Strategic Research and Innovation Agenda for Climate Change Science (2026-2035)

Inspiring the European Research Area to Provide Effective Responses to Climate Change

Acknowledgements

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- Overall coordination: Johannes Wagner (ANR)
- Working Group Leads: Gerhard Krinner (CNRS, overall scientific coordination); Joonas Merikanto (FMI); Gregor Laumann (DLR); Frank McGovern (EPA); Lola Kotova (GERICS); Roger Street (CMCC); Karina Standal (CICERO)
- Strategic oversight: Giulia Galluccio (CMCC); Petra Manderscheid (BELSPO)

The following experts (in alphabetical order) have substantively contributed to the development and drafting of the SRIA: Solveig Aamodt (CICERO); Sonja Åman (UiO); Alexander Bisaro (Adapt 3E); Kristian Blindheim Lausund (FFI); Erika Coppola (ICTP); Michael Depuydt (BELSPO); Magali Dreyfus (CNRS); Anne-Maria Eikeset (NBIM); Joshua Ettinger (Mason4C); Alexandre Fernandes (IIED Europe); Jan Fuglestvedt (CICERO); Jeremy Gault (UCC); Helene Hewitt (UK Met Office); Steffen Kallbekken (CICERO); Gregor Laumann (DLR-PT); Martine Legris (CERAPS, Lille University); María Máñez (GERICS-HEREON); Matilde Monnier (ANR); Claudia Morsut (UiS); Dirk Notz (UHH); Spyridoula Ntemiri (GRFU); Silke Ötsch (SOFI, Göttingen and Kassel University); Antti-Ilari Partanen (FMI); Christopher Phillips (UCC/EPA. Ireland); Anne-Hélène Prieur-Richard (ANR); Alexandra Revez (UCC); Ali Rhouma (PRIMA); Trude Storelvmo (UiO); Chiara Trozzo (CMCC); Ine Vandecasteele (EEA); Jonas Vestby (PRIO); Rolf von Kuhlmann (DLR).

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Maximizing the synergy of European research Governance and Innovation for Climate Action

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Executive Summary

The world is off track to meet the long-term climate goals outlined in the Paris Agreement. Instead of slowing down, the pace of climate change is accelerating. Europe is the fastest-warming region in the world. This is leading to extensive detrimental social, economic, environmental, and health consequences.

Urgent action is needed to mitigate greenhouse gas (GHG) emissions and to adapt to the unavoidable impacts of climate change. This imperative is embedded in European policies which are tailored to achieving climate neutrality and becoming climate-resilient by 2050, in line with the goals of the Paris Agreement (PA). Delivering on these policy goals necessitates a robust and dynamic scientific foundation.

There has been significant investment in climate research and innovation by the European Union (EU) and across the European Research Area (ERA) which encompasses EU member states and associated countries. However, key issues remain and critical knowledge gaps persist that must be addressed to inform a managed and timely transition to a climate-neutral, climate-resilient, and prosperous economy and society.

This Strategic Research and Innovation Agenda (SRIA) has been developed by the MAGICA project as an information resource for the ERA. The SRIA is structured around four Strategic Research Challenges:

1. Improved Understanding of the Earth's Climate System
2. Scientific Underpinnings of Societal Transformation for Climate Action
3. Scientific Underpinnings of Climate Adaptation - Towards Climate Resilience
4. Scientific Underpinnings of Greenhouse Gas Management and Carbon Dioxide Removal

The SRIA outlines research and innovation priorities that address these challenges. In doing so, the SRIA aims to act as a resource and inspiration for Research Funding and Research Performing Organisations across the ERA. Its ambition is to inform and support alignment of national research programmes and the next EU Framework Programme (FP10). Accordingly, the SRIA emphasises the need for coordinated and sustained climate research funding, and holistic and integrated research approaches to advance knowledge, innovation, and policy for more effective climate action in Europe and beyond.

Key Priorities of the Strategic Research and Innovation Agenda

Responding to New Global Realities: An Imperative for Climate Research and Policy

Shifting global alliances in an increasingly volatile geopolitical context are reshaping research priorities and funding landscapes. Climate misinformation and disinformation, political polarisation, and declining trust in public institutions and scientific knowledge pose significant barriers to effective climate action. In this context, investing in robust, autonomous, and well-coordinated European climate research is essential – covering data collection, management, analysis, interpretation, synthesis, and information provision. Doing so will contribute to strengthening the EU's strategic autonomy, ensuring that Europe continues to lead in climate science and action.

Improving Process Understanding and Projections of the Earth's Climate System

A robust scientific understanding of the Earth's climate system is critical for guiding effective climate action and ensuring the success of climate mitigation and adaptation strategies. Reliable, long-term climate data underpin accurate projections, inform policy, and help track progress toward stabilising global temperatures. Understanding how climate stabilisation unfolds in a warmer world and its effects on oceans, land, and dependent systems is crucial. Targeted investments in observational data, high- performance computing capacity, and robust and coordinated data management will not only strengthen climate science but also enhance the EU's strategic autonomy and resilience to geopolitical shocks, supporting long-term climate resilience and informed decision-making.

Strengthening Social Sciences and Humanities to Enable Effective Climate Action

Progress towards climate neutrality and resilience requires deep societal transformations. This demands a stronger focus on social sciences and humanities (SSH) in climate research. As emphasised in the Heitor Report, SSH play a vital role in understanding the social, economic, and political dimensions of climate change and in ensuring a just transition towards climate resilience and neutrality. Greater investment in SSH and transdisciplinary approaches can enhance transformative climate governance and policies and is crucial for improved climate communication, including countering growing misinformation and disinformation.

Enhancing Mitigation Strategies and Adaptation Choices to Build Climate Resilience

Building climate resilience requires deep GHG emission reductions in the decades to 2050 and significantly scaling up adaptation actions to address the unavoidable and intensifying impacts of climate change. Achieving this will require the creation and exchange of robust, relevant, and usable evidence and knowledge.

To address economic and societal shocks and to deliver informed climate mitigation and adaptation strategies, decision-makers must understand climate risks and adaptations and mitigation solutions and their potential for integration across sectors and at various spatial and temporal scales. It also involves assessing the adequacy and effectiveness of current mitigation and adaptation policies to inform better targeted responses and improvements, including how these policies can work together. As such, evaluating the intrinsic risks and unintended consequences of mitigation and adaptation measures, including their potential conflicts, is essential to enhance and sustain our journey to climate neutrality and climate resilience.

Advancing GHG Management Systems and CDR Technologies and Governance

Governments and organisations require accurate data on GHG emissions and removals to inform policies, set and report on emission reduction targets, and measure progress. Such data can contribute to enhance transparency and accountability. Because of slow progress in reducing GHG emissions, both engineered and ecosystem-based approaches for carbon dioxide removal (CDR) have become a critical area of research and policy action. Yet, CDR methods remain technologically immature, costly, or environmentally uncertain, with potentially adverse ecological effects. Ethical concerns also persist, particularly the risk that CDR may be misused to delay meaningful emission reductions. To ensure that CDR contributes effectively and equitably to net-zero goals, sound governance arrangements and implementation strategies based on robust interdisciplinary research are essential.

Recommendations for Implementing the SRIA

Enhancing Access to Research Infrastructures

Europe hosts world-class research infrastructures (RIs) for climate science. Sustained investment in the maintenance, expansion, and accessibility of these RIs is vital to ensure reliable, continuous observations and high-performance computing systems that underpin robust climate modelling and extreme event attribution. Enhancing such platforms will improve data quality and usability for both researchers and policymakers. Given growing geopolitical uncertainties, a coordinated European approach is crucial to strengthen observational networks and develop strategies to ensure data resilience, integrity, availability, and quality.

Supporting Research Collaboration Across Disciplines, Scales, and Borders

Addressing the complex, interconnected challenges of climate change requires integrated, inter- and transdisciplinary research that spans disciplines, sectors, and borders. The SRIA promotes such collaboration to enhance the quality, relevance, and societal impact of climate research and innovation. Embedding societal readiness into climate research ensures inclusiveness, adaptability, and positive outcomes. Multi-level cooperation – linking local to regional and global actors – is also vital for generating and exchanging actionable knowledge and enabling joint innovation for achieving climate neutrality and resilience.

Fostering Open Science to Increase the Quality of Climate Research

The proposed climate research should be conducted in compliance with the highest scientific standards of transparency and openness. An Open Science (OS) approach is critical in accelerating climate action by enhancing knowledge-sharing, collaboration, and transparency. It involves making scientific knowledge, research findings, data, and methodologies freely available. Ultimately, OS will accelerate scientific progress and enhance the quality of climate research.

