

## Article

# A Review of Climate-Related Indices for Insurance Risk Management and Resilience

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## Abstract

Climate change is reshaping risk worldwide, with many extreme events becoming more frequent and severe. Insurance plays a critical role in societal resilience by providing financial protection against climate-related losses. Climate indices translate climate information into actionable metrics that can support risk assessment, risk management, and resilience. Yet their diversity and broad scope make their application challenging. This paper reviews climate-related indices by grouping them into six categories and summarising their purpose and potential insurance applications. The review highlights how different types of indices can support actuarial functions across the insurance sector and emphasises the need for purpose-built indices that incorporate socio-economic characteristics alongside climate information to improve risk assessment and help address the climate protection gap.

**Keywords:** climate risk; risk assessment; risk management; climate resilience; parametric insurance

## 1. Introduction

Climate change is one of the most serious challenges of the 21st century, affecting ecosystems, economics, financial systems, infrastructure, and human well-being [1]. Within the hazards and climate risk literature, a substantial body of research has documented the economic impacts of extreme weather events, including direct damages to assets and infrastructure, indirect disruptions to economic activity, and broader consequences for financial and insurance systems [2–4]. Global economic losses from weather-related disasters have increased markedly over recent decades, driven not only by changes in hazard frequency and intensity, but also by growing asset exposure in vulnerable regions and persistent gaps in insurance coverage [2,5]. Evidence from catastrophe loss databases, including Munich Re NatCatSERVICE and Swiss Re sigma, further indicates that weather-related events account for a major share of disaster-related economic damages globally, while the gap between total and insured losses remains substantial in many regions, highlighting the persistent climate protection gap [6,7]. As climate impacts intensify and financial exposure grows, the need for reliable monitoring tools becomes increasingly important. In this context, climate indices help identify patterns and trends across regions and over time [8,9].

In general, an index is a tool that translates complex data into a single metric, enabling straightforward interpretation, monitoring, and comparison across regions. Similarly, in climatology, climate indices are developed to characterise climate conditions, detect anomalies, capture trends, and quantify variability. These indices are commonly derived



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from physical climate variables such as temperature, precipitation, wind patterns, and sea level. Climate indices are widely used for diagnostics and play a crucial role in climate modelling, forecasting, and assessing the socio-environmental impacts of climate change [8,9].

Over time, climate indices have evolved from relatively simple diagnostic tools into a diverse set of indicators used across scientific, policy, and financial domains. Early climate indices were developed as simple tools to track large-scale atmospheric and oceanic patterns, detecting anomalies and helping to understand climate dynamics, such as the El Niño–Southern Oscillation (ENSO) and the North Atlantic Oscillation (NAO) [10,11].

As observational datasets expanded and awareness of climate change and climate variability increased, climate indices began to play a broader role in tracking long-term trends and extremes. Indices based on temperature, precipitation, and heat extremes were increasingly used to assess changes in the frequency and intensity of climate hazards and to support climate model evaluation and impact studies [8]. At the same time, growing evidence of rising weather-related losses highlighted the relevance of climate indicators from scientific monitoring to practical applications in risk management and policy. Increasing economic damages from weather-related disasters and associated insurance losses have underscored the need for risk metrics that capture evolving hazard patterns and support societal decision-making [5].

Climate indices are now used beyond scientific research and climate monitoring. They increasingly inform policy discussions, regulatory frameworks, ESG (Environmental, Social, and Governance) investment strategies, insurance risk models, and public communication. This shift reflects growing demand for tools that connect climate data with real-world decision-making in policy, finance, and planning.

As their use has expanded, climate indices have also become more diverse in terms of purpose and design. Some indices are developed primarily to support policy engagement and performance assessment. For example, the Climate Risk Index (CRI) focuses on the observed impacts of extreme weather events by combining information on economic and human losses [12]. Similarly, the Climate Change Performance Index (CCPI) assesses national mitigation efforts using indicators related to greenhouse gas emissions, renewable energy use, energy efficiency, and climate policy [13]. In parallel, other indices have been developed to support applications in finance, insurance, and actuarial science. The Actuaries Climate Index (ACI) tracks changes in extreme climate conditions relevant to actuarial risk assessment in North America, focusing on physical climate risk [14]. The Actuaries Climate Risk Index (ACRI) extends the ACI framework by linking extreme climate conditions to observed economic losses, thereby providing a more direct connection between physical climate change and financial risk [15].

These differences across climate-related indices reflect variations in purpose, data sources, methodology and scope. Some indices rely solely on meteorological and environmental data, such as temperature, precipitation, or sea level, while others integrate physical climate information with emissions data, socio-economic indicators, or policy-related measures. The methods used to construct indices also vary, from relatively simple statistical calculations to approaches involving expert judgement. This diversity can create challenges when indices are applied outside their original context, particularly in the insurance sector. Because many climate indices were developed for monitoring purposes, they may not always align well with insurance applications or product design.

Despite their growing importance, limited effort has been made to systematically review or compare climate indices in terms of their purposes and applications within the insurance sector. Existing studies often focus on specific indices and their applications, or the economic consequences of climate-related extreme events, with less attention given to

how different indices may support insurance-related objectives. This paper contributes to the literature by reviewing a range of climate-related indices, comparing their characteristics and applications, and discussing their relevance for insurance use.

This paper does not aim to provide an exhaustive catalogue of climate-related indices. Given the large and rapidly evolving number of available indices, the review focuses on representative examples relevant to climate risk assessment and insurance applications. Selection was guided by the extent to which indices are well documented, widely cited, internationally recognised, or influential in practice. Indices that are narrowly sector-specific, poorly documented, experimental, or limited to a single geographic context without broader methodological relevance were not considered. Although not exhaustive, the selected indices capture the principal approaches currently used to characterise climate-related risks and their implications for insurance.

The remainder of the paper is structured as follows. Section 2 presents a comparative review of selected climate indices, organised into different functional groups. Section 3 discusses the relevance and applicability of climate-related indices within the insurance sector, including their use across key actuarial functions and in parametric insurance product design. Section 4 concludes the paper and discusses how climate indices can be better designed and applied to support insurance applications.

