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Climate services in the tourism sector: From data to service design and delivery decisions

1. Introduction

Tourism is a climate-sensitive sector that is strongly influenced by the state of the natural environment (Scott *et al.*, 2019). Favourable climate conditions enhance a destination's attractiveness, visitor participation and tourism expenditures (Lemesios *et al.*, 2024; Baños-Pino *et al.*, 2023), while adverse climate events pose risks to tourists and reduce visitor numbers (Steiger *et al.*, 2024; Hewer, 2020). The potential impacts of climate and weather therefore dynamically drive a range of aspects of tourism planning, including tourists' destination choices, operators' resource allocations and destinations' adaptation strategies (McKercher *et al.*, 2023; Poli *et al.*, 2024).

To address these complex planning needs, climate services (CSs) have emerged as critical tools for tourism stakeholders. Defined by the World Meteorological Organization (WMO, 2025b) as 'the provision and use of climate data, information and knowledge to assist decision-making,' CSs support tourism planning across different temporal scales – from a tourist's real-time choice of activity to the seasonal preparation strategies and long-term infrastructure investments made by destinations and resorts (Scott and Lemieux, 2010).

Over the past decade, research has deepened our understanding of the two-way relationship between climate and tourism, with research methodologies and service scopes continually expanding (Scott *et al.*, 2011; De Freitas, 2017; Rutty *et al.*, 2021). Despite the growing consensus that the use of climate information is primarily a social science challenge, the production and delivery of CSs are still approached as a matter of natural science (Findlater *et al.*, 2021). A systematic review is therefore necessary to evaluate current research on CSs in tourism, identify gaps and guide further developments.

Three key factors highlight the timeliness of this systematic review for future tourism service studies. First, rapid advances in climate science and information technology are creating new opportunities to innovate CSs. Second, the changing climate is shaping future travel patterns and increasing the complexity of decision-making in tourism, particularly as climate perceptions vary between generations (Schönherr and Pikkemaat, 2023). Third, there is a need to bridge the divide between climate science capabilities and the actual information needs of tourism stakeholders (Jebeile and Roussos, 2023). This review is therefore guided by the following interconnected research questions (RQs):

RQ1. What is our current knowledge of CSs for various tourism activities?

RQ2. How are CSs in tourism produced and delivered?

RQ3. What are users' needs for and barriers to using CSs in tourism?

RQ4. What are the implications and directions for further research on CSs in tourism?

These RQs seek to examine the current status and potential of CSs in tourism. For researchers, this review identifies critical theories and methods for further study and provides a framework for understanding CS production and delivery mechanisms in tourism; for practitioners, it offers insights into key areas for improving effective CS delivery and utilisation. The rest of the paper is structured as follows: Section 2 reviews the literature on climate and tourism decision-making, with an examination of CS development in tourism. Section 3 details the methodology. Section 4 presents findings, addressing the first three RQs. Sections 5 and 6 address the last RQ by discussing the implications, suggesting future research directions and offering conclusions.

2. Related literature

2.1 Climate, weather and tourism

As defined by the WMO (2025a), 'weather' is the transient state of the atmosphere, while 'climate' describes the long-term average weather conditions for a particular location. Climatic elements therefore act as both appealing and limiting factors, influencing both tourist decisions and tourism operations (De Freitas, 2003). People generally seek places with the greatest comfort and aesthetic experience of climate conditions (Gómez-Martín, 2005). The demand for a favourable climate has thus spurred the development of various nature-based tourism products, such as sun and beach tourism, snow tourism and winter sports tourism. Climate is consequently considered an intangible destination asset and a crucial factor in shaping the image of a destination (Day *et al.*, 2013).

Climate not only directly generates tourism but also works alongside other basic resources to influence tourism development (Gómez-Martín, 2005). Changes in climate and weather can significantly affect tourists' destination choices, satisfaction during visits and even spending behaviours (McKercher *et al.*, 2023; Shen *et al.*, 2023). Climate-driven landscape transformations, such as rising sea levels and shifting snowfall patterns, also either enhance or detract from a destination's image, visitor numbers and economic performance (Seetanah and Fauzel, 2018; Liu *et al.*, 2021). To mitigate these impacts, adaptive strategies have been extensively researched, including preparing facilities for extreme climate events (Huynh and Piracha, 2019), risk communication optimisation (Psaroudakis *et al.*, 2021) and substitution and coping strategies (McCreary *et al.*, 2019). Long-term climate change is also reshaping future travel patterns, promoting sustainable tourism practices (Butler, 2024; Mihalic, 2024) and requiring stakeholders to balance climate-related opportunities and risks (Liu *et al.*, 2025). This evolving landscape underscores the urgency of converting climate and weather data into useful products and services.