Building Complementarities with other Climate Research Initiatives

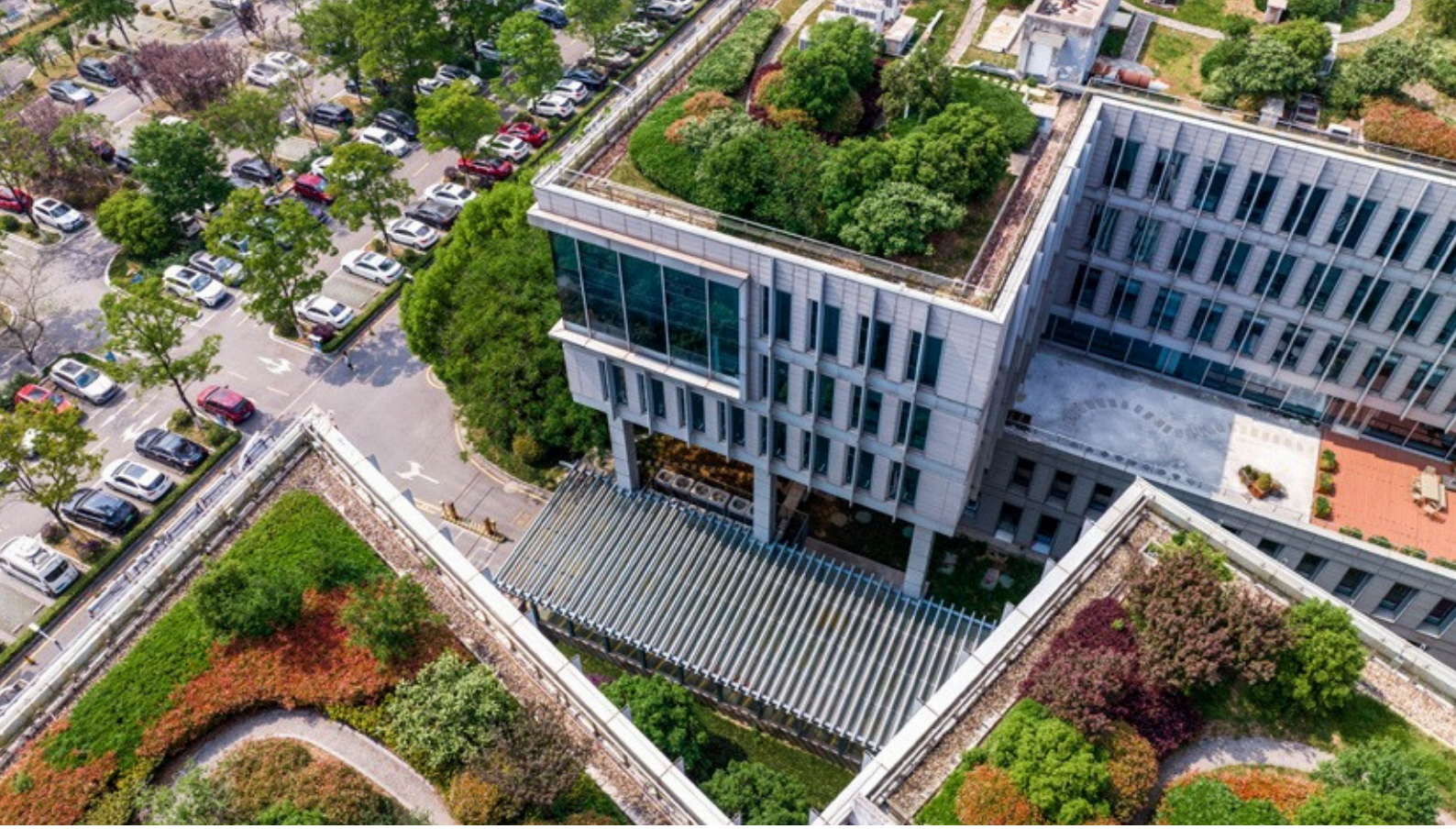
To effectively and efficiently advance climate research and innovation, it is crucial to build complementarities and synergies with existing climate-related research initiatives, programmes, and infrastructures while avoiding duplication of efforts. Coordinated action across the ERA will maximise the impact of investments, ensure coherent progress, and accelerate the delivery of transformative climate knowledge. The research priorities identified in this SRIA should therefore be pursued in close collaboration with existing national and EU-funded research schemes, innovation ecosystems, and international initiatives.

The Equinox Process: Enabling Effective Knowledge Transfer

To deliver on the research and innovation priorities identified in the SRIA and its transfer to the policy domain, robust and dynamic mechanisms are essential. A strategic mechanism for conveying the results of the SRIA is the Equinox Process – an innovative initiative designed to advance climate knowledge for policy and action by fostering engagement at the science-policy-society interface. Facilitating and maintaining two-way dialogues between researchers and societal actors enables the co-design of research and allows for iterations between scientific findings and learnings from practice.

List of abbreviations

AC	Associated Country of the European Union
AFOLU	Agroforestry, Forestry and Other Land Use
AI	Artificial Intelligence
AMOC	Atlantic Meridional Overturning Circulation
ANR	French National Research Agency
AR6	Sixth Assessment Report of the IPCC
BECCS	Bioenergy with Carbon Capture and Storage
CCU	Carbon Capture and Utilisation
CDR	Carbon Dioxide Removal
CLRTAP	Convention on Long-Range Transboundary Air Pollution
CMCC	Euro-Mediterranean Center on Climate Change
CMIP	Coupled Model Intercomparison
CNRS	Project French National Centre for Scientific Research
CO2	Carbon Dioxide
CRCF	Carbon Removal Certification Framework
CRD	Climate Resilient Development
CSA	Coordination and Support Action
DAC	Direct Air Capture
DestinE	Destination Earth
DG RTD	Directorate General for Research and Innovation (European Commission)
DLR	German Aerospace Center
DUT	Driving Urban Transitions Partnership
EC	European Commission
ECMWF	European Centre for Medium-Range Weather Forecasts
ECS	Equilibrium Climate Sensitivity
ENES	European Network for Earth System Modelling
EPA	Environment Protection Agency, Ireland
ERA	European Research Area
ERA4CS	European Research Area for Climate Services
ESA	European Space Agency
ESM	Earth System Models
ETS	EU Emissions Trading System
EU	European Union
EUCRA	European Climate Risk Assessment
FMI	Finnish Meteorological Institute
GCP	Global Carbon Project
GERICS	Climate Service Center Germany
GHG	Greenhouse Gas(es)
HEU	EU's Horizon Europe R&I programme
HILL	High Impact-Low Likelihood
IAM	Integrated Assessment Model
ICOS	Integrated Carbon Observation System Research Infrastructure
IPCC	Intergovernmental Panel on Climate Change
JPI Climate	Joint Programming Initiative Connecting Climate Knowledge for Europe
JPI Oceans	Joint Programming Initiative Healthy and Productive Seas and Oceans
JPI Cultural Heritage	Joint Programming Initiative on Cultural Heritage
KH-SLR	Knowledge Hub on Sea Level Rise
MAGICA	Maximizing the synergy of European research Governance and Innovation for Climate Action
MEA	Multilateral Environmental Agreement
MRV	Monitoring, Reporting, and Verification
MS	Member State of the European Union
NbS	Nature-based Solutions
NDC	Nationally Determined Contributions
OS	Open Science
PA	Paris Agreement
RCN	Research Council of Norway
R&D	Research and Development
RFO	Research Funding Organisation
RI	Research Infrastructures
SDG	Sustainable Development Goals
SLCF	Short-lived Climate Forcers
SRC	Strategic Research Challenge
SRIA	Strategic Research and Innovation Agenda
SRM	Solar Radiation Modification
SSH	Social Sciences and Humanities
TCR	Transient Climate Response
UKRI	UK Research and Innovation
WCRP	World Climate Research Programme
WMO	World Meteorological Organisation



1

Advancing European Climate Research for a Climate-Neutral and Resilient Society

Human-caused climate change is continuing largely unabated, spurred by greenhouse gas (GHG) emissions and increasing atmospheric concentrations that continue to rise. Current atmospheric concentrations of GHGs are higher than at any point in hundreds of thousands of years. They are changing the planet's energy balance, which remained largely stable through-out human history. Recent years have been the warmest on record, with Europe being the Earth's fastest-warming region[1]. Global warming intensifies multiple and concurrent hazards, creating compound and cascading risks that are increasingly complex and difficult to anticipate and to manage, resulting in extensive detrimental socio-economic, environmental, and health consequences.

The imperative of climate action is embedded in European policies including the European Green Deal (2019), the European Climate Law (2021), and the EU Adaptation Strategy (2021). These frameworks align with international commitments such as the Paris Agreement (2015). Europe's stated goals are to achieve climate neutrality and become climate-resilient by 2050. Many countries in the ERA, both EU members and non-members, have adopted climate laws and policies at national levels with similar ambition and intent. Achieving these goals requires profound societal, political, and economic transformations. In addition, ensuring a just transition towards climate neutrality[2] and climate resilience[3] is critical to protect those at risk and to improve climate action outcomes (IPCC 2023).

(1) Copernicus Climate Change Service (C3S) and World Meteorological Organization (WMO), 2025: European State of the Climate 2024, https://doi.org/10.24381/14j9-s541

This approach is embedded in EU frameworks which aim to promote fairness and inclusivity in climate action.

The transition to a climate-neutral and climate-resilient society must be grounded in the best available science. This is the guiding rationale for developing this Strategic Research and Innovation Agenda (SRIA): to build a common vision for climate research in the European Research Area (ERA) that provides timely, reliable, policy-relevant,
and actionable knowledge to support Europe in the pursuit of climate neutrality and climate resilience.

ERA possesses world-leading scientific expertise and infrastructure for climate-related research, covering both the natural and social sciences. Strategic planning and sustained investment in scientific research and observation have placed Europe at the forefront of climate knowledge generation. However, with intensifying climate change and increasing geopolitical uncertainties, further progress is essential to refine our understanding of anthropogenic climate change and related risks, including risks arising from inadequate responses to climate change, and to develop actionable climate solutions for Europe and beyond, which are themselves resilient to other types of shocks and crises such as pandemics and conflicts.