## 2. Climate Indices

Given the rapid growth in the number of climate indices, it is not practical to review them all. This paper therefore focuses on a selected set of indices that reflect a range of types, applications, and sectors. Selection was guided by relevance to climate-related impacts and mitigation or adaptation objectives, availability of documentation on structure and methodology, and evidence of use in academic literature, policy reports, or professional practice. Priority was given to indices with broad geographical applicability, along with those recognised by established institutions such as the United Nations (UN), World Meteorological Organization (WMO), European Union (EU), and Environment Agency (EA).

From an insurance perspective, hazard alone is insufficient for understanding climate risk. Two locations exposed to identical climatic hazards may experience substantially different losses due to differences in socio-economic vulnerability, insurance penetration, adaptive capacity, and financial resilience. Consequently, indices that capture the broader context of climate risk are included because they provide complementary dimensions of climate-related insurance risk.

In this paper, the reviewed indices are broadly divided into two overarching groups according to the aspect of climate-related risk they capture. The first group comprises indices that are directly linked to climatic conditions and physical climate risk. This includes weather-related indices and actuarial indices, which use meteorological observations and climate-related extremes to characterise physical hazards and their potential consequences.

The second group comprises indices that provide contextual information on climate-related risk and represent complementary dimensions of climate-related insurance risk. These include environmental and performance indices, vulnerability and readiness indices, social and deprivation indices, and financial indices. Although these measures do not quantify climatic conditions directly, they capture factors that may influence the impacts of climate-related events, including environmental performance, preparedness, socio-economic conditions, and financial system exposures.

The indices are further organised into six functional categories according to these two broad groups:

a. Climate hazard indices:

**Weather-related indices**, based on observed climate and meteorological variables.

**Actuarial indices**, which currently use historical climate extremes to quantify physical climate risk for insurance applications.

b. Climate risk context indices:

**Environmental and performance indices**, which assess mitigation efforts and environmental sustainability.

**Vulnerability and readiness indices**, which integrate environmental and socio-economic indicators to evaluate climate risks and adaptive capacity.

**Social and deprivation indices**, which capture social vulnerability and inequality dimensions associated with climate impacts.

**Financial indices**, which evaluate climate alignment and transition risks within financial markets.

Each index is reviewed using a common set of descriptive criteria, including its purpose, data sources, calculation approach, output format, spatial and temporal coverage, intended users, and key strengths and limitations.

a. Climate Hazard Indices

### 2.1. Weather-Related Indices

Weather-related climate indices are among the earliest and most widely used types of climate indices. They are typically derived directly from meteorological data and are used to monitor changes in the frequency, intensity, and distribution of weather extremes, as well as long-term climate variability.

#### Key Examples

**Climdex:** A collection of climate indices developed by the Expert Team on Climate Change Detection and Indices (ETCCDI) in collaboration with the University of New South Wales Climate Change Research Centre and partners. It includes more than 50 indices derived from daily temperature and precipitation data, capturing different aspects of climate extremes, such as consecutive dry days, frost days, heavy precipitation events, and warm spell durations. These indices provide a globally standardised framework for detecting and analysing trends in extreme weather and climate variability, which focus on historical climate only, not forecasting.

The indices are calculated using station observations and gridded datasets, including Global Historical Climatology Network (GHCN), Gridded Temperature and Precipitation Climate Extremes Indices (HadEX2), and Gridded land surface extremes indices (HadEX3), with coverage generally spanning from 1961 to the present [16]. Climdex is particularly useful for researchers, climate scientists, and adaptation planners who require consistent and comparable indicators of weather extremes over time and space. Its outputs help inform climate impact assessments, regional risk evaluations, and the development of adaptation strategies in both research and policy contexts [17–19].

The Climdex team also provides open-source software including an R-package for calculating the indices using any compatible daily weather dataset. A notable application is the study in [20], which applied the Climdex methodology to assess climate extremes across Central America.

**European Climate Assessment & Dataset (ECA&D):** A Europe-focused climate dataset developed under the European Climate Support Network (ECSN). It provides information on observed changes in weather and climate extremes, offering over 70 indices derived from more than 20,000 daily station observations across 65 countries in Europe and the Mediterranean. These indices capture a wide range of variables, including temperature and precipitation extremes, sunshine duration, snow depth, global radiation, sea level pressure, humidity, wind speed, maximum wind gusts, and prevailing wind direction.

The ECA&D is widely used by national meteorological services, researchers, and climate policy institutions as a key resource for analysing regional climate extremes and variability [21–23]. Its comprehensive, long-term dataset supports applications in climate monitoring across Europe and the Mediterranean. Since 2010, ECA&D has formed the core climate data node for the Regional Climate Centre (RCC) in WMO Region VI (Europe and the Middle East), and contributed to international initiatives such as the Global Framework for Climate Services (GFCS) [24].

In addition to the raw indices, ECA&D provides user-friendly outputs such as interactive maps and time series plots, which help support visualisation of climate extremes and trends. These outputs enhance accessibility for both technical users and decision-makers. To further support research and education, ECA&D also offers downloadable gridded datasets, spanning from 1950 to the present, for non-commercial research use. Its combination of broad spatial coverage, high temporal resolution, and consistent methodology makes it an important resource for evidence-based climate monitoring and decision-making at national and regional levels [24].

Alongside the indices discussed above, several other weather-related indices are widely used in climate analysis. These include the U.S. Climate Extremes Index (CEI), which combines multiple indicators of climate extremes [25]; the Standardised Precipitation Index (SPI) for monitoring drought severity [26]; the Palmer Drought Severity Index (PDSI) for long-term drought tracking [27]; and tools such as the European Climate Data Explorer (ECDE), which provides interactive access to climate indices and datasets for Europe [28].

### **Purpose and Application**

Weather-related indices are widely used to support climate model evaluation, infrastructure planning, disaster risk reduction, and climate impact assessment. They are particularly well-suited to describing historical patterns of climate extremes and variability across regions and time.

### **Strengths**

These indices are derived from direct and standardised meteorological data, ensuring scientific reliability. They are typically supported by well-documented methodologies and updated regularly. Their structure allows for comparison across regions and timescales, and they can be readily integrated into broader climate trend analyses and long-term assessment frameworks.