Tourism climatology is an interdisciplinary field bridging tourism and climate research that was first comprehensively discussed at a workshop held by the International Society of Biometeorology's Commission on Climate, Tourism and Recreation (CCTR; Matzarakis and De Freitas, 2001). De Freitas (2017) reviewed the development and conceptual underpinnings of tourism climatology since then – particularly advances in the multifaceted climate–tourism interface. With the enhancement of research on the relationships between climate and tourism, the focus of this field is gradually shifting towards more systemic and interdisciplinary perspectives, including addressing the challenges of collaborative partnerships and systems resilient to extreme weather events (Rutty *et al.*, 2021).

2.2 Climate services in tourism

At the third World Climate Conference, the WMO proposed the Global Framework for Climate Services (GFCS) to support, strengthen and coordinate the development, delivery and use of CSs at the global, regional and national levels (see Figure 1). The GFCS provides guidance for large-scale CS deployment, which paradoxically reveals the need to review smaller-scale empirical research at the local level.

A foundational review by Scott and Lemieux (2010) of early CS applications in tourism informed later research, and following the WMO's report identifying tourism as an application sector (Kolli, 2014), advances in climate modelling precision (Giorgi, 2019) and big-data analytics for tourism management (Li *et al.*, 2018) catalysed further research in the field. CSs now range from standard short-term products like forecasts and warnings to customised long-term solutions for destination management (Damm *et al.*, 2020; Matthews *et al.*, 2021).

CSs have always been a key focus of the CCTR for addressing climate change risks, opportunities and tourist well-being (Rutty *et al.*, 2021). However, practical implementation in tourism still has ongoing issues, such as supply-demand gaps and the identification of needs through assumptions rather than investigations (Mahon *et al.*, 2021; Findlater *et al.*, 2021). Considering the new opportunities brought by digital innovations, technological breakthroughs and advances in tourism climatology, a systematic review is thus essential to benchmark recent progress, identify existing gaps and determine emerging research priorities in this evolving field.

3. Methodology

To identify eligible articles, this paper employs the preferred reporting items for systematic reviews and meta-analyses (PRISMA) framework (Page *et al.*, 2021) to ensure a replicable, scientific and transparent process with minimal bias. This section details the review process and outlines the steps for article selection, screening and assessment.

3.1 Data search

Four databases were used to select the publications for analysis: Web of Science, Scopus, ScienceDirect and Taylor & Francis Online. Data were collected in October 2024 using the search string shown in Table I on titles, abstracts and keywords fields.

3.2 Data screening and selection

From an initial 895 articles, 287 duplicates were removed. The remaining records were further screened against the following criteria to ensure their relevance: 1) original, peer-reviewed research articles rather than book chapters, conference proceedings, literature reviews or commentaries; 2) publication in English-language journals; 3) publication between 2014 and 2024; and 4) a focus on climate or weather information products or services within the tourism context.

The article selection process is illustrated in Figure 2 using the PRISMA flow diagram. A detailed screening of titles, abstracts and full texts, together with a snowball method for identifying other relevant literature from article references, resulted in 69 articles for inclusion in the final review.

3.3 Data analysis

For the final included articles, bibliometric data – including year of publication, publication journals, research methods, geographic distribution, tourism types and related climate variables – were initially recorded in a spreadsheet to capture basic characteristics and address RQ1. The qualitative data analysis software NVivo 14 was then used to synthesise relevant content from the articles to address RQ2 and RQ3 (O’Neill *et al.*, 2018). The results are reported in the next section.

4. Review findings

4.1 General article information

4.1.1 Publication details

Figure 3(a) illustrates the evolving research landscape of CSs in tourism over the past 10 years. Although there have been fluctuations in frequency, the overall volume of publications shows a gradual upward trajectory. In terms of publication sources, 69 of the included articles originated from 35 journals across various disciplines. Figure 3(b) presents the top 10 journals ranked by quantity, showing that most articles were published in the fields of climatology and meteorology, followed by tourism, hospitality and leisure studies. A few articles also originated from geography, environmental science, information science and other fields.

