WEATHER CLIMATE WATER

WORLD METEOROLOGICAL ORGANIZATION

GREEN CLIMATE FUND

Developing the Climate Science Information for Climate Action

WMO-No. 1287

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LIST OF ACRONYMS

CBA	Cost-Benefit Analysis
C3S	Copernicus Climate Change Service
CEA	Cost-Effectiveness Analysis
CIP	Climate Information Platform
CMIP	Coupled Model Intercomparison Project
CMIP5	Coupled Model Intercomparison Project Phase 5
CORDEX	Coordinated Regional Downscaling Experiment
CRED	Centre for Research on the Epidemiology of Disasters
DRC	Democratic Republic of the Congo
DRR	Disaster Risk Reduction
ECMWF	European Centre for Medium-Range Weather Forecasts
ECVs	Essential Climate Variables
EDGAR	Emissions Database for Global Atmospheric Research
EM-DAT	International Disaster Database
ENSO	El Niño–Southern Oscillation
ERA5	ECMWF Reanalysis Model Fifth Generation
ESS	Environmental and Social Safeguards
ET-CCDI	WMO Expert Team on Climate Change Detection and Indices
ET-SCI	WMO Expert Team on Sector-specific Climate Indices
EWS	Early Warning System
FCOVER	Fractional Cover
GCF	Green Climate Fund
GCOS	Global Climate Observing System
GCM	Global Climate Models
GDP	Gross Domestic Product
GHG	Greenhouse Gas
GPCs	Global Producing Centres
IG3IS	Integrated Global Greenhouse Gas Information System
INMC	National Institute of Meteorology and Geophysics (Cabo Verde)
IPCC	Intergovernmental Panel on Climate Change
LDC	Least Developed Countries
MCA	Multi-Criteria Analysis
NAMAs	Nationally Appropriate Mitigation Actions

NAO	Northern Atlantic Oscillation
NAPs	National Adaptation Plans
NAPAs	National Adaptation Plans of Action
NCF	National Climate Forum
NCOF	National Climate Outlook Forum
NDCs	Nationally Determined Contributions
NetCDF	Network Common Data Form
NFCS	National Framework for Climate Services
NMHSs	National Meteorological and Hydrological Services
NOAA	National Oceanic and Atmospheric Administration
RCCs	Regional Climate Centres
RCM	Regional Climate Models
RCOFs	Regional Climate Outlook Forums
RCPs	Representative Concentration Pathways
SAM	Southern Annular Mode
SDG	Sustainable Development Goal
SIDS	Small Island Developing State
SMHI	Swedish Meteorological and Hydrological Institute
SOCAT	Surface Ocean CO_2 Atlas
TNAs	Technology Needs Assessments
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
WCRP	World Climate Research Programme
WMO	World Meteorological Organization

GLOSSARY OF TERMS[1]

Adaptation: In human systems, the process of adjustment to actual or expected climate and its effects, in order to moderate harm or exploit beneficial opportunities. In natural systems, the process of adjustment to actual climate and its effects; human intervention may facilitate adjustment to expected climate.

Adaptive capacity: The combination of the strengths, attributes and resources available to an individual, community, society or organization that can be used to prepare for and undertake actions to reduce adverse impacts, moderate harm or exploit beneficial opportunities.

Anthropogenic: Resulting from human activities or produced by human beings.

Atmosphere: The gaseous envelope surrounding the Earth. The dry atmosphere consists almost entirely of nitrogen (78.1% volume mixing ratio) and oxygen (20.9% volume mixing ratio), together with a number of trace gases, such as argon (0.93% volume mixing ratio), helium and radiatively active greenhouse gases (GHGs) such as carbon dioxide (0.035% volume mixing ratio) and ozone. In addition, the atmosphere contains greenhouse gas water vapour, whose amounts are highly variable but typically around a 1% volume mixing ratio. The atmosphere also contains clouds and aerosols.

Capacity: The combination of all the strengths, attributes and resources available to an individual, community, society or organization that can be used to achieve established goals.

Capacity-building: The process by which individuals and organizations obtain, improve and retain the skills, knowledge, tools, equipment and other resources required to perform at a higher capacity.

Climate: Climate, in a narrow sense, is usually defined as the average weather, or more rigorously, as the statistical description in terms of the mean and variability of relevant quantities over a period of time, ranging from months to thousands or millions of years. The classical period for averaging these variables is 30 years, as defined by the World Meteorological Organization. The relevant quantities are most often surface variables such as temperature, precipitation and wind. Climate in a wider sense is the state, including a statistical description, of the climate system. In various chapters in this guide, different averaging periods, such as a period of 20 years, are also used.

Climate action: Scaled-up activities and interventions that reduce GHG emissions and strengthen resilience and adaptive capacity to climate-induced impacts.

Climate change: A change in the state of the climate that can be identified (for example, by using statistical tests) by changes in the mean and/or the variability of its properties, and that persists for an extended period, typically decades or longer. Climate change may be due to natural internal processes or external forcings, or to persistent anthropogenic changes in the composition of the atmosphere or land use.

Climate data: Time series or spatial data on climate variables derived from observations as well as data products, such as gridded data and numerical model (re)analyses, predictions and projections.

Climate extreme (extreme weather or climate event): The occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. For simplicity, both extreme weather events and extreme climate events are referred to collectively as 'climate extremes'.

Climate finance: This term is applied both to the financial resources devoted to addressing climate change globally and to financial flows to developing countries to assist them in addressing climate change.

Climate forecast: See Climate prediction.

Climate impact: A consequence of climate variability and change (actual or expected) for natural and human systems. For example, damage to coastal infrastructure.

Climate index: A calculated value, from a climate variable or variables, that reduces complex conditions to a single number. For example, the number of frost days or the Standardized Precipitation Index.

Climate indicator: A climate variable, index or parameter used to describe climate conditions and trends. For example, projected average temperature over a future 30-year time period.

Climate information: When climate data is used for specific purposes, for example, to produce summaries, tables, graphs, maps, reports and analyses, it becomes information (for example, products that describe

1 Information is sourced from WMO, IPCC, GCF and UNFCCC materials.

historical, current and future climate conditions). Climate information can entail future predictions and projections on monthly, seasonal or decadal timescales and their impact on natural and human systems.

Climate Information Platform (CIP): A web-based, data access platform developed by the Swedish Meteorological and Hydrological Institute (SMHI), with support from WMO and the GCF, which assembles and provides access to the most reliable hydroclimatic data and technical resources for climate science inputs relevant to the development of the climate science information for a project proposal or plan (see https://climateinformation.org/).

Climate prediction: A climate prediction (or forecast) is a probabilistic statement about the future climate on timescales ranging from seasons to decades. It is based on conditions that are known at present (initial conditions) and assumptions about the physical processes that will determine future changes. A climate prediction quantifies (with associated uncertainty) whether seasonal, annual or decadal averages or extremes will be higher, the same or lower than the climatological average.

Climate product: A derived synthesis of climate data. A product combines climate data with climate knowledge to add value.

Climate projection: A climate projection is the simulated response of the climate system to a scenario of future emission or concentration of GHGs and aerosols, generally derived using global climate models. Climate projections are distinguished from climate predictions by their dependence on the emission/concentration/radiative forcing scenario used, which is in turn based on assumptions concerning, for example, future socioeconomic and technological developments that may or may not be realized. Unlike climate predictions, projections are not initialized using present-day observations but start their simulations in the past (often pre-industrial).

Climate-related socioeconomic or environmental outcome: A climate impact or climate-related objective that the climate action seeks to affect and improve. For example, reduced risk of damage to coastal infrastructure.

Climate risk: A climate-related risk created by a range of climatic hazards. Some hazards are slow in their onset (such as changes in temperature and precipitation leading to droughts or agricultural losses), while others happen more suddenly (such as tropical storms and floods).

Climate science information: The scientific underpinning for determining that an action may be needed as a result of a country's changing climate situation. It is the scientific foundation upon which climate action can be selected.

Climate services: Information and products that enhance users' knowledge and understanding about the impacts of climate change and/or climate variability so as to aid the decision-making of individuals and organizations and enable preparedness and early climate change action. Such services involve provision of high-quality data from national and international databases on temperature, rainfall, wind, soil moisture and ocean conditions, as well as maps, risk and vulnerability analyses, assessments, and long-term projections and scenarios. Depending on the user's needs, these data and information products may be combined with non-meteorological data relating to, for example, agricultural production, health trends, population distributions in high-risk areas, road and infrastructure maps for the delivery of goods, and other socioeconomic variables.

Climate system: The climate system is a highly complex system consisting of five major components: the atmosphere, the oceans, the cryosphere, the land surface, the biosphere and the interactions between them. The climate system evolves in time under the influence of its internal dynamics and because of external forcings, such as volcanic eruptions and solar variations, and anthropogenic forcings, such as the changing composition of the atmosphere and land-use change.

Climate variable: An instrumentally observed, measured or calculated quantity reflecting the state of the climate system. For example, temperature, precipitation, sea level or glacier mass.

Climate variability: Variations in the mean state and other statistics (such as standard deviations, the occurrence of extremes, and so forth) of the climate at all spatial and temporal scales beyond that of individual weather events. Variability may be due to natural internal processes within the climate system (internal variability), or to variations in natural or anthropogenic external forcing (external variability).

Climatic contributing factor: A climate variable, index or parameter that has been shown to be causally associated with a socioeconomic or environmental impact or outcome. For example, heatwaves, floods and ocean acidification.

Climpact: A software package maintained at the University of New South Wales (UNSW) to calculate climate indices (proposed by WMO Expert Teams) that are relevant for the health, agriculture, water and other climate-sensitive sectors. The calculated indices are derived from time series of daily temperature and rainfall data (see https://climpact-sci.org/).

Conference of the Parties (COP) (of the UNFCCC): A supreme decision-making body of the United Nations Framework Convention on Climate Change (UNFCCC). All States that are Parties to the Convention are represented at the COP, at which they review the implementation of the Convention and any other legal instruments that the COP adopts, and take decisions necessary to promote the effective implementation of the Convention, including institutional and administrative arrangements.

CORDEX: A World Climate Research Programme framework to evaluate regional climate model performance through a set of experiments aimed at producing regional climate projections by dynamically downscaling global climate models to provide information on much smaller scales with much greater detail and more accurate representation of localized extreme events. This information is critical for supporting the more detailed impact and adaptation assessment and planning that is vital in many vulnerable regions of the world.

Coupled Model Intercomparison Project (CMIP): A project designed to better understand past, present and future climate changes arising from natural, unforced variability or in response to changes in radiative forcing in a multi-model context. This understanding includes assessments of model performance during the historical period and quantifications of the causes of the spread in future projections.

Disaster: Severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic or environmental effects that require an immediate emergency response to satisfy critical human needs and that may require external support for recovery.

Disaster risk management (DRM): Processes for designing, implementing and evaluating strategies, policies and measures to improve the understanding of disaster risk, foster disaster risk reduction and transfer, and promote continuous improvement in disaster preparedness, response and recovery practices, with the explicit purpose of increasing human security, well-being, quality of life, resilience and sustainable development.

Disaster Risk Reduction (DRR): Both a policy goal or objective, and the strategic and instrumental measures employed for anticipating future disaster risk, reducing existing exposure or vulnerability to hazard, and improving resilience.

Early warning systems (EWSs): The set of capacities needed to generate and disseminate timely and meaningful warning information to enable individuals, communities and organizations threatened by a hazard to prepare and to act appropriately, and in sufficient time, to reduce the possibility of harm or loss.

Ecosystem: A functional unit consisting of living organisms, their non-living environment, and the interactions within and between them.

El Niño–Southern Oscillation (ENSO): A basin-wide warming of the tropical Pacific Ocean east of the dateline. This oceanic event is associated with a fluctuation of a global-scale tropical and subtropical surface pressure pattern called the Southern Oscillation. This coupled atmosphere-ocean phenomenon, which reoccurs on preferred timescales of two to about seven years, is often measured by the surface pressure anomaly difference between Tahiti and Darwin and/or the sea-surface temperatures in the central and eastern equatorial Pacific. The cold phase of ENSO is called La Niña. During an ENSO event, the prevailing trade winds weaken, reducing upwelling and altering ocean currents such that the sea-surface temperatures warm, further weakening the trade winds. ENSO and La Niña events significantly affect wind, sea-surface temperature and precipitation patterns in the tropical Pacific and throughout the Pacific region and in many other parts of the world.

Exposure: The presence of people, livelihoods, environmental services and resources, infrastructure, or economic, social or cultural assets in places that could be adversely affected.

Extreme weather: An event that is rare at a particular place and time of year. Definitions of 'rare' vary, but an extreme weather event would normally be as rare as, or rarer than, the 10th or 90th percentile of a probability density function estimated from observations. By definition, the characteristics of what is called extreme weather may vary from place to place in an absolute sense. When a pattern of extreme weather persists for some time, such as a season, it may be classified as an extreme climate event, especially if it yields an average or total that is itself extreme (for example, drought or heavy rainfall over a season).

Global climate model (GCM): A model designed mainly for representing climate processes on a global scale. It provides the essential means to study climate variability for the past, present and future. It is based upon the physical laws governing the climate processes (atmosphere, land surface, ocean and sea ice), and interactions of all of the components of the climate system, expressed in the form of mathematical equations in three dimensions.

Global Framework for Climate Services (GFCS): A global partnership of governments and organizations that produce and use climate information and services. It seeks to enable researchers and the producers and users of the information to join forces to improve the quality and quantity of climate services worldwide, particularly in developing countries.

Green Climate Fund (GCF): The main operating entity of the financial mechanism of the UNFCCC with the purpose of making a significant contribution to the global efforts towards reaching the goals set by the international community to fund adaptation and mitigation actions that address climate change.

Greenhouse gases (GHGs): Those gaseous constituents of the atmosphere, both natural and anthropogenic, which absorb and emit radiation within the spectrum of thermal infrared radiation emitted by the Earth's surface, by the atmosphere itself and by clouds. This property is responsible for the differential warming of the Earth's surface compared to a planet without said atmosphere. Water vapour (H_2O), carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4) and ozone (O_3) are the primary GHGs in the Earth's atmosphere. Moreover, there are a number of entirely human-made GHGs in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances, dealt with under the Montreal Protocol. Besides CO_2, N_2O and CH_4, the Kyoto Protocol deals with the GHGs sulfur hexafluoride (SF_6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs).

Hazard: The potential occurrence of natural or human-induced physical events that may cause loss of life, injury or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision and environmental resources.

Hydrology: Science that deals with the waters above and below the land surfaces of the Earth; their occurrence, circulation and distribution, both in time and space; their biological, chemical and physical properties; and their interaction with their environment, including their relation to living beings.

Intergovernmental Panel on Climate Change (IPCC): A United Nations body for assessing the science related to climate change. The mandate of IPCC is to provide policymakers with regular scientific assessments on climate change, its implications and potential future risks, as well as to put forward adaptation and mitigation options.

Land: The solid part of the Earth's surface or a factor of production comprising all natural and human-made resources including all of the Earth's surface, plants grown in it, structures built on it, mineral deposits and water resources.

Maladaptation: Actions that may lead to increased risk of adverse climate-related outcomes, increased vulnerability to climate change or diminished welfare, now or in the future.

Mitigation (of climate change): A human intervention to reduce the sources or enhance the sinks of GHGs.

Mitigation (of disaster risk and disaster): The lessening of the potential adverse impacts of physical hazards (including those that are human-induced) through actions that reduce the hazard, exposure and vulnerability.

National Adaptation Plans (NAPs): A process established under the Cancun Adaptation Framework (CAF) to enable Parties to formulate and implement NAPs as a means of identifying medium- and long-term adaptation needs and developing and implementing strategies and programmes to address those needs. It is a continuous, progressive and iterative process which follows a country-driven, gender-sensitive, participatory and fully transparent approach.

National Adaptation Programmes of Action (NAPA): A process for Least Developed Countries (LDCs) to identify priority activities that respond to their urgent and immediate needs to adapt to climate change – those for which further delay would increase vulnerability and/or costs at a later stage.

National Climate Outlook Forums (NCOFs)/National Climate Forums (NCFs): An extension of RCOF to the national level. Please see RCOF.

National Frameworks for Climate Service (NFCS): A multi-stakeholder user interface platform enabling the development and delivery of climate services at a country level.

Nationally Determined Contributions (NDCs): Report submitted every five years by each Party to the Paris Agreement indicating its highest possible ambition for climate mitigation and adaptation actions and for promoting sustainable development and environmental integrity (in accordance with Decision 1/CP.21).

NMHSs: An abbreviation that encompasses both National Meteorological Services (NMSs) and National Hydrological Services (NHSs). The abbreviation NMHS also refers to a national hydrometeorological service (if hydrology and meteorology are combined in a single institution).

Non-climatic contributing factor: A non-climatic condition, set of assets or other socioeconomic or environmental entity or process, the interaction of which with climate contributes causally to an impact or outcome. For example, land use.

Ocean: A body of saline water that composes a large part of a planet's hydrosphere. In the context of Earth, it refers to one or all of the major divisions of the planet's world ocean – they are, in descending order of area, the Pacific, Atlantic, Indian, Southern and Arctic Oceans.

Reanalyses: Estimates of historical atmospheric temperature and wind or oceanographic temperature and current, and other quantities, created by processing past meteorological or oceanographic data, using fixed state-of-the-art weather forecasting or ocean circulation models, with data assimilation techniques. Using fixed data assimilation avoids effects from the changing analysis system that occur in operational analyses. Although continuity is improved, global reanalyses still suffer from changing coverage and biases in the observing systems.

Regional Climate Centre (RCC): A centre designated by WMO to create regional climate products, including long-range forecasts to support regional and national climate activities.

Regional climate model (RCM): A numerical climate prediction model forced by specified lateral and ocean conditions from a general circulation model or observation-based data set (reanalysis) that simulates atmospheric and land surface processes, while accounting for high-resolution topographical data, land-sea contrasts, surface characteristics and other components of the Earth system.

Regional Climate Outlook Forum (RCOF): A forum that brings together different expert groups to facilitate the assessment of available seasonal predictions and the development of consensus-based, user-relevant outlooks for the region of interest.

Representative Concentration Pathways (RCPs): Scenarios that include time series of emissions and concentrations of the full suite of GHGs, aerosols and chemically active gases, as well as land use/land cover. The word 'representative' signifies that each RCP provides only one of many possible scenarios that would lead to the specific radiative forcing characteristics. The term 'pathway' emphasizes that not only the long-term concentration levels are of interest, but also the trajectory taken over time to reach that outcome.

Resilience: The ability of a system and its component parts to anticipate, absorb, accommodate or recover from the effects of a hazardous event in a timely and efficient manner, including through ensuring the preservation, restoration or improvement of its essential basic structures and functions.

Risk (disaster): The likelihood over a specified time period of severe alterations in the normal functioning of a community or a society due to hazardous physical events interacting with vulnerable social conditions, leading to widespread adverse human, material, economic or environmental effects that require an immediate emergency response to satisfy critical human needs and that may require external support for recovery.

Sustainable development: Development is believed to be 'sustainable' when it balances the needs of present and future generations without compromising the Earth system's capacity to preserve and reproduce itself. Sustainable development embraces the so-called triple bottom line approach to human well-being by which the world's societies should build on a combination of economic development, environmental sustainability and social inclusion.

Technology Needs Assessment (TNA): A set of country-driven activities leading to the identification, prioritization and diffusion of environmentally sound technologies for mitigation and adaptation to climate change.

Uncertainty: A state of incomplete knowledge. Uncertainty about future climate arises from the complexity of the climate system and the ability of models to represent it, as well as the inability to predict the decisions that society will make.

United Nations Framework Convention on Climate Change (UNFCCC): An international environmental treaty adopted on 9 May 1992 and signed into force on 21 March 1994 to stabilize greenhouse gas concentrations in the atmosphere at a level that would prevent dangerous anthropogenic interference with the climate system.

Vulnerability: The propensity or predisposition to be adversely affected. Exposure and vulnerability are dynamic, varying across temporal and spatial scales, and depend on economic, social, geographic, demographic, cultural, institutional, governance and environmental factors.

Vulnerable communities: Climate change and climate variability tend to worsen existing poverty and exacerbate inequalities, especially for those disadvantaged by gender, age, race, class, caste, indigeneity and (dis) ability. Vulnerable communities are groups that are particularly vulnerable when a disaster strikes and take a relatively high share of the disease burden associated with emergencies.

Weather: State of the atmosphere at a specific time, as defined by various meteorological elements.

World Meteorological Organization (WMO): An intergovernmental organization with 193 Member states and territories with the purpose of facilitating worldwide cooperation in the establishment of stations for making meteorological, hydrological and other geophysical observations; promoting the establishment and maintenance of systems for the rapid exchange of meteorological and related information; promoting standards; furthering the application of meteorology to aviation, shipping, water problems, agriculture and other human activities; promoting activities in operational hydrology and close cooperation between meteorological and hydrological services; and encouraging research and training.

FOREWORD

The Paris Agreement calls for an effective and progressive response to the urgent threat of climate change on the basis of the best available scientific knowledge. Tools and resources to help develop the scientific information for supporting climate action are therefore a critical part of achieving the Paris Agreement's goals.

Climate science contributes to a better understanding of how socioecological systems are affected by climate and by human-induced climate change. Responses identified based on climate science are likely to be most effective in helping to prevent adverse impacts. Climate science also provides an important part of the evidence base for identifying and selecting the investments necessary for adapting to a changing climate.