### **Limitations**

These indices rely on historical data with limited capacity for forecasting future conditions. They do not incorporate socio-economic or ecological impacts, which may limit their usefulness in comprehensive climate risk assessment. In addition, their accuracy depends on dense and quality-controlled observational networks, which may be lacking in data-scarce regions.

## **2.2. Actuarial Climate Indices**

Actuarial climate indices are developed to track climate-related risks with direct relevance to actuarial analysis, especially within the insurance and pension sectors. They focus on extreme climate conditions that may influence long-term liabilities, capital requirements, and solvency. These indices typically combine multiple weather-related variables to capture shifts in climate volatility that may affect outcomes such as mortality, morbidity, property losses, and overall financial exposure.

## Key Examples

**Actuaries Climate Index (ACI):** A composite index designed to track changes in the frequency and severity of extreme climate conditions across the United States and Canada. Developed collaboratively by four major North American actuarial associations, the ACI is based on six climate indicators: extreme high and low temperatures, heavy precipitation, drought, wind speed, and sea level rise. These indicators are calculated using meteorological and oceanographic data from government and research datasets such as GHCN, CLIMDEX, NOAA, the Permanent Service for Mean Sea Level (PSMSL), and the National Centers for Environmental Prediction (NCEP), and are expressed as standard deviations from a baseline period of 1961–1990. The index is updated quarterly and presented in both national and regional formats, enabling spatial and temporal comparison of climate trends [14].

The ACI does not attempt to model financial losses but serves as an empirical signal of increasing climate volatility. It is primarily used by actuaries, insurers, and public policymakers to support climate-aware risk assessment, monitor long-term climate shifts, and integrate environmental considerations into actuarial forecasting [29–31]. The ACI is publicly available and forms a foundational reference in discussions around the insurance industry’s exposure to physical climate risks.

**Actuaries Climate Risk Index (ACRI):** Builds upon the ACI by incorporating economic exposure data to estimate the potential financial impact of climate extremes in the United States. While the ACI tracks six indicators of climate variability, the ACRI focuses on the four most statistically significant indicators, extreme low and high temperatures, heavy precipitation, and wind speed, and combines them with region-specific loss data from the Spatial Hazard Events and Losses Database for the United States (SHELDUS) and the NOAA. This integration allows the ACRI to translate changes in climate extremes into estimated economic losses measured in U.S. dollars [15].

The ACRI is designed to provide decision-makers in the insurance, pension, public policy sectors, and the general public with a clearer understanding of how shifts in climate patterns may affect financial outcomes over time. It is particularly useful for scenario analysis, capital stress testing, and regulatory reporting frameworks that seek to align financial risk with environmental change. The ACRI supports actuarial and risk professionals in bridging the gap between observed climate data and its implications for financial systems [15].

On top of the ACI and ACRI, other actuarial initiatives are emerging at national and regional levels. The ACI methodology has been replicated in academic work in some countries, while in Australia the Institute of Actuaries has developed a national version tailored to local conditions and risk assessment needs [32,33].

## Purpose and Application

They are primarily informative, providing context on changing climate extremes that is relevant to actuarial risk assessment, scenario analysis, and long-term capital planning.

## Strengths

These indices are developed by and for the actuarial profession, which ensures their conceptual relevance and interpretability within the field. They integrate multiple physical climate variables that are closely relevant to insurance risks and are often available at a regional or subregional level. In addition, their methodologies are transparent and publicly documented, with regular updates that support ongoing monitoring and evaluation.

## Limitations

They rely on relatively simple aggregation methods, typically applying equal weights across components. In addition, they have yet to be widely integrated into mainstream actuarial practice or regulation on a global scale. Overall, they primarily provide descriptive measures of observed climate conditions, with limited incorporation of forward-looking, scenario-based risk assessment.

### b. Climate Risk Context Indices

#### 2.3. Environmental and Performance Indices

Environmental and performance indices are composite measures used to evaluate how countries or regions perform in relation to climate action, environmental health, and sustainability. They typically combine data on emissions, renewable energy use, policy implementation, and other ecological indicators to evaluate climate mitigation efforts and ecological impact.

### Key Examples

**Climate Change Performance Index (CCPI):** A tool developed by Germanwatch, designed to enhance transparency in international climate politics by evaluating and comparing national climate protection performance. It assesses 63 countries, which together account for over 90 per cent of global greenhouse gas emissions.

The CCPI evaluates performance across four key areas: greenhouse gas emissions, renewable energy, energy use, and climate policy. The greenhouse gas emissions are measured using data from PRIMAP-hist, the FAO, and the UNFCCC, covering all major sectors. Energy-related indicators are based on data from the International Energy Agency (IEA). Climate policy performance is assessed through an annually updated survey of national climate and energy experts, typically from civil society organisations within each country. The index combines these quantitative and qualitative components into a weighted scoring system that results in a composite score, scale from 1 to 100 (the higher the better), and overall country ranking [13].

The CCPI is particularly useful for policymakers, advocacy groups, researchers, and international organisations seeking to benchmark progress, identify leaders and laggards, and inform climate negotiations or national policy planning [34–37]. Its country-level comparisons help highlight both ambition and implementation gaps, supporting accountability and transparency in global climate governance.

**Environmental Performance Index (EPI):** A global ranking tool developed by Yale University and Columbia University to assess national environmental performance. It assesses 180 countries using 58 indicators across 11 issue categories, covering areas such as climate change mitigation, environmental health, and ecosystem vitality. The index tracks how well countries are managing key environmental challenges and highlights both high performers and those lagging behind.

Data for the EPI are sourced from a wide range of international institutions, including the World Bank, FAO, PRIMAP-hist, and the Community Emissions Data System (CEDS), among others. These data are transformed into standardised indicators, and then weighted and aggregated into a composite score ranging from 0 to 100 for each country [38].

The EPI is widely used by policymakers, international organisations, researchers, and sustainability advocates to assess national progress toward environmental goals, benchmark performance, and inform policy development [39,40]. It is frequently cited in discussions related to international commitments such as the UN Sustainable Development Goals, the climate targets of the 2015 Paris Agreement, and the biodiversity goals outlined in the Kunming–Montreal Global Biodiversity Framework [38].

In addition to the CCPI and EPI, several other environmental and performance-focused indices have been developed with varying focus areas. Examples include the Global Green Economy Index (GGEI), which assesses progress toward green economic transition across countries [41], and the Ocean Health Index (OHI), which evaluates the ecological and social sustainability of marine systems [42].