4.1.2 Geographic distribution and tourism types

Applying the United Nations World Tourism Organization's (UNWTO, 2019) classifications to the included articles, five tourism types were identified: coastal tourism, mountainous and natural tourism, snow tourism, urban tourism and rural tourism, as shown in Figure 4. If a study covered multiple tourism types at one or more destinations (Zhang *et al.*, 2022; Velea *et al.*, 2022), each type was recorded separately; if the tourism type was unspecified in the study, it was classified as 'general'.

As shown in Figure 4, the most featured region was Europe (36), followed by Asia (21) and North America (7), with fewer articles from other continents. In the European context, coastal tourism – particularly in the Mediterranean region, such as Spain and Greece – was the most frequent research topic, followed by urban tourism, snow tourism and mountainous and natural tourism. In contrast, studies in Asia most commonly fell under the 'general' category, meaning they featured comprehensive analyses or comparisons across broad regions; urban tourism and coastal tourism in Asia also featured relatively frequently.

In terms of tourism types, coastal tourism – or '3S' (sun, sea and sand) tourism – was the most frequently examined category. Studies on coastal tourism typically focus on summer, when sunshine and warm temperatures create ideal conditions for activities such as swimming, surfing and sunbathing (Rutin, 2010). These coastal leisure activities are highly sensitive to temperature, wind conditions, sea-surface conditions, sunshine and severe weather. CSs are therefore essential for monitoring climate variables to determine the optimal timing for such activities (Nalau *et al.*, 2017).

Snow tourism has an even stronger seasonal dependence and primarily occurs in winter and early spring. Winter activities like skiing and snowmobiling depend on snow resources in traditional high-latitude and high-altitude regions, such as the Alps and Arctic (Mayer *et al.*, 2023; Lamers *et al.*, 2018), or are popularised by sporting events like the Winter Olympics (Yu *et al.*, 2024). Forecasting snowfall quality and quantity is therefore essential for snow tourism operations (Köberl *et al.*, 2021). These tourism types are also closely linked to their climate conditions, which in turn influence the design and delivery of CSs.

Urban tourism ranks as the second most prevalent type overall and offers a wide range of cultural, architectural, technological, social and natural activities (e.g., sports events, sightseeing, shopping) in urban spaces. This is followed by mountainous and natural tourism, which takes place in geographical areas like hills or mountains and involves outdoor leisure activities such as camping, heritage sightseeing and national park excursions. Both urban tourism and mountainous and natural tourism prioritise thermal comfort analysis, but most of the studies showed no specific seasonal preference, with a minority focusing on summer.

4.1.3 Theories and methods

Of the 69 articles, only nine explicitly stated their underpinning theories, while most followed a data-driven climate science approach without evident theoretical guidance. The theories and concepts mentioned are primarily related to decision-making, such as prospect theory (Nguyen and Chang, 2023), risk aversion (Köberl *et al.*, 2021) and the Driver-Pressure-State-Impact-Response model (Ding and Liang, 2021). Additionally, a few articles drew on co-creation theory (Font Barnet *et al.*, 2021; Morin *et al.*, 2021) from design studies, the regional adaptation framework (Huynh and Piracha, 2019) from environmental science or the practice-arrangement bundle (Lamers *et al.*, 2018) from sociology.

As illustrated in Figure 6, the included articles predominantly employed quantitative research methods. The most frequent such method was climate data analysis (35), which assesses a destination's climate suitability based on historical climate data. Similarly, climate model simulation (13) predicts future tourism suitability through computer modelling. Questionnaires and surveys (14) were also commonly used to understand end users' perceptions of CSs or the influence of climate factors on tourist behaviours.

Qualitative studies were less prevalent, with interviews (7) the primary method for gathering insights from stakeholders' viewpoints and both workshops and focus groups (3) facilitating collaborative insights. Other approaches included design-based research (5) related to CS application systems and case studies (4) to examine CS scenarios.