Recognizing the contribution of science-based decision-making in responding to climate change, the Green Climate Fund (GCF) and WMO have partnered to provide the global community with access to new climate information, tools and guidance to develop the scientific information for climate action decisions. These resources and products respond to a growing demand from multiple stakeholders of the GCF and the WMO and others to have access to such tools and information platforms to guide the development of climate actions, particularly for adaptation and resilience projects. The aim of providing these products is to help countries identify and select the most effective climate actions to overcome the challenges of climate change. In doing so, the guidance can contribute to country-level decision-making and the mobilization of climate finance.

The methodology in the present guide provides access to data, state-of-the-art model outputs, tools and case examples. These include a web-based Climate Information Platform (CIP) that provides interactive maps and graphs summarizing key climate change indicators at the local level. These indicators are derived from updated climate models combined with procedures drawn from global and regional climate model intercomparison projects such as CMIP. The CIP also provides access to Climpact – a statistical tool that calculates context-specific climate indicators and high-impact event indicators from daily temperature and precipitation data, used for identifying trends and variability at the local level. The present guide describes how to use these data and tools, and how to access expert assistance if needed. Additional data, tools and methods, and examples of their use in different sectoral and geographic contexts, are provided in two supplementary Annexes.

The voluntary use of the present guide and associated resources is expected to build country-level institutional capacities to strengthen climate services capabilities. The use of climate data and information supports developing countries, least developed countries (LDCs) and small island developing states (SIDS) particularly in decision-making, and in identifying and implementing climate actions or any other goals on their development agenda.

The GCF and WMO will regularly update these products based on feedback from countries, partners, project developers and other key stakeholders.

1. INTRODUCTION

Anthropogenic climate change is a critical issue that must be addressed to ensure sustainable development. Climate impacts on human activities and nature are far-reaching. Extreme weather and climate events – such as heavy rainfall, floods, droughts, heatwaves and tropical cyclones – are major contributors to loss of life and damage to infrastructure and the environment. Changes in the magnitude and frequency of these events and slow onset phenomena associated with climate change – like glacial retreat, sea-level rise and ocean acidification – affect the balance in ecosystems otherwise needed to sustain human and natural life, and threaten to turn back the advances made over the past decades in socioeconomic development.

By analysing and making clear the relationships among the Earth system's components and their disturbances and perturbations, climate science contributes to a better understanding of the susceptibility of socioecological systems to climate change. When acted upon, climate science can help to safeguard economic and human development and the environment from adverse climate impacts. Such information can be used to plan and design investments that increase the adaptive capacity and resilience of vulnerable populations.

The value of climate science for decision-making depends on the use of the best available data for characterizing the climate system and dealing with uncertainties. Reliable, high-resolution and timely climate information is, therefore, a crucial input for decisions intended to promote adaptation to climate change and minimize impacts associated with climate-related hazards.

As the steps of the methodology presented in this guide will show, past, present and projected future climate information is necessary in order to understand how the climate affects a region or sector. The conclusions drawn from implementing the methodology can support the identification of science-based climate actions and the design of climate services that respond to the local context, address potential vulnerabilities and promote resilience to future climatic conditions.

Climate science for decision-making

The Paris Agreement (2015) calls for "strengthening scientific knowledge on climate, including research, systematic observation of the climate system and early warning systems, in a manner that informs climate services and supports decision-making" (Article 7, paragraph 7 (c)). The Paris Agreement also calls on Parties to undertake rapid reductions in greenhouse gas (GHG) emissions in accordance with and to pursue adaptation actions based on and guided by the best available science.

The Intergovernmental Panel on Climate Change (IPCC) similarly calls for solutions intended to address climate variability and change that are effective under current and expected future climate conditions.[2] This underscores the need for climate science to be part of decision-making in policy, investment and other societal applications. At the same time, climate science continuously evolves based on new research and findings. To be relevant for policymaking and decision-support, the scientific process must be informed by local knowledge and context and continually updated as lessons are learned.

In doing so, climate science strengthens countries' capacities in responding to the agendas they may be seeking to address. Meanwhile, the data and information generated from science-based processes enrich local and global data sets and assessments in a virtuous cycle for better decision-making.

Strengthening country capacity

A climate science-based approach strengthens a country's capacity for climate analysis and delivery of climate services through institutions such as National Meteorological and Hydrological Services (NMHSs) – as well as strengthens the capacity to identify and select climate action priorities. Monitoring the past, present and projected future status of climate enriches countries' abilities to track climate conditions in their local contexts. Such monitoring provides evidence for country-level contributions to the Paris Agreement Global Stocktake (GST), including the preparation of national communications and future reports under the Paris Agreement transparency framework. Climate science information also contributes to formulating and implementing other climate-related national policies, including the climate-relevant objectives of the United Nations Sustainable Development Goals (SDGs) and the Sendai Framework for Disaster Risk Reduction (DRR).

2 Intergovernmental Panel on Climate Change (IPCC), 2018: *IPCC Special Report on Global Warming of 1.5°C*, https://www.ipcc.ch/sr15/.

Enriching local and global assessments

Adoption of climate science as an essential element of the framework for climate action facilitates aggregation of scientific findings concerning national and local conditions into WMO and IPCC global processes. This can enrich national, regional and global data sets and assessments. Such data are a crucial input for climate research, on which the IPCC process, as well as forecast systems for managing climate variability and change, depend. As better data and information are made available through globally aggregated data sets and models, they can enhance local decision-making processes; and as local data and processes improve, they can feed back into global initiatives, thereby generating a virtuous cycle of both local and global benefits for decision-making.

Climate science for climate finance

Climate science is relevant to climate finance in at least three ways: (a) it supports the selection of transformative climate actions; (b) it promotes effective implementation of climate actions; and (c) it facilitates countries' access to finance.

Selecting transformative climate actions

Climate science provides information required for identifying and selecting investments necessary for adapting to a changing climate situation. Climate science is an essential aspect that ensures that the proposed intervention will generate climate-adaptive benefits for vulnerable populations, communities and sectors.[3]

Since climate finance seeks to support climate actions that address climate variability and change at local, national or transnational levels, results obtained through climate actions are strengthened when investments draw upon scientific evidence concerning climate risks and opportunities that need to be understood, identified, assessed and addressed.

Climate science information also ensures that funding dedicated to supporting climate action addresses climate impacts as opposed to other non-climate-related development needs or priorities. It is expected that climate actions will likely enhance countries' development agendas that can and should be supported, but as a co-benefit of climate finance. This leverages climate finance in a targeted way that uses climate science to select actions that will indeed address countries' climate change issues.

Furthermore, climate science information contributes to selecting and designing actions that address climate variability and change, and in a manner envisaged to lead to transformational impacts. A scientific basis provides the foundation on which actions can be selected. These actions can be more transformative when the science demonstrates the need for investment and can show where impacts will be greatest. This information can equip project planners and designers to think more innovatively and address future climate impacts in a more transformative way.

Using climate science to identify how climate variability and change contribute to climate impacts, and selecting effective actions based on that knowledge, can also prevent actors from selecting actions that may inadvertently lead to maladaptation. Avoiding maladaptation requires paying attention to multiple climatic and non-climatic contributing factors and to future impacts of proposed interventions to ensure that their selection and implementation do not somehow erode sustainable development.

Promoting effective implementation

Context-specific climate information can generate more effective results at the local level, increasing the effectiveness of climate actions. By clearly establishing relationships between climatic and non-climatic contributing factors and their impacts, and between climate actions and their outcomes, the use of climate information in the planning and design of projects results in more effective implementation. It also increases the likelihood of actions achieving their intended results.

By building and improving on national, regional and global data sets, observations and analyses, climate science provides a more comprehensive understanding of what is happening locally in terms of climate trends, variability and change, thereby informing appropriate response actions. Evidence about climate drivers and impacts at a high resolution allows decision makers to size, plan and design solutions that respond more effectively to local circumstances and needs. This should ultimately lead to a smoother implementation of the selected actions.

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3 Selecting climate actions based on the climate science information also provides donor countries and development partners with increased assurance that the commitments they are making toward supporting adaptation finance and investments are indeed being met. Tracking and reporting (Hattle, A.; Roy, C; Dejgaard, H. P; et al. *Climate Adaptation Finance: Fact or Fiction*; CARE International, 2021. https://careclimatechange.org/climate-adaptation-finance-fact-or-fiction/) of such investments has shown that projects characterized as adaptation finance have, at times, been over- or under-reported. Assessing the extent to which the actions address adaptation needs through the climate science information provides donor countries and development partners with a criterion that assures that the commitments they are making are indeed adaptive.

Facilitating access to finance

Climate science enables public and private actors, including development financing institutions, governments and private sector investors (such as financiers and project developers) to take an evidence-based approach to addressing risks arising from climate variability and change. An evidence-based approach: (a) provides greater certainty that an intervention is more likely to address impacts in any given area of focus; (b) accommodates for better upfront planning and design of investments; and (c) mitigates potential risks. This makes science-based investments more attractive to climate financiers. The increased certainty, as well as opportunities for better planning and risk mitigation, in turn, facilitates countries' access to climate finance.

A methodology for developing the climate science information for climate action

Climate science information is the scientific underpinning for determining that an action may be needed as a result of a country's changing climate situation. It is the scientific foundation upon which climate action can be selected. WMO and GCF have prepared the present guide to support countries in developing the climate science information for climate actions. It provides guidance for ensuring that climate actions are supported by the best available science.

Specifically, the methodology described in this guide provides steps for developing the climate science

Box 1. Benefits of the methodology

Specific benefits from the use of this methodology include:

Access to data and information

- Identification of internationally standardized, globally comparable and scientifically verified sources of observed and model data and information necessary for assessing climate variability and change as well as for monitoring and reporting on the implementation of the Paris Agreement;
- Transparency and integrity in data rescue, data collection, quality control, analysis and interpretation provided via a coherent, comprehensible, and transparent consultative stakeholder process supported by local and international expertise;
- Tailored scientific information addressing the requirements of specific climate action decisions at local, regional and national levels;
- Incentivization for continued use of climate data and information for characterizing the climate system in relation to evolving vulnerabilities;
- Identification of gaps in data (availability, quality, applicability), observing systems and services needed for climate action at the local, national and regional scale – and allowing those gaps to be addressed during project design.

Improved decision-making

- Identification of climatic and non-climatic factors contributing to impacts and outcomes relevant to a specific sector, geographic region or area on which the climate action will focus;
- A better understanding of climate impacts to select scientifically grounded actions that will improve associated outcomes;
- Improved communication of climate information understandable to policymakers, adaptation practitioners, industry and other stakeholders relevant to investment decisions.

Increased effectiveness of climate actions

- Selecting climate actions using an objective science-based approach to identify associations between the past, present and projected future states of climate and their impacts;
- Selection and prioritization of a range of scientifically sound options for adaptation and mitigation actions based on high-quality observational data, scientifically validated climate change projections and peer-reviewed literature;
- Capacity-development opportunities arising through interaction among a range of partner organizations, from the international to the national level, with mandates for, and recognized experience in, climate data and services provision, and project development.

These advantages constitute opportunities for fostering the science-policy interface and removing hindrances to accessing climate finance.

information for activities seeking climate finance. It addresses climate-sensitive sectors and is particularly relevant for adaptation investments. Its many benefits are outlined in Box 1. The methodology's utility can be extended to support interventions that climate-proof mitigation actions by improving their resilience to climate variability and change.[4] However, the thrust of the methodology is on selecting adaptation actions.

The methodology helps users identify past, present and future climate conditions affecting society and the environment, and select effective actions under current and anticipated climate conditions. To do this, the methodology involves a four-step process:[5]

Step 1 – Identify the area of focus
Step 2 – Identify relevant climatic contributing factors and data
Step 3 – Identify relevant non-climatic contributing factors
Step 4 – Select effective climate actions.

Scientific framework

The methodology draws on three categories of climate indicators that constitute its scientific framework:

1. State of the climate indicators;
2. Context-specific climate indicators; and
3. High-impact events indicators.

These categories of indicators can be used to describe the past and current state of the climate, as well as to project future climate conditions. The scientific framework, and a compendium of data, tools and methods for applying it, are further elaborated in Annex I.

Climate Information Platform

A key online tool for developing the climate science information for climate action is the Climate Information Platform (CIP) hosted by the Swedish Meteorological and Hydrological Institute (SMHI). The WMO, GCF and SMHI collaborated to develop the CIP for users to access site-specific climate data and information (see Box 2).[6] The methods, tools and procedures provided by the CIP ensure that the outputs from their application and use are based on state-of-the-art scientific evidence.

Box 2. Climate Information Platform

www.climateinformation.org

The Climate Information Platform (CIP) is a publicly accessible web-based platform providing access to data, tools and guidance to assist in the development of the climate science information for climate action. The CIP provides interactive maps and graphs summarizing precalculated climate indicators. Climate change indicators available through the CIP are produced from quality-assured state-of-the-art climate models and procedures drawn from global and regional climate model intercomparison projects.

Climate information available through the platform is provided on two levels to address the needs of different users:

(1) Site-Specific Reports, for an instant climate change overview for any location worldwide; and
(2) Data Access Platform, for more precise data selection for further analysis and download.

These capabilities give an instant summary of climate change metrics and their reliability for any site on the globe.

The CIP provides information on past climate change trends based on model data for the reference period 1981–2010, as well as on projected future changes in the climate system. It also supports web-based access to Climpact (https://climpact-sci.org) for calculating context-specific climate indicators and high-impact event indicators for site-specific daily temperature and precipitation data. This offers the basis for identifying trends and variability at the local level (see *Guide to Climatological Practices* (WMO-No. 100).

The platform also offers guidance on how to link global changes to local observations, as well as on the basics of climate science.

Target audience

The target audience for the present guide includes all stakeholders whose collaboration enables the climate science value chain that links climate information to climate actions. These actors span climate project developers to decision makers engaged in climate-sensitive sectors – from climate forecasters working in NMHSs to urban management authorities and private sector entities.

4 Methodologies for supporting mitigation investments are available separately for implementing IPCC Guidelines for National Greenhouse Gas Inventories (refined in 2019) and documenting observed atmospheric GHG concentration levels and emissions reported by countries. These can be found at: www.ipcc.ch/site/assets/uploads/2019/06/SB-50_TFI-side-event_2019-Refinement.pdf.

5 Please see Section 3 for an illustrative summary of the four methodology steps and detailed flowcharts.

6 Photiadou, C.; Arheimer, B.; Bosshard, T. et al. Designing a Climate Service for Planning Climate Actions in Vulnerable Countries. *Atmosphere* **2021**, *12* (1), 121. https://doi.org/10.3390/atmos12010121.

- **Relevant national authority** – national focal point; ensures that the methodology is implemented within a consultative framework; convenes relevant stakeholders; reviews key documents and interventions to ensure that climate actions are addressing Nationally Determined Contributions (NDCs), National Adaptation Plans (NAPs), and/or other national and sectoral strategies; and supports identifying, prioritizing, and selecting climate actions.

- **NMHSs** – national authoritative sources of observed historical weather, water and climate data, and associated products; provide data and information from hydroclimatic data sets and climate projections at local, national and regional scales.

- **Other relevant national and sectoral experts** – provide information on impacts of climate variability, change and extremes, exposure, vulnerabilities, and risks and opportunities in the climate-sensitive sectors prioritized; contribute to obtaining the data and elaborating the science needed to analyse and assess impacts – including documenting data, information or knowledge gaps that impede the assessment of climate impacts. These experts should also support identifying, prioritizing and selecting climate actions.

- **WMO Secretariat and experts** – provide scientific guidance as well as supplementary climate and sector-specific data, internationally or regionally certified methods and toolkits, and products based on data on past and current climate and future climate projections for the country.

- **Project proponents** – include international and national entities that assist in overall project development and implementation. These entities can include United Nations agencies, multilateral organizations, bilateral agencies, international or local financial institutions, national or regional development banks, and other public or private sector entities involved in the design, development and/or financing of eventual climate actions.

Structure of this guide

This guide is structured as follows:

- **Section 1** introduces the methodology and defines its purpose and target audience.

- **Section 2** explores what constitutes best available climate science and highlights the difference in the climate science information for mitigation and adaptation actions.

- **Section 3** explains the four steps of the methodology to develop the climate science information for climate action.

- **Section 4** provides an overview of the key technical resources through which stakeholders can access the climate data and products needed for developing the climate science information.

- **Section 5** discusses options for developing the climate science information in contexts with limited coverage of observation networks or limited data.

- **Section 6** focuses on enabling mechanisms for implementing the methodology. These mechanisms promote access to the expertise necessary for assembling the inputs needed to prepare the climate science information and to correctly interpret the scientific results.

- **Section 7** offers some final reflections relevant for implementing the methodology at the country level and how capacity developed through its implementation reinforces the process.

- **Annex I** provides a resource for accessing data, methods and tools, structured in line with the scientific framework of the methodology. It also provides steps and criteria for assessing data requirements and data adequacy. It draws on guidance material developed over the past decades by WMO experts, consistent with internationally agreed standards.

- **Annex II** provides examples of how the process described in this guide has been implemented in four countries, including LDCs and SIDS, to develop the climate science information for a range of climate actions across a wide variety of sectors and geographies.

2. THE CLIMATE SCIENCE INFORMATION FOR CLIMATE ACTION

The IPCC[7] defines climate science as cumulative scientific findings based on a large body of tested and proven physical processes and principles, compiled and verified over several centuries of detailed laboratory measurements, observational experiments, numerical model simulations and theoretical analyses.[8] Drawing upon the accumulation of scientific knowledge, the IPCC regularly assesses and consolidates such knowledge to create a synthesis of best available science within the climate change domain.

The consensus reflected in IPCC assessments, and the calibrated language used around uncertainty and confidence, are fundamental to increasing decision makers' trust in climate science. Putting climate science first is a highly disciplined and trustworthy way of ensuring objectivity in decision-making. This climate science-first approach tends to quantify and address climate risks through global data analysis.

This may, however, end-up excluding knowledge and practices outside the boundaries of formal scientific processes that could otherwise contribute meaningful perspectives and solutions to climate change challenges. The climate science-first approach consequently reduces the potential for situational, individual and collective pieces of knowledge and initiatives (for example, indigenous, local or community-based) to be legitimized and included in the climate scientific discourse relevant for climate action.[9]

Therefore, leveraging context-specific local knowledge that is scientific and objective while steered through a stakeholder-driven, country-owned approach is preferred when determining what climate actions will be most viable and effective in local contexts.

Towards best available science

The IPCC has made efforts to go beyond the traditional climate science-first approach recognizing that making use of the best available science should entail a stakeholder-driven process that engages local knowledge producers.[10]

Elaborating on the climate science information requires knowledge of context-specific past, present and potential future states of climate, as well as knowledge about associated socioeconomic and environmental impacts of climate and non-climatic factors contributing to those impacts. A stakeholder-driven process, involving local knowledge producers, helps to identify and select the highest-resolution, highest-quality relevant and available data, and to interpret them appropriately for application in local contexts.

Furthermore, country-led engagement is critical to ensure a core principle of country ownership. Meaningful national consultations through participatory processes involving a broad range of stakeholders also allow countries to identify areas of focus and select investments that are aligned with national and other policies, increase stakeholder buy-in and promote sustainability. Country ownership empowers recipient countries, increasing their capacity to develop, plan, manage and implement activities.

Climate science for mitigation actions

The climate science for mitigation has been fundamental to understanding that reducing anthropogenic emissions of GHGs is vital for limiting climate change and its impacts. The science behind the necessity for mitigation actions is well-established and IPCC has amply documented the needs for mitigation investments.[11]

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7 WMO and the United Nations Environment Programme (UNEP) established the IPCC in 1988 with the role of assessing the scientific, technical and socioeconomic information relevant for understanding the risk of human-induced climate change. The IPCC was created to provide policymakers with regular scientific assessments on climate change, its implications and potential future risks, as well as to put forward adaptation and mitigation options. IPCC assessments document the state of knowledge on climate change and identify where there is agreement in the scientific community on topics related to climate change and where further research is needed. These can be accessed on the IPCC website: www.ipcc.ch.

8 Intergovernmental Panel on Climate Change (IPCC), 2007: *AR4 Climate Change 2007: The Physical Science Basis*, https://www.ipcc.ch/report/ar4/wg1/.

9 Hulme, M. *Reducing the Future to Climate: A Story of Climate Determinism and Reductionism. Osiris* **2011**, 26 (1), 245–266. https://doi.org/10.1086/661274.

10 Intergovernmental Panel on Climate Change (IPCC), 2014: *AR5 Climate Change 2014: Impacts, Adaptation, and Vulnerability*, https://www.ipcc.ch/report/ar5/wg2.

11 The scientific information for mitigation is fully described in IPCC Assessment Reports and Special Reports. For example, further reading is available at: http://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_summary-for-policymakers.pdf.

The methodology presented in the present guide is not primarily a resource for developing mitigation-related investments. Resources relevant for mitigation actions are highlighted in Box 3. The climate science behind climate-proofing mitigation actions, however, could be developed using this methodology.

Box 3. Scientific resources available for mitigation actions

Greenhouse gas emission and fluxes data sources

GHG concentrations and emission databases, national communications, UNFCCC emission inventories, and other sector-specific information should be used to establish an emission baseline before the start of mitigation projects. Observation-based emission estimates are highly recommended, if feasible, especially for emission baseline evaluation and to document emission reductions associated with the project implementation.