### **Purpose and Application**

Environmental and performance indices are commonly used to support international climate negotiations, tracking progress toward global targets such as the Paris Agreement, promote transparency and accountability, and raise public awareness of environmental and climate-related issues. They are also widely used in public communication to highlight differences in national climate and environmental performance.

### **Strengths**

These indices offer high-level summaries that are accessible to both policymakers and the general public. They incorporate a broad range of environmental and energy metrics, enable international comparison, enhance transparency, and support the monitoring of climate governance and sustainability goals.

### **Limitations**

These indices often rely on subjective weighting schemes or qualitative assessments, which may affect consistency and interpretability. Their typically annual update cycles may also limit responsiveness to fast-changing climate conditions. In addition, they focus on national-level data, which may overlook critical subnational or local variations, and they do not always capture physical climate changes or underlying vulnerabilities directly.

## **2.4. Vulnerability and Readiness Indices**

Vulnerability and readiness indices assess the extent to which a country or region is exposed and sensitive to the impacts of climate change, and in some cases how effectively it can respond. They typically integrate data on environmental hazards, socio-economic factors, and institutional capacity to provide a comprehensive assessment of climate risk and adaptive readiness.

### **Key Examples**

**Climate Risk Index (CRI):** Developed annually by Germanwatch to evaluate and rank the impacts of extreme weather events on over 170 countries worldwide. It serves as a retrospective, impact-based indicator often used in discussions of vulnerability, focusing on human and economic losses resulting from climate-related disasters. The CRI does not assess future risk or adaptive capacity; instead, it reflects how severely countries have been affected by extreme weather in the past.

The index draws data from the EM-DAT international disaster database, World Bank, and International Monetary Fund (IMF). It uses indicators such as the number of deaths, death rates per 100,000 inhabitants, total economic losses in US dollars, and losses per GDP. These indicators are weighted and aggregated into a CRI score and ranking over a 20-year period (from 1993 to the previous 3-year period) to provide a long-term perspective, alongside an annual index for a short-term perspective on vulnerability [12,43].

The CRI is particularly useful for policy discussions for advocacy groups to support calls for adaptation financing, loss and damage mechanisms, and stronger global climate commitments. It is frequently cited in international climate negotiations and publications to support calls for targeted climate resilience measures in vulnerable countries such as [44–46]. By highlighting which countries are most affected by climate-related events, the

CRI helps to contextualise vulnerability and guide the global discourse on responsibility, resilience, and resource allocation in the face of climate change [12].

**ND-GAIN (Notre Dame Global Adaptation Initiative):** This index measures both a country's vulnerability to climate change and its readiness to improve resilience. Developed by the University of Notre Dame, the index assesses 182 countries using a combination of 45 core indicators grouped into two dimensions: vulnerability and readiness.

Vulnerability is evaluated across six life-supporting sectors, including food, water, health, ecosystem services, human habitat, and infrastructure, based on a country's exposure, sensitivity, and adaptive capacity. Readiness considers the economic, governance, and social factors that affect a country's ability to implement climate adaptation strategies. The overall index provides a single comparative score on a scale from 0 to 100 (the higher the better) that balances both challenges and capabilities. The data used to calculate these indices are drawn from international organisations, including the World Bank, WHO, WDI, FAOSTAT, and AQUASTAT, among others [47].

The ND-GAIN index is widely used by development agencies, researchers, and international organisations to prioritise adaptation investments, identify at-risk countries, and monitor resilience trends over time [48–50]. Its transparent methodology and long-term data coverage, from 1995 to the previous 3-year period, make it particularly useful for cross-country comparisons, regional analyses, and policy planning.

Along with these key examples, the indices included in the vulnerability group can vary depending on their domains and scale. For example, the Climate Vulnerability Index (CVI) assesses risk to World Heritage Sites [51], while other variants such as the U.S. Climate Vulnerability Index [52], the Global Data Lab Vulnerability Index (GVI) [53], and the World Risk Index (WRI) [54] focus on broader socio-economic, geographic, or disaster-related vulnerabilities.

### Purpose and Application

The vulnerability and readiness indices are used to identify countries or regions most at risk from climate impacts and inform the allocation and prioritisation of adaptation funding. They support the development of national and regional adaptation strategies and highlight inequities in climate vulnerability.

### Strengths

These indices are multidimensional and integrative, combining both physical and social aspects of vulnerability. They are widely used by policymakers, NGOs, and donors to support climate adaptation planning. Their standardised formats enable comparison across time and geography.

### Limitations

They are reliant on the availability and quality of data, which can be limited in low-income regions. Their rankings are sensitive to methodological choices such as indicator selection and weighting. In addition, they may oversimplify complex local contexts and adaptation pathways, and their outputs are often broad, lacking sector-specific detail.

### 2.5. Social and Deprivation Indices

Social and deprivation indices are designed to measure socio-economic disadvantage, which is closely linked to climate vulnerability and adaptive capacity. Although not originally developed for climate risk assessment, they are widely used in public health and social policy, and are increasingly applied in climate justice and resilience planning.

## Key Examples

**Social Deprivation Index (SDI):** The SDI has been developed in several national contexts, with one well-known version created by the Robert Graham Center in the United States. The SDI was designed to quantify socio-economic disadvantage in small geographic areas and is widely used in health equity research, social policy, and environmental justice assessments. In its U.S. application, the SDI is constructed using census data from the American Community Survey 5-year estimates, incorporating seven indicators covering poverty rates, education attainment, housing status, unemployment, and access to transportation. These indicators are standardised and aggregated into a deprivation score ranging from 1 to 100, which is assigned to geographic units such as ZIP codes or census tracts. The resulting index ranks areas on a scale of relative deprivation, allowing policymakers and researchers to identify communities with systemic disadvantage [55].

The SDI has become a tool for identifying populations with heightened vulnerability to climate risks due to overlapping social and economic stressors. It is particularly valuable for informing place-based adaptation planning, healthcare delivery, and resource allocation. The SDI is currently used by public health agencies, urban planners, and academic institutions, and has been integrated into environmental justice screening tools and community resilience frameworks [56–58].