4.2 Key components of CSs in tourism

Three main components of CSs in tourism emerged from the reviewed articles: tourism climate indexes, climate models and interactive information products. Drawing on the GFCS framework, Figure 7 illustrates these components in the process of transforming intangible climate data into actionable information.

4.2.1 Tourism climate index

Research on climate indexes is extensive. These indexes can be classified into two categories: The first comprises indexes of human thermal perception, such as Physiological Equivalent Temperature (PET) and the Universal Thermal Climate Index (UTCI), and the second consists of composite indexes, which typically blend thermal, physical and aesthetic facets of the tourism climate (De Freitas, 2003). Notable examples of the latter category are the Tourism Climate Index (TCI; Mieczkowski, 1985) and the Holiday Climate Index (HCI; Scott *et al.*, 2016), which are prevalent in the included articles. Moreover, researchers are increasingly developing specialised indexes tailored to particular tourism activities, such as the Ski Climate Index and the Camping Climate Index (Demiroglu *et al.*, 2021; Ma *et al.*, 2020). These indexes convert meteorological data into readable and comparable information for tourism planning.

4.2.2 Climate model

The studies in this review related to prediction models predominantly focused on long-term climate models, with limited attention to short-term weather forecasting models. Climate models are an essential component of CSs. Common examples are the Global Climate Model (GCM) and the Regional Climate Model (RCM), with the latter more frequently used in the included articles due to its higher resolution and localised outputs. These climate models typically use over three decades of historical observational data to project future climate conditions under standardised climate scenarios across multi-decadal timescales (Demiroglu *et al.*, 2021; Morin *et al.*, 2021).

4.2.3 Climate information products and services

Information products and services are the most comprehensive forms of CSs, integrating data from climate indexes and climate model analyses. They enable users to access and understand processed climate data, offering functions that support a range of tourism decision-making.

Table II summarises the functions of the CSs from the included articles. The most frequently mentioned function assesses the climate suitability of a destination, including current evaluations and future predictions, using long-term climate index calculations. Another common focus was on climate and weather information hubs, which provide climate data from historical records for short-term forecasts and long-term projections. Some of the studies also focused on early warnings and risk communication for extreme weather events, particularly for outdoor attractions. There were also climate-based tourism recommendation services, such as travel planning recommendations for tourists and market evaluations for operators. Current CSs retain the core functions of those reviewed by Scott and Lemieux (2010) but with a growing emphasis on long-term climate analysis and climate suitability assessment. Furthermore, weather derivative products, such as tourism market evaluations and insurance, remain underexplored in academic research, indicating a lack of cross-sector collaborations.

4.2.4 Stakeholders and their roles

From the WMO's definition of CSs and a consensus of the relevant literature, CS stakeholders can be broadly categorised as either providers or users (see Table III). CS providers can be classified into three types: 1) ***research institutions and universities*** – the main entities conducting academic climate tourism research; 2) ***national meteorological and hydrological services (NMHSs)*** – responsible for monitoring and collecting raw climate data and for developing climate and weather services for research and public use; and 3) ***private businesses*** – these are the least frequently mentioned and use secondary climate data to provide services to the public. Additionally, regional initiatives, like the INDECIS and Copernicus Climate Change Service (C3S) projects, involve partnerships across multiple provider groups for larger-scale actions.

The CS users in tourism are many and diverse (Scott *et al.*, 2011) and can be categorised into five main types: 1) ***government agencies*** – local policymakers and tourism departments, excluding NMHS departments, that use climate data for policy and planning; 2) ***destination management organisations (DMOs)*** – the leading organisational entities that coordinate and manage destinations' development and marketing; 3) ***attraction and event operators*** – responsible for the operation and management of specific attractions or big events; 4) ***private service businesses*** – operators of climate-sensitive businesses, which are typically small to medium-sized; and 5) ***tourists*** – individuals or groups engaging in recreational activities.

Early studies mainly examined CSs from a single perspective – either providers or users. However, the current review identified a promising trend of more studies seeking to integrate both perspectives and proposing the co-production of CSs by providers and users. This possibility reflects the increasingly diversified and dynamic roles of tourism stakeholders.

4.3 Production and delivery of CSs in tourism

The production and delivery phases involve observing climate data, processing data with tourism objectives and developing applications. CS providers are the main actors in these phases.