Information and data on emissions, land use, and GHG fluxes are available from several sources. Additional information on these sources is provided in Annex I:

- International emission databases
The European Commission's in-house Emissions Database for Global Atmospheric Research (EDGAR) estimates anthropogenic GHGs on a country-by-country basis, thereby contributing to enhanced transparency and completing the global picture with time series for each country. Fossil CO_2 emissions from 1970 to 2017 are included in the latest version of EDGAR, EDGARv5.0. This database gives an overview of country-by-country fossil CO_2 emissions from 1990 to 2017. Historic fossil fuel emission data, 1950 to present CO_2 emission estimates, are derived primarily from energy statistics published by the United Nations.[12]

- Land use
Information on the state of and the changes in land use can be retrieved from the Copernicus Land Monitoring Service (https://land.copernicus.eu/global). The relevant product and parameter is 'Fraction of Green Vegetation Cover'. Fractional cover (FCOVER) refers to the proportion of a ground surface that is covered by vegetation. This global product has been offering 300 m resolution since 2014 and 1 km resolution since 1999.

- Greenhouse gas fluxes
There are some estimates of the monthly CO_2 biogenic fluxes (Land Use, Land-Use Change and Forestry (LULUCF) plus natural biogenic fluxes) from inverse modelling. This product is produced by the Copernicus Atmospheric Monitoring Services (https://apps.ecmwf.int/datasets/data/cams-ghg-inversions/). The latest data set is version v18r2, covering the period 1978–2018.

- Ocean uptake
One tool which estimates ocean GHG uptake is offered by CarbonTracker (https://carbontracker.org), a CO_2 measurement and modelling system developed by the United States of America National Oceanic and Atmospheric Administration (NOAA) to keep track of sources (emissions to the atmosphere) and sinks (removal from the atmosphere) of CO_2 around the world. CarbonTracker uses atmospheric CO_2 observations from a host of collaborators and simulated atmospheric transport to estimate these surface fluxes of CO_2. The current release of CarbonTracker provides global estimates of surface-atmosphere fluxes of CO_2 from January 2000 through December 2018. Another data source that addresses ocean uptake is the Surface Ocean CO_2 Atlas (SOCAT, https://www.socat.info that represents a synthesis activity for quality controlled, surface ocean fCO_2 (fugacity of CO_2) observations by the international marine carbon research community. SOCAT enables quantification of the ocean carbon sink and ocean acidification and evaluation of ocean biogeochemical models. The latest SOCAT version (version 2020) has 28.2 million observations from 1957 to 2020 for the global oceans and coastal seas.

- Atmospheric concentrations
The World Data Centre for Greenhouse Gases (WDCGG, https://gaw.kishou.go.jp) is a World Data Centre (WDC) operated by the Japan Meteorological Agency (JMA) under the Global Atmosphere Watch (GAW) programme of the WMO. WDCGG collects, archives and distributes data provided by contributors on GHGs (such as CO_2, CH_4, CFCs, N_2O) and related gases (such as CO) in the atmosphere and elsewhere.

Climate-proofing mitigation actions

Climate-proofing mitigation actions mean seeking to ensure the resilience of such investments. This entails ensuring that mitigation interventions that contribute to reduced GHG emissions and atmospheric concentrations will continue to do so under conditions of climate variability and anticipated future climate change.

Energy systems, for example, need to be optimized for their environments and be resilient to weather extremes, climate variability and climate change. Energy sector planning and operation are markedly affected by meteorological events. With an ever-growing global energy demand (an increase of about 30% in the past 10 years), expanding energy systems are increasingly exposed to the hazards of weather and climate.[13] It is

12 United Nations Energy Statistics, 2017: https://unstats.un.org/unsd/energystats/pubs.

13 World Meteorological Organization (WMO) and Global Framework for Climate Services (GFCS). *Energy Exemplar to the User Interface Platform of the Global Framework for Climate Services*, WMO: Geneva, 2017.

therefore critical to assess what both past and future climate scenarios reveal about observed and expected changes in temperature, precipitation, wind speed, solar radiation, humidity and mean sea-level pressure – all factors which modulate the performance of generation and transmission assets and affect energy demand.

Such considerations are relevant for the transition towards greener and more sustainable energy systems, which is taking place against a backdrop of climate variability and change. Given the dependency of renewable energy generation and demand on weather and climate, it is important to develop robust climate science-based tools to advise energy planners and policymakers.

Climate science for adaptation actions

In the case of adaptation, climate science should support the basis on which selected actions would help to reduce exposure and/or vulnerabilities to climate variability and change, and/or enhance opportunities arising from changing climate conditions. In addition to identifying climatic contributing factors, climate science should be combined with analysis of the degree of exposure and vulnerability of affected people and assets to current and future climate conditions as a basis for identifying, prioritizing and selecting adaptation needs.

A methodology for adaptation actions

The methodology described in the present guide focuses on developing the climate science information for adaptation actions. Its utility can also be extended to support interventions that climate-proof mitigation activities, since climate-proofing is an adaptation intervention.

Key terminology

Users of the present guide may benefit by referring to Box 4 on some key terminology used to support the implementation of a climate science-based methodology (a glossary of additional terms has also been provided in the Glossary of terms section).

Box 4. Key terminology

- **Climate impact** – A consequence of climate variability or change (actual or expected) for natural and human systems.

  Example: Damage to coastal infrastructure

- **Climate-related socioeconomic or environmental outcome** – A climate impact or climate-related objective that the climate action seeks to affect and improve.

  Example: Reduced risk of damage to coastal infrastructure

- **Climate variable** – An instrumentally observed, measured or calculated quantity reflecting the state of the climate system.

  Example: Temperature, precipitation, sea level or glacier mass

- **Climate data** – Time series or spatial data on climate variables derived from observations as well as data products, such as gridded data and numerical model (re)analyses, predictions and projections.
- **Climate index** – A calculated value, from a climate variable or variables, that reduces complex conditions to a single number.
- *Example: Number of frost days or Standardized Precipitation Index (SPI)*
- **Climate indicator** – A climate variable, index or parameter used to describe climate conditions and trends.

  Example: Projected average temperature over a future 30-year time period

- **Climatic contributing factor** – A climate variable, index or parameter that has been shown to be causally associated with a socioeconomic or environmental impact or outcome.

  Example: Heatwaves, floods, ocean acidification

- **Non-climatic contributing factor** – A non-climatic condition, set of assets, or other socioeconomic or environmental entity or process, the interaction of which with climate contributes causally to an impact or outcome.

  Example: Land use

3. THE METHODOLOGY

The methodology described here is designed to provide guidance toward the identification and selection of scientifically grounded adaptation actions. Its implementation requires drawing upon state-of-the-art climate science data, tools and methods which can be used to develop robust climate analyses. In most cases, performing the analysis will demand scientific and sectoral expertise to complement national stakeholders, and the inclusion of such skills – using national and/or international experts – is strongly recommended.

The use of a common methodology and its underpinning resources creates the potential for aligning efforts on a global scale to support the country-led, scientifically grounded, objectively driven selection of adaptation climate actions.

The methodology supports the selection of climate actions by helping to identify and characterize the past, present and future behaviour of multiple climatic contributing factors across spatial and temporal scales that are associated with climate impacts that need to be addressed to improve climate-related socioeconomic and environmental outcomes.

Four steps of the methodology

The climate science information for effective climate actions can be developed in four steps (see Figure 1). These steps should not be interpreted as a strictly linear process. For example, climate-related data (Step 2) could be collected partially in parallel with data relating to non-climatic factors (Step 3). However, it is important that no actions are proposed or selected (Step 4) prematurely, and until after the joint analysis of both climatic and non-climatic contributing factors.[14]

Step 1 – Identify the area of focus

Identify a specific sector or geographic region from national climate-related priorities in NDCs, NAPs and/or other nationally relevant strategies, plans and policies as an area of focus.

Step 2 – Identify relevant climatic contributing factors and data

Identify relevant climate indicators, the variability and change of which contribute, or could contribute, to socioeconomic or environmental impacts in the selected area of focus. In this step, data on climatic contributing factors are obtained, processed and analysed.

Step 3 – Identify relevant non-climatic contributing factors

Identify the non-climatic contributing factors, which include infrastructural assets, natural resources, governance systems, socioeconomic characteristics such as demography, and associated processes that may interact with climate variability and change. Non-climatic contributing factors, together with the climatic contributing factors identified in Step 2, combine to create the climate-related socioeconomic or environmental impacts that can be addressed through climate action.

Step 4 – Select effective climate actions

Arrive at a selection of climate actions based on three criteria: adequacy, feasibility and cost-effectiveness. The result of this selection can be prioritized into a potential investment pipeline based on the country's needs and the actions' alignment with partners' or donors' specific investment criteria.[15]

The implementation of each step of this methodology leads to the next. The completion of the four steps, however, does not signal the end of the methodology's utility. The implementation of Step 4 – selecting effective climate actions – should be followed up with regular assessments and learning to determine whether the selected actions are achieving their expected outcomes. This process is beyond the immediate scope of implementing the methodology since designing, planning, implementing and assessing selected climate actions are subsequent activities. However, those lessons can feedback into future implementations of the methodology, especially when selecting future climate actions.

Furthermore, the implementation of all four steps could signal areas for data/information, capacity, institutional and operational strengthening needed for NMHSs

14 The methodology is illustrated diagrammatically in Figure 2.

15 For example, the GCF uses its six Investment Criteria when screening potential funded activities for investment support. These criteria include: (i) Impact potential; (ii) Paradigm shift potential; (iii) Sustainable development potential; (iv) Needs of the recipient; (v) Country ownership; and (vi) Efficiency and effectiveness. More information on GCF's Investment Criteria can be found at: https://www.greenclimate.fund/projects/criteria.

and other relevant actors involved in developing the climate science information. As an outcome of Step 4, these needs could also be noted as actions requiring support. As these identified needs are addressed and capacities are developed over time, this feeds back into strengthening successive implementations of the methodology.

In this way, there is a virtuous cycle built into the methodology. Each step leads to the next, but every iteration of the methodology's implementation also strengthens future implementations.

Expertise and stakeholder requirements

Identification and application of the technical resources relevant for developing the climate science information for climate action is an expert-guided process. This process provides a unique opportunity for climate scientists and sectoral and other subject matter experts to participate in co-production practices, improve mutual understanding, and ultimately, select effective climate actions for addressing a country's current and emerging climate change conditions. Including such subject matter experts in the proposal design is strongly recommended.

This collaborative process involves a mix of national, regional/international, and sectoral experts and focal points. National experts should include representatives from NMHSs and line ministries and other climate and sector specialists. These national experts could be supported and complemented by WMO or other inter-governmentally identified experts or those from WMO specialized centres and partner organizations.

Methodology implementation

Step 1 – Identify the area of focus

Step 1 identifies a specific sector or geographic region on which the climate science information will focus, by reviewing priorities established through existing country-level policy documents, national climate change strategies, and other relevant strategies and plans.

Identifying an area of focus from among multiple climate policy priorities should be a national decision informed by a consultative, stakeholder-driven, expert-assisted process. This consultative process should ideally be convened by a relevant national authority in its role as the national focal point for coordinating the implementation of the methodology.

At the national level, key stakeholders include the NMHS, sector experts, and local or regional experts from universities or research centres. These experts and stakeholders have relevant knowledge about ongoing priorities, as well as access to relevant information, and other technical resources. Relevant expertise that can be sourced internationally includes competencies around climate policy, climate interactions with climate-sensitive sectors and geographic contexts, data and methods, and tools and techniques for generating analytical inputs and analyses.

Effective interdisciplinary and cross-sectoral collaboration is an important prerequisite for leveraging climate data and information into actionable decisions that blend climate knowledge with sector-specific expertise in local contexts. Therefore, the stakeholder consultative process in Step 1 involves partnership-building, iterative dialogue, and feedback among providers and users of climate information, though they may have had limited or no previous interaction.[16]

Establishing strong collaborative engagement at this stage seeks to ensure that subsequent stages will also benefit from the collective knowledge and that the eventual selection of climate actions will be country-driven.

Countries have usually identified climate-related priorities through national communications, National Adaptation Plans of Action (NAPAs), Technology Needs Assessments (TNAs), Nationally Appropriate Mitigation Actions (NAMAs), NAPs and NDCs, as well as in sectoral policies, strategies and action plans. These documents typically highlight a diverse range of climate-sensitive sectors and geographic contexts and may also contain indicative analyses and projections of temperature, precipitation and water dynamics for current and future periods.

Additional information relevant to the priorities under consideration may be obtained by a literature review (peer-reviewed studies and grey literature). For example, sector experts involved in Step 1 may be aware of unpublished reports commissioned by their ministries. These resources can provide background about the area of focus and be used to improve outcomes in that area.

16 For example, involving private sector entities as part of the stakeholder consultation process can provide valuable information on how they see climate affecting their operations. The private sector can also provide insight on how they use climate information, their requirements and whether there are opportunities for improving the quality of this information to support better business and operational decision-making. Identifying gaps in data and information and improving the quality of such outputs can be considered a co-benefit of implementing this methodology.

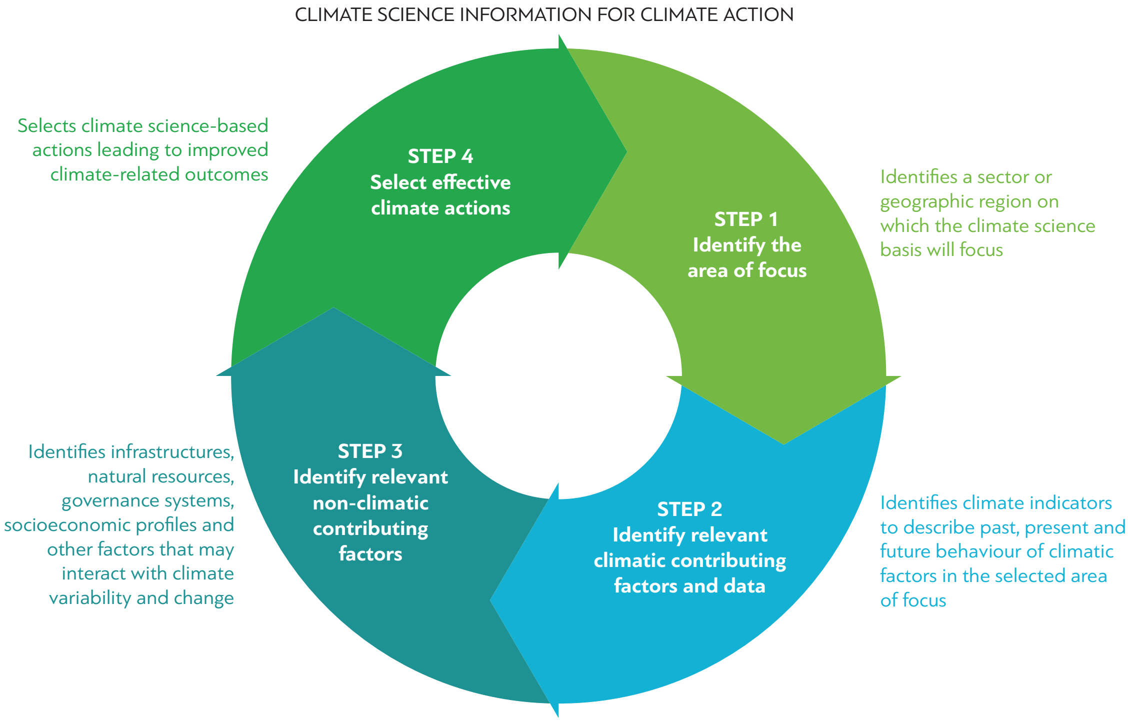

Figure 1. Four-step methodology for developing the climate science information for climate action

Process for Step 1

Through this consultative process, key national and sectoral stakeholders identify a specific national climate priority, climate affected sector(s) – such as energy, transport, urban, land use and forestry, livelihoods, health, food and agriculture, water, resilient infrastructure, ecosystems and ecosystem services – and/or a specific geographic region on which to focus, for which the climate science information for climate action can be developed (see Box 5 for an illustration of this process).

Step 2 – Identify relevant climatic contributing factors and data

Step 2 identifies the specific climatic contributing factors associated with the climate-related impacts relevant to the area of focus identified in Step 1. For example, an area of focus related to agriculture would require climatic information on precipitation, temperature, and soil moisture, among other relevant climatic contributing factors. Whereas an area of focus on coastal erosion may require climatic information on storm surge and sea-level rise. In this step, climate data that shows the historical trends, variability and extremes, and projected future changes is obtained, analysed, and interpreted.

Climate analyses require a preparatory phase during which data inputs are collected, structured, quality checked, and analysed. Specific climate expertise required for Step 2 focuses on climate data management: data sourcing, data quality control, data analysis, climate monitoring, climate projections, data visualization, and communication of climate products. Experts should be able to apply existing WMO guidance in these areas (see Annex 1). In Step 2, climate and data experts will interact with sector experts and other local stakeholders to identify relevant climate contributing factors associated with impacts in the area of focus.

Scientific framework

The climatic contributing factors and data required to implement this methodology are grouped into three categories of climate indicators. Together, these three categories of indicators form the scientific framework that underpins this methodology:

1. State of the climate indicators;
2. Context-specific climate indicators; and
3. High-impact events indicators.

Box 5. Case example for identifying the area of focus

Saint Lucia

The case of Saint Lucia exemplifies the role played by national policies and consultations among key national and sectoral focal points in identifying the specific sectoral impacts to address, and corresponding desired outcomes. Preserving and protecting forest cover in the face of climate variability and change is identified as a priority in the Third National Communication on Climate Change in Saint Lucia.

Moreover, a 2009 Forest Inventory estimated that Saint Lucia's forests store approximately 5.5 million tons of carbon. Due to the rapid development presently occurring in Saint Lucia, the health and sustainability of its forests will play a pivotal role in storing carbon and preventing it from entering the atmosphere.

hrough a stakeholder consultation process, development of a wildfire policy to address the forestry sector was identified as an area of focus. This included the design of management measures for addressing present and future fire-related incidents. The climate science information for this specific area of focus can be developed using climate indicators relevant to the forestry sector and fire behaviour (see Table 1 in Step 2). Key measures identified through the climate science information analyses to protect forests and preserve and/or enhance their benefits under current and expected climate conditions include:

- Implementation of wildfire policy through the use of data on location, availability of resources, weather predictions, topography, air quality and predictions on fire behaviour for present and future fire incidents;
- Increase tree cover outside of forest-protected areas through the use of climate-vegetation models and satellite data sets;
- Forest protection through the use of downscaled data from climate scenarios and their combination with water, crop, forestry and economy models.

The **state of the climate indicators** comprise eight fundamental indicators characterizing overall atmospheric surface conditions and composition, and the state of the oceans and cryosphere relevant for a wide range of applications. The state of the climate indicators are drawn from a larger set of Essential Climate Variables (ECVs)[17] monitored by the Global Climate Observing System (GCOS).[18] Historical data are available for the state of the climate indicators and many other ECVs. Projections of future averages and statistics of variability for a subset of ECVs can be obtained from climate models.

Context-specific climate indicators are indicators associated with impacts in particular climate-sensitive sectors or geographic areas. The context-specific indicators comprise: the full set of ECVs; climate indices that can be calculated from historical data, for example using Climpact; projections of climate indicators such as those that can be generated from the CIP; and any other variable or index found to be associated with climate impacts in a specific context. Their diversity encompasses the wide range of climatic contributing factors that can be associated with socioeconomic or environmental impacts across the range of potential areas of focus.

High-impact events indicators identify specific climatic conditions associated with broad-based, multi-sectoral, or otherwise significant socioeconomic or environmental impacts. High-impact events are characterized in terms of magnitude and duration, location and timing. They include drought, floods, tropical cyclones, heatwaves and other hazards. Climpact can be used to calculate a variety of high-impact event indices.[19]

By selecting the relevant indicators from each of these categories for a particular area of focus and documenting their past trends and variability and expected future changes, it is possible to obtain an overall picture of the trajectory of the characteristics of the climate system relevant for identifying potential climate action options.

Process for Step 2

Given the enormous volume of potentially relevant climate data and products available, it is essential to

17 For a full list of Global Climate Observing System (GCOS) Essential Climate Variables (ECVs), see https://gcos.wmo.int/en/essential-climate-variables/table.

18 GCOS regularly assesses the status of global climate observations of the atmosphere, land and ocean, and produces guidance for its improvement. GCOS expert panels maintain definitions of ECVs which are required to systematically observe Earth's changing climate. The observations supported by GCOS contribute to solving challenges in climate research and underpin climate services and adaptation measures.

19 A complete list of the sector-specific climate indices that are possible to calculate with Climpact is available at https://climpact-sci.org/indices/. Climpact cannot be used for calculating indices related to tropical cyclones, storms, tornadoes or sea waves, among other high-impact weather events. It can, however, provide information about extreme events identifiable from daily precipitation and temperature time series.

define which are appropriate for addressing a specific area of focus and where to find them.

Step 2 requires gathering data for two time frames in order to identify the climatic contributing factors:

1. **Historical data:** Historical observations that can be used to assess long-term trends, variability and extremes; and
2. **Projection data:** Projections generated from climate models used to estimate future changes of relevant climatic contributing factors.

Historical data

NMHSs, depending on the level of their observational capacity, should be able to provide data for selected ECVs and their historical trends, variability and extremes, through their monitoring of observed daily temperature, precipitation, cryosphere (snow cover, sea ice, glaciers) and sea level. In addition to NMHS data, many global and regional climate data sets from research centres, data hubs, reanalysis and climate modelling centres, and satellite agencies from the WMO network are also available. When assessing historical variability, trends and extremes, the data sets should be quality controlled, consistent and of a homogenized time series.