**Index of Multiple Deprivation (IMD):** An official measure of relative deprivation across small geographic areas in England, developed by the UK Ministry of Housing, Communities and Local Government. It combines data across seven distinct domains: income, employment, education, health, crime, barriers to housing and services, and the living environment. Each domain includes multiple indicators sourced from government datasets. These indicators are weighted, aggregated, and standardised to produce a single deprivation score and national rank across England. The IMD provides fine-scale spatial detail that allows policymakers, researchers, and public agencies to identify and compare patterns of deprivation at the neighbourhood level. It is typically updated every three to five years, depending on the availability of relevant national datasets [59].

In recent years, the IMD has been increasingly used to identify areas of heightened climate vulnerability, such as susceptibility to heatwaves, flooding, and poor air quality, due to compounding socio-economic disadvantages. It is widely used by local governments, the National Health Service (NHS), academia, and the UK's Climate Change Committee to inform place-based policy interventions, resource allocation, and climate adaptation planning [59–61].

In addition to the SDI and IMD, other social and deprivation indices are used depending on national or thematic focus. For example, the Scottish Index of Multiple Deprivation (SIMD) provides comparable data for small areas in Scotland [62], while the OECD Better Life Index, also known as the Good Life Index, measures well-being and quality of life based on indicators such as income, health, education, and civic engagement [63].

## Purpose and Application

Although not always labelled as “climate indices”, social and deprivation-related indices are used to guide climate adaptation and resilience efforts by identifying populations most vulnerable to climate hazards. In practice, they are commonly used alongside hazard information to inform place-based decision-making and the prioritisation of public support. By incorporating socio-economic conditions, these indices help explain why similar climate hazards can result in very different impacts across communities.

## Strengths

These indices offer several advantages, particularly in their ability to provide high-resolution geographic insights, often down to the neighbourhood or community level. They

are widely used in public policy, disaster planning, and public health contexts, offering a socio-economic lens through which to understand climate vulnerability.

### Limitations

When applied in climate contexts, these indices are not inherently climate-related and must be combined with environmental or hazard data to support climate resilience planning. Their structure and variable selection can vary substantially across countries or regions, limiting international comparability. In addition, some rely on datasets that may be outdated, while certain variables may have only an indirect or weak relationship to actual climate resilience outcomes.

#### 2.6. Climate-Related Financial Indices

Financial and investment-oriented climate indices are designed to evaluate how well financial assets, portfolios, or markets align with climate goals, particularly emissions reduction targets, transition risk, and ESG performance. They play an increasingly important role in sustainable finance by guiding capital flows toward climate-resilient and environmentally responsible investments.

### Key Examples

**FTSE TPI Climate Transition Index:** Developed by FTSE Russell in collaboration with the Transition Pathway Initiative (TPI), designed to serve as a benchmark for climate-aware equity strategies. It covers core markets including the United States, Japan, and Australia, as well as a global core infrastructure index. The index evaluates publicly listed companies based on their exposure to climate-related risks and their progress toward a low-carbon transition. It integrates TPI's forward-looking assessments of corporate carbon performance and climate governance, alongside FTSE's proprietary data on carbon emissions, fossil fuel reserves, and green revenues. The series comprises 13 weighted equity indices that tilt toward companies demonstrating strong alignment with climate transition goals [64].

The FTSE TPI Climate Transition Index is useful for a range of financial and policy-focused stakeholders, particularly those committed to aligning investments with long-term climate goals. It is actively used by institutional investors, including Brunel Pension Partnership and other members of the TPI Asset Owner Network, as part of net-zero investment frameworks and climate risk mitigation strategies [64,65].

**S&P Green Bond Indices:** A rules-based benchmark developed by S&P Dow Jones Indices in collaboration with Infrastructure Credit Alpha Group LLC. It tracks the global market of fixed-income securities that are formally labelled as "green" and certified by the Climate Bonds Initiative (CBI). Eligible securities earmark their proceeds for projects such as renewable energy, energy efficiency, clean transport, sustainable water management, and climate adaptation infrastructure. The index incorporates a range of bond characteristics, including maturity, coupon type, credit rating, and currency, using data from Thomson Reuters and S&P Securities Evaluations (SPSE). Outputs are presented as market-weighted total return indices, accompanied by standard fixed-income performance metrics such as yield and duration [66].

These indices are widely used by institutional investors, ESG-focused asset managers, and green bond fund managers to benchmark sustainable fixed-income portfolios, support the creation of green bond ETFs, and align with climate-related investment strategies. They are also used by insurers, pension funds, and sovereign wealth funds for monitoring the performance and evolution of the green bond market [67].

In addition to the FTSE TPI Climate Transition Index and the S&P Green Bond Index discussed here, several other financial indices support climate-aligned investing. These include other types of green bond indices, such as the Bloomberg MSCI Green Bond

Index and the Solactive Green Bond Index, which track investment-grade bonds financing environmentally beneficial projects [68,69]. The FTSE Green Impact Bond Index Series adds an additional layer of analysis by focusing on the measurable environmental outcomes of funded projects [70]. Similarly, the GSS Bond Index family, such as the iBoxx® Global Green, Social & Sustainability (GSS) Bond Index and the Bloomberg GSS Bond Index, covers a broader set of labelled fixed-income instruments, including Green, Social, and Sustainability bonds [71,72].

### **Purpose and Application**

Financial climate indices are designed to support climate-aware investment decision-making and portfolio management. They provide benchmarks for investors seeking to align with climate goals and support ESG and net-zero strategies. In practice, these indices help investors screen assets, compare performance across markets, and monitor progress toward stated climate objectives.

### **Strengths**

A key strength of financial climate indices is their ability to promote transparency and comparability within the green finance market. By providing standardised metrics, they support the reallocation of capital toward low-carbon and sustainable investments. Many financial indices are designed to align with or map to emerging regulatory frameworks, such as the EU Taxonomy for sustainable activities. Furthermore, many indices are regularly updated and widely adopted by financial institutions, contributing to their credibility and practical usefulness.

### **Limitations**

They often lack a direct connection to physical climate risks or measurable environmental impacts, which can reduce their effectiveness in assessing real-world climate performance. In some cases, indices rely on voluntary disclosures from issuers or corporations, which can result in incomplete or inconsistent data and increase exposure to greenwashing risks. These indices also tend to prioritise mitigation outcomes and may overlook broader considerations such as social co-benefits or adaptation financing needs.