4.3.1 Development process

In the included articles, raw climate data are mostly collected from the infrastructure of NMHSs (i.e., meteorological stations). Research institutions can then access the data via open APIs from national weather networks to analyse specific destinations, which was the most common approach identified in this review. A few studies supplemented official data with researcher-deployed micro weather stations or crowdsourced citizen-contributed data (Psaroudakis *et al.*, 2021; Ciurana and Aguilar, 2020). Compared to official approaches, such data collections spanned shorter durations – from days to months.

To improve index accuracy and better align CS offerings with user demands, some research has engaged tourism specialists (i.e., industry representatives) in the development process (Font Barnet *et al.*, 2021; Morin *et al.*, 2021). However, research on this collaborative approach is still in its early stages.

4.3.2 Information delivery channels

Climate and weather information has two main delivery channels: media tools and mediators. Media tools dominate current practices – for tourists, primary delivery channels include mobile apps, official or private websites and web portals, social media and e-mail alerts (Rutty and Andrey, 2014). Webcam access is also used to enhance tourists' engagement with destination scenarios (Ciurana and Aguilar, 2021; Gómez-Martín *et al.*, 2017). While early studies noted then-emerging digital CSs (Scott and Lemieux, 2010), advances in social media and web technologies now enable real-time, cross-regional weather updates. Additionally, on-site delivery channels include billboards and display screens, while traditional media such as TV and radio broadcasts remain in use but are critiqued for their generality and inaccuracy (Nalau *et al.*, 2017).

Mediators – both institutions and individuals – also facilitate information delivery. Tourists can consult local experts or acquaintances (Nalau *et al.*, 2017), while tourism operators can obtain information from counterparts or industry networks (Mahon *et al.*, 2021).

Table IV presents the frequency with which the information delivery channels were mentioned in the included articles. Although digital tools, such as mobile apps and websites, are now the most common delivery methods in practice, a significant portion of the articles addressed decision-making information in visual and text formats through research publications rather than through media tools or mediators.

4.3.3 Information presentation formats

Designing accessible formats is critical for translating climate data into comprehensible information for non-expert users. Among the research articles, numeric calculated climate index data might be transformed into intuitive ratings (e.g., 'ideal,' 'acceptable' and 'dangerous'), while the Climate Tourism Information Scheme (CTIS) tool (Matzarakis, 2014) converts the ratings into colour-coded blocks within a visual climate calendar to help identify optimal visit times. Visualisation tools, such as GIS, might also be used to vividly display climate patterns on visual maps.

For climate and weather information delivered via media tools, such as weather forecasts in mobile apps, common formats included written descriptions with numeric values, graphics (e.g., charts, maps) and real-time webcam imagery. Some studies also suggested emoticons or colour coding to simplify complex information for non-expert users (Font Barnet *et al.*, 2021), enabling them to assess conditions at a glance.

4.4 Utilisation and challenges of CSs in tourism

4.4.1 Climate- and weather-related decisions

The CS users' decisions mentioned in the included articles at different levels and time scales are shown in Table V. The highest-level decisions are strategic and made by local authorities using long-term climate projections. These then inform marketing and operational decisions for destinations and attractions using short- to mid-term climate information. On a shorter timescale, tourists plan and adjust their itineraries according to weather forecasts. A few of the studies also analysed disaster risk reduction activities, which engage multiple stakeholders in early prediction, warning and evacuation in response to extreme weather events.

4.4.2 Barriers to using climate information

The effective uptake of CSs in tourism faces several significant barriers, including users' capabilities, the content of CS provision, the usability of CS tools and the cost of CS access.

1) Limited user knowledge and trust

Research shows that potential users may not fully recognise climate risks, which diminishes the perceived urgency of CS adoption. Some stakeholders may also have difficulty finding reliable climate data or understanding the uncertainties in forecasts, fostering both distrust and reluctance to use CSs (Damm *et al.*, 2020; Nalau *et al.*, 2017). This knowledge and trust gap hinders informed and adaptive decision-making.

2) Gap between CS provision and user needs

Research emphasises the importance of providing CSs that fit users' specific demands and the geographic and climatological contexts of the relevant locations (as indicated in Figure 5). However, research also indicates that the available information itself may not be precise or accurate enough for users to make confident decisions (Ciurana & Aguilar, 2021). Further studies suggest that many CS offerings fail to meet users' specific needs; for instance, weather websites rarely adapt information to tourism activities (Gómez-Martín *et al.*, 2017).