Sub-daily meteorological measurements, daily values of maximum and minimum temperature, daily precipitation and other meteorological variables, subject to their quality and consistency, can be used to extract time series of climate extremes and trends and to generate context-specific climate information. Since climate, in contrast to the weather, is assessed from long-term statistics, 30 years of observations are generally the lower limit for performing reliable analyses of trends[20] and extremes.[21] However, in the absence of a full 30 years of instrumentally recorded data, such data might still provide valuable information on the interannual climate variations and the behaviour of extremes, particularly if climatic data match sectoral impact data and other data sources.

Projection data

The CIP provides access to precalculated climate change indicators that can be used to project future trends, variability and change using both regional and global climate models (RCMs and GCMs). These have been developed under the Coordinated Regional Downscaling Experiment (CORDEX) and using ensembles from the Coupled Model Intercomparison Project Phase 5 (CMIP5)[22] from ten CORDEX domains covering the world.

These climate models produce daily time series for the desired number of grid points in a geographical domain. These outputs cannot be considered as future forecasts of daily weather. However, they are used to generate averages and statistics of variability for future periods. To help make assessments for the future, climate change indicators in the CIP are provided for different periods:

- A standard period (1981–2010, absolute values);
- Early century (2011–2040, recent and expected future change values);
- Mid-century (2041–2070, expected future change values); and
- End of the century (2071–2100, expected future change values).

Identifying climatic contributing factors

The key aspect of Step 2 is to decide which climatic contributing factors are pertinent from among all possible climate characteristics relevant to the area of focus. For example, in the case of agriculture, these would include phenomena like dry spells, extreme

20 There is a need for a relatively stable reference period for long-term climate variability assessments and climate change monitoring. Historically, climatological standard normals were calculated every 30 years for 30-year periods (1901–1930, 1931–1960, 1961–1990 and so on). For the specific purpose of long-term climate monitoring, the normals calculated for the period 1 January 1961–31 December 1990 are referred to as a stable WMO reference period and should be retained in perpetuity or until such time as a compelling scientific reason to change the period arises. However, there is also a need for more frequent calculations of climatic normals in a changing climate. A more recent averaging period, such as 1981–2010, would be viewed by many users as more 'current' than 1961–1990. Therefore, now climatological standard normals are calculated every ten years for 30-year periods at the start of every decade. For more information see *Guide to Climatological Practices* (WMO-No. 100).

21 The WMO *Guidelines on the Definition and Monitoring of Extreme Weather and Climate Events* (forthcoming) defines extreme events as anomalies (departure from average) and percentiles which depart from a WMO climatological standard normal or base period, and/or which have the potential to cause negative socioeconomic impacts. The IPCC (2012) defines climate extreme (extreme weather or climate event) by the occurrence of a value of a weather or climate variable above (or below) a threshold value near the upper (or lower) ends of the range of observed values of the variable. For simplicity, both extreme weather events and extreme climate events are referred to collectively as climate extremes. For further information, see: IPCC. Glossary of Terms. In *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation*; Field, C. B.; Barros, V.; Stocker, T. F. et al., Eds.; Cambridge University Press: Cambridge, UK, and New York, USA, 2012. https://archive.ipcc.ch/pdf/special-reports/srex/SREX-Annex_Glossary.pdf.

22 More than 100 modelling groups around the world were involved in both CORDEX and CMIP5 communities (Eyring, V.; Bony, S.; Meehl, G. A. et al. Overview of the Coupled Model Intercomparison Project Phase 6 (CMIP6) Experimental Design and Organization. *Geoscientific Model Development* **2016**, 9, 1937–1958. https://gmd.copernicus.org/articles/9/1937/2016) with the responsibility to provide the best quality-assured climate data following agreed international standards. This model data is produced and quality controlled in collaborative climate-modelling frameworks coordinated by the World Climate Research Programme (WCRP). CORDEX outputs have a higher resolution than those of CMIP. For more information, visit www.cordex.org and www.wcrp-climate.org/wgcm-cmip.

temperatures and frosts, among others. In a case like a built environment or infrastructure, high-impact events such as floods, hail and wave height, among others, could be most relevant.

Sector and climate experts can use the scientific framework to identify the climate indicators that are relevant and for which the data are available. The climate experts can then generate information on those indicators for the past, present and future. The information generated needs to be analysed and assessed and then interpreted to establish which indicators are causally associated with climate impacts relevant for the area of focus. Those which show such causality are considered to be the climatic contributing factors. See Box 6 for an illustration of this process.

Box 6. Case example for identifying relevant climatic contributing factors

Cabo Verde

In Cabo Verde, Climpact was used to generate indices relevant to the priorities identified in the national policy documents. The country focal points agreed to develop the climate science information for the disaster risk reduction sector. As recognized by several national strategies, such as the National Strategy for Disaster Risk Reduction (DRR) in Cabo Verde, the small island developing State has experienced a significant escalation in the number of disasters linked to the occurrence of extreme weather events such as increased precipitation. The National Institute of Meteorology and Geophysics (INMC) provided national and sectoral decision makers with observed time series data from 13 automatic weather stations installed across the country that were subsequently processed by Climpact experts to generate precipitation indices. Through calculation and analysis of these indices, decision makers observed an increase in the frequency of above-average annual precipitation values after 2008, and that higher precipitation years were regularly followed by periods of low precipitation and drought.

Through further historical analysis of the indices, national, regional and global experts noted that these wet-drought cycles have been occurring since 1980. The same pattern was found in several islands of the archipelago. These results facilitated the identification options to address risks and opportunities associated with increased precipitation values, such as the establishment of a national early warning system.

Meanwhile, climate projections generated from the CIP helped decision makers in the DRR sector to better understand potential future changes in precipitation, a major source of climate risk for the country, and specifically an increased frequency and severity of extreme precipitation events. Climate indicators generated using the CIP projected an overall 4% increase in the total annual precipitation expected in the archipelago during the 2011–2040 period under an RCP 8.5 scenario. These results, in addition to the historical trends of increased precipitation values detected in Climpact indices, pointed to a possible increase in flood periods, and in the annual values of water discharge and run-off.

This information was jointly assessed by a working group composed of DRR and climate experts who analysed the upward trend in the total quantity of rainfall during the rainy season. On the basis of the history of hydrometeorological hazards in Cabo Verde and the island's conditions of exposure and vulnerability, DRR national experts inferred that increased occurrence of extreme rain events in short periods of time may lead to floods of greater intensity, and potentially to an increase in associated damage and losses, in specific locations of Cabo Verde. This information was used to target DRR interventions in high-risk areas.

Measures identified based on the analysis include:

- Development of vulnerability maps and identification of risk scenarios for hazardous areas where natural disasters typically occur;
- Definition of criteria and rules for warning and alert dissemination;
- Creation of a common database/platform for sharing information and data for all users and stakeholders;
- Development of contingency and action plans for specific climate impacts;
- Empowerment of communities and individuals to respond appropriately in a timely manner to extreme events;
- Implementation of civil structures to minimize the impact of disasters;
- Enhancement of coordination mechanisms and integration of the efforts of the various public and private entities.

Illustrative climate indicators

To guide users, Table 1 illustratively shows climate indicators that could be obtained and incorporated into an analysis for climate-sensitive sectors. The indicators fall within the three categories of the scientific framework as described above. In practice, the availability of data on the indicators shown in the table may be limited.[23] Users can reference this table for examples of historical and projected indicators relevant by sector. Experts, including sector specialists and the NMHS, can determine the specific historical and projected indicators that are relevant in specific local contexts.

Table 1. Illustrative climate indicators by sector

Sector	State of the climate indicators	Context-specific climate indicators	High-impact events indicators
Energy	Means, trends and variability of • Temperature • Precipitation • Sea level • CO_2, methane and other greenhouse gases	Other Essential Climate Variables: • Solar irradiance • Cloud properties • Aerosols • Wind speed and direction • Sea-subsurface currents • Wave height • Sea-surface salinity • Sea-surface temperature • Soil moisture • River discharge • Pressure • Ozone profiles Additional climate variables and indices relevant for climate action: Water run-off • Wind gust estimation • Extreme low and high streamflow • Tides • Wave direction • Wave spectrum • Other air quality indices • Humidity (affecting electricity) • Wind production index • Solar production index	• Percentage of days when daily maximum temperature > 90th percentile • Heatwave frequency • Heatwave duration • Heatwave magnitude • Total annual precipitation from heavy rain days • Warm spell duration index • Total annual precipitation from very heavy rain days

23 Information on indices that can be generated from historical daily temperature and precipitation data using Climpact and on indicators for which future projections can be generated through the Climate Information Platform, and web links to these resources for further information, is provided in section 4. Potential sources of additional information for the variables listed in Table 1 are extensively provided in Annex I.

Sector	State of the climate indicators	Context-specific climate indicators	High-impact events indicators
Transport	Means, trends and variability[24] of: Temperature • Precipitation • CO_2, methane and other greenhouse gases	Other Essential Climate Variables: Solar irradiance • Ozone • Aerosols • Wind speed and direction • Pressure • Wave height • River discharge • Cloud properties • Additional climate variables and indices relevant for climate action: Air quality • Photochemical smog indices • Water run-off • Humidity (affecting energy conversion efficiency)	• Percentage of days when daily maximum temperature > 90th percentile • Heatwave frequency • Heatwave duration • Heatwave magnitude • Total annual precipitation from heavy rain days • Total annual precipitation from very heavy rain days
Urban	Means, trends and variability (high resolution) of: Temperature • Precipitation • CO_2, methane and other greenhouse gases • Sea level	Other Essential Climate Variables: Anthropogenic water use • Ozone • Solar irradiance • Land cover • Soil moisture • River discharge • Wind speed and direction • Pressure • Wave height • Water vapour • Cloud properties • Air temperature • Additional climate variables and indices relevant for climate action: Solar irradiance index • Shading orientations of buildings • Heat fluxes	• Percentage of days when daily maximum temperature > 90th percentile • Heatwave frequency • Heatwave duration • Heatwave magnitude • Annual total precipitation index • Total annual precipitation from heavy rain days • Total annual precipitation from very heavy rain days • Extreme winds

24 The aviation industry operates both at ground level and in the troposphere. Consequently, the aviation sector would have an interest in knowing the means, trends and variability of critical parameters of interest such as temperature, wind speed and direction, pressure and cloud properties, in the vertical and not only at surface/ground level.

Sector	State of the climate indicators	Context-specific climate indicators	High-impact events indicators
		• Other air quality indices • Green cover fraction • Urban emission inventory • Urban canopy structure • Wind chill factor • Catchment area • Water quality • Humidity index	
Land use and forestry	Means, trends and variability of: Temperature • Precipitation • Sea level • CO_2, methane and other greenhouse gases • Glacier mass balance • Arctic and Antarctic sea ice	Other Essential Climate Variables: Groundwater • Anthropogenic water use • Fire – burnt areas • Land cover • Vegetation biomass • Permafrost • Ozone • Wind speed and direction • Solar irradiance • Water vapour • Soil moisture • Cloud properties • Land-surface temperature • Soil carbon • Leaf area index Additional climate variables and indices relevant for climate action: Potential Fire Index • Rate of forest cover change • Green cover fraction • Monthly maximum value of daily maximum temperature index • Standardized Precipitation Evapotranspiration index	• Consecutive dry days • Warm spell duration index • Heatwave frequency • Heatwave duration • Heatwave magnitude • Keetch-Byram Drought Index (Wildfires) • Fire danger rating

Sector	State of the climate indicators	Context-specific climate indicators	High-impact events indicators
Livelihoods	Means, trends and variability of: Temperature • Precipitation • Sea level • CO_2, methane and other greenhouse gases • Glacier mass balance • Arctic and Antarctic sea ice • Ocean heat content • Ocean acidity	Other Essential Climate Variables: Groundwater • Anthropogenic water use • Fire – burnt areas • Land cover • Vegetation biomass • Sea-surface temperature • Sea-surface salinity • Marine habitat properties • Permafrost • Soil moisture • River discharge • Wind speed and direction • Solar irradiance • Water vapour • Cloud properties • Land-surface temperature • Wave height • Ocean surface heat flux Additional climate variables and indices relevant for climate action: Monthly maximum value of daily minimum temperature index • Monthly maximum 1-day precipitation index • Monthly maximum consecutive 5-day precipitation index	• Standardized Precipitation Index • Total annual precipitation from heavy rain days • Total annual precipitation from very heavy rain days • Percentage of days when daily maximum temperature > 90th percentile • Heatwave frequency • Heatwave duration • Heatwave magnitude
Health, food and water	Means, trends and variability of: Temperature • Precipitation • Sea level • CO_2, methane and other greenhouse gases • Ocean heat content • Ocean acidity	Other Essential Climate Variables: Soil moisture • Groundwater • Anthropogenic water use • Aerosols • Fire – burnt areas • Land cover • Permafrost • Ocean surface heat flux	• Warm spell duration index • Consecutive dry days • Standardized Precipitation Index • Total annual precipitation from heavy rain days • Total annual precipitation from very heavy rain days • Number of very heavy rain days index

Sector	State of the climate indicators	Context-specific climate indicators	High-impact events indicators
		• Sea-surface temperature • Sea-surface salinity • Marine habitat properties • Plankton • River discharge • Wind speed and direction • Solar irradiance • Water vapour • Land-surface temperature • Wave height • Lightning • Subsurface current Additional climate variables and indices relevant for climate action: Photochemical smog indices • Standardized Precipitation Evapotranspiration index • UV index • UV radiation • Pollen counts • Monthly maximum value of daily maximum temperature index • Monthly maximum value of daily minimum temperature index • Monthly maximum 1-day precipitation index • Percentage of days when daily maximum temperature > 90th percentile • Monthly maximum consecutive 5-day precipitation index • Annual total precipitation index	• Percentage of days when daily maximum temperature > 90th percentile • Number of tropical nights index – annual count of days when daily minimum temperature > 20 °C • Heatwave frequency • Heatwave duration • Heatwave magnitude • Daily precipitation intensity index

Sector	State of the climate indicators	Context-specific climate indicators	High-impact events indicators
Resilient infrastructure	Means, trends and variability of: Temperature • Precipitation • Sea level	Other Essential Climate Variables: Wind speed and direction • River discharge • Fire – burnt areas • Wave height • Ocean surface heat flux • Sea-surface temperature • Subsurface currents • Solar irradiance • Land-surface temperature • Land cover • Lightning • Permafrost Additional climate variables and indices relevant for climate action: Water run-off • Wind speed index • Fire index • Hail • Tides • Monthly maximum consecutive 5-day precipitation index • Standardized Precipitation index • Monthly maximum value of daily maximum temperature index • Percentage of days with above-average temperature	• Number of tropical nights index – annual count of days when daily minimum temperature > 20 °C • Total annual precipitation from heavy rain days • Total annual precipitation from very heavy rain days

Sector	State of the climate indicators	Context-specific climate indicators	High-impact events indicators
Ecosystems and ecosystem services	Means, trends and variability of: Temperature • Precipitation • Sea level • CO_2, methane and other greenhouse gases • Glacier mass balance • Arctic and Antarctic sea ice • Ocean heat content • Ocean acidity	Other Essential Climate Variables: Groundwater • Anthropogenic water use • Wind speed and direction • Fire – burnt areas • Land cover • Vegetation biomass • Permafrost • Wave height • Ocean surface heat flux • Sea-surface temperature • Sea-surface salinity • Nutrients availability • Marine habitat properties • Plankton • Permafrost • Soil moisture • River discharge • Solar irradiance • Land-surface temperature • Subsurface current Additional climate variables and indices relevant for climate action: Water run-off • Water levels • Tides • Standardized Precipitation index • Annual total precipitation index • Percentage of days with above-average temperature	• Warm spell duration index • Cold spell duration index • Total annual precipitation from heavy rain days • Total annual precipitation from very heavy rain days • Heatwave frequency • Heatwave duration • Heatwave magnitude

Interpreting the results from Step 2

Analysis of the past trends, variability and extremes, and potential future changes in climatic contributing factors for the specific area of focus provides evidence for interpreting how the climate affects or may affect, an area of focus.

The historical information can be used to assess trends, variability and extremes. Projection information, sourced from the CIP, can be used to assess the future expected climate conditions. Together, the historical and projection information can be used to assess the extent to which the identified indicators are climatic contributing factors relevant to an area of focus.

In interpreting this information, expert judgment needs to be applied to assess the relevance of each to the analysis. Information on climatic averages and statistics of variability for future periods is important for strategic decisions and those involving long-term commitments. However, stakeholders should be aware of the limitations of climate change projections. This includes considerations such as:

- Ensuring that the selected timescales are relevant for decisions that need to be made. For example, an infrastructure intervention requires a longer timescale of analysis than an early warning systems intervention addressing climate-related hazards that are emerging or already clearly present.

- Ensuring that the efforts placed on perfecting the projections do not devolve into an exercise of diminishing returns. This causes unnecessary costs, time and resources, which may not necessarily generate better results. Experts should be able to determine when the information is sufficient to provide conclusive analysis and interpretation.

- Recognizing that information from projections is inherently uncertain. Experts, as well as outputs from the CIP, can help in determining the robustness of the results.

For the purposes of assessing the robustness of projections of future climate, two important factors need to be considered:

1. The extent of agreement among the projections from the different climate models; and

2. The extent to which the projected climate changes correspond with historical trends.

The extent of agreement among the projections from the different climate models

When trying to determine the extent of emphasis to place on projections of future climate it is important to understand that a climate model is a numerical representation of the climate system, and thus does not provide a perfect description of the system. The representation of the physical laws governing the climate system differs between models. Model complexity also differs between climate models. Some models include more processes than others. This means that climate models will give different results. The size of these differences can be large or small depending on model, region, season or variable. A model may perform well for some regions/seasons/variables and worse for others.

The usual way to handle these differences is to utilize model ensembles, where several climate models are used together. The use of ensembles enables estimations of the certainty of results. The spread can be significant, partly because models describe climatological processes in different ways. This is the advantage of model ensembles. If the same response is seen in several models, the result is more certain. If the responses vary from model to model, the result is less certain. The agreement on the sign of change is a confidence metric based on the number of models agreeing on a decrease, no change or an increase in the climate change signal of a climate indicator.

When interpreting the results of whether a certain climatic indicator is projected to change and should be part of the basis for proposing a climate change action, a user should take into consideration that the more models that agree on a sign of change, the more confident the user can be about the sign of change to occur in the future.

The CIP provides the qualitative assessment of the validity of model outputs and guides users on how to assess the uncertainty in projected climate changes. It gives an indication of how large the change is for each climate indicator (small, medium and large) and in which direction (increase, decrease, no change) the indicator is moving. This helps the user to focus on the cases which indicate more robust signals.

The extent to which the projected climate changes correspond with historical trends

A second consideration for assessing the robustness of projections of future climate is the extent to which the projected climate changes correspond with historical trends at a given location of interest. Direct comparison of historical climate indicators with their corresponding projected values is not possible in all cases.[25] However, by juxtaposing historical and projected future values of relevant climatic contributing factors where both are available – and generally comparable indicators in cases where they are not – an overall picture of the trajectory of the climatic contributing factors can be obtained.

Experts can review the analysis and results to understand past, present and future climate. Based on interpretation and assessment, users can identify the relevant climatic contributing factors that are causally associated with the climate impacts relevant for the area of focus. These become the climatic contributing factors to be used in further steps.

Box 7. Case example for interpreting climate analysis results

Cabo Verde

The case of Cabo Verde offers an example of the complexity of interpreting climate model results. In developing the climate science information for the energy sector, climate experts used the CIP to investigate what the climate could look like over the upcoming decades to assess water run-off for renewable energy generation. The projected temperature change for RCP 4.5 is a 1 °C increase over the next 40–50 years (coinciding with the 2041–2070 period). Country experts recognized this projection as broadly in line with the trend for the past 40 years. However, the projected precipitation showed a negative change (–3%), therefore with an opposite sign in respect of the historical trend.

National, regional and international climate expert interactions helped to analyse the results generated by the CIP for historical observed trends. Experts observed that precipitation signals were more mixed than the temperature signals in climate projection models which indicate important uncertainties in precipitation-related climate change indicators important for different sectors and locations.

To overcome this issue, in Cabo Verde, climate experts created a list of projected changes and ordered those with the more robust signals. The sign of change with the highest number of models, defined as the dominant change type, was used to design a specific course of action in bullet points, as given below. Climate experts also acknowledged that even if all models indicated little or no change, this was still a robust signal, which can be important information for adaptation strategies.

A number of areas were also identified as needing work in order to support the adaptation and mitigation measures. Some of those were targeted at expanding and improving the national hydrometeorological network so that it could facilitate the correction of biases in global and regional data when compared with local observations. Greater availability of local observations permits such biases to be adjusted using bias-correction methods.

The measures identified promote the use of an appropriate renewable energy mix based on the energy potential of the climate-related variables identified and quantified (wind and solar). Proposed actions also relate renewable energy to energy efficiency, infrastructure and other energy-intensive sectors such as transport, water, fishery and tourism:

- Production of water for consumption from solar, wind and wave energy;
- Promotion of solar energy systems for wastewater treatment;
- Solar pumping for agriculture;
- Ice production and fish preservation using renewable energies;
- Improvement of the smart grid with production and control of energy distribution;
- Construction of energy storage structures;
- Establishment of renewable energy micro grids (such as domestic solar energy systems);
- Construction of a comprehensive network of energy suppliers and incubators for clean energy producers.

Step 2 results in the identification of climatic contributing factors. However, this may not provide a complete explanation. Step 3 will help determine the extent to which these factors are contributing to impacts and outcomes relevant to an area of focus.