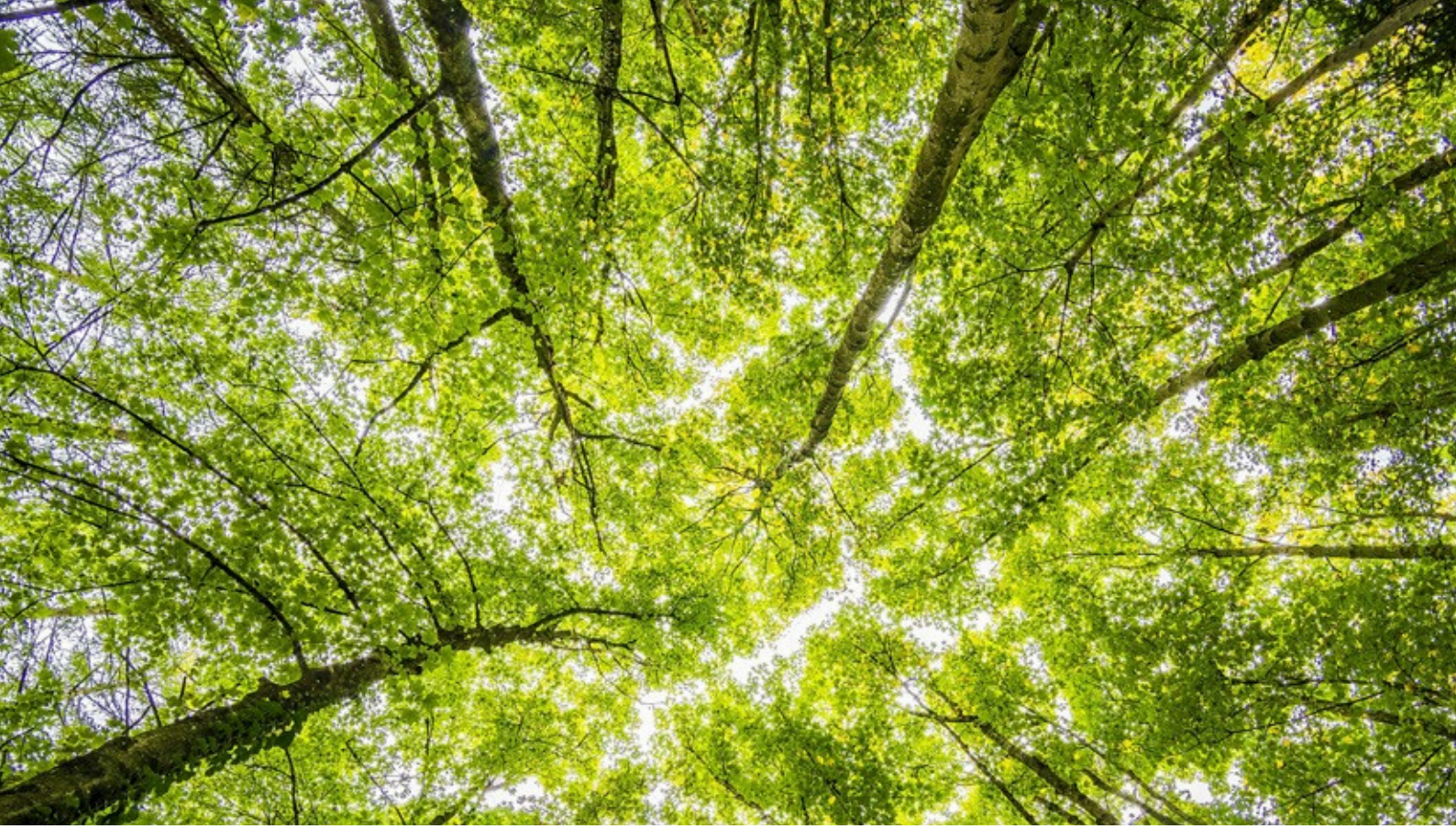
The transformations Europe is undergoing and needs to tackle on its path towards climate neutrality and resilience call for knowledge creation, dissemination and exploitation, resource sharing, and long-term, concerted actions based on a common agenda. These needs are intensified by differences in policies and institutional settings across Member States (MS). Despite significant climate-related investment through Horizon Europe (HEU), the funding landscape remains fragmented: although the European Commission (EC) funding is substantial, most resources are provided by national, bilateral, or multilateral instruments managed by MS and Associated Countries (AC). In addition, there is currently no HEU Partnership dedicated to climate research.

The need for substantial and coordinated investment in climate sciences is amplified by the rapidly evolving geopolitical context. Shifting global alliances and geopolitical instability are reshaping research priorities and funding landscapes. Climate disinformation, political polarisation, declining trust in institutions, and deliberate, intensified attacks against scientific knowledge and its relevance for decision-making pose significant barriers to effective climate communication and policy uptake. In such an environment, autonomous, coordinated, and well-funded European climate research is essential.

Ultimately, this SRIA aims to inform the ERA to provide effective responses to climate change by inspiring and aligning national research programmes and the next EU Framework Programme (FP10) in the realm of climate sciences. By enhancing climate research and innovation in the Single Market (Letta Report), the SRIA offers a pathway for Europe to continue leading in climate action. These efforts will also contribute to making ERA's research system more resilient against geopolitical shocks and changes, thereby strengthening Europe's overall strategic autonomy. Robust climate sciences as outlined in this SRIA will thus inform effective climate action and contribute to enhanced European resilience and competitiveness (Draghi Report).

The scope of the SRIA mirrors research and innovation activities covered by HEU Cluster 5 Destination 1 - "Climate sciences and responses", including Earth system science, research related to climate mitigation and adaptation, as well as social sciences and humanities in relation to climate action. As such, this SRIA does not contain research relating to energy, industry, or transport and mobility. Yet, the SRIA's priorities hold relevance across these sectors given their cross-cutting nature.

(2) Climate Neutrality is "a state in which human activities result in no net effect on the climate system. In terms of emissions, climate neutrality entails a balance between emissions and removals of GHGs from the atmosphere. In terms of a temperature limit, climate neutrality can be considered to denote a state in which human activities cause no additional increase to the global average surface temperature" (Climate Neutrality Forum Report, 2025, 2026).
(3) Climate Resilience: The IPCC defines resilience as "the capacity of interconnected social, economic and ecological systems to cope with a hazardous event, trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure." Climate resilience is generally considered to be the ability to recover from, or to mitigate vulnerability to, climate-related shocks. It includes the abilities to reorganise and learn, and aims to strengthen the ability of all to address vulnerability to climate risks and to adapt to a changing climate. Essentially, climate resilience allows societies to prepare for and cope with unavoidable climate risks.



2

Mission, Objectives and Structure of the SRIA

This Strategic Research and Innovation Agenda (SRIA) is designed to serve as a unifying framework for shaping climate research within the European Research Area (ERA) over the coming decade (2026 - 2035). Rooted in the mission to support Europe in achieving climate neutrality and becoming climate-resilient by 2050, it intends to act as a robust yet flexible compass to navigate uncertainties in a rapidly evolving world. As such, the SRIA aims to inspire and align both EU and national research programmes.

Alignment with European and International Climate Policy Goals

The SRIA is aligned with key European policy frameworks such as the European Climate Law (2021), the European Green Deal (2019), and the EU Adaptation Strategy (2021) and similar national legislation and frameworks. It also supports achievement of the goals of the Paris Agreement (PA) and the Sustainable Development Goals (SDGs).

Central to this alignment are three overarching policy targets: 1) Limiting global warming to well below 2°C, and make efforts to limit warming to 1.5°C; 2) Achieving durable climate neutrality in Europe by 2050; 3) Enhancing climate resilience to adapt to existing and unavoidable climate impacts.

The SRIA recognises that achieving these goals requires systemic transformation that must be guided by the best available science, following an integrated and inclusive approach. Based on the analysis of IPCC reports and remaining knowledge gaps and needs, the SRIA prioritises the generation of policy-relevant knowledge to help design effective and integrated climate mitigation and adaptation measures, whilst accounting for trade-offs – for example related to land use – and enabling synergies with broader societal objectives such as biodiversity protection, industrial competitiveness, and social equity.

Objectives and structure of the SRIA

The following strategic objectives arise from this mission

1. Accelerating climate action by advancing knowledge and its dissemination;
2. Harnessing the potential of the ERA by fostering excellence and collaboration;
3. Integrating nexus issues (e.g. water-food-energy-ecosystem interconnections) into climate research;
4. Maximising synergies with broader policy frameworks, such as the UN Sustainable Development Goals and national climate strategies;
5. Supporting science-policy-society co-production of actionable climate knowledge.

Progress towards climate neutrality and resilience relies on enabling deep societal transformations - changes in how societies and economies function at various levels to decarbonise and prepare for and cope with unavoidable climate risks -, on improved understanding of fundamental processes of the Earth's climate system, and on progress on carbon dioxide removal (CDR). Therefore, the SRIA is structured along four interconnected Strategic Research Challenges:

1. Improved Understanding of the Earth's Climate System;
2. Scientific Underpinnings of Societal Transformation for Climate Action;
3. Scientific Underpinnings of Climate Adaptation - Towards Climate Resilience;
4. Scientific Underpinnings of Greenhouse Gas Management and Carbon Dioxide Removal.