3) Difficulty in understanding and using CS tools

Because most CS providers are research institutes and climate professionals, they tend to prioritise the accuracy of climate data over user-friendly design. This can result in overly technical outputs that challenge non-expert users. For example, technical language can make it difficult for users to extract useful information, while descriptive text may convey vague information that confuses them (Gómez-Martín *et al.*, 2017). Even customised information can be 'too basic and too flowery' to support operational decisions (Nalau *et al.*, 2017). This highlights the need for more effective CS translation tools to support users' understanding.

4) Financial and capacity constraints

Research indicates that tourists and recreational users have a relatively low willingness to pay for CS app subscriptions. Businesses with financial constraints are also more inclined to allocate funds to other, seemingly more urgent, matters (Psaroudakis *et al.*, 2021). The impacts of climate and weather may appear negotiable rather than urgent when budgets are tight; overcoming this barrier may therefore require innovative business models in the CS market.

5. Discussion

Based on the results of RQ1–3, this section aims to explain the theoretical and practical implications for both researchers and practitioners; it also presents existing research gaps and proposes future research directions.

5.1 Theoretical implications

This systematic review updates our knowledge of CSs in tourism by examining their development, delivery, usage and gaps. The review articles by De Freitas (2017) and Rutty *et al.* (2021) summarised the research progress on climate and tourism over the past decade in expanding our understanding of complex climate–tourism relationships. Their analyses are consistent with our findings that most relevant articles are grounded in norms and frameworks that are part of climate science, showing how local climate and weather affect tourism and how CSs are designed and delivered. The research methods we identified were data-driven and predominantly quantitative (see Figure 6), indicating a significant methodological imbalance. This focus on numeric data creates a scientific dilemma in which researchers (or CS providers) put too much emphasis on climate data while neglecting qualitative factors, such as users' experiences, attitudes and demands. This insight aligns with Findlater *et al.* (2021), who argued that, although CSs promise better decisions for users, they primarily focus on better data accuracy.

A few studies in this review focused on the co-production of CSs in tourism, indicating a shift from analysing climate–tourism correlations to adopting a user-centred perspective on service design. However, viewing research from the users' perspective is not widespread, leaving many key issues unanswered, such as whether user demands align precisely with climatic variables, how cross-sectoral collaborations enhance CSs and whether users can contribute insights and resources rather than being merely service consumers. This indicates a theoretical gap in the field and underscores the need for interdisciplinary research. Integrating concepts, theories and methods from other social science fields is therefore an imperative, such as the servitisation of CSs (Harjanne, 2017) or theories of production (Vincent *et al.*, 2018).

The current study also facilitates the understanding of CSs in tourism by providing a framework that outlines the key elements of and mechanisms between the supply and demand sides (see Figure 8). The framework illustrates how climate data is collected by the provider community and transformed into actionable information to support the user community and reveals a predominantly supply-driven process. However, a research trend towards demand-driven approaches is emerging that emphasises user engagement and collaboration; nevertheless, there remains a lack of explicit guiding frameworks. The framework in Figure

8 presents a comprehensive picture of the existing mechanisms of CS design and delivery, offering a reference for future theoretical development in this field.

5.2 Practical implications

While many of the included articles claim to contribute to tourism stakeholders, their academic language and complex data presentations prevent non-expert users – especially private service businesses and tourists – from seeking and fully understanding scientific recommendations. Currently, separating providers from users is a common practice in the CS field, yet this divide hampers mutual understanding. Future work should therefore explore strategies to bridge this binary divide. One potential approach identified in the review is to establish bidirectional or multilateral collaboration methods, such as climate information brokerage mechanisms (Mahon *et al.*, 2021), or positioning researchers and designers as intermediaries to facilitate co-creation (Font Barnet *et al.*, 2021).

ICT advances have also introduced novel communication techniques. Examples include real-time monitoring via webcams (Ciurana and Aguilar, 2021), semantic web-enabled knowledge graphs for tourism advice (Wu *et al.*, 2023) and geospatial vulnerability mapping (Camatti *et al.*, 2024). These suggest the potential for emerging technologies, such as AI, to enhance CS design and delivery.