Step 3 – Identify relevant non-climatic contributing factors

Step 3 identifies relevant non-climatic contributing factors for the area of focus. Non-climatic contributing factors include things like population density, health care coverage/availability, resource usage, access to

25 The indicators for which information on projected future states is available from climate models is more limited than for which historical data are available such as for ECVs and Climpact indices. In addition, low-frequency oscillations might influence local climate in a given country/territory. If so, projections might not correspond to the signals of historical trends, especially when historical records are relatively short.

basic infrastructure, and other socioeconomic and environmental type indicators where there is a known relationship between observed changes in climate and its societal impact.[26] Step 3 identifies which non-climatic contributing factors are relevant for the area of focus based on those relationships. Non-climatic contributing factors, together with the climatic contributing factors identified in Step 2, determine what the current and potential future socioeconomic and environmental impacts may be on the area of focus.

Step 3 requires the engagement of thematic and subject matter specialists who can provide knowledge on the socioeconomic and environmental impacts for their given areas. Such expertise could include sector specialists, economists, policy planners, engineers and other specialized expert stakeholders. The tasks of these specialists, together with climate experts, include: providing data sources and relevant peer-reviewed or grey literature that documents historical impacts; ensuring that the scientific resources are understood and appropriately applied; identifying and analysing the interactions of climatic and non-climatic contributing factors from the scientific resources being used; and interpreting the results.

The data needed for Step 3 includes data on climate impacts as well as data on the non-climatic contributing factors associated with those impacts.[27] These two sets of data will allow for the relationship between the climatic contributing factors (identified in Step 2) and non-climatic contributing factors to be established in the process of this step.

Relationships between climatic and non-climatic contributing factors and the impacts to which they contribute may be non-linear. Impacts may materialize when the values of either type of contributing factor exceed a certain threshold.[28] Identifying these key thresholds, where they exist, provides important information for the further identification of effective climate actions.

Data on non-climatic contributing factors can be time series, such as population data, agricultural yield, the incidence of water-borne or vector-borne diseases, water supply, energy demand and energy output, among other relevant data needed for analysis. Non-climatic contributing factors can also be analysed using spatial data – such as on population density, critical infrastructure, or important land uses and their attributes – for assessing exposure and vulnerability.[29] These non-climatic contributing factors data should be correlated with the time series climate variables and indices identified in Step 2. This enables an assessment of the relative contributions of each using statistical methods.

Data on non-climatic contributing factors should be appropriately quality controlled and, where appropriate, detrended by sector experts to account for trends arising from non-climatic drivers; otherwise spurious relationships could be inadvertently concluded. For example, agricultural production in many countries has increased in recent decades due to improved machinery and methods. The contribution of these non-climatic contributing factors to such growth may have been enhanced or offset by climatic contributing factors, such as a trend towards increasing or decreasing soil moisture over the same period. Accounting for trends and variability in the non-climatic contributing factors in this step helps to identify their respective contributions to socioeconomic and environmental impacts and outcomes. If trends associated with non-climatic contributing factors are not comprehensively understood, on the other hand, relationships with trends in climatic contributing factors, such as increasing or decreasing soil moisture, that also occurred over the same period, may be improperly identified when, in fact, the two may be unrelated.

Very often there is insufficient data available on non-climatic contributing factors to allow for a robust statistical relationship between the climatic and non-climatic contributing factors to be established. In this case, analysis of non-climatic contributing factors would have to be based on empirical published studies, government reports or grey literature that may be available, combined with expert knowledge. However, the gaps should be noted as something to be addressed through data improvement measures.

26 For example, the occurrence of dengue fever can be analysed by understanding the relationship between climatic contributing factors, such as temperature, rainfall and humidity, and non-climatic contributing factors, such as population exposure, health care availability, quality of water sanitation and treatment, or other similar socioeconomic type indicators.

27 Data for non-climatic contributing factors can often be obtained from ministries of finance, planning, development, energy, health, or other key ministries; national statistical offices; and/or Central Bank Yearbooks.

28 For example, simply having more land-use polices does not necessarily lead to more favourable impacts. Rather, it is having the relevant policies that will achieve the intended outcomes. Similarly, continued increases in rainfall do not necessarily lead to continual increases in crop production. Beyond a certain threshold, rainfall may damage production.

29 Vulnerabilities are the characteristics of such non-climatic contributing factors that make them more or less likely to experience negative impacts when exposed to climatic contributing factors that affect them.

Process for Step 3

Non-climatic contributing factors are identified on the basis of the extent to which their response to and interaction with climatic contributing factors could lead to climate-related impacts relevant for the area of focus. Specialist experts begin by identifying and gathering information and data on non-climatic factors potentially relevant to the area of focus. They then assess the degree of association between these factors and the climatic contributing factors identified in Step 2 to determine the extent to which they contribute to climate-related impacts.

For example, in the health sector, a country may identify that vector-borne disease incidence is on the rise. Experts could run a statistical analysis to verify whether transmission may be related to climatic contributing factors such as higher temperature and changing precipitation patterns, which were identified in Step 2. In this example, the results may show that there is a strong relationship between the relevant climatic contributing factors (rising temperatures and increased precipitation) associated with non-climatic contributing factors (such as increased number of people infected), thereby warranting the need for climate action.

Conversely, the rising incidence of disease could in fact be due to other factors such as unplanned urbanization and increasing rates of migration. The climate situation may be exacerbating the problem but the extent needs to be analysed in order to verify all underlying causes and determine the key drivers. Sector-specific expert judgment, local knowledge, and further analysis and study of potential relationships are needed to verify the results.

In another instance, using the water sector as an example, a region may be experiencing a reduction in water resources. However, the results from Step 2 may show that precipitation levels are the same and projected to be so in the coming years. Meanwhile, relevant non-climatic contributing factors such as population growth, increased tourism, poor water management and system losses may be the key drivers imposing the stress on water resources.

This latter example illustrates that while the water levels may be decreasing, the relationship between the relevant climatic and non-climatic contributing factors is unfounded. As such, the decreasing water availability appears to be due to non-climatic contributing factors as described in the example; not necessarily due to a changing climate situation in the region. While these non-climatic contributing factors are relevant and warrant further study and intervention to resolve the impending water availability issue, seeking to address this as climate action is unlikely to prove effective as it may not resolve the true underlying causes. Further examples are outlined in Box 8.

Box 8. Case examples for identifying relevant non-climatic contributing factors

Cambodia

In Cambodia, climate indices generated using Climpact helped to establish thresholds and probabilities of occurrence for specific health-related hazards, such as heatwaves. The analysis of historical trends of exceedance of these temperature thresholds identified a significant upward trend in temperatures above 29 °C for the period 1981 to 2010. Further projected into the future, this showed a potential to dramatically increase vector-borne disease transmission (such as malaria and dengue). The information provided by climate indices was interpreted in synergy with non-climatic considerations that could exacerbate or override the effects of climate on vector-borne diseases, such as urbanization and migration.

Some of the adaptation options for addressing the health impacts of climate change identified through the climate science information analyses are listed below:

- Vulnerability assessment of the national health system structure and health facilities to disruption by extreme events and long-term climate trends;
- Investments in the national health system infrastructure to strengthen the resilience of information and communication systems, health facilities and professional staff to extreme events and long-term climatic changes;
- Training on climate-sensitive disease prevention and control;
- Mainstreaming of climate change and health risks into public health programmes, in-service training and curricula;
- Awareness campaigns on climate change-related impacts on water, sanitation and food hygiene;
- Establishment of a national committee for health and disaster preparedness, management and response;
- Development of a health early warning system for priority climate-sensitive diseases;
- Promotion of intersectoral and international collaboration on health adaptation options;
- Enhancement of disaster preparedness and response at the community level.

Democratic Republic of the Congo

In the climate science information for the agricultural sector in the Democratic Republic of the Congo, national experts showed how increasing variability in seasonal rainfall, augmented frequency and magnitude of droughts, and occurrence of weather extremes represent a physical hazard for the ecosystem and the natural resource base of communities. However, the propensity of communities and individuals to be negatively affected by climate variability and change was recognized to be exacerbated by non-climatic contributing factors such as population growth, degradation and overuse of natural resources, and difficulties in accessing health or education facilities. These additional non-climatic contributing factors were then considered for the identification of climate responses, as well as for ensuring cultural, environmental and socioeconomic acceptability of the proposed actions.

Based on the observed climate trends and simulated projections, a number of adaptation measures were recommended, whose identification combined a biophysical assessment with socioeconomic data to identify vulnerable groups of people and areas. As diversification of livelihoods increases resilience to climate change, measures such as ecosystem restoration and soil conservation were identified to contribute to enhanced resilience of the agriculture sector as a whole, in addition to crop and livestock management. The recommended measures include:

- Using adapted varieties (early and drought-resistant);
- Promoting alternative crops;
- Developing livestock farming;
- Adopting agroforestry systems;
- Building reservoirs and retention basins;
- Promoting integrated crop protection;
- Using short-cycle varieties, maize, rice and beans;
- Strengthening soil conservation practices;
- Implementing comprehensive crop protection strategies.

Non-climatic contributing factors

The non-climatic contributing factors that will be relevant in any context will depend on the specific area of focus. To guide users, Table 2 illustrates non-climatic contributing factors that might be obtained through Step 3 for most sectors. These non-climatic contributing factors have been grouped into five categories based on the *Guidance on Integrated Urban Hydrometeorological, Climate and Environment Services Volume II: Demonstration Cities* (WMO-No. 1234).[30]

Table 2. Illustrative examples of non-climatic contributing factors (non-exhaustive)

Non-climatic contributing factors					
Sector	Geophysical	Natural resources	Socioeconomic	Governance	Infrastructure
Energy	• Topography such as low-lying areas • Volcanic and seismic region • Small land mass (e.g. SIDS) • Tsunami prone areas	• Natural resources capital • Biodiversity	• Energy access • Water consumption • Energy demand • Individual and collective behaviour • Energy consumer satisfaction • Population welfare	• Public electricity network • Public awareness • Public education • Energy price • Financial liquidity of the market • Oil and fossil fuel market	• Tourism infrastructure • Transport systems • Energy storage structures • Quality of electricity systems • Household appliances • Air conditioning units • Oil and gas installations placement • Maritime fuel transportation
Transport	• Low-lying land including land reclaimed from the sea • Volcanic and seismic region • Small land mass (e.g. SIDS)	• Natural resources capital • Biodiversity • Soil characteristics	• Energy access • Energy demand • Water consumption • Individual and collective behaviour • Energy consumer satisfaction • Population welfare • Land use	• Urban planning • Public electricity network • Public awareness • Public education • Energy price • Financial liquidity of the market • Oil and fossil fuel market • Public roads regulations and management	• Tourism infrastructure • City infrastructure • Transport systems • Energy storage structures • Urbanization

30 The organization of this table into five categories of non-climatic contributing factors, as well as the illustrative examples of factors that can be used for analysis is borrowed from WMO-No. 1234 Guidance on Integrated Urban Hydrometeorological, Climate and Environment Services – Volume II: Demonstration Cities (2021). Another useful reference for guidance on obtaining non-climatic contributing factors is the WMO-GFCS Energy Exemplar (2017). This document is particularly relevant to the energy, transport, and urban sectors, and is available at: https://public.wmo.int/en/resources/library/energy-exemplar-user-interface-platform-of-global-framework-climate-services.

Non-climatic contributing factors					
Sector	Geophysical	Natural resources	Socioeconomic	Governance	Infrastructure
Urban	• Topography such as low-lying areas • Volcanic and seismic region • Dry land • Small land mass (e.g. SIDS) • Coastal area • Mountainous area	• Natural resources capital • Biodiversity • Ecosystems degradation • Soil characteristics	• Demography • Oil and fossil fuel dependency • Energy demand • Energy access • Water consumption • Individual and collective behaviour • Land use	• Urban planning • Public electricity network • Public awareness • Public education • Public roads regulations and management	• Urban green areas • Tourism infrastructure • City evolution • Transport systems • Energy storage structures • Urban density • Urban fabric (high or low building density, urban canyons, green urban areas)
Land use and forestry	• Dry land • Volcanic and seismic region • Small land mass (e.g. SIDS)	• Biodiversity • Ecosystems • Forest pests and diseases • Soil characteristics • Land cover type	• Forest management (deforestation for agricultural purposes) • Land use management • Crops industry • Water systems • Livelihood structure • Combustible materials (litter) management	• Forest laws • Public safety management • National/ sectoral economic development plans • Public roads regulations and management • Oil and fossil fuel market and regulations	• Roads and drainage infrastructure • Urbanization • Tourism infrastructure

Non-climatic contributing factors					
Sector	Geophysical	Natural resources	Socioeconomic	Governance	Infrastructure
Livelihoods	• Dryland • Topography such as low-lying areas • Volcanic and seismic region • Small land mass (e.g. SIDS)	• Crop diseases • Manure and biomass • Livestock • Vector-borne diseases • Non-communicable diseases • Water-borne and food-borne infections • Soil characteristics • Sedimentation • Biodiversity and ecosystem	• Food systems • Water systems • Income/ livelihood dependency • Unemployment • Urbanization • Sanitation practices • Migration • Poverty • Livelihood dependency • Gender/age inequality • Agricultural practices • Crop productivity and diversification • Irrigation practices • Water demand • Tourism/ Eco-tourism • Waste practices	• Agricultural policy • Agricultural services • Grommet information • Forest laws • Climate services • Public waste management • Crop insurance • Public health policy • Public education • Public awareness • National health facilities • Public water supply • Public sanitation practices	• Irrigation systems • Health system infrastructure • Communication systems • Sanitation, waste and energy infrastructure • Public mass transportation systems • Water infrastructures • Potable water treatment operations and distribution • Sewage system

Non-climatic contributing factors					
Sector	Geophysical	Natural resources	Socioeconomic	Governance	Infrastructure
Health, food and water	• Dryland • Topography such as low-lying areas • Volcanic and seismic region • Small land mass (e.g. SIDS)	• Crop diseases • Manure and biomass • Livestock • Vector-borne diseases • Non-communicable diseases • Water-borne and food-borne infections • Pollution • Soil characteristics • Sedimentation • Biodiversity and ecosystem	• Food systems • Water systems • Income / livelihood dependency • Unemployment • Urbanization • Migration • Poverty • Gender/age inequality • Agricultural practices • Livelihood dependency • Economic sector competition • Irrigation practices • Crop diversification • Tourism/ Eco-tourism • Water demand	• Agricultural policy • Agricultural services • Agrometeorological information • Forest laws • Climate services • Public waste management • Crop insurance • Public health policy • Public education • Public awareness • National health facilities • Sanitation practices including for public sanitation • Water supply	• Agricultural techniques • Irrigation systems • Crop storage systems • Fertilizers • Health system infrastructure • Communication systems • Sanitation, waste and energy infrastructure • Public mass transportation systems • Water infrastructures • Potable water treatment operations and distribution • Sewage system • Water distribution system • Hotels storage system

Non-climatic contributing factors					
Sector	Geophysical	Natural resources	Socioeconomic	Governance	Infrastructure
Resilient infrastructure	• Low-lying land including land reclaimed from the sea • Dryland/ desert dust • Volcanic and seismic region • Small land mass (e.g. SIDS) • Land slide/ mountainous area • Coastal area	• Biodiversity • Vector-borne diseases • Gastro-intestinal and cardiovascular diseases • Livestock mortality	• Agricultural and fishery production • Food and nutritional systems • Rural unemployment • Economic/ income diversification	• Public communication protocols • Community support policies • National and international partnerships	• Roads management • Drainage infrastructure • Urban density • Urban fabric
Ecosystems and ecosystem services	• Topography such as low-lying areas • Volcanic and seismic region • Dryland • Small land mass (e.g. SIDS)	• Erosion • Wave-induced sediment transport • Biodiversity • Seaweed fluxes • Ecosystems • Diseases • Land cover type	• Coastal urbanization • Livelihood dependency • Tourism/ eco-tourism • Marine pollution • Illegal fishing practices • Extraction and mining • Oil exploitation • Water systems • Agricultural systems	• Public awareness • Early warning systems • Health care • Governance arrangements of marine protected areas • Beach and coastal public management • Public awareness • Public education	• Dikes • Sea walls • Fisheries infrastructures • Boats, vessels and fishing equipment • Beach-cleaning machinery • Coastal defences • Coastal urbanization

Interpreting the results for Step 3

The non-climatic contributing factors identified in Step 3, along with their relationship to climatic contributing factors identified in Step 2, provide the scientific information for determining the extent to which climate currently affects, and/or is projected to affect the area of focus. Experts, local stakeholders and specialists should determine what are the key non-climatic contributing factors affecting an area of focus, and examine the relationships between those factors and the climatic contributing factors identified in Step 2.

Irrespective of the exact contributions of climatic and non-climatic factors to observed or projected impacts, so long as it can be clearly established that climate change is relevant then there is a need for experts to consider interventions that could support climate action in the corresponding sector.[31]

31 It is important to note, however, that even though a relationship between climatic and non-climatic contributing factors may exist – thereby establishing the need for climate action – there may be interventions outside the climate domain (non-climate finance related) that need to be made in order for the climate action to be effective. In such cases, experts could help countries in sequencing interventions in order to ensure that potential climate actions can achieve their expected results. For example, installing updated irrigation systems for local farmers may venture to address climate impacts being experienced in a region's agriculture sector. However, if the region has significant leakages within its water distribution network, weak institutional capacity at the utility-level, or other constraints, investments in a new irrigation system, irrespective of how advanced it may be, is unlikely to achieve its intended results. Instead, investments in areas like operations and maintenance to fix the existing leakages, which are unrelated to climate, need to be made if the investments in irrigation, which is linked to climate, are to be effective. Planning and sequencing interventions with such considerations allows for more effective use of resources and brings better results on the ground.

Step 4 – Select effective climate actions

Step 4 entails identifying and proposing effective climate actions that respond to the climate contributing factors identified in Step 2, through structural and non-structural measures, including those actions that may be identified from the analysis of non-contributing factors in Step 3.

The process of these earlier steps should have scientifically shown that there is a current or projected link between climate change and its impact on the area of focus. Based on this link, there is a need to select climate actions that can lead to improved climate-related outcomes and resilience for the area of focus.

The process of Step 4 can be done by, firstly, identifying what potential climate actions address the links between the changing climate and the area of focus; and secondly, screening those actions against the following three criteria:

1. Adequacy;
2. Feasibility;
3. Cost effectiveness.

These criteria should be applied sequentially when screening potential ideas. The climate actions satisfying all three of them could be considered for climate finance support.[32]

Step 4 requires expertise in project and programme development, in addition to the key climate and sectoral knowledge experts who have already been a part of the earlier steps. Project and programme development expertise can help in the selection of which climate actions to pursue and assist in incorporating the ideas into proposals seeking climate finance.

Process for Step 4

The first part of Step 4 is to identify possible climate actions that address the links between the climate and its impact on an area of focus. These links should have been determined through the results of Steps 2 and 3.

With the help of sectoral, project development and other local experts, relevant ideas for potential climate actions can be generated. A project itself does not need to be known or devised at this time, but potential actions need to be considered. These actions must be locally contextualized and address the climate-related link for the area of focus. For instance, since rising temperatures (verified through the process of Step 2) over a long period can lead to lower crop yields (verified through the process of Step 3), proposed actions should seek climate-resilient outcomes that can protect the agricultural yield such as from these possible climate-induced changes.[33]

Once ideas for potential actions are generated, they can be screened against the three criteria of adequacy, feasibility and cost-effectiveness.

Adequacy

Adequacy refers to the degree to which an action addresses the link between the climate situation and its corresponding impact.

Adequacy ensures that the identified actions lessen the risks and reduce exposure and vulnerability of people and assets to climatic contributing factors. Furthermore, adequacy ensures that the actions identified are effective within the range of prevailing climate variability and extremes, as well as under anticipated future climate conditions. This means that in order to be adequate, the action should also be inherently climate-resilient. For example, a sea wall that protects against coastal inundation under current conditions should also do so under conditions of projected sea-level rise. Such measures can also be non-structural, such as better land-use planning, zoning and use of early warning systems.

To determine the adequacy of any proposed action is to establish whether a proposed action will either address or lead to the improved socioeconomic and/or environmental climate-related outcomes expected. In order to do this, experts must first define what outcome(s) is/are being sought and then determine through their expert judgment and a consultative process whether the proposed action can deliver the expected outcome(s) in a climate-resilient way.

Feasibility

Feasibility refers to the degree to which an action is practical and implementable under local conditions.

In the context of the present methodology, screening an action for feasibility ensures that it is capable of being implemented with a strong likelihood of achieving its

32 The three criteria introduced as a part of Step 4 of this methodology are not to be confused with investment criteria that may be specific to any sources of climate finance. Step 4 of this methodology is intended to support countries in identifying possible climate actions which are supported by the climate science information. Aligning those selected actions to GCF's Investment Criteria (or any other funder's criteria) is a follow-on process for countries and project proponents to consider and is outside the scope of the present methodology.

33 This could include ideas such as provisioning for drought-resistant agricultural practices, introducing heat tolerant crop varieties, providing the region with additional water supply for irrigation or even diversifying the region's economic base from agriculture to some other non-climate impacted productive sector entirely.

expected socioeconomic and/or environmental climate-related outcome(s). A climate action that addresses a link to the climate issue in an area of focus, and is implementable in a local context, can be considered feasible.

Identifying which actions are feasible is done based on consultations with stakeholders. Those affected by climatic impacts in the area of focus, as well as those potentially affected by or involved in the implementation of actions to address those impacts, should be consulted. The process should also be informed by experts who have experience in developing and implementing projects in the type of actions being proposed. Their expert judgment, knowledge of the sector in which the action is expected to take place and lessons learned from other contexts, could all be used to help determine whether a proposed action can be considered feasible.