A cross-cutting challenge across all six categories is the trade-off between methodological complexity and practical usability. Detailed indices such as Climdex and ECA&D offer fine-grained climate information but typically require advanced technical expertise, specialised software, and significant processing time, which limits their accessibility for operational insurance decision-making. In contrast, composite indices such as the EPI or FTSE TPI Climate Transition Index are more accessible and policy-relevant, but may rely on less transparent methodologies, including expert weighting schemes or voluntary corporate disclosures, which can introduce subjectivity and reduce comparability across contexts. This trade-off is particularly important for insurance applications, where indices must be not only scientifically credible but also operationally tractable, verifiable by counterparties, and defensible to regulators and reinsurers.

For an overview of climate-related index groups and their key characteristics, see Table 1.

**Table 1.** Summary comparison of climate index groups.

| Index Group                            | Objective                                                                   | Key Example Indices                                                     | Primary Users                                                 | Data Sources                                    | Aggregation Method                         | Outputs                                                    | Strengths                                                              | Key Limitations                                                  | Data Sensitivity & Stability                          |
|----------------------------------------|-----------------------------------------------------------------------------|-------------------------------------------------------------------------|---------------------------------------------------------------|-------------------------------------------------|--------------------------------------------|------------------------------------------------------------|------------------------------------------------------------------------|------------------------------------------------------------------|-------------------------------------------------------|
| <b>Weather-Related</b>                 | Track climate variability and extreme events                                | Climdex, ECA&D, CEI, SPI, PDSI                                          | Researchers, meteorological services, planners                | Meteorological observations                     | Statistical aggregation of observations    | Time series of climate extremes; standardised indicators   | Based on objective, standardised observations; long-term comparability | Retrospective only; requires dense observational networks        | Sensitive to data coverage; stable over time          |
| <b>Environmental &amp; Performance</b> | Assess national climate/environmental performance and sustainability        | CCPI, EPI, GGEL, OHI                                                    | Polymakers, NGOs, academics                                   | Emissions data, energy stats, policy surveys    | Expert-weighted composite scoring          | Country scores and international rankings                  | Supports benchmarking and accountability; covers broad indicators      | Subjective weighting; limited granularity; mostly annual updates | Sensitive to indicator selection and weighting choice |
| <b>Vulnerability &amp; Readiness</b>   | Identify exposure and/or capacity to adapt to climate impacts               | ND-GAIN, CRI, CVI, WRI                                                  | Development agencies, donors, governments                     | Disaster losses, socio-economic, governance     | Expert- or PCA-based indicator aggregation | Composite scores; regional/national rankings               | Multidimensional approach combining social and environmental data      | Subjective weighting; may oversimplify local dynamics            | Sensitive to indicator selection and weighting choice |
| <b>Social &amp; Deprivation</b>        | Identify socio-economic disadvantages influencing climate vulnerability     | SDI, IMD, SIMD, OECD Better Life Index                                  | Local authorities, health systems, researchers                | Census, national surveys, deprivation databases | Census-based deprivation scoring           | Deprivation scores; spatial rankings                       | High-resolution; policy relevance                                      | Not climate-specific; varying update frequency                   | Dependent on census update cycles                     |
| <b>Financial</b>                       | Evaluate how financial assets align with climate targets and ESG principles | S&P Green Bond Index, FTSE TPI Climate Transition Index, GSS Bond Index | Investors, asset managers, sustainable finance, pension funds | Corporate disclosures, bond markets, emissions  | Rules-based market weighting               | Market-weighted indices, ESG alignment scores              | Supports ESG investing; enables benchmarking; regulatory alignment     | Can lack physical risk link; susceptible to greenwashing risks   | Sensitive to disclosure                               |
| <b>Actuarial</b>                       | Quantify climate risks relevant to insurance                                | ACI, ACRI, AACI, FACI                                                   | Actuaries, insurers                                           | Meteorological and financial loss data          | Equal-weighted risk indicators             | Standardised climate risk indices; economic loss estimates | Directly relevant to actuarial and solvency work; regionally granular  | Geographically limited; backward-looking; limited global uptake  | Dependent on baseline assumptions                     |

### 3. Climate Index and Insurance

Climate change presents significant challenges for the insurance sector because climate-related risks are increasingly characterised by non-stationarity. Historical observations may no longer provide a reliable guide to future losses, as the frequency, severity, and geographic distribution of extreme weather events continue to evolve. Traditional actuarial approaches, which rely heavily on historical claims experience, may therefore underestimate emerging risks unless they are complemented by forward-looking information on future hazard conditions.

For many non-life insurance products, annual policy renewals allow insurers to adjust premiums in response to changing risk conditions. However, persistent increases in climate-related losses may require substantial premium increases over time, potentially reducing the affordability and availability of insurance coverage in high-risk areas. This may contribute to a widening protection gap, with an increasing share of climate-related losses remaining uninsured [73].

The impacts of climate change are also likely to be non-linear and interconnected. Similar hazard events may generate very different losses depending on local socio-economic conditions, levels of preparedness, and adaptive capacity. Furthermore, climate-related events may trigger broader systemic effects through supply chains, infrastructure networks, financial markets, and other interconnected systems. As a result, insurers increasingly require information not only on physical hazards but also on the broader environmental, social, and financial factors that influence climate-related losses.

Climate indices have gained increasing attention as tools that can provide standardised information on both physical hazards and the wider context in which climate risks emerge. In order to clarify the role of climate indices across insurance applications, it is useful to distinguish the following actuarial functions. Pricing and reserving focus on individual insurance contracts and expected losses; portfolio risk management considers the spatial concentration of exposures and potential accumulation of losses; capital management assesses the resilience of the entire balance sheet under extreme loss conditions; and climate stress testing evaluates insurer performance under defined physical and transition scenarios.

#### 3.1. Climate Indices Across Insurance Functions

##### a. Pricing, underwriting and reserving

For underwriting, pricing, and reserving, insurers require forward-looking and spatially granular estimates of hazard frequency and severity in order to assess expected losses. In principle, this requires probabilistic information on event occurrence and intensity, typically expressed through exceedance probabilities or return periods.