5.3 Future directions

The final objective of this study is to identify existing gaps and propose future research directions. Building upon the findings, several promising areas are outlined in this section.

5.3.1 Demand-driven framework for CSs in tourism

While the GFCS offers macro-level and international guidance, there remains a lack of micro-level and localised frameworks for researchers and practitioners to develop and deliver CSs based on real needs. This review found that the development of CSs is predominantly supply-driven and linear, with research institutions, universities and NMHSs taking the lead. Although some studies acknowledge the importance of understanding user demands, researchers often start with their expertise and then presume users' needs rather than genuinely investigating them. This supply-driven approach stems from the singular reliance on climate science to the neglect of knowledge and methodologies from other relevant disciplines.

Future work is therefore needed to improve the theoretical foundations for the application of CSs in tourism. A demand-driven framework should be developed that integrates knowledge and theories from climate science, service design, tourism management and other areas to advance the emerging field. Additionally, more qualitative research is needed to properly understand users alongside the existing data-driven approaches that emphasise climate data precision.

5.3.2 In-depth investigation of diverse user needs

The review indicated that the needs of tourist users are complex and vary by demographics, geographic location and tourism type. For instance, government agencies and DMOs mainly use long-term climate projections for infrastructure and service planning (Miszuk *et al.*, 2016), while tourists and businesses are more interested in short-term weather information for immediate travel plans and operations (Damm *et al.*, 2020). However, some of the articles used vague terms such as 'tourism stakeholders' or 'tourism operators', without clearly identifying the user types. Although the research outcomes appear to cover many users, the failure to address context-specific user needs undermines the precision of the CSs and the users' trust in them.

Additionally, as Rutty *et al.* (2021) noted, climatology research is highly concentrated in temperate, developed countries – especially in Europe – which is consistent with the findings of the current review. Studies in Asia, which were second most common in the review, have appeared only since 2019. Dominant tourism types also differ between regions, exacerbating the impact of the geographic imbalance in the research and underscoring the differences between cultural contexts. CS design must therefore be tailored to specific tourism types, regions and demographics because distinct needs may exist.

5.3.3 Design of communication tools for translating climate information

Although early studies stressed the need to deliver climate information in forms that are relevant and interpretable by users (Scott *et al.*, 2011), the reviewed articles still show communication gaps. Many articles highlighted issues with weather websites or portals, such as overly complex information presentation and technical jargon that prevent non-experts from understanding the data. Furthermore, despite some of the papers claiming that their findings benefit users, non-experts in the tourism sector are unlikely to consult journal articles, indicating a disconnect between climate science research output and practical applications.

A key insight from this review is the need to explore how climate information tools can be designed to be more user-friendly. Emerging information and communication technology breakthroughs like the IoT and AI offer opportunities to bridge this divide. For instance, next-generation tools could employ machine learning to dynamically adapt information based on a user's profile and provide destination-specific advice. Furthermore, communication challenges are faced not only by users but also by providers. Although researchers have suggested enabling scientists – the CS providers – to construct better data and information portals (Bessembinder *et al.*, 2019), it might be unrealistic to expect climate experts to independently design user-friendly communication tools. This is where intermediary roles, like brokers and designers, could help. Effective communication should be a two-way process, enabling users to understand and act on information while informing climate experts about the format and content they should provide.

5.4 Limitations

While this review offers insights into current CS research, it has limitations. First, the scope of the review is not confined to particular tourism types, user types or geographic contexts, meaning the findings may lack specificity. Future research could benefit from a more detailed examination of spatio-temporal scales and user segmentation. Second, this review only includes journal articles, which ensured peer-reviewed quality but potentially overemphasised the scientific community's role, neglecting industry practitioners. Future reviews could benefit from incorporating rigorously reviewed cases and reports of successful CS applications in tourism for a more comprehensive perspective.

6. Conclusion

CSs are used in the tourism sector to support operational and management decisions and enhance tourist well-being. This systematic review explored the status and trends in research into the design and delivery of CSs in tourism. It identified key stakeholders and their roles, examined production mechanisms and pinpointed four primary barriers to effective CS use: limited user knowledge and trust, a gap between the content of CS provision and users' needs, difficulty in comprehending and using CS tools and financial pressure and capacity constraints. Insights from the review suggest the establishment of a demand-driven framework for CS development, with theoretical and methodological enhancements; investigations into the diversity of user demands for tailored services; and improvements in the usability of communication tools. The review also found an overemphasis on data in current tourism CS research, further highlighting the need to shift the focus of future research from merely generating better data towards better service design and delivery.