These Strategic Research Challenges[4] reflect the need to reinforce the role of social sciences and humanities (SSH) in shaping climate solutions.

Stronger investment in SSH is essential for understanding and addressing the social, economic, and political dimensions of climate change and proposed actions, and ensuring a just transition considering co-benefits and trade-offs. This will help increase the societal relevance of climate research and may eventually inform the design of more inclusive and effective policies, gaining enhanced public support.

Achieving climate neutrality and climate resilience requires a holistic, systemic approach that transcends disciplinary boundaries. The present SRIA therefore contains intentional overlaps between the four Strategic Research Challenges (SRCs), allowing for valuable synergies and complementarities. These overlaps across the different research priorities are explicitly acknowledged in the SRIA, strengthening its overall coherence.

Relevant cross-cutting and nexus themes such as One Health[5], biodiversity protection, water resilience, just transition, and digital transformation are also embedded across the four SRCs. The SRIA further provides recommendations for strategic collaboration between Research Funders[6] in the ERA. As such, the SRIA for Climate Change Science seeks to actively contribute towards building a resilient, sustainable, and just climate future in Europe and beyond.

(4) Each of these four overarching Strategic Research Challenges is structured by Core Themes that group identified priorities for future climate research.
(5) The SRIA understands One Health as defined by the OHHLEP as an integrated, unifying approach that aims to sustainably balance and optimise the health of people, animals, and ecosystems. It recognises that the health of humans, animals, plants, and the wider environment (including ecosystems) are closely linked and interdependent, and that climate change reinforces existing and future threats to One Health.
(6) For example: EU Member States, Associated and other European countries, the European Commission, etc.

3

Strategic Research Challenges Guiding Future Climate Research

3.1 Strategic Research Challenge 1: Improved Understanding of the Earth's Climate System

By improving our understanding of the Earth's climate system and its dynamic responses to anthropogenic and natural drivers, climate science provides and enhances the foundation for informed mitigation and adaptation policies.

Yet, critical uncertainties remain. A better quantification of Earth system feedbacks to climate change is needed to constrain key climate metrics such as the equilibrium climate sensitivity (ECS). There is also a clear need for continued investigation on potential abrupt or irreversible changes, such as the shutdown of the Atlantic Meridional Overturning Circulation (AMOC), ice sheet collapse, or forest dieback to advance the understanding of committed changes from GHG emissions and warming to date, and risks caused by further emissions.

A better understanding of the climate impacts of short-lived climate forcers (SLCFs), and aerosols in particular, is important for narrowing uncertainties in climate sensitivity and refining global and regional climate projections. In addition, the consequences of approaches such as carbon dioxide removal (CDR) on the Earth's climate system are not well understood. At the same time, highly controversial intervention options such as solar radiation modification (SRM) require careful scientific scrutiny. Integrated assessment models (IAMs) must evolve through transparent evaluation, improved documentation, and broader biophysical, socio-economic, and climate adaptation representation to better support policy.

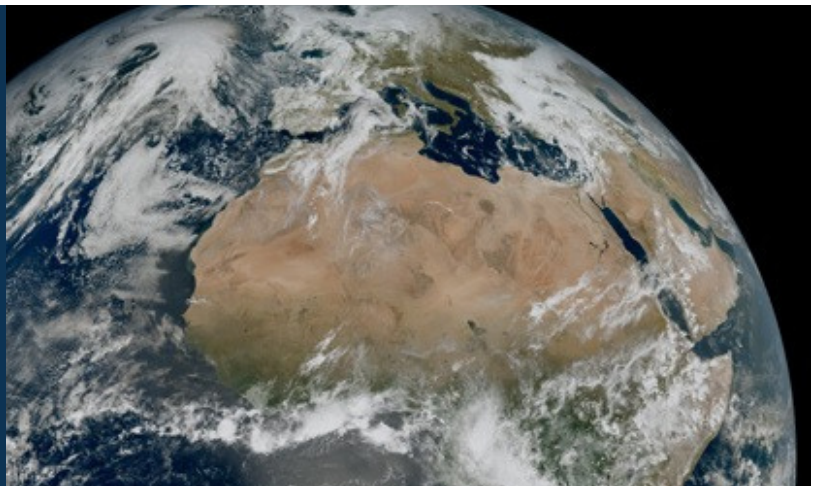
Ongoing transformative advances in climate research include improved descriptions of Earth system processes, high-resolution Earth system modelling at global and regional scales, enhanced observational capabilities, machine-learning approaches, and advanced data integration. Many of these innovations, particularly those involving machine learning, rely on open, high-quality climate data, underscoring the critical need for sustained investment in data recovery, digitisation, analysis, long-term archiving, open accessibility, and importantly, on filling the gaps in regional data coverage. Ensuring continued European leadership in fundamental climate sciences in the context of geopolitical challenges, transformative technological and conceptual advances, and major international initiatives (such as the International Polar Year 2032-2033), requires coordinated planning and support.

The research priorities for this Strategic Research Challenge are grouped in three Core Themes:

1) Improved process understanding;
2) Data collection and management;
3) Methodological developments.

CORE THEME 1:

Improved Understanding of the Warming Climate System



A comprehensive understanding of the Earth system interactions and feedbacks is the basis for improving climate projections and assessing climate risks. Despite long-standing progress, significant knowledge gaps persist regarding key physical and biogeochemical processes, especially those related to cloud feedbacks, aerosol-climate interactions, circulation changes, and future changes in natural carbon sources and sinks. Filling these knowledge gaps will significantly enhance our ability to project climate change impacts with greater confidence and precision. Enhanced and region-specific understanding of climate risks and extremes is crucial for disaster preparedness and resilience, and for driving innovation in climate services and just mitigation and adaptation policies (see Strategic Research Challenges 2 and 3).

A. Reducing uncertainties in climate sensitivity and regional climate responses

Improved understanding of how the Earth system responds to anthropogenic emissions is critical for informing climate policy and risk assessments. Two key areas – constraints on climate sensitivity and the role of short-lived climate forcers (SLCFs) – are intertwined, with prospects for reducing uncertainties in global and regional climate projections. Uncertainties in equilibrium climate sensitivity (ECS), transient climate response (TCR), and feedback mechanisms remain a major challenge in estimating the likelihood and impacts of high-end global warming scenarios; these uncertainties are, to a large part but not exclusively, linked to cloud processes. Poorly constrained historical aerosol radiative forcing also limits our ability to constrain ECS and TCR using historical records. At the same time, SLCFs – particularly aerosols and their interactions with clouds – represent one of the largest sources of uncertainty in near- to mid-term climate projections, especially at regional scales.

Furthermore, ocean heat uptake, which regulates Earth's climate on longer timescales, is poorly understood. Therefore, future research should:

- Constrain upper-bound climate sensitivity through improved paleoclimate evidence, better understanding and quantification of different types of cloud feedbacks and their sensitivity to global warming level, and observational constraints on radiative forcing;
- Reduce uncertainties in aerosol-cloud interactions and other SLCF dynamics, improving the attribution of observed climate trends and enabling more accurate near-term and regional climate projections;
- Enhance understanding of the interplay between air quality measures and climate, particularly how aerosol mitigation policies may influence the frequency and intensity of regional extremes;
- Advance model-observation comparisons of both natural and anthropogenic SLCF emissions and concentrations with a dual focus on densely populated regions or emission hotspots on the one hand, and relatively pristine regions on the other;

- Advance high-resolution ocean modelling: targeted observational, and paleoclimate studies to better understand and quantify ocean heat uptake, improving the representation of temporal dynamics of global warming and regional responses.

Related to: SRC3 – CT1

B. Enhancing knowledge on regional climate dynamics and extreme weather risks

Climate change increasingly impacts our lives through more severe and frequent extreme events, such as heatwaves, floods, and heavy precipitation events as well as gradual, long onset changes such as rising sea levels and shifting weather patterns. These events are likely to disrupt societies and economies, damage infrastructure, and adversely affect human and animal health and ecosystems (see SRC 3 – Adaptation). Substantial gaps remain in representing regional climate dynamics, particularly regarding extremes. Progress in this area requires enhanced modelling resolution, targeted observations, analysis of paleoclimatic evidence, and a better understanding of the physical mechanisms – both thermodynamic and dynamic – that drive regional variability and extremes. Future research may contribute to understanding these risks by:

- Better quantifying present and future precipitation (mean, variability, extremes) from global to local spatial scales;
- Assessing dynamic and thermo-dynamic drivers of regional-scale climate change and extreme event intensity and frequency;
- Enhancing research efforts on specific regions with particular forcing dynamics (e.g. SLCF vs. GHG, Europe and South-East Asia), and on regions with particular response dynamics (e.g. due to specific regional-scale feedbacks or complex geography such as in coastal and mountain areas);
- Investigating links between extremes and High Impact-Low Likelihood (HILL) outcomes (with extreme events as potential triggers and outcomes).