Most weather-related and actuarial indices are derived from historical observations and expressed as deviations from a baseline climate period. While they are useful for identifying changes in climate variability and long-term trends, they do not directly provide the probabilistic structure required for actuarial pricing or reserve estimation. As a result, their use in pricing frameworks is indirect and generally requires integration within catastrophe modelling or similar stochastic risk models.

Within this framework, weather-related and actuarial indices are the most directly relevant for pricing and reserving because they describe the underlying physical hazard conditions that drive insurance losses and can be combined with climate projections to inform forward-looking risk assumptions. Other index categories play more complementary roles: vulnerability and social indices may provide contextual information on heterogeneous loss outcomes driven by socio-economic conditions, environmental and performance indices

capture longer-term adaptation and mitigation trends, and financial indices are primarily relevant for the asset side of insurers' balance sheets rather than liability valuation.

b. Portfolio risk management and accumulation risk

Climate indices can support portfolio risk management by identifying spatial clustering of hazard exposure and broad accumulation patterns across insured portfolios. This provides insight into diversification benefits and concentration risk at the portfolio level.

Weather-related and actuarial indices are particularly useful for identifying geographic concentrations of physical hazard exposure. When combined with exposure data, vulnerability and social indices can help refine accumulation analysis by identifying areas where hazard levels may result in more severe impacts due to socio-economic conditions.

c. Climate stress testing

Climate indices are particularly useful in climate stress testing, which evaluates insurer resilience under severe but plausible scenarios rather than relying on full probability distributions. Weather-related and actuarial indices provide structured representations of physical hazard changes such as temperature extremes, precipitation intensity, drought, and storm variability.

For climate scenario analysis, actuarial and vulnerability indices offer some useful insight into the direction and relative magnitude of climate risk shifts, but their retrospective orientation and coarse spatial resolution limit their value for quantitative scenario modelling. Financial indices are particularly relevant for transition risk scenarios affecting investment portfolios, including shifts in asset prices and policy-driven market changes.

d. Capital management and solvency

Climate stress testing is closely linked to capital management under frameworks such as Solvency II. However, the two serve different purposes: stress testing is scenario-based, whereas capital requirements are derived from probabilistic estimates of extreme losses over a defined risk horizon.

Under Solvency II-related frameworks, stress tests are used to assess capital adequacy under adverse scenarios, typically combining scenario assumptions with modelled loss impacts. In this context, climate indices can support qualitative scenario design, particularly in describing physical hazard changes. However, they do not directly produce the probabilistic loss distributions required for regulatory capital calculations.

This limitation has been highlighted by the European Insurance and Occupational Pensions Authority [74], which notes that current climate risk metrics are often insufficiently granular or probabilistic for direct integration into standard solvency models.

Overall, climate indices can support capital modelling indirectly through hazard specification and scenario construction, but they cannot substitute for the stochastic modelling frameworks required for Solvency II capital requirements.

e. Regulatory disclosure and climate reporting

Climate disclosure refers to the process through which insurers assess and report their exposure to climate-related risks across both the underwriting and investment sides of the balance sheet. This includes physical risks from climate hazards affecting insurance liabilities, as well as transition risks arising from policy, technological, and market changes affecting asset values. Within the insurance sector, disclosure is increasingly shaped by supervisory frameworks such as Solvency II and international standards, including the Task Force on Climate-related Financial Disclosures (TCFD) and the International Sustainability Standards Board (ISSB), with the aim of improving transparency and comparability of climate-related risk exposures.

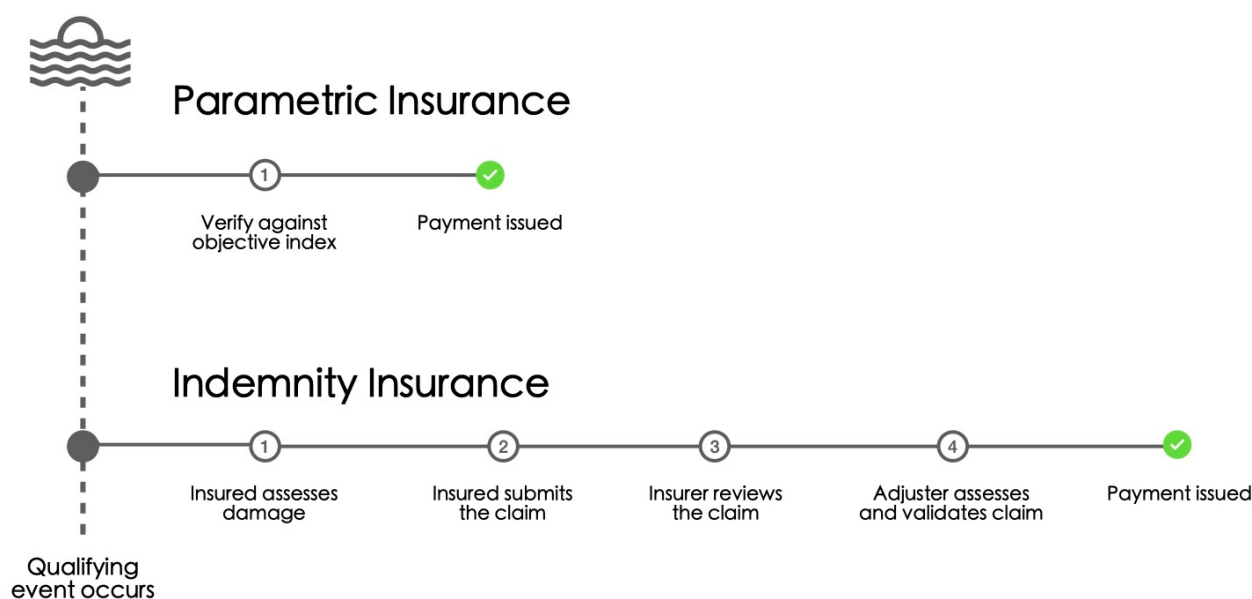
In this context, climate indices can provide standardised indicators to support disclosure across both sides of the balance sheet. Weather-related and actuarial indices are primarily relevant for reporting physical risk exposures in underwriting portfolios, while financial indices are particularly relevant for transition risk disclosure on the asset side.