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Table I. Terms used to search articles' titles, abstracts and keywords. (Source: authors)

'climate service$' **OR** 'climat* information' **OR** 'weather service$' **OR** 'weather information' **OR** 'meteorolog*'
AND
'touris*' **OR** 'recreation' **OR** 'leisure'

Note. The dollar sign ($) represents zero or one character. The asterisk (*) represents any number of characters, including none.

Table II. Functions of CS usage in the included articles. (Source: authors)

Type of function	Function of CSs in tourism	Article count
Destination climate suitability assessment	Tourism climate suitability assessment	28
	Future tourism climate suitability prediction	12
Climate and weather information hub	Weather forecast	19
	Weather nowcast	3
	Seasonal climate forecast	3
	Historical database	1
Others	Tourism information and recommendation	4
	Early warning and risk communication	2
	Tourism market evaluation	1

Table III. Main types of CS providers and users in the tourism sector. (Source: authors)

CS providers		CS users	
Type	**Example**	**Type**	**Example**
Research institutions and universities	Major universities	Government agencies	Local authority, policymakers, tourism department
National meteorological and hydrological services (NMHSs)	National Oceanic and Atmospheric Administration (NOAA),	Destination management organisations (DMOs)	Tourism office, national park authority
	China Meteorological Administration (CMA)	Attraction and event operators	Resort operators, ski resort operators, sports event planners
Private businesses	Private weather services, tourism consultancies	Private service businesses	Hoteliers, tour operators, surfing schools
Collaboration	INDECIS, C3S	Tourists	Surfers, skiers, recreationists

Table IV. Delivery channels for climate and weather information. (Source: authors)

Category	Information delivery channel	Article count
Digital media	Mobile app	9
	Website	8
	Web portal	4
	Social media platform	2
	Webcam access	2
	Noticeboard and display screens	2
	E-mail	1
Traditional media	TV and broadcast media	4
Mediators	Individual (acquaintances)	1
	Institution (counterparts)	1
Others	Research publication	32

Table V. Main types of CS users' decisions. (Source: authors)

Decision Type	Actions	Users	Example
Strategic	Strategy and policymaking	Government agencies	The result … is an important and necessary sciential basis which helps the orientation of development and tourism territory organisation of the governments. (Van *et al.*, 2019)
	Site and type planning	Government agencies; DMOs; attraction and event operators	Information primarily facilitated upstream decisions like siting new tourism operations related to the physical development process. (Mahon *et al.*, 2021)
	Infrastructure and services investment		Tourism stakeholders can utilise this information to … invest in infrastructure and services. (Yu *et al.*, 2023)
Marketing and promotion	Marketing campaign	DMOs; attraction and event operators; private service businesses	It will be important to carry out a change in promotional planning according to changes in weather conditions. (Font Barnet *et al.*, 2021)
Operational	Operational management	DMOs; attraction and event operators; private service businesses	PROSNOW® represents a meteorological prediction and snow management system for ski resorts. (Köberl *et al.*, 2021)
	Adaptive management		It is important to have a 'plan B' of alternative activities and tourist products for customers. (Font Barnet *et al.*, 2021)
	Pricing and budgeting		Long-range forecasts were mostly used for marketing and finance and budgeting. (Ayscue *et al.*, 2015)
	Communication with tourists		The company displayed daily weather forecasts on their notice board, more for the information of tourists. (Nalau *et al.*, 2017)
Disaster risk management	Risk assessment and management	Government agencies; attraction and event operators; tourists	Establishing concrete procedures for evacuating the visitors in case of an emergency. (Psaroudakis *et al.*, 2021)
Travel	Itinerary planning	Tourists	Serve as information for tourists concerning the timing of travel and the destination choice. (Damm *et al.*, 2020)
	Travel preparation		Planning how to dress oneself or one's children. (Rutty and Andrey, 2014)
	Adaptive and adjustment actions		Skiers are likely to reschedule their visits or select different gear (clothing). (McCreary *et al.*, 2019)