However, stakeholders should be aware that a climate action that cannot be implemented due to practical constraints in the local context is not a feasible option, irrespective of how effective it may have been in another context. Such practical considerations at the local level could include capacity or technological, financial, institutional or human resource constraints which could result in an action being deemed infeasible.[34] Feasibility constraints also include potential adverse consequences of actions that, while effective in adapting to climate conditions, could adversely affect society or the environment in other ways. For example, moving people out of hazardous areas, such as coastal zones or flood plains, can reduce societal exposure to climate-related hazards. However, such actions can still create social and economic disruption or other unintended consequences (that is, maladaptation).[35] Similarly, actions could have adverse consequences on the environment, such as climate actions that involve the implementation of infrastructure. Stakeholders need to anticipate such constraints and consequences of climate actions when screening for feasibility.[36]

Non-technical considerations may also be evaluated as part of the feasibility study (see Box 9).

Box 9. Introducing non-technical considerations to a science-based methodology

It is important that the actions identified in Step 4 respond to the scientific findings from Steps 2 and 3. However, the methodology recognizes that there may be other aspects related to the local context that require consideration in the process of selecting potential climate actions. The methodology, therefore, affords flexibility within this step (as part of the screen against feasibility) to accommodate practical considerations. For example, political economy, capacity, governance and other factors can be considered when screening potential climate actions for their feasibility. However, these factors must be considered with appropriate consultation, input, and buy-in by all relevant stakeholders to determine their pertinency.

Cost effectiveness

Cost-effectiveness refers to the degree to which an action demonstrates impact in relation to the financial and economic costs of its implementation.[37]

Assessing cost-effectiveness requires data and information on the costs of inputs and activities needed to generate the outcome(s) from an action. There is a range of approaches that could be used to support the selection of a climate action based on its cost-effectiveness, but the three most frequently used approaches are:[38]

1. Cost-Benefit Analysis (CBA);
2. Cost Effectiveness Analysis (CEA);
3. Multi-Criteria Analysis (MCA).

Experts should be able to guide the process of constructing indicative financial and economic cost scenarios using any of the above approaches,[39] or

34 Such constraints can be alleviated by drawing on donor support, technical assistance or other solutions, but for the purposes of the present methodology, these initiatives would fall outside the scope of selecting a climate action.

35 Intergovernmental Panel on Climate Change (IPCC), 2018: *Special Report: Global Warming of 1.5 °C*, https://www.ipcc.ch/sr15/.

36 Experts should take note to address any of these consequences within the eventual design of a project if it is selected for further development and considered for climate finance support.

37 Whereas the feasibility criteria looked at factors that are more qualitative in nature, screening actions for cost-effectiveness should be a quantitative exercise that looks at best estimates of financial and economic costs. For example, while assessing feasibility, stakeholders may have recognized that a certain action involves relocating vulnerable populations, which could cause undue economic and social stress, which qualitatively can be assessed to determine whether such an action should be considered feasible. However, using the same example, when assessing cost-effectiveness, experts should be able to show at least at an indicative level what the financial and economic cost of relocation would entail. This could involve quantifying aspects such as job loss to the economy, costs associated with retraining/reskilling moved workers, physical relocation costs and others, which experts should be able to capture, calculate and provide for assessment.

38 United Nations Framework Convention on Climate Change (UNFCCC). *Assessing the Costs and Benefits of Adaptation Options: An Overview of Approaches*; UNFCCC: Bonn, Germany, 2016. https://climate-adapt.eea.europa.eu/en/metadata/guidances/assessing-the-costs-and-benefits-of-adaptation-options-an-overview-of-approaches.

39 The present guide is not intended to provide further information on how to apply these cost-effectiveness determination approaches. This guide is mentioning them to give the reader a sense of what is most frequently used when assessing cost-effectiveness. Experts, including project developers, who should be a part of this step in the methodology, should already be familiar with these approaches.

others, to determine whether proposed actions can be considered cost-effective.

In the context of the present methodology, for an option to be cost-effective it would need to satisfy the following two elements:

1. That the costs of implementing the proposed action are considered reasonable to the stakeholders who may bear those costs; and

2. That in relation to the costs of implementing an action, it will generate the expected outcome(s).

For the costs of a proposed action to be considered reasonable means that experts and relevant stakeholders agree that its cost seems within an acceptable range of expectations.[40] This involves knowing what the costs of implementing similar actions have been, as well as expert input and judgment that would go into devising the calculations and analysis to estimate the cost of the proposed action in the local context.

Additionally, to be cost-effective, an action should generate the expected outcome(s) in relation to the costs of its implementation. When quantitatively analysed, the costs of implementing an action should derive outcome(s) that meet or exceed its costs. If, however, the costs of implementation far exceed any derived impacts, experts and stakeholders could assess whether an alternative action may result in better outcome(s).[41]

Interpreting the results for Step 4

Because these criteria are expected to be applied sequentially – from adequacy to feasibility to cost-effectiveness – results from each screening should determine whether a potential action should be further considered. For example, if a potential action satisfies the adequacy criteria it can then be considered further to be screened for feasibility, and so on. If during any part of the screening, a potential climate action does not satisfy one of the criteria, stakeholders could screen other proposed climate actions to try and select only those that meet all three. Climate actions that meet all three criteria can be selected for further development.

Step 4 of the present methodology provides the result of having selected effective climate actions that are grounded in a science-based process. Furthermore, with the involvement of relevant experts and stakeholders through consultative processes, the actions selected are likely to receive greater support in any processes that subsequently follow. These could include developing engineering studies, ESS studies, pre/feasibility studies, concept notes, funding proposals, or others as needed. These subsequent processes fall outside the scope of this methodology but are relevant and important nonetheless toward obtaining climate finance support.

Additional considerations from implementing step 4

Although the primary objective of Step 4 is to select effective climate actions, the process of implementing the four steps of this methodology may have identified additional needs and opportunities for scientific support. These can include, among others: (a) enhancement of operational hydrometeorological systems and associated services; (b) opportunities to address data gaps and research needs and strengthen the quality of climate information to support better decision-making by users of such information;[42] and (c) strengthening functions to monitor and assess the effectiveness of climate action implementation.

Step 4 should consequently identify specific capacity and/or technical gaps and challenges, or other barriers to climate science development, to be addressed. Capacity needs may include strengthening NMHS capability to support climate-related planning, policy and project implementation, as well as improving data resources and availability relevant to climate-sensitive sectors. Actions that strengthen NMHS interoperability with WMO regional and global centres are particularly critical since the operational exchange of data and products

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40 Irrespective of what impact or outcomes an action can generate, if the costs of implementing the action is too high or cannot be borne in a way that is considered financially reasonable, such actions are not likely to be implemented. Examples of this can be seen in certain cutting-edge technological innovations that may prove to have positive impacts, but for which the cost makes them unimplementable. Another example is that a certain action may be able to achieve expected outcome(s) but the scale at which the action would need to be implemented may need to be so large that the associated costs would make it unimplementable.

41 'No regrets' measures are an exception to this analysis. For example, in developing the climate science information for the health sector in Cambodia, projections of future changes in climatic contributing factors associated with communicable diseases – including diarrhea, malaria and dengue – are highly uncertain due to model limitations. Many of the identified adaptation options for addressing the health impacts of climate change are therefore 'no regrets' measures (for example, investing in health system infrastructure by ensuring that information systems, health facilities and professional staff are resilient to high-impact events). These measures focused on enhancing health coverage to reduce risks of these climate-related diseases in vulnerable regions of the country. Irrespective of the cost-effectiveness, such actions were chosen due to the critical nature of the issue faced in that local context.

42 Users of climate information could include public or private sector actors which rely on better weather and climate data and information to support their operations. Ministries, infrastructure operators (such as for airports, maritime ports and public utilities, among others), farmers and other private sector entities all rely on high-quality hydrometeorological data and information for planning, risk reduction and operational level decision-making.

with these centres can significantly enhance the data, information and services an NMHS can provide at the country level.

Strengthening functions to monitor and assess the effectiveness of the selected actions may also be needed.[43] Monitoring and assessing effectiveness is outside the scope of this methodology, since it is performed during and post-project implementation. Project effectiveness is a function not only of the scientific soundness of project design but also of implementation capacity, management effectiveness and other factors, some of which may be outside of project control. However, documented effectiveness of climate action is an essential component of the climate services value chain, and strengthening capacity will help experts and stakeholders when considering climate actions to be implemented in the future.[44] Lessons learned from having assessed the effectiveness of prior climate actions can be particularly useful to draw upon within Step 4 when screening whether a proposed climate action may be adequate, feasible and cost-effective.

All these needs can be addressed either through project proposal development and their corresponding budget, project implementation, or other requested support.[45]

Box 10. Case examples for identifying effective climate actions

Saint Lucia

Significant climate-related risks for Saint Lucia include the weakening of the marine ecosystems including mangrove coastal defences, threats from storms and flooding to natural and build coastal infrastructure, and salt intrusion and water quality issues. Low-lying areas and those lacking robust coastal defences are particularly exposed to inundation, and the tourism sector is particularly vulnerable to impacts on revenues.

Nature-based solutions, such as mangroves restoration, were identified among the best actions to consider as a natural coastal protection mechanism, minimizing local biophysical threats, adapting to long-term ocean chemistry and climate change, and providing communities with livelihood opportunities. Ecosystem-based adaptation options identified include:

- Coral reef restoration: Species selection; training of local scientists and marine stakeholders in micro fragmentation techniques; propagation of coral fragments; out-planting exercises to nearby coral reefs; and a 3-year monitoring programme of the growth, survival and resilience of fragments facing extreme heat stress events.
- Establishment of a Network of Marine Managed Areas (MMA): Each MMA was divided into Marine Reserves, Fishing Priority Areas, Multiple Use Areas, Yacht Mooring Areas and Recreational Areas designated to conserve the natural marine environment and ensure sustainable use and development of the fishing and tourism sectors.
- Sargassum Early Warning and Management: Communicating reliable long and medium-term forecasts of Sargassum (seaweed) arrivals provides early warning for managing impacts. Measures identified include integrating predictions from the sub-regional Sargassum outlook bulletin into the Fisheries Early Warning and Emergency Response (FEWER) mobile app as a means of communicating the forecasts and their implications to the fisheries sector in a simple format.

Democratic Republic of the Congo

Analysis in the course of developing the climate science information for effective climate action in the energy sector in the Democratic Republic of the Congo (DRC) showed that temperature and rainfall changes were likely to affect key productive sectors and national socioeconomic conditions. Electricity generation in the DRC relies heavily on hydroelectric power (more than 95% of total production),[46] and the country is expected to face increasing uncertainty and fluctuations in electricity production as long-term rainfall patterns change. Not only will unreliable power supply hurt the industrial activities and livelihoods of people, but will likely also have adverse effects by

43 Assessing effectiveness is perennially found to be the weakest link and most neglected part in the climate services value chain (see *2019 State of Climate Services: Agriculture and Food Security* (WMO-No. 1242) and *2020 State of Climate Services: Risk Information and Early Warning Services* (WMO-No. 1252)). Project developers should include measures to assess effectiveness of climate actions in the project design, including provisioning for it in the project budget.

44 Essential resources and guidance relevant for assessing and documenting the effectiveness of climate action are provided in *Valuing Weather and Climate: Economic Assessment of Meteorological and Hydrological Services* (WMO-No. 1153) and implementation guidelines of the Integrated Global Greenhouse Gas Information System (IG3IS) (https://ig3is.wmo.int/en/about/what-we-do). WMO-No. 1153 provides authoritative methods for assessing the socioeconomic benefits for climate services relevant for adaptation. IG3IS implementation, as part of projects aimed at increasing the resilience of carbon sinks and climate-proofing measures for increasing energy efficiency and the proportion of the energy mix obtained from renewable energy systems, provides scientific evidence of the effectiveness of such measures in reducing GHG concentrations in the atmosphere, as well as information for precise targeting of emissions sources.

45 Such additional support may be requested from the GCF Readiness and Preparatory Support Programme.

46 https://www.greenclimate.fund/sites/default/files/document/funding-proposal-fp096-afdb-democratic-republic-congo.pdf.

increasing dependence on fossil fuels and biomass. The latter scenario is likely to have impacts on forest ecosystems and land use, and their potential to contribute to emissions associated with deforestation and forest degradation.

Solutions focused on the diversification of renewable energy systems. The climate science information for the DRC deployed the best meteorological data available to estimate the potential resources for implementing hydro and solar power, but also served to highlight the limitations of current in situ hydrometeorological observations, which are particularly critical for exploiting potential energy sources such as solar and wind. Therefore, the climate actions identified also included strengthening the hydrometeorological systems and services needed to implement renewable energy systems. The ultimate aim is to improve the quality of electrification planning by providing a database made available to the public for partnerships with the private sector and other stakeholders for the development of hydroelectric and solar photovoltaic projects. This in turn contributes to:

- Increasing the electricity access rate for households;
- Reduction of the use of thermal energy by private enterprises;
- Containment of the mining energy usage;
- Promotion of the use of solar energy supplemented by small hydropower and biomass (waste);
- Implementation of a tax appropriate to the sector;
- Facilitation of private actors' access to grants and low-rate loans available from renewable energy incentive institutions;
- Increase in budgetary resources allocated to investments in the energy sector.

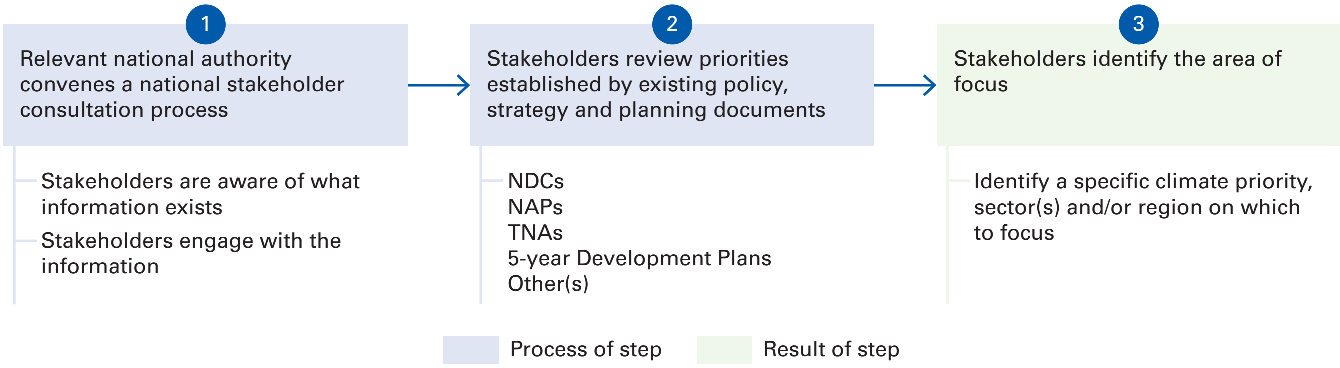
Illustrative summary of the methodology steps

Figure 2 (Steps 1–4) maps the process for each of the four steps proposed by the methodology. It is intended to be illustrative and provide guidance at a high level. The explanation of each step described in section 3, as well as the process maps in Figure 2, are intended to be a guiding framework to articulate the methodology and its processes. Experts and stakeholders may need to adjust the implementation of each step based on local needs and context, as appropriate.

The stakeholders mentioned are also intended to signal the key resource people that would add value to each step. However, to the extent that additional relevant expertise, stakeholders and local knowledge can be included, the more consultative and robust are likely to be the results. More participation of relevant experts across ministries, agencies and sectors will also foster cross-collaboration and learning which are likely to strengthen and develop overall country expertise and capacity.

STEP 1: IDENTIFY THE AREA OF FOCUS

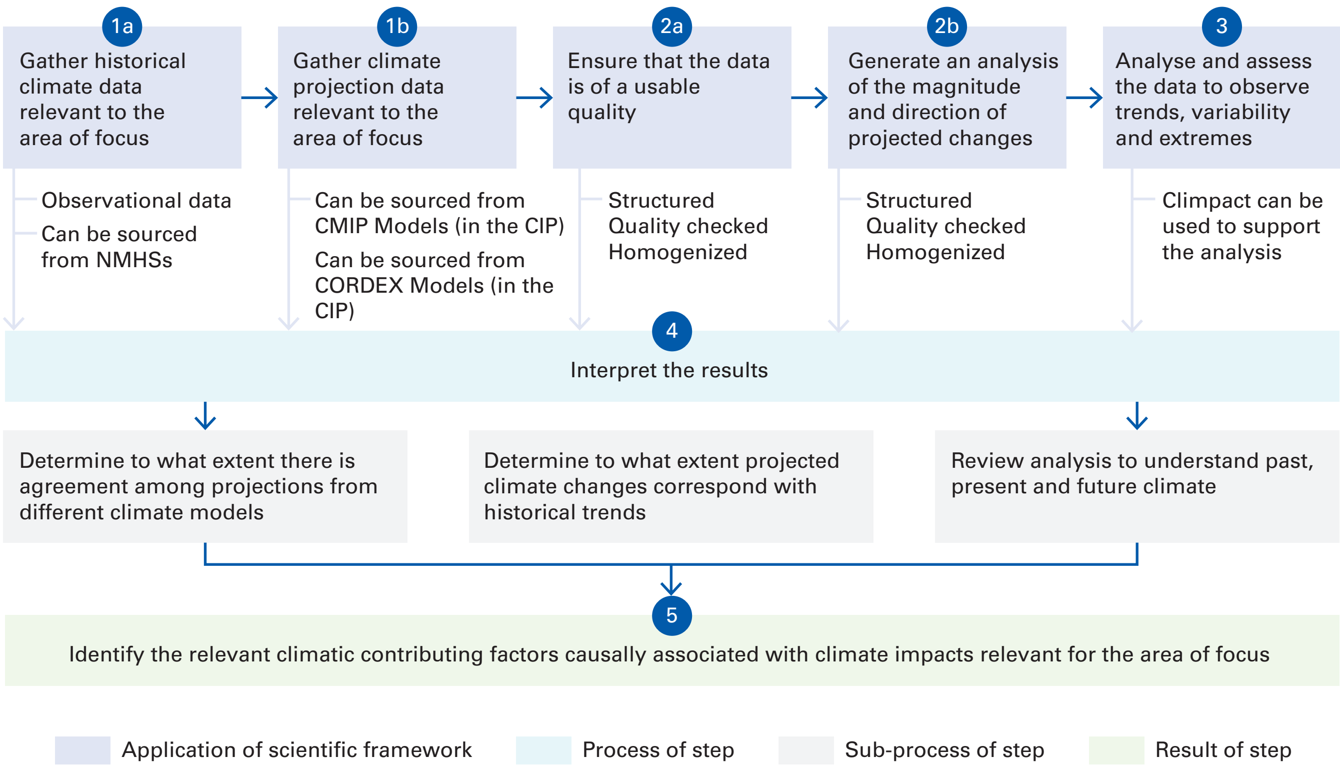
Key stakeholders: NMHS, sector experts, other local knowledge producers



STEP 2: IDENTIFY RELEVANT CLIMATIC CONTRIBUTING FACTORS AND DATA

Key stakeholders: NMHS, climate and data experts, sector experts, other local knowledge producers

The key aspect of Step 2 is to decide which climatic contributing factors are pertinent from among all possible climate characteristics relevant to the area of focus. This can be done using the methodology's **scientific framework**, which includes: (i) state of the climate indicators; (ii) context-specific climate indicators; and (iii) high-impact events indicators.



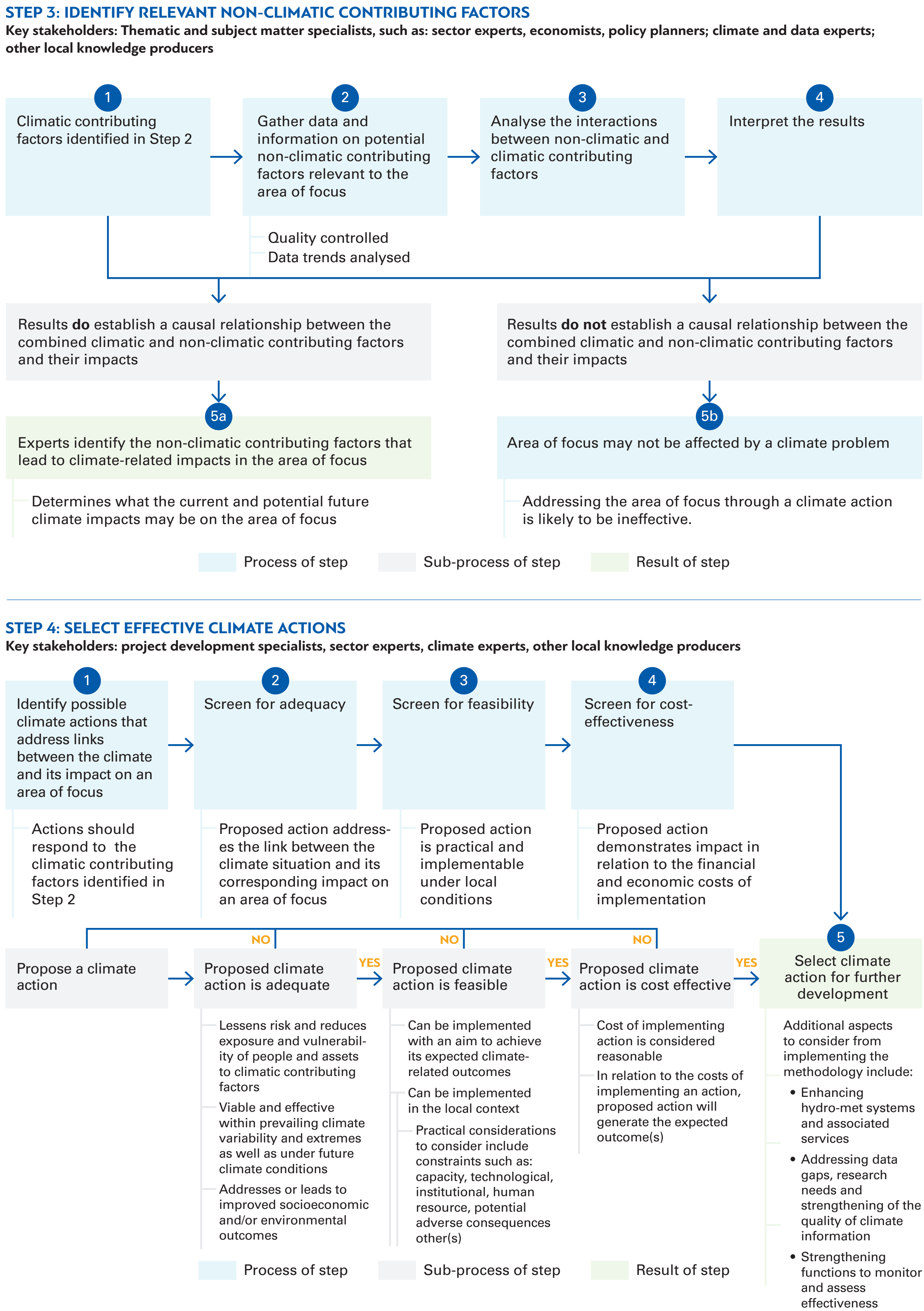


Figure 2. Illustrative summary of the methodology steps

4. KEY RESOURCES, TOOLS AND DATA

Users can access a variety of technical resources that support the implementation of the present methodology. The first two of these resources are tools to help users access data:

1. **The Climate Information Platform (CIP)** – Provides access to precalculated climate and water indicators, key summaries, confidence metrics, guidance and visualizations.