Across the insurance functions examined above, climate indices provide valuable information for understanding and assessing climate-related risks. In many actuarial applications, they are used alongside probabilistic loss models and other analytical frameworks to support decision-making. The following section examines parametric insurance, a particular insurance product design in which climate indices are directly embedded in contract design and used to determine payouts.

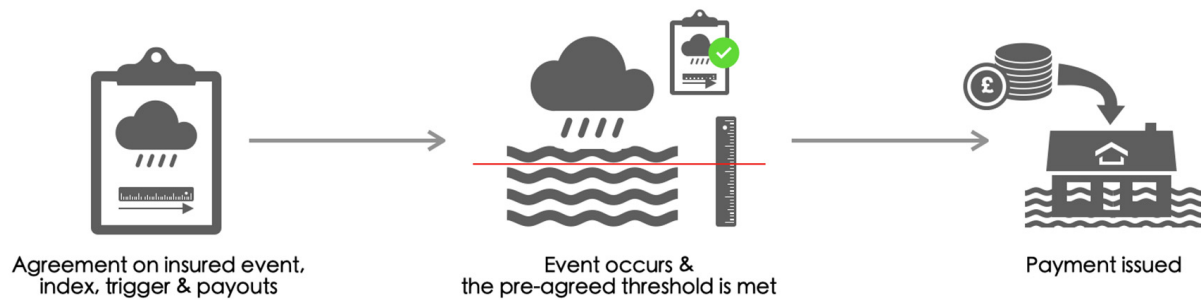
### 3.2. Parametric Insurance

Parametric insurance represents a specific case of insurance in which climate indices are directly used to define contract payouts. It has emerged as a complementary approach to traditional indemnity coverage. In traditional indemnity insurance, policyholders are compensated based on the actual financial losses incurred following a climate-related event. Claims are assessed after the event and require a detailed evaluation of physical damage and resulting economic loss. This is to ensure that the payout reflects the policyholder's actual loss experience, which is its principal advantage: coverage is individualised, and policyholders are compensated for what they genuinely lost. However, this accuracy comes at a cost. Loss adjustment is time-consuming and administratively expensive, particularly when many claims are filed simultaneously following a large-scale event. Settlement can take weeks or months, which is problematic in disaster contexts where affected households and businesses need liquidity quickly.

By contrast, parametric (or index-based) insurance does not depend on observed losses. Instead, it provides a pre-agreed payout when a predefined threshold of an observable climate variable or index is exceeded, as illustrated in Figure 1. Observable variables typically include rainfall, temperature, wind speed, or other measures of hazard intensity. These indices act as contractual triggers for payout rather than as proxies for realised damage, as illustrated in Figure 2. Once an agreed index exceeds a predefined threshold, an automatic payout is triggered.



**Figure 1.** Comparison of payout processes under parametric and indemnity-based insurance.



**Figure 2.** Parametric insurance payout processes.

This design enables faster, more transparent, and more cost-effective payouts by reducing operational costs and eliminating time-consuming loss verification processes, and is particularly valuable in low-income or disaster-prone regions, where traditional insurance is often unavailable or too slow [75,76]. In practice, a range of climate indices are used as triggers across different regions and hazard types. For example, rainfall indices have been widely employed in agricultural insurance schemes across Africa and Asia to protect farmers from drought-related losses, with evidence of both demand and impact documented across multiple contexts [76–79]. Similarly, wind speed thresholds are used in the Caribbean and the US to support disaster risk financing mechanisms [80,81]. Unlike indemnity products, which require post-event loss verification by an adjuster, parametric products are designed precisely around index triggers, making weather-related indices a natural fit for the parametric context.

This fundamental distinction means that parametric insurance is directly linked to measurable climate indices, whereas indemnity insurance is only indirectly related to climatic variables through the observed losses they may generate. However, it also introduces basis risk, since the index value may not perfectly correspond to the actual losses experienced by policyholders. This risk can result in situations where a policyholder experiences real losses without triggering a payout, undermining trust in the product. Conversely, payouts may also be triggered despite limited or negligible losses, creating additional financial burdens for insurers [80]. Moreover, the choice of pre-agreed index itself contributes to basis risk, and the magnitude of this risk varies by index type. Basis risk is not uniform; it depends on the spatial granularity of the index, the correlation between the index variables and actual losses, and differences in exposure within the index’s coverage area. Weather-related indices derived from station observations, for instance, can be geographically or temporally misaligned with actual losses at the farm or property level.

The discussion above provides a conceptual mapping between climate-related indices and key actuarial functions. Rather than representing direct actuarial inputs, climate indices are generally used alongside catastrophe models, climate projections, and other analytical tools. This framework helps identify where different types of indices can contribute to insurance decision-making and highlights opportunities for improving the integration of climate information within insurance practice.

#### 4. Discussion

This paper presents a review of climate-related indices and their applicability across key insurance functions, including underwriting and pricing, reserving, capital and solvency management, and climate stress testing, as well as their role in parametric insurance product design. Climate indices are primarily designed for environmental monitoring, scientific analysis, and policy support. In contrast, insurance applications require forward-looking, probabilistic representations of financial losses under uncertainty [82]. This structural difference limits their direct use in actuarial modelling.

Climate indices are most directly applied in parametric insurance product design, where weather-related and extreme event indices are used to define objective payout triggers. They are also highly relevant for insurance functions such as climate stress testing, where they provide structured inputs for constructing coherent physical and transition risk scenarios, particularly when combined with climate model outputs. In pricing, reserving, and capital and solvency management, however, their role is indirect, as these functions require probabilistic loss distributions and dependency structures that are not embedded in index frameworks.

A key finding of this review is that climate-related indices are most informative when considered as components of a broader risk assessment framework. Individual indices typically capture specific dimensions of climate risk, such as physical hazards, environmental performance, financial exposure, or socio-economic vulnerability. However, insurance decision-making requires an integrated understanding of hazard, exposure, vulnerability, and potential financial consequences. As a result, climate indices are most useful when combined with climate projections, exposure information, catastrophe models, and actuarial methods rather than being used in isolation.

Overall, climate indices should be understood as supporting instruments within insurance analytics rather than standalone actuarial tools. Their value depends on how effectively they are embedded within broader modelling systems that translate climate information into probabilistic estimates of financial risk.

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