume, and Urrego (2013), Bigerna (2018), Cai et al. (2016), Chabot and Bertrand (2023), Ciccarelli, Kuik, and Martínez Hernández (2024), Colelli, Wing, and De Cian (2023), Huang and Hong (2024), Kahn et al. (2021), Karlsson and Ziebarth (2018), Kotz, Kuik, et al. (2024), Letta and Tol (2019), Lucidi, Pisa, and Tancioni (2024), Miller et al. (2021), Mukherjee and Ouattara (2021), Otrachshenko and Popova (2022), Otrachshenko, Popova, and Tavares (2021), Otrachshenko, Popova, and Solomin (2017), Quante et al. (2024), Rubio-Cabañez (2024), Saucy et al. (2021), Schleypen et al. (2022), Vielma et al. (2024)	22

Note: NP denotes the number of publications.

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