Related to: SRC3 – CT1

C. Improving understanding of Carbon Dioxide Removal and natural carbon sinks

The carbon cycle plays a central role in climate change and substantial knowledge gaps remain. Natural carbon sinks have removed about half of historical anthropogenic CO_2 emissions, but their future capacity is uncertain, and some reservoirs (e.g. permafrost and peatlands) may also become carbon sources. To complement deep emission reductions and natural sinks, carbon dioxide removal (CDR) is a key element in scenarios that limit global warming to 2°C or 1.5°C by 2100 (see SRC 4 – CDR). However, technologies that interact with the Earth system processes such as afforestation, reforestation, ocean alkalinisation, ocean iron fertilisation, or artificial ocean upwelling, can have cascading effects on biodiversity or ocean productivity. These effects and related trade-offs are not well understood and quantified. Research should therefore:

- Advance our understanding of carbon cycle feedbacks, in particular the methane cycle, high-latitude processes, and carbon cycle in coastal hotspots. Carbon cycle feedbacks are also constrained by the resilience of ecosystems under climate change and local pressures that need to be better considered in Earth System Models (ESMs);
- Investigate asymmetric responses of the carbon cycle to CDR. This can also subsequently help optimise simplified climate models;
- Quantify specific Earth System responses to CDR methods and their potential interactions;
- Advance the understanding of fundamental carbon and nutrient cycle processes such as source and sink dynamics on regional scales, and assess the relative magnitudes of natural and land-use induced fluxes;
- Provide observationally constrained improved future projections of the ocean and land carbon sinks in a changing climate;
- Enhance the understanding of durability and timescale of reversibility of carbon storage subject to factors such as wildfires and human pressure on land or on the seafloor;
- Conduct analysis of anthropogenic sources of the main GHGs, including the use of observations to address emissions hot-spots;

- Support more frequent temporal and spatial analysis of emissions, the drivers of emissions, and updates to local, regional and global budgets of the main GHGs as provided under the Global Carbon Projeect (GCP).

Related to: SRC4

D. Assessing risks of Solar Radiation Modification (SRM)

Careful and transparent research is required to provide a detailed documentation of unintended or currently ignored side effects and risks of large-scale implementation of solar radiation modification (SRM). Research on SRM must be strictly controlled, focused on risks of SRM, and refrain from any activities potentially leading to operational deployment. This is urgent and important because future (coordinated or uncoordinated) use of such maladaptive responses to climate change is a distinct possibility with major direct and indirect global consequences. Care must be taken for the existence of such research projects not to be used as a reason to justify reduced mitigation efforts. In particular, theoretical and modelling research focusing on risks and ethical concerns is needed to:

- Quantify the potential effects of SRM on extreme weather events, precipitation patterns and other climate patterns on all spatial and temporal scales;
- Assess the potential impacts on ecosystems of different SRM options;
- Assess the broad spectrum of possible side effects related to a real-world application of SRM, including physical systems, societies, and climate policy, also using transdisciplinary approaches addressing ethical and legal concerns.

Related to: SRC2 – CT1, CT4; SRC3 – CT1, CT2

E. Investigating the potential for abrupt and irreversible changes in the Earth system

Particular components of the climate system, such as the Atlantic Meridional Overturning Circulation (AMOC), ice sheets and the Amazon rainforest, may be subject to abrupt and irreversible changes as climate change proceeds. Despite large existing efforts, remaining knowledge gaps include:

- Identifying the likelihood of these changes, their thresholds (duration and amplitude of the forcing), their temporal dynamics, early warning signals, paleoclimatic evidence, interactions between tipping elements, and improved modelling;
- Reducing uncertainty in Greenland and Antarctic ice-sheet mass loss, identified as the major source of uncertainty in regional and basin-specific sea-level rise projections for Europe, and clarifying its implications for the timing and magnitude of committed sea-level rise;
- Assessing the impacts of significant climate system changes on ecosystems and human habitat.

Related to: SRC2 – CT1; SRC3 – CT1

CORE THEME 2:

Enhancing Data Collection and Management to Enable Comprehensive Climate Assessment

3

Reliable, long-term climate data are fundamental to detect trends, attribute causes, and inform climate policy. Despite advances in climate monitoring, significant gaps remain in observational coverage, particularly in under-sampled regions such as the polar areas, the African continent, and deep oceans. Inconsistencies in data collection methodologies and barriers to data sharing further limit researchers' ability to conduct comprehensive climate assessments. Additionally, geopolitical uncertainties highlight the importance of perennial European networks, able to maintain long-term collaboration with international initiatives, and autonomous data collections. Making targeted investments in reliable data collection and robust data management will contribute to strengthening the EU's strategic autonomy, while positioning Europe as a reliable custodian of global climate data with open and equitable access for all. Addressing these challenges is crucial for several reasons: it will improve the accuracy of climate models and extreme event attribution through enhanced observational data, thereby improving climate projections and risk assessments, increase the accessibility of high-quality climate data for researchers and policymakers, and strengthen global coordination of climate monitoring efforts.

A. Strengthening systematic climate observations and data availability and quality

Openly accessible, continuous, long-term observations are vital for understanding various aspects of climate change, for evaluating and constraining model projections, and for regular assessments of the state of the global climate (such as Earth's energy imbalance, glacier and ice sheet mass balances, carbon budgets, etc.). It is therefore crucial to put continuous investment on data recovery (including AI-based techniques), digitisation, archiving, availability and ease of access. European investments in this domain are essential to ensure data are available, reliable, and robust, including necessary and strategic redundancy on the European and global scale. This also includes continued long-term funding for model data infrastructures such as Coupled Model Intercomparison Project (CMIP) collections.

Specific funding should be allocated to future research to address the following aspects:

- Comprehensive assessments of gaps in observation systems and data availability to provide guidance on what systems need to be extended, completed, revised, or could be phased down, and what additional investments and collaborations are required;
- Detailed evaluation of vulnerability of observational networks and data collections to geopolitical shocks to develop and implement strategies to improve their resilience, and develop monitoring of direct effects of geopolitical shocks on emissions and carbon sources and sinks.

Related to: SRC2; SRC3; SRC4.

B. Improving and broadening data recovery for historical climate reconstructions

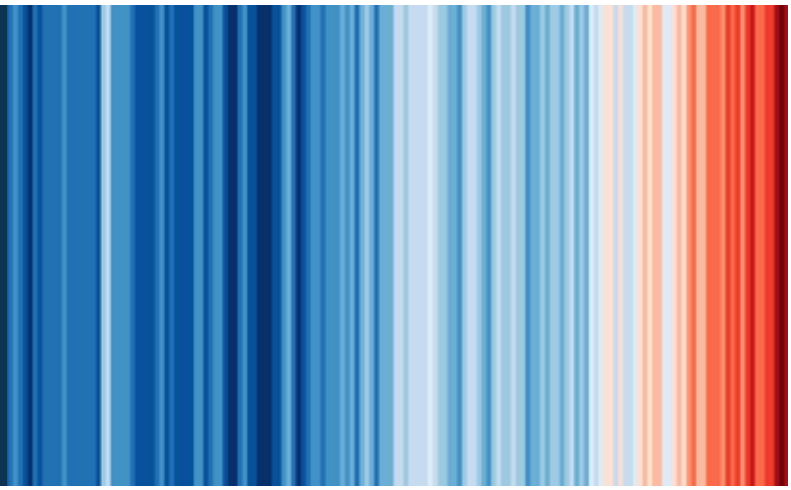
A better understanding of spatial-temporal climate variability depends on an improved quantification of past changes on all scales. This includes development and implementation of AI-assisted data recovery methods, but also a geographical broadening of classical and AI-assisted data recovery efforts in and beyond Europe, possibly including citizen science. Specific funding should address the following topics:

- Scanning, digitisation, and quality control of currently unavailable instrumental weather records, for both land and marine domains, with associated development of image repositories, software tools for data rescue, and open access collated global datasets, enabling an effective end-to-end pipeline from archive to climate data product;
- Collect a wider range of – or different – proxy records with novel data recovery methods, and generate new records and new approaches to recover rates and magnitude of past changes and the frequency of extremes;
- Create open databases for standardised and digitised proxy records;
- Develop uncertainty quantification of proxy records by systematic method comparisons and exploring the effects of parameter uncertainty.

Related to: SRC1 – CT1

CORE THEME 3:

Methodological Developments for Global and Regional Climate Projections and Mitigation and Adaptation Options



The complexity of climate processes necessitates continuous advancements in modelling techniques to enhance predictive capabilities and to inform climate mitigation and adaptation strategies, while better quantifying associated uncertainties. Current climate models, particularly global models, face computational and structural limitations that hinder their ability to capture fine-scale processes, extreme event dynamics and singular events, limiting our exploration of uncertainties. By integrating novel methodologies such as AI-enhanced modelling, and in parallel continuing and amplifying efforts to improve physical parameterisations, several outcomes can be achieved: improved climate projections at regional and global scales will enhance assessments of climate risks and policy impacts; strengthened adaptation planning will result from better representation of extreme weather events and local climate impacts; and increased confidence in long-term climate projections will support effective mitigation strategies. It is also important to enhance integrated assessment models (IAMs) to better capture climate effects of mitigation options and associated uncertainties regarding climate change, feedbacks, socioeconomic change (including societal tipping points), and technological development. Furthermore, IAMs need to represent the effects of climate change on adaptation capacities and options. These advancements are essential for informing effective climate policies.