2. **Climpact**[47] – A tool that is accessible via the CIP to help users generate sector-specific climate information from daily observed historical temperature and precipitation data to calculate context-specific and high-impact event indicators.

Three additional resources comprise categories of indicators from the scientific framework of this methodology, which in particular are utilized when implementing Step 2:

3. **State of the climate indicators** – Eight fundamental indicators for characterizing overall atmospheric surface conditions and composition, and the state of the oceans and cryosphere relevant for a wide range of applications;

4. **Context-specific climate indicators** – Indicators that are associated with impacts in climate-sensitive sectors or geographic areas;

5. **High-impact events indicators** – Climatic conditions associated with broad-based, multi-sectoral, or otherwise significant socioeconomic or environmental impacts.

Additional information on data sources and indicators can be found in Annex I. Each of these five technical resources will now be examined in more detail below.

Climate Information Platform (CIP)

The CIP[48] assembles and provides access to the most reliable hydroclimatic data and technical resources for climate science inputs. The CIP offers guidance on relevant data and tools needed to prepare the climate science information for climate actions. It provides easy access to many climate and water indicators defined by experts and produced from quality-assured, state-of-the-art climate models from global and regional model intercomparison projects. These come in the form of interactive maps, charts and summary reports concerning climate change for any location on the globe, as well as for instructions on how to combine global sources with locally generated data.

A feature of this platform is that it provides the user with an ensemble of multiple global climate model results. This enables the outputs to include an indication of the confidence level in the estimates of future climate conditions. The confidence levels are calculated per domain, per indicator and per RCP. The outputs include an indication of the magnitude of the change for each indicator (small, medium and large), which helps the user to select which indicators to view in more detail. The outputs also include an assessment of model ensemble agreement, which gives an indication of how robust the signal is and in which direction it goes (increase, decrease or no change). If many models of the ensemble agree on a direction of change, then the result can be considered more robust.

CIP offers precalculated climate and water indicators from CMIP5[49] and CORDEX[50] at different grid resolution and catchment scales. Climate indicators are calculated from raw (non-bias-adjusted) and bias-adjusted GCM and RCM daily precipitation and daily mean, maximum and minimum temperature. The spatial resolution for indicators from raw GCM is 2 degrees (200 km). Most hydrological processes as well as project impacts occur at much smaller scales, so a further downscaling of the GCM information is necessary. For indicators from raw and bias-adjusted RCM and bias-adjusted GCM, the resolution is 0.5 degrees (about 50 km).

47 Climpact is developed thanks to the contributions from the Australian Research Council.

48 The CIP was developed by the Swedish Meteorological and Hydrological Institute (SMHI) under WMO auspices.

49 CMIP5 is the Coupled Model Intercomparison Project Phase 5. CMIP is the standard experimental protocol for studying the output of coupled atmosphere-ocean general circulation models. CMIP provides a community-based infrastructure that supports climate model diagnosis, validation, intercomparison, documentation and data access. This framework enables a diverse community of scientists to analyse the global models in a systematic fashion, a process which helps make models better. The international climate modelling community has participated in this project since it began in 1995. Further information on CMIP5 can be accessed at: PCMDI - CMIP5 Overview (llnl.gov).

50 CORDEX is the Coordinated Regional Climate Downscaling Experiment (CORDEX). CORDEX is responsible for advancing and coordinating the science and application of regional climate downscaling models through global partnerships. The project office has been hosted by SMHI since 2009. Further information about CORDEX is available at: cordex.org.

Daily precipitation and mean, minimum and maximum temperature from both GCMs and RCMs are then bias-adjusted using the Distribution-Based Scaling method[51] with HydroGFD, a global gridded reference data set.[52] Bias-adjusted variables from GCM and RCM are used to calculate the climate indicators at a 0.5 degree spatial resolution. The bias-adjusted variables (precipitation and three temperature variables) are also used as forcing input for the global hydrological model World-Wide-Hype[53] to calculate water-related indicators at catchment resolution.

When bias-adjusted climate indicators and downscaled GCM/RCM data are unavailable for a specific region or are still too coarse, statistical downscaling can be used. Essential for doing statistical downscaling is the availability of a long time series (ideally 30 years) of local weather data or a high-resolution reanalysis data set. A statistical relationship is developed between the historical climate data and the output of the climate model for the same historical period. That relationship is then used to create a future projection of climate data (assuming that the relationship continues to be valid). Statistical downscaling can be combined with bias correction. CIP offers an extensive knowledge base on statistical downscaling and on how to perform regional climate analysis. See Box 11 for more information on downscaling methods.

In summary, the CIP provides access to:

Indicators

- Climate indicators (such as temperature, precipitation, dry spells and others) at a resolution of 2 to 0.5 degrees both from raw and bias-adjusted GCM and RCM (CMIP and CORDEX) data. These indicators follow the definitions of the WMO technical commissions.

- Water indicators (such as run-off, discharge and aridity) at catchment scale from bias-adjusted GCM and RCM (CMIP5 and CORDEX) data. The water indicators are defined by experts of the Hydrology R&D Unit of SMHI and are based on previous experience on regional and global water services.[54] Water indicators at the catchment scale are suitable for local-scale analysis since they provide information at a higher resolution and describe local and regional processes.

Box 11. Common approaches for downscaling

GCMs are important tools to assess future changes in temperature, precipitation and wind speed. However, GCMs are run at a very coarse resolution, with grids often larger than 100 km^2. This is too coarse for many policy or project applications. To resolve this issue, different downscaling techniques have been developed.

Dynamical downscaling

For dynamical downscaling, a higher resolution climate model is used. These models are often called regional climate models (RCMs). RCMs nest into the GCM and provide finer-scale information of 50 km or less. RCMs use lower resolution climate models (in most cases GCMs) as boundary conditions and physical principles to reproduce local climate. RCMs developed under CORDEX provide outputs on a grid size of 0.44 degrees (~45 km^2). RCMs are computationally intensive, so for some regions, only limited RCM output data is available.

Statistical downscaling

For statistical downscaling, a statistical relationship is developed between the historically observed climate data and the output of the climate model for the same historical period. The relationship is used to develop future climate data. Statistical downscaling can be combined with bias correction. Linear regression is a simple, widely used method for bias correction.[55] The method establishes a linear relationship between one large-scale climate indicator, for example, GCM- or RCM-simulated humidity, and local-scale observed humidity. This relationship is developed by assessing locally observed data and correlating it with GCM or RCM output.

Simple interpolation

Simple interpolation is used to estimate unknown values that lie between known values. The concept of simple interpolation relies on the assumption that the rate of change between the known values is constant. Through simple interpolation, a coarse grid can be converted to a finer grid by averaging the values between each pair of grid points and assigning the average value to an intermediate point mid-way between the two original points.

- Climate and water indicators provided for a reference period (1981–2010, as absolute values) and for future

51 Yang, W.; Andréasson, J.; Graham, L. P. et al. Distribution-based Scaling to Improve Usability of Regional Climate Model Projections for Hydrological Climate Change Impacts Studies. *Hydrology Research* **2010**, 41, 211–229. https://doi.org/10.2166/nh.2010.004.

52 Berg, P.; Donnelly, C.; Gustafsson, D. Near-real-time Adjusted Reanalysis Forcing Data for Hydrology. *Hydrology and Earth System Sciences* **2018**, 22, 989–1000. https://doi.org/10.5194/hess-22-989-2018.

53 Arheimer, B.; Pimentel, R.; Isberg, K. et al. Global Catchment Modelling Using World-Wide HYPE (WWH), Open Data, and Stepwise Parameter Estimation. *Hydrology and Earth System Sciences* **2020**, 24, 535–559. https://doi.org/10.5194/hess-24-535-2020.

54 Merks, J.; Photiadou, C.; Ludwig, F. et al. Comparison of Open Access Global Climate Services for Hydrological Data. *Hydrological Sciences Journal* **2020**. http://dx.doi.org/10.1080/02626667.2020.1820012.

55 For both bias adjustment and downscaling, more complex methods, including non-parametric methods (quantile mapping) and methods with machine learning, are regularly developed and implemented.

time periods (2011–2040, 2041–2070 and 2071–2100) according to specific RCPs based on different emission scenarios (such as RCP 2.6, 4.5, and 8.5). The change in six key indicators (temperature, precipitation, aridity, soil moisture, water discharge and water run-off) are listed at the top of the generated overview.

Summaries and visualization

- Instant climate change summary reports for any site on the globe and guidance on how to link global changes to local observations. Specific tools provided in the CIP include the site-specific report, the data access platform and a link to the Climpact web-based version. In the site-specific report, the user can select a location by entering the name of a city or coordinates, or by clicking directly on the integrated global map. This tool provides a climate overview for a specific region where it is possible to sort indicators by the magnitude of change and robustness. Maps, graphs and summary texts are readily available (downloadable as PNG files). The platform provides interactive maps and graphs, with the possibility to download data in NetCDF or Excel format for further analysis and local tailoring, and PNG files of graphs.

Downscaled information and global coverage

- Ten regional CORDEX domains (Africa, Middle East and North Africa, North America, South America, Central America, West Asia, the Arctic, Australia, East Asia and Europe) are included in the current version, aimed at helping users to get a fast overview of the projected change at a selected location. Global coverage is also offered from CMIP GCM indicators.

Climpact

Climpact is an open source, online software package maintained at the University of New South Wales (UNSW) in coordination with WMO, that helps users to generate sector-specific climate information by extracting relevant time series of context-specific climate indicators and climate extremes from historical meteorological data.[56] It uses historical daily values of maximum and minimum temperature, and daily precipitation, to calculate over 60 different climate indices. Climpact can calculate indices for individual stations, gridded observations or gridded climate model output, permitting both spatial and temporal analysis. See Box 12 for details of Climpact data quality management.

Box 12. Quality control of daily station data

Climpact indices are derived from historical daily temperature and precipitation data. Before they are used, such data need to be quality assured. The relevant data should be selected based on their quality and consistency for characterizing the climate characteristics affecting the selected geographic areas or sectors. As there may be potentially substantial differences in climatic conditions within the country, it is important to ensure that enough data is available to adequately reflect spatial variations in climate. For example, it is common for weather stations[57] to be located near or within human settlements. Therefore, it is important to determine how balanced the location of cities and rural areas are in relation to observation stations.

During the data identification process, several issues related to data quality and adequacy can emerge. These can include suspiciously extreme values, abrupt changes in the distribution of values – arising, for example, from a relocation of the station or a significant change in its surroundings – and gaps in the data time series. The data must therefore be quality controlled – Climpact itself includes some auxiliary steps for data quality control – and homogenized before they are aggregated into monthly and annual time series of climate indices by Climpact.

Climpact derives basic statistical relationships between user-provided sector data and climate indices, helping users to demonstrate a robust link between climate and sectors of interest. Many Climpact indices are relevant to the health, agriculture and water sectors. They describe the frequency, duration and intensity of various climate extremes at monthly and annual resolutions. The indices can also be calculated to identify high-impact events or climate extremes, including heatwaves, cold spells, meteorological droughts and precipitation extremes. Climpact indices have been recommended by Expert Teams of WMO Technical Commissions.

Climpact can be applied to assess variability and trends in historical climate data. However, Climpact should not be used to assess variability and trends in daily values for future or projected climate outputs. Rather, the variability of projected values of future precipitation

56 WMO, in collaboration with the University of New South Wales (Australia) and its Centre of Excellence for Climate Extremes, provides a web-based version of the Climpact software tool, which was originally developed by the WMO Commission for Climatology's Expert Team on Sector-Specific Climate Indices (ET SCI). The ET-SCI was an international team of inter-governmentally selected climate scientists dedicated to improving the availability and consistency of sector-specific climate indices through the creation of software, regional workshops, research and training material.

57 The *Guide to Instruments and Methods of Observation* (WMO-No. 8), Volume III, Chapter 9 requires stations to be outside of human settlements.

and temperature can be expressed through statistics of variability for future periods (for example, 2041–2070).[58]

State of the climate indicators

State of the climate indicators are eight indicators describing the overall state of the climate in a given country or context (see Table 3). These eight indicators are a sub-set of the Essential Climate Variables (ECVs) and have been selected due to the characterization they offer of the key features of the state of the climate – past, present and future. The state of the climate indicators are traditionally based on in situ observations; although recently, satellite observations and reanalyses are also used.

Table 3. State of the climate indicators

Atmospheric surface indicators
• Temperature • Precipitation
Atmospheric composition
• CO_2
Oceanic indicators
• Sea level • Ocean heat content • Ocean acidification (sea water pH)
Cryosphere indicators
• Arctic and Antarctic sea ice • Glacier mass balance

The state of the climate indicators includes surface temperature and precipitation (two key surface indicators fundamental to human activities), CO_2 concentration (an important diagnostic of the human influence on the climate), and sea level, ocean heat content and ocean acidification (three indicators for monitoring on the state of the ocean). Additional indicators reflect the state of the cryosphere, including sea ice in polar regions and glacier mass balance (the latter of which is relevant in both polar and high mountain areas).

Not all state of the climate indicators are relevant in all locations, and their trends, variability, extremes and future changes are subject to varying degrees of uncertainty on climate timescales. By selecting the relevant indicators for a country or context, and documenting their past, present and expected future behaviour, it is possible to obtain an overall picture of the trajectory in which changes in the climate system might affect and inform potential options for climate action.

The preferred source of data on the state of the climate indicators, and for climate data in general, is locally observed data. When local data are unavailable or insufficient, they can be complemented with data from global sources.

Context-specific climate indicators

Context-specific climate indicators are indicators associated with impacts in climate-sensitive sectors or geographic areas. Climate affects almost every socioeconomic sector to one degree or another: social (housing, education, and health), productive (agriculture, tourism, industry, and trade), and infrastructure (water and sanitation, energy, telecommunications, roads, railroads, airports). The climatic contributing factors associated with impacts across the full range of climate-sensitive sectors are extremely diverse. The set of context-specific indicators offers a commensurately diverse group of climate variables and indices from which those most relevant to any specific area of focus can be selected.

The universe of context-specific climate indicators includes:

The remaining ECVs beyond the state of the climate indicators

\+

Climpact indices

\+

Indicators derived from climate projections such as may be generated through the CIP

\+

Any other relevant climate indicators

Data on the context-specific climate indicators can be sourced from local station data, the CIP (for projections) and other global data sets identified in Annex I.

High-impact events indicators

High-impact events indicators identify specific climatic conditions associated with broad-based, multi-sectoral or otherwise significant socioeconomic or environmental

58 Although it is possible to run projected future daily values of temperature and precipitation that are output by climate models through Climpact, and calculate indices based on them, in the same way that Climpact can calculate indices based on historical daily values of these variables, the projected daily values are fundamentally different than historical daily values in that the projected values are not valid for particular days and therefore do not constitute a time series from which a temporal trend can be derived. Rather, the projected daily values provide a distribution of values from which expected average values over a future 30 year period can be calculated.

impacts. Many high-impact events have widespread and significant impacts across multiple sectors. Extreme events can result in significant loss of life and economic losses equivalent to a high proportion of a country's GDP. Therefore, tracking the past and present probabilities of occurrence of high-impact events, and predicting and projecting their future behaviour, is key for averting, minimizing and addressing associated damages to assets and people.

The WMO typology of high-impact events includes avalanches, cold waves, drought/dry spells, dust storms/sandstorms, extra-tropical cyclones, floods, fog, haze/smoke, frost, hail, heatwave, high UV radiation, icing, freezing rain, landslide/mudslide and debris flow, lightning, pollen, pollution/polluted air, rain/wet spells, snow, snowstorms, space weather events, high seas/rogue waves, storm surges/coastal floods, thunderstorms/squall lines, tornadoes, tropical cyclones, tsunamis, volcanic ash, wildland/forest fires and wind.[59]

Since climate varies regionally, the threshold for what constitutes a high-impact event will differ from location to location. An extreme value of a climate variable in one location may be within the normal range in a different location.[60] Impacts associated with high-impact events – such as droughts, heatwaves, floods and storms – are a function not only of the magnitude and duration of the event, but also of the degree of exposure and the vulnerabilities of socioeconomic or environmental assets to the event.

To gain a uniform perspective on observed changes in weather and climate extremes the Expert Team on Climate Change Detection and Indices (ETCCDI) of the World Climate Research Programme (WCRP) has defined a core set of descriptive indices of extremes. These describe characteristics of extremes, including frequency, amplitude and persistence.

The core set includes 27 extremes indices for temperature and precipitation.[61] Many ETCCDI indices are based on percentiles[62] with thresholds set to assess moderate extremes that typically occur a few times every year, rather than once-in-a-decade weather events. Day-count indices based on percentile thresholds are expressions of anomalies relative to the local climate.[63] These anomalies have fixed rarity, with thresholds chosen to be exceeded at a fixed frequency (often 10%) during the base period that is used to define the thresholds. Consequently, the values of the thresholds are site-specific. Such indices allow for spatial comparisons because they sample the same part of the probability distribution of temperature and precipitation at each location.

For temperature, the percentile thresholds are calculated from five-day windows centred on each calendar day to account for the mean annual cycle. For precipitation, the percentile thresholds are calculated from the sample of all wet days in the base period. Building on the ETCCDI outputs, further methodology and recommended additional indices relevant for sectoral applications were developed by the WMO Expert Team on Sector-specific Climate Indices (ET-SCI). Additional indices can be used for characterizing high-impact events such as the Standardized Precipitation Index (SPI), which can be used for monitoring events like droughts.[64]

Information on high-impact events affecting countries and locations within countries can be obtained from disaster databases. Examples include the International Disaster Database (EM DAT) maintained by the Centre for Research on the Epidemiology of Disasters (CRED), and the DesInventar disaster information management system,[65] which provides access to sub-national scale data for approximately 90 countries.

Other resources

Annex I provides references for methods and tools for data analysis, as well as some sources for prediction and projection information. These materials (which are not intended to be exhaustive) include: global climate data sets; good practices and standards for using climate indices, indicators and extreme events analysis; and operational considerations defined by WMO and its scientific and technical network. Some references for emission mitigation-related data can also be found in Annex I.

59 Resolution 12 (Cg-18) and Annex I – WMO Methodology for Cataloguing Hazardous Weather, Climate, Water and Space Weather Events (*World Meteorological Congress: Abridged Final Report of the Eighteenth Session* (WMO-No. 1236))

60 This could also be true at sub-national scales for large national territories.

61 Zhang, X.; Alexander, L.; Hegerl, G. C. et al. Indices for Monitoring Changes in Extremes Based on Daily Temperature and Precipitation Data. *WIRES Climate Change* **2011**, *2* (6), 851–870. http://dx.doi.org/10.1002/wcc.147.

62 The reason for choosing mostly percentile thresholds rather than fixed thresholds is that the number of days exceeding percentile thresholds is more evenly distributed in space and is meaningful in every region.

63 Day-count extremes based on percentile thresholds tend to be more suitable for spatial comparisons rather than those based on absolute thresholds.

64 Information on the SPI and other drought indicators can be found at https://www.droughtmanagement.info/literature/GWP_Handbook_of_Drought_Indicators_and_Indices_2016.pdf.

65 Disaster loss data for Sustainable Development Goals and Sendai Framework Monitoring System, https://www.desinventar.net.

5. DEVELOPING CLIMATE SCIENCE INFORMATION WITH LIMITED OR ABSENT DATA

Information on past and present weather and climate conditions is usually based on instrumental observations. However, some countries may lack information on the current and past state of the climate due to the absence or limited coverage of observation networks, or inadequacy of data. Many countries also struggle to maintain their observing networks, leading to insufficient coverage and a paucity of observations. The number and geographic location of stations where meteorological variables are recorded may change significantly over space and time as new stations are created while others are abandoned, resulting in few high-quality, long time series. This can hamper the quality and availability of information needed to underpin a scientifically-based climate analysis.