3

A. Enhancing the performance, development, and application of global, regional and sub-regional climate models

Detailed and robust regional projections of climate change are an essential scientific backbone for effective climate mitigation (see SRC 2) and adaptation (see SRC 3). During the coming decade, machine learning applications, trained with high- resolution reanalyses, regional or global climate models, are likely to become the dominant type of tools both for downscaling and bias-correcting large-scale lower-resolution climate model output. While this development might in part be "organic", there will remain a need to accompany this trend with appropriate funding at various scales, including at the coordinated European level. At the same time, there remains a constant need to further enhance the performance of physically-based climate models as reference systems. It is critical to support coordinated efforts to ensure robustness, reproducibility, and inter-comparability of such models. To contribute to these methodological developments, further research is needed to:

- Advance uncertainty quantification and physically consistent bias corrections of climate projections at all spatial scales to identify and address caveats in methodology (such as questionable trustworthiness of machine-learning algorithms under unprecedented climate conditions) and remaining gaps in system understanding and climate forecasting;
- Produce large ensembles of regional climate projections to improve understanding of extremes and to provide training data for machine learning applications;

- Build machine learning applications to quantify local climate risks and their likelihoods.

Related to: SRC2 – CT1, CT4; SRC3 – CT1, CT3

B. Consolidating and evaluating integrated assessment models (IAMs)

There is a strong need for transparent, well-documented and evaluated IAMs to assess climate policy options and their interaction with other policy goals, including adaptation and sustainable development. Such evaluations must be robust and user-centred to have meaningful policy impact. Research should therefore:

- Evaluate the climate modules of IAMs, as well as simple climate models, transparently under a wide range of scenarios, including scenarios with large-scale CDR (see SRC 4);
- Integrate climate feedbacks to socioeconomic drivers that serve as inputs to IAMs, and to the processes and functions modelled within IAMs, particularly related to costs, socio-economic dynamics, technological development and feasibility constraints of mitigation and adaptation actions (e.g. effects on agriculture, vegetation carbon storage, wildfire prevalence, macro- economic impacts);
- Expand model scope to cover broader sustainability dimensions (e.g. circular economy, sufficiency, biodiversity) and socio-economic heterogeneity and lifestyle changes (e.g. consumption habits, dietary changes, adoption of technologies) at different scales (see SRC 2);
- Include bio-geophysical effects and ecosystem impacts of mitigation options (e.g. albedo changes, biodiversity impacts from afforestation) in IAMs;
- Improve integration of air-quality and regional climate impacts of different short-lived climate forcers in IAMs;
- Improve IAM frameworks to better capture uncertainties in climate processes, societal and technological development, and geopolitical constraints, and to integrate climate impacts and adaptation options into scenario assessment;
- Co-design model scope and inputs with relevant political and societal stakeholders to better tailor scenarios and outputs to stakeholders' needs for enhanced policy utility and uptake.

Related to: SRC2; SRC3; SRC4.

3.2 Strategic Research Challenge 2: Scientific Underpinnings of Societal Transformation for Climate Action

Impactful climate action requires profound societal transformations at all levels to drive deep GHG emission reductions and enable climate resilient societies and sustainable economies. This challenge is amplified by growing international rivalry, lack of trust in multilateral processes, and public protests for and against climate action in many contexts. Future research should therefore explore the shifts in governance arrangements, socio-political relations, socio-economic and cultural factors, and knowledge systems that are required to enable a fair and sustainable transition towards a climate neutral and climate resilient society that safeguards the well-being of future generations and ecosystems.

The corresponding research priorities are grouped in four Core Themes: 1) Transformative Climate Governance and Policies; 2) Climate Action Perceptions; 3) Just Transition and Resilience; and 4) Linkages between Climate Change, International Security, and the Global Economy.

CORE THEME 1:

Enhancing Transformative Climate Governance and Policies

Achieving climate neutrality and addressing climate change impacts will put profound challenges on current governance arrangements and established ways of policy-making. In a context of geopolitical reconfiguration and public protests for and against climate action, governance processes must be capable of navigating complexity, adapting to uncertainty inherent to scientific, geopolitical, economic and societal dynamics, and ensuring equitable outcomes. This necessitates a deeper understanding of the mechanisms and structures that govern climate policy and action, including critical examination of how policies, institutional arrangements, key actors, and financial and legal frameworks function and interact across and within multiple levels of governance and sectors. It also demands a nuanced and systematic analysis of how climate policies produce differentiated impacts across communities, how power dynamics and vested interests influence outcomes and accountability, and how public trust and participation can be cultivated and sustained to enable more responsive, inclusive, and impactful climate policies and governance.

A. Assessing policy instrument effectiveness and interactions for climate mitigation and social justice

To strengthen the design and implementation of policies aimed at reducing GHG emissions across sectors, deeper understanding of their effectiveness, synergies, and trade-offs associated with other policy instruments across temporal and spatial scales is needed. This includes careful consideration of distributional impacts, unintended consequences, and co-benefits. Future research should:

- Develop emissions pathways and scenarios to 2050 and beyond, linking short-, medium-, and long-term actions tailored towards respecting the Paris Agreement (PA) temperature goal. This would focus on informing sectoral and cross sectoral mitigation policies and strategies (including Nationally Determined Contributions (NDCs)) using top-down and bottom-up analysis, while assessing the challenges of managing sectoral and systemic transformations, including macro-economic impacts of decarbonising key sectors such as industry, energy, transport, agriculture, etc.;
- Conduct empirical analysis, such as ex-post evaluations and comparative studies, to estimate actual emission reduction outcomes of specific instruments, while enabling the assessment of interactive effects within policy mixes. This also includes assessing the effectiveness and equity implications of climate policy instruments in crisis and post- conflict contexts;
- Complement quantitative analyses with in-depth qualitative research to explore the socioeconomic implications of policies, and the practical and institutional challenges faced in their implementation. This is, for example, important in the global carbon market, where unintended consequences and equity concerns are pronounced;
- Advance comprehensive, mixed-method, and interdisciplinary research approaches, building on and further developing existing frameworks, such as One Health, to explore

links, synergies, co-benefits, and trade-offs of specific climate measures across policy areas to assess their environmental effectiveness, social equity, and political feasibility.

Related to: SRC1 – CT2; SRC4 – CT1

B. Investigating transformative climate governance across spatial scales

Transformative climate governance seeks to move beyond incremental change towards systemic societal transformation. It requires accountable institutional frameworks that promote just and sustainable futures amid urgent mitigation and adaptation needs. Achieving this entails navigating societal, political, institutional, environmental, and economic constraints while safeguarding welfare, competitiveness and ecosystems. The overarching aim of this research is to foster institutional learning and governance innovation, and to generate insights that are both aspirational and grounded in practical realities. To contribute to this, research should:

• Investigate how current institutional, political, and economic systems enable or hinder systemic transformation across key sectors, such as energy, manufacturing, or food production. These sectors are central to everyday life and provide entry points to connect mitigation and adaptation strategies in a coherent, cross-sectoral way;

- Develop a holistic understanding of the role of local authorities and civil society in ensuring transparency, welfare, participation, and the safeguarding of climate priorities to identify how climate governance can remain effective under conditions of multiple crisis, including post-conflict recovery, natural disasters, geopolitical reconfiguration, fiscal pressure, etc.;
- Explore how power dynamics, vested interests, and historical inequalities shape climate policy design and implementation. Understanding how these forces interact with different governance modes (centralised, decentralised, polycentric) is essential to assess their influence on inclusivity, legitimacy, and effectiveness of climate action;
- Support longitudinal and comparative studies that are grounded in the socio-political and ecological realities of different regions. Interdisciplinary approaches are critical to capturing the complexity of transformations and identifying pathways that are contextually appropriate and socially just. Such assessments must include land use transitions and trade-offs to inform realistic mitigation and adaptation pathways.

Related to: SRC3 – CT3 and CT4

B. Exploring frameworks and pathways to transforming financial flows for climate action

Significant increases in both public and private flows of finance are necessary to enable climate resilient low emission development and respond to climate-related losses and damages. Research must generate a nuanced understanding of how financial systems, institutional incentives, and political economy interact. This requires interdisciplinary inquiry and iterative experimentation to explore how finance and its wide range of investors - from seed investors and venture capital firms, to institutional investors with different time horizons and investment strategies - interrelate with broader transformative processes. In particular, research is needed to:

- Unpack the perceptions, motivations, and behaviours of investors, governments, and regulators in mobilising finance for climate mitigation and adaptation, with particular attention to how cultural, regional, and institutional differences shape climate risk assessments in investment decisions. Such research should also critically examine how regulatory and policy frameworks may unintentionally reinforce short-termism or risk aversion, limiting climate-aligned investments;
- Develop reliable metrics to demonstrate the long-term social and economic costs of inaction, while framing climate resilience as an investment, not a cost. Here, research should move beyond identifying barriers to informing the creation of incentives, innovative financial instruments (including green bonds and blended finance), and governance mechanisms that enable climate finance to be mobilised and scaled across diverse economic contexts;
- Study mechanisms that involve sectoral organisations, such as trade unions, and socio-ecological organisations in climate-related financial decisions to support more just and resilient investment pathways.

Research should also explore how public procurement and multilateral cooperation can support decarbonisation and climate resilience objectives;

- Investigate the role and impact of shadow financial systems (e.g. shadow banks, offshore finance, and cryptocurrencies) in shaping the climate transition, while examining how emerging technologies and digital finance innovations (such as fintech, blockchain) shape opportunities (e.g. improved climate finance efficiency and transparency) and risks in climate finance.

Related to: SRC3 – CT3

D. Examining the evolution of legal frameworks and the role of litigation in climate governance and action

Legal frameworks and climate litigation are emerging as powerful and complex forms of climate governance, influencing public policy, corporate behaviour, and societal debates. As legal action increasingly serves both to promote and to challenge climate-related measures, it reveals underlying tensions, evolving legal and political norms and power dynamics within societies and governance systems. Studying litigation is essential to understand how law is mobilised in practice, by whom, and with what consequences. To fully grasp the role of legal frameworks and litigation in climate governance, research should:

- Investigate how environmental and climate laws, reflecting the deeper tensions driving or obstructing the transition to climate neutrality and resilience, develop over time, influenced by electoral cycles, political mandates, and shifting societal values;
- Analyse the diverse range of actors (such as states, corporations, NGOs, youth movements, Indigenous communities, etc.) engaged in climate litigation. Understanding their motivations, strategies, and alliances is essential for evaluating the broader implications of legal action. Research could also support mapping and connecting these actors, contributing to knowledge exchange and capacity building;
- Explore how legal challenges shape public and private climate governance and why similar court cases result in different outcomes across jurisdictions, shedding light on institutional, cultural, and political factors;
- Assess how litigation reveals conflicts between competing priorities, such as biodiversity protection versus energy infrastructure, or mitigation versus adaptation, and how courts navigate these trade-offs;
- Track long-term impacts of national and international court rulings on climate matters (e.g. state obligations, loss and damage, relationships with human rights, and intergenerational justice, etc.) and examine how decisions are implemented or contested over time, particularly in the current context of geopolitical shifts and political polarisation.

Related to: SRC3 – CT4

CORE THEME 2:

Understanding the Role of Climate Action Perceptions in Societal Transformation

Support and acceptance from the general public, the business sector and governments are essential for the successful implementation of climate policies. Amidst rising political polarisation and shifting geopolitical dynamics, it is critical that policies are perceived as transparent and legitimate. This necessitates a deeper understanding of how climate action perceptions are shaped by political ideologies, experiences of extreme events (e.g. economic shocks, natural disasters and conflicts), and the information environment which is increasingly influenced by misinformation, disinformation, and declining trust in science and institutions. Transdisciplinary research approaches that integrate diverse perspectives and knowledge systems are particularly well-suited to address the rise of 'alternative facts' and the instrumentalisation of science. A deeper understanding of climate action perceptions is essential to inform how responsibilities for climate mitigation and adaptation can be communicated in meaningful and trustworthy ways.

3

A. Understanding the formation of climate action perceptions

Despite increasing awareness of climate change and related impacts, societal responses to climate action range from engagement, indifference, and scepticism, to denial and rejection. Understanding how social norms, values, experiences, and socio-political dynamics shape perceptions of the general public, institutions, the business sector and governments on climate change and climate action is essential for designing more effective climate strategies and identifying means to address climate scepticism and denial. This includes understanding the factors and mechanisms that drive popular movements for and against climate action and their impacts on climate policy backlash, trust towards science, and consequences on the behaviour and discourse of public, corporate, and societal actors. Research is also needed to analyse how specific actors capitalise on perceived marginalisation and people's perception of climate justice.

Research within this area should therefore:

- Examine how power relations, socio-cultural norms and values, socio-economic conditions, ideologies, religion, and education shape climate action perceptions and engagement among companies, communities, institutions and the general public. This includes understanding how these factors influence climate narratives, dimensions of trust, and public acceptance for climate action;
- Examine how perceptions of economic fairness, economic security and transition risks (e.g. concerns about job losses, energy costs, regional economic decline, and household financial stability) shape climate action support and influence attitudes toward climate policies, and how such perceptions interact with longer-term climate concerns across different communities and sectors;
- Investigate how perceptions of climate change and climate action are influenced by experiences with climate change impacts, economic shocks, conflicts and disasters;

- Explore the emergence of popular movements for and against climate actions, and their impacts on public perceptions of climate change and climate action;

Related to: SRC3 – CT2

B. Understanding the role of media and societal actors in climate information, misinformation, and disinformation

The media – traditional and social – plays a powerful role in shaping public understanding of climate change. However, the growing presence of misinformation and disinformation has created confusion, polarisation, and resistance to climate action. Understanding how climate narratives are formed and exploited by various societal actors is critical for communicating climate science and policy effectively. Therefore, research should:

- Explore how traditional and social media, literature, and film shape public discourses on climate action, including the spread of misinformation and disinformation, such as greenwashing and selective climate messaging, that may create confusion about genuine climate action;
- Examine how various societal actors use these platforms to advance different ideological and political goals and influence public perception on climate action;
- Investigate how climate communication can be tailored to engage diverse audiences and promote climate action in socially legitimate ways;
- Encourage interdisciplinary collaboration to develop practical tools for countering misinformation and disinformation, thereby building climate intelligence.

Related to: SRC3 – CT3; Section 6.3

CORE THEME 3:

Enabling Just Transition and Resilience in Climate Action

The acceleration of climate change is likely to reinforce existing social, economic and environmental challenges. Simultaneously, the transition towards climate neutrality and resilience risks increasing polarisation between marginalised communities and 'climate elites' who can afford to choose mitigation and adaptation measures. Research is needed to understand how climate action can be made more just, inclusive, and context-sensitive. This is particularly relevant at the local level where bottom-up driven climate action can be more effectively tailored to community needs and contexts. Critical, holistic perspectives and transdisciplinary approaches involving local governance and societal actors are required to enable mutual support between local, meso-, and macro-level. By expanding this knowledge base, research can contribute to the integration of climate action with broader development goals and support resilient futures grounded in fairness, sufficiency, and systemic transformation.

3

A. Exploring local climate solutions for climate-friendly lifestyles and thriving communities

Local climate solutions offer opportunities to align climate action with broader sustainability goals, such as reducing socio-economic inequalities, improving health and well-being, and fostering inclusive economic development. However, more research is needed to understand how place- based, context-specific approaches can be scaled, sustained, and integrated into wider systems of change to promote low-carbon, climate resilient lifestyles. Understanding change in preferences, practices, and behaviours at the individual, community, and economy-wide level is key to enabling societal transformation. Research should therefore:

- Generate evidence on how alternative socio-economic models, such as circular and sharing economies or local energy solutions (e.g. community-owned renewable energy projects) can deliver multiple sustainability benefits while enabling the transition to climate neutrality and resilience;
- Explore leverage points for accelerating change in social and technological systems and examine the dynamic interactions between individual behaviours, social norms, and structural conditions and their variations across geographies, social groups, and over time to promote climate-friendly lifestyles;
- Explore and test options for retaining context-specific place-based solutions that can be scaled and integrated into wider systems of change to promote climate resilient and low-carbon lifestyles;
- Engage with the concepts of sufficiency and de-growth by examining lived experiences of economic contraction and identifying strategies for managing its socio-economic implications;
- Support the integration of wider societal development agendas (such as the Agenda 2030 and beyond) into climate action to ensure sustainable outcomes while accounting for potential trade-offs and synergies;
- Advance integrated analyses focusing on urban areas to better understand their specific constraints, enablers, and trade-offs

for climate action.
Related to: SRC1 – CT3; SRC3 – CT2, CT3

B. Building forms of learning and knowledge from a social justice and capability perspective to foster climate action

Knowledge gaps exist on which policy and societal engagement measures can help build skills development and social dynamics for engendering and sustaining societal resilience. Furthermore, research is needed on how to favour integration of diverse knowledge systems, including indigenous and local stakeholders to ensure a better basis for climate action. Meaningful and innovative stakeholder engagement that moves beyond tokenism may help pre-empt public resistance and enhance the legitimacy and distributional fairness of climate governance outcomes. Therefore, research should:

- Encourage the development of participatory, community-led research projects that test new models of governance, mainly at the local level. Co-produced approaches can help ensure that climate policies are more responsive to local needs and promote ownership among affected population, as well as address the need for integrating different knowledge systems and epistemic justice challenges;
- Investigate the role of local narratives, practices, and innovations such as circular and sharing economies or local energy solutions in delivering multiple sustainability benefits while supporting climate action and knowledge transfer between contexts, geographies, and sectors;
- Explore intersectional dimensions of marginalisation and contextual vulnerability (e.g. class, gender, ethnicity, age, socio-economic status, war, migration) and generational injustices from, and related to, climate impacts and climate action.

Related to: SRC3 – CT2, CT3

CORE THEME 4:

Investigating the Linkages between Climate Change, International Security, and the Global Economy

The low-carbon transition is unfolding alongside growing geopolitical turbulence, shaping resource demands, trade relations, and power balances worldwide. Yet, there is limited evidence on how these dynamics affect both environmental systems and societal resilience, or how international developments shape national and local climate action. Existing governance regimes are largely sectoral, leaving critical cross-cutting impacts and response measures, such as those on food, biodiversity, migration, water, and energy, poorly understood. As climate change intensifies, pressures on natural resources, livelihoods, and supply routes are expected to grow, potentially contributing to and amplifying conflict dynamics with global and local consequences (e.g. migration, food insecurity). Linking assessments of the impacts of climate change and climate action on the global economy and international security will be increasingly important for Europe in the coming decade.