Climate science information can still be developed where observations are limited or of lower quality. Analyses performed with lower quality data do not make the inference less scientific, but it does increase uncertainties. Thus, a key step to ensuring that the climate analysis is based on the best available science is to assess the adequacy and quality of the data.

Approaches for addressing limited or absent data

In cases where the quality and/or adequacy of data are limited, two main approaches can be considered to still provide a scientifically robust analysis:

1. Use of remote-sensing observations combined with gridded data or extrapolated information from neighbouring areas with similar climate conditions;[66]
2. Use of high-quality, peer-reviewed reanalysis products.

The choice of approach, or combination of approaches, must be a case-by-case decision depending on the local context and area of focus being addressed (see Box 13 for examples). The climate expert involved in the process should help choose the appropriate approach(es) – and corresponding data sets – and be able to demonstrate how reliable the products may be for any given application and context, and whether the outputs from applying the approach(es) is suitable for further analysis and use.

Box 13. Case examples for developing the climate science information with limited or absent data

Cabo Verde

Cabo Verde developed the climate science information for its energy sector by combining observations (in situ and satellite-derived) and reanalysis (ERA5 reanalysis). ERA5[67] combines historical observations into global estimates using advanced modelling and data assimilation techniques. ERA5 covers the period 1950 to the present day. Despite limited observation data in the country, by using ERA5, numerous measures were identified in Cabo Verde (see Box 7).

Saint Lucia

In Saint Lucia, the climate science information was developed for addressing problems affecting the country's fisheries and marine sectors. The analysis recognized the weaknesses of baseline data on the state of the marine ecosystems and current monitoring activities. High-resolution and uninterrupted time series data sets at the species level are unavailable for the country. Nonetheless, a strong climate case was developed on the basis of peer-reviewed regional literature,[68] which assesses more than 30 years (1985–2017) of heat stress exposure in the wider Caribbean at eco-regional and local scales by using remote-sensing techniques. By drawing on historical heat exposure patterns, this work produced a new baseline and regionalization of heat stress in the Saint Lucia basin. The study was deployed to design adaptation measures to enhance marine areas conservation and planning efforts. No-regret options were proposed to conserve the natural marine environment and ensure sustainable use of natural resources in the fishing and tourism sectors (see Box 10).

66 Bias-correction uses available station data to correct systematic over/under-estimation of values of the variable of interest by the satellite sensor. When in situ observations are not available, the bias adjustment is extrapolated based on data from other regions.

67 The fifth generation of the European Centre for Medium-Range Weather Forecasts (ECMWF) reanalysis model (ERA5) provides hourly estimates of a large number of atmospheric, land and oceanic climate variables. The data cover the Earth on a 30 km grid and resolve the atmosphere using 137 levels from the surface up to a height of 80 km. ERA5 includes information about uncertainties for all variables at reduced spatial and temporal resolutions. More information is available at: https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era5.

68 Muñiz-Castillo, A. I.; Rivera-Sosa, A.; Chollett, I. et al. Three Decades of Heat Stress Exposure in Caribbean Coral Reefs: A New Regional Delineation to Enhance Conservation. *Scientific Reports* **2019**, *9*. https://www.nature.com/articles/s41598-019-47307-0.

Remote-sensing observations and extrapolation

Remote-sensing products may be adequate for some purposes in some regions, assuming they have been bias-corrected.[69] If no data set is appropriate and available (although at least temperature data should be obtainable), then strong qualitative arguments and expert knowledge can be used concerning climate variability and change in contexts with similar climates (for example, sourced from regional peer-reviewed literature) or statistically extrapolated from nearby regions with reliable data and quality cover.

Reanalysis

Reanalysis is another way of scientifically grounding the process where data are insufficient or absent. The advantage of reanalysis is that it is an effective data gap filler since it applies the same physical laws tested in data-rich areas to data-lacking areas.

In numerical weather analysis and prediction, 'analysis' refers to the process of creating an internally consistent representation of the environment on a four-dimensional grid (three space dimensions plus time) by combining a huge number of observations with a physically-based model. Reanalysis uses the same process, but it is done days, weeks, or even years later.

Reanalysis can complement observed data and provide complete and consistent atmospheric fields by objectively combining historical observations with modern numerical weather prediction model forecasts, while accounting for estimated errors in both.[70] Most reanalyses, however, only go back to circa 1950 or 1979, so as to use the most comprehensive observing network while avoiding inconsistencies arising from major changes in it, such as the introduction of extensive upper-air observations or satellite data.[71] By assimilating only surface observations, historical reanalyses can avoid some of these inconsistencies and extend further back in time.

Recent comparative studies with independent observations, other reanalyses and satellite products demonstrate, for example, that the 20th Century Reanalysis version 3 (20CRv3, https://psl.noaa.gov/data/gridded/data.20thC_ReanV3.html) can reliably produce atmospheric estimates on scales ranging from individual weather events to long-term climatic trends.[72] Comparisons with station-biased precipitation data sets over regional and monthly scales indicate that the longest currently available reanalysis back to the early nineteenth century (20CRv3) captures variability remarkably well for 1901–2015. Comparisons with a satellite-station blended product over the period 1979–2015 further support this assessment.[73]

However, there are several issues that warrant caution from using reanalysis, as there are still mean biases in temperature, wind and precipitation, as well as in the location and orientation of the tropical convergence zones. Also, the quality of the southern hemisphere fields is generally less accurate than the northern hemisphere and thus have less confidence. There is evidence that acquiring more observations, particularly by digitizing paper records from the eighteenth and nineteenth centuries, could have strong effects on the performance of future versions of reanalysis.[74]

Output of reanalysis

The output of a reanalysis is a uniform grid and no missing data. It is important to note that the reanalysis values are not 'real' data.Rather, they are estimates of real data based on unevenly distributed observational data. The result is an integrated historical record of the state of the atmospheric (also land, and in some cases ocean) environment for which all the data have been processed in a consistent manner.

While reanalysis outputs can be used in place of observational data, this must be done with care because the relative influence of the observations and the model is different for different climatic variables. For example, certain variables are strongly influenced

69 Alexander, L. V.; Bador, M.; Roca, R. et al. Intercomparison of Annual Precipitation Indices and Extremes over Global Land Areas from in situ, Space-based and Reanalysis Products. *Environmental Research Letters* **2020**, 15 (5). https://doi.org/10.1088/1748-9326/ab79e2.

70 Kalnay, E.; Kanamitsu, M.; Kistler, R. et al. The NCEP/NCAR 40-year Reanalysis Project. *Bulletin of the American Meteorological Society* **1996**, *77* (3), 437–472. https://doi.org/10.1175/1520-0477(1996)077<0437:TNYRP>2.0.CO;2.

71 Slivinski et al. (2019) published the longest, globally resolved, six-hourly reanalysis back to 1836–2015, with an experimental extension spanning 1806–1835: Slivinski, L. C; Compo, G. P.; Whitaker, J. S. et al. Towards a More Reliable Historical Reanalysis: Improvements for Version 3 of the Twentieth Century Reanalysis System. *Quarterly Journal of the Royal Meteorological Society* **2019**, *145* (724), 2876–2908. https://rmets.onlinelibrary.wiley.com/doi/10.1002/qj.3598

72 Slivinski, L. C.; Compo, G. P.; Whitaker, J. S. et al. An Evaluation of the Performance of the Twentieth Century Reanalysis Version 3. *Journal of Climate* **2021**, *34* (4), 1417–1438. https://doi.org/10.1175/JCLI-D-20-0505.1.

73 Slivinski, L. C.; Compo, G. P.; Whitaker, J. S. et al. An Evaluation of the Performance of the Twentieth Century Reanalysis Version 3. *Journal of Climate* **2021**, *34* (4), 1417–1438. https://doi.org/10.1175/JCLI-D-20-0505.1.

74 Slivinski, L. C.; Compo, G. P.; Whitaker, J. S. et al. An Evaluation of the Performance of the Twentieth Century Reanalysis Version 3. *Journal of Climate* **2021**, *34* (4), 1417–1438. https://doi.org/10.1175/JCLI-D-20-0505.1.

by the observational data used, while some are purely model-derived, and for different locations (see *Guide to Climatological Practices* (WMO-No. 100)).

Inadequate projection information

Every climate context is different, and the climate information that is relevant for underpinning effective climate action therefore also differs from one context to the next. As discussed in the section on interpreting the results from Step 2, such differences include the relevance of, and therefore the weight that should be given to, climate information across different climate time frames. As with historical data, there are cases where climate projection information may not fully reflect the state-of-the-art with respect to what is technically possible. In such instances, when far-future climate conditions are less important than observed trends, variability and extremes, analyses can focus on local climate variability – which drives most climate-related risks – and on observed trends (rather than on pursuing increasingly sophisticated and expensive options to refine climate projections), to assess whether recent events are within the range of natural variability or symptomatic of longer-term shifts.[75]

A physical theory should also be considered when anticipating future climate, especially when projection information is limited. For example, it is well known that as the atmosphere warms it is able to hold more moisture and that this could lead to an intensification of extreme rainfall events.[76] Thus, even in the absence of state-of-the-art projections, it may be reasonable to recommend adaptation to more extreme rainfall. If a region is heavily influenced by ENSO, then one may infer, based on projections of more frequent extreme La Niña and El Niño events under climate change,[77] that ENSO effects on regional climates may also increase in the future.

Considerations for additional support to increase hydrometeorological systems and services capacities

As a co-benefit of implementing the present methodology, stakeholders may conclude that improvements of the observation network, strengthening of NMHS capacities, and development of data management and service-provision expertise need to be part of the selected climate action, either as a project investment or other support sought from partners. Such proposed actions could be considered for donor support, especially since they arise from an objectively driven identification of needs and through a stakeholder consultation process at the national level.

75 Dessai, S.; Lu, X.; Risbey, J. S. On the Role of Climate Scenarios for Adaptation Planning. *Global Environmental Change* **2005**, *15* (2), 87–97. https://doi.org/10.1016/j.gloenvcha.2004.12.004.

76 Trenberth, K. E.; Dai, A.; Rasmussen, R. M. et al. The Changing Character of Precipitation. *Bulletin of the American Meteorological Society* **2003**, *84* (9), 1205–1218. https://doi.org/10.1175/BAMS-84-9-1205.

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6. ENABLING MECHANISMS AND PARTNERS

The processes involved in preparing the climate science information for climate action require interactions among diverse stakeholders. These interactions can be supported on an ongoing basis by mechanisms that bring together the necessary expertise for implementing this methodology and that promote the continuous development of capacities for identifying and addressing needs for climate science and associated services.

Preparing climate science information requires a wide range of interdisciplinary expertise. This includes expert climatologists, climate modellers, hydrologists, social scientists, adaptation/mitigation and sector specialists, project developers, and managers, among others that may be considered relevant based on the local context. To cover this full range of skills and expertise, national, regional and international specialists will normally need to be mobilized to complement the team of national and/or regional stakeholders.

More broadly, climate science-based climate action involves the establishment and continuous enhancement of a value chain that links the identification of information needs, and the production and delivery of information and services, to user decisions. Global and regional stakeholders that support elements of this climate services value chain include international organizations, economic commissions, financial institutions and the private sector.

The enabling mechanisms described below promote stakeholder engagement for climate science-based action. They do so by promoting interaction at the national level as well as by providing entry points for engagement – in supporting roles – by regional and global actors.

National Meteorological and Hydrological Services

At the national level, because of the key role that NMHSs play in observing, collecting and providing access to hydrological, weather and climate information, they are a critical resource for developing climate science information. NMHSs' contributions extend from operating the national hydrometeorological observing networks that provide the principal inputs for science-based climate action, through to the quality control, processing, analysis and interpretation of climate data for decision-support.

The role of NMHSs is therefore pivotal in sustaining national climate and hydrological observations as well as providing relevant information as inputs for the preparation of climate finance investments. Implementing objective, scientific, data-driven, evidence-based analyses and processes to arrive at climate finance decisions, enhances the quality and aims to increase the effectiveness of investments while promoting the climate resilience sought by countries and funders. In executing their role, NMHSs thereby enable countries' access to climate finance.

NMHSs' ability to fulfil their role depends not only on involvement in climate action but also on providing a wide range of climate services continuously on an operational basis. Such products and services include early warnings and specialized information needed for decision-making in climate-sensitive sectors. Therefore, to be effective, NMHSs need to continually engage with stakeholders from sectors affected by climate, such as agriculture, disaster risk reduction, energy, transport, health and water, among others.

National Frameworks for Climate Services

Effective and efficient climate services involve the ongoing accumulation of knowledge about the recent past, current, as well as future state of the climate system and identification of the type and form of services and information about the climate and its impacts that are needed by the community at large and within specific productive sectors that are particularly sensitive to climate variability and change. They also involve the provision of a range of advisory services and decision-support products based on climate knowledge, driven by identified needs. The climate science information for a project is an example of such decision-support.

To achieve the above on an ongoing basis requires establishing a coordination mechanism to enable different types of institutions and actors to collaborate and work together to co-design, co-produce, and deliver and use climate services. A National Framework for Climate Services (NFCS) is a mechanism for enabling the coordination and collaboration required to ensure that all the elements of the value chain for the production and application of effective climate information services are effectively addressed through the identification of gaps, needs and priorities for implementation.

The *Step-by-step Guidelines for Establishing a National Framework for Climate Services* (WMO-No. 1206) as a mechanism for engaging with the users of climate services provides details on how NFCSs do this in three fundamental ways:

1. **Gather knowledge about users and their needs** – Understand the climatic elements that are relevant to the users; how the users wish to receive information; how the users are likely to interpret the information; for what purpose the information will be used; the decision process of the users; and how the information might improve the decision-making processes;

2. **Make the information service simple, accessible and timely** – Provide products that can be understood and readily applied by the users, along with easy access to follow-up professional advice;

3. **Ensure quality** – Provide products that have been developed with skill and with an understanding of possible applications and analytical techniques, complete with proper documentation and backed by thorough knowledge of up-to-date data availability and characteristics.

An NFCS will provide:

- A platform for institutional coordination, collaboration and co-production among relevant technical departments across line ministries at national and subnational levels;

- A legal framework for collaboration at the national level to generate and share user-oriented climate information services to support policy and planning, and for use by the relevant social and economic sectors;

- An opportunity to bridge the gap between available climate information services and user needs at national, sub-national and local levels, continuously identifying user needs for climate services, communicating available products and services to users in the relevant sectors, obtaining feedback from users and documenting socioeconomic benefits;

- A vehicle for scientific coordination to synthesize the state of the climate at the national and regional level, and distil climate knowledge outputs for policy makers' actions founded on scientific evidence;

- An operational bridge between climate research, NMHSs and other relevant national institutions, to increase collaboration and improve services by working together on climate knowledge, and by sharing data and expertise;

- A functional chain for linking climate knowledge to maximize the application of climate information and products by identifying gaps, needs and priorities to inform investments or actions of all stakeholders for improving the delivery of climate services;

- An opportunity for enhancing the contribution of climate information services to the NAP process and implementation of NDCs by countries.

Given the NMHS's important role in the value chain for the provision of climate information and services, the NMHS should be a leading institution in mobilizing and reaching out to partner institutions and stakeholders in the value chain and users of climate services to operationalize an NFCS.

User engagement platforms and National Climate Forums

The interface between users of climate information and providers of climate services is complex, multifaceted and particularly challenging. The interface should ensure effective user engagement to address their needs and requirements. Three broad categories of user engagement exist: (a) websites and web-based tools; (b) interactive group activities; and (c) focused relationships between a provider and a user. The WMO *Guidance on Good Practices for Climate Services User Engagement* (WMO-No. 1214) as well as National Climate Outlook Forums are two resources for establishing these types of engagements.

WMO Guidance for user engagement

The WMO *Guidance on Good Practices for Climate Services User Engagement* (WMO-No. 1214) provides guidance on how to undertake effective engagement between users of climate information for decision-making and providers of climate services. The guidance is primarily intended for the providers of climate services, in particular for NMHSs, but will also be of use to other organizations involved in the development, delivery and use of climate services, and should be an important contribution to all involved in the Global Framework for Climate Services (GFCS).

National Climate Outlook Forums

National Climate Outlook Forums and National Climate Forums (NCOFs/NCFs) facilitate the provision of standardized climate products based on high-quality climate information from Global Producing Centres (GPCs), Regional Climate Centres (RCCs) and Regional Climate Outlook Forums (RCOFs) at relevant timescales at the national level. The NCOF/NCF process is also expected to help communicate climate information, including climate outlooks, along with the associated uncertainties, in a consistent and effective manner. The sustained interaction enabled by NCOFs would ultimately lead to a risk management approach that makes use of probabilistic forecasts building resilience in climate-sensitive sectors.

Intergovernmental Panel on Climate Change focal points

It is particularly important to engage IPCC focal points[78] and other IPCC stakeholders in the preparation of the climate science information for climate action. IPCC focal point engagement serves multiple purposes, including:

- Increasing the expertise available, since IPCC experts will be familiar with, and have access to, relevant data sets and tools;
- Helping in ensuring consistency between information used in the development of the climate science information and information appearing in IPCC reporting; and
- Facilitating organization by IPCC and other experts of a peer-reviewed publication on the climate science information, if desired by a country, which will enrich references for the IPCC to draw upon for the preparation of future reports, especially in parts of the world not well covered by such literature.

WMO scientific community

WMO is a community of NMHSs, regional and global centres, partner institutions, and hundreds of intergovernmentally nominated and confirmed experts on all aspects of weather, water and climate. The methodology outlined in this guide – including the technical resources, enabling mechanisms and their underpinning methodologies, and those that support it (see Annex 1) – are outputs of WMO, its governance processes and partners. Many experts including WMO Members, centres and collaborating institutions have contributed to the development of these resources and they, and many others from the WMO community, are available to support their implementation.

Multilateral community

WMO is continuously engaging with a broad range of stakeholders in order to enhance weather, climate, water and environmental services. The United Nations System, international and regional organizations, multilateral development banks and international financial institutions are key partners in promoting and supporting implementation of the climate science information for climate action. They play an important role in contextualizing climate data for specific focus areas and climate-sensitive sectors, co-producing knowledge and technical resources, enhancing an understanding of climate risks and impacts, and enabling access to climate finance for climate action investments. Given the complexity of the climate challenge, the provision of such elements leads to enhanced cooperation, improved decision-making as well as increased effectiveness of science-based climate actions.

78 A list of national focal points is available at https://www.ipcc.ch/apps/contact/interface/focalpoints.php.

7. CONCLUSION

The selection of climate actions based on high-quality observational data and scientifically validated climate change projections supports context-relevant actions that build resilience against extreme weather events and climate change. The present guide explains how to select climate actions in this way, using a climate science-based methodology. It offers a coherent process to identify associations between the past, present and projected future states of climate and their impact on a given area of focus. The benefits resulting from implementing this science-based methodology for selecting climate action contribute to achieving the goals of the Paris Agreement of reducing vulnerability and increasing the adaptative capacity of the most climate-sensitive countries, regions and populations.

The improved understanding of how the changing climate situation in the local context links to a selected climate action contributes to the accumulation, refinement and continuous expansion of knowledge in this area. Through the effective involvement of relevant stakeholders and institutions, the development of the climate science information spurs a virtuous process of knowledge production and validation that is inclusive, objective, transparent and situationally relevant. This knowledge, when embedded in the local context and driven by local needs, expands and enriches the definition of best available climate science. It incorporates site-specific data, observations and local expertise that can enhance local-level adaptation to increased climate variability and change. Furthermore, it increases the scientific robustness of climate finance and countries' abilities to access it.

Implementation of the methodology requires broad country-level stakeholder engagement that brings together the best available local knowledge, expert guidance, objectivity and transparency into the process. This should be complemented by international expertise which can bring additional credibility and integrity when implementing the methodology.

Broad engagement is essential for: identifying the relevant climate information and products needed; data collection, quality control, analysis and interpretation; and eventual decision-making for selecting proposed climate actions. Furthermore, given the major impact that climate change could increasingly have on countries' development outcomes, it is important to strengthen the collaboration among key institutions to enable them to collectively determine the climate concerns and challenges their country is likely to face.

Additionally, capacity-development efforts should enable continuous enhancements to data, tools, and methods in an ongoing manner. The process of developing the climate science information will strengthen national capacities, and when such capacities need to be further bolstered, the process encourages noting gaps in data, information, and expertise, and requesting additional support from donors to address such gaps. Data sourcing assistance, climate expertise, and capacity-development support should be provided so that subsequent iterations of developing the climate science information for climate action are better-informed and expertly grounded.

The present methodology is, in this way, a circular reinforcing process. It can be considered as a capacity-development opportunity whereby at every iteration of its implementation, knowledge – as well as data availability and quality, NMHS capability, and other local expertise – should be strengthened. This continually reinforcing cycle enhances the science as well as the decision-making capabilities needed for the selection of climate actions.

Enhanced country-level engagement through broad stakeholder consultation and interaction among international and national experts and institutions, implemented through this methodology, will create enabling conditions for future improved scientific contributions into national policy and planning processes. Therefore, the application of such a methodology creates value beyond the implementation of an individual country-level activity or investment. Such a methodology ultimately also contributes to the implementation of integrated international agendas on sustainable development, disaster risk reduction, and of course, global climate change.

ANNEX I. GUIDANCE ON METHODS, TOOLS AND DATA

[Provided separately: https://library.wmo.int/index.php?lvl=notice_display&id=21974]

ANNEX II. COUNTRY CASE STUDIES

[Provided separately: https://library.wmo.int/index.php?lvl=notice_display&id=21974]

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