3

A. Securitisation and impact of different international governance regimes

The processes of securitisation of climate – meaning that political actors move from understanding climate as a regular policy issue to an issue of "security" – can have an impact on international political processes and entities, for instance in the UN Security Council. Increasing rivalry and reconfigurations of alliances in international politics call for studies on how an increased focus on security affects the climate transition and international climate negotiations. Further knowledge is needed on how the consequences of climate change and climate (in)action can be integrated into global security discussions and regional solutions. Future research in this realm should:

- Explore the different understandings and narratives connected to climate mitigation and adaptation across policy areas and regimes in global governance;
- Understand the extent of securitisation of climate in international and regional political processes and its implications for national and local policy-making and solutions;
- Investigate how political processes at international, regional, and national levels may ensure more inclusive and holistic climate policy solutions, through integrating knowledge of democracy and participation in research on the securitisation of climate change and climate action.

B. Exploring Europe's possibilities as a climate leader in a reconfigured geopolitical context

Geopolitical turbulences increasingly affect the international institutional structures that were initially designed to deal with climate change and climate action at the global level. Changes in power relations, resource use and distribution also affect traditional political cleavages, which may cause new alignments and realignments in international politics and multilateral processes.

Research could help foster European and global cooperation for the benefit of society and nature by:

- Investigating how changes in international security and trade politics impact the functioning of the UN system, and the roles European countries and the EU can play in advancing global climate governance;

- Exploring how changes in political parties and movements spread across countries, both within Europe and transnationally, and how these changes impact the possibilities for just transitions and wider climate cooperation.

C. Understanding global resource flows for a sustainable climate transition

The shift to decarbonisation (e.g. low-carbon energy systems, manufacturing, mobility) is reshaping global patterns of resource use and trade. The transition to a climate-neutral society and economy relies heavily on critical minerals (e.g. copper, lithium, nickel, cobalt, rare earth elements), raising questions about environmental, social, and geopolitical consequences and climate security outcomes. Current resource flows are linked to labour exploitation, environmental degradation, and unequal power dynamics in global trade. As climate action intensifies, understanding how to govern these flows fairly is essential to avoid reinforcing global injustices. Future research in this area should:

- Investigate how the low-carbon transition will alter resource flows and uses and trade dynamics, including supply chains, across countries and regions;
- Explore the role of critical materials in enabling climate neutrality and resilience, and the risks associated with competition, scarcity, and geopolitical tensions, and their implications for the feasibility of envisioned climate and energy transitions;
- Examine how climate finance flows and green investment patterns interact with resource extraction, exploring whether current financing mechanisms adequately account for the social and environmental costs of critical material supply chains;
- Assess the implications of mining and processing practices of critical minerals for human rights, environmental justice, and international cooperation.

Related to: SRC3 – CT1

3

3.3 Strategic Research Challenge 3: Scientific Underpinnings of Climate Adaptation - Towards Climate Resilience

The UNEP Adaptation Gap Report (2024) underscores the urgent need to significantly scale up adaptation to address intensifying climate impacts. This need is recognised in the EU Adaptation Strategy (2021) which aims to make adaptation more systemic, faster, and smarter, thereby strengthening climate resilience. Progress in climate adaptation depends on robust, relevant and usable knowledge tailored to the needs of decision and policy-makers. It also requires research and innovation across all spatial and governance levels to enable the effective use of such knowledge. Key research and innovation gaps include the development of climate information and decision-support tools that reflect the complex, evolving nature of climate risks and therefore of the required adaptation. Further priorities involve generating compelling evidence on the rationale for adaptation to drive timely, systemic action that aligns with societal values, and enhancing knowledge about how to overcome adaptation barriers and strengthen enabling conditions for resilience.

Improved methodologies for monitoring and evaluating the adequacy and effectiveness of adaptation action and fostering integration with climate mitigation is required to enable continuous learning and improvement and to minimise unintended consequences or maladaptation.

The research priorities for this Strategic Research Challenge are grouped in four Core Themes: 1) Climate-related hazards, vulnerabilities, risks and impacts; 2) Socio-economic implications and benefits of climate adaptation; 3) Bottlenecks and enabling conditions; 4) Evaluating adaptation measures towards more integrated adaptation and mitigation.

CORE THEME 1:

Understanding Current and Future Hazards, Vulnerabilities, Risks, and Impacts to Inform Adaptation Actions

Decision-makers need a clear understanding of climate risks and vulnerabilities within and across sectors and at different spatial and temporal scales to inform adaptation planning and implementation, including to address climate-related shocks and thereby enable resilience. However, translating knowledge on climate risks and resilience into practical actions to reduce socio-economic vulnerability and identify impactful adaptation pathways remains challenging. Therefore, it is crucial to establish and maintain constant two-way dialogues between researchers, decision-makers, and practitioners to allow for effective translation and iterations between scientific findings and learnings from experimentation and experience from practice. This involves the co-design and co-development of supportive tools and guidance, thereby connecting science and the intended users.

A. Building a knowledge base on compound and cascading risks and slow-onset events for informing effective adaptation measures

Understanding and addressing the growing complexity of climate risks is essential for designing effective, context-specific adaptation measures. In particular, there is a pressing need to improve the evidence base on potential losses and damages including those from compound and cascading risks, as well as from HILL events, and from slow-onset events. Strengthening this knowledge will enable better-informed decision-making and more targeted resilience strategies. Key research and innovation gaps include:

- Developing robust knowledge on compound and cascading risks, HILL events, and slow-onset events such as sea-level rise and chronic water scarcity under different global warming scenarios in order to inform adaptation planning and implementation and to highlight where ambitious mitigation efforts can reduce long-term climate risks;
- Advancing basin-specific and local sea-level rise and extreme sea level projections, and integrating these into coastal zone management and maritime spatial planning frameworks, while rigorously evaluating the long-term effectiveness of nature-based and hybrid coastal adaptation measures;
- Investigating how diverse and complex climate stressors and associated climate risks are transmitted across borders and sectors and demonstrating how adaptation can benefit from taking a systemic approach. Additionally, this should include examining the roles transnational and context-specific adaptation measures could play in addressing cross-border risks;
- Improving the effectiveness and usability of early warning systems and capacities across the range of climate risks, including through co-design and co-evaluation towards continuous learning and improvement;
- Assessing climate risks and impacts on tangible and intangible cultural heritage as an increasingly recognised category of slow-onset and compound risk, while exploring the potential of cultural heritage – including traditional and indigenous knowledge, historical building techniques, and heritage-based practices – as a resource to inform and strengthen adaptation and resilience strategies;

- Advancing the evidence base on the psychological and mental health dimensions of climate change impacts and adaptation – including eco-emotions such as anxiety, grief, and solastalgia – to inform effective prevention and coping strategies and to account for the largely overlooked societal costs of climate inaction;
- Co-developing this knowledge base with stakeholders to ensure its relevance and practical utility in decision-making processes. This includes producing practical guidance to support policy-makers and practitioners at different governance levels (EU, national, regional, local) in applying this knowledge to design and implement effective adaptation strategies, while also identifying opportunities for better alignment with climate mitigation and other development goals. Tools to support the identification, prioritisation, and hierarchisation of risks are also required to inform tailored, context-specific adaptation action, especially at the local level.

Related to: SRC1 – CT1 and CT2; SRC2 – CT1

B. Exploring and demonstrating means of more effectively conducting risk and adaptation assessments from global to local spatial scales

Engaging stakeholders in co-designing, co-developing, and co-evaluating climate risk and adaptation assessments and provision of supportive resources is needed to enhance adaptation planning and implementation. Research and innovation should include:

- Enhancing the relevance and usability of sector-specific assessments prioritising food and water security, critical infrastructure, urban and community resilience, health (physical and mental) and well-being, social and geopolitical security, coastal areas, ecosystem services, cultural heritage, and the financial sector;
- Investigating and demonstrating means of adapting decision-support resources to facilitate updating context-specific applications and thereby supporting continuous learning and improvement;
- Exploring means and demonstrating the benefits of enhancing the relevance and usability of climate information and decision-support resources through context- specific translation targeting policy-makers, municipalities, industries and citizens;
- Developing means (e.g. frameworks) to support more systemic adaptation planning and implementation, allowing sector-specific assessments to consider evolving interdependencies with other sectors and supporting transboundary adaptation.

Related to: SRC2 – CT3; SRC 3 – CT4

CORE THEME 2:

Exploring and Articulating Socio-Economic Implications and Benefits of Climate Adaptation

Climate change adaptation initiatives often fail to consider the social, economic, and environmental consequences of proposed adaptation measures. Yet, consideration of potential socio-ecological and socio- economic implications is important for identifying limits of adaptation. In addition, consideration of social inequities, such as the implications for vulnerable groups who often lack the resources and resilience needed to effectively respond to and recover from climate-related risks, is critical to inform and support adequate investment and policy prioritisation, specifically in communities with higher vulnerability. Demonstrating the tangible benefits of increasing climate resilience through effective adaptation can also enhance social acceptance for such measures across diverse communities. Moreover, identifying and communicating the potential co-benefits of adaptation measures for mitigation and other development goals can reinforce synergies between the two pillars of climate action and ensure more sustainable outcomes.

A. Understanding and demonstrating the socioeconomic costs and benefits of climate adaptation

Robust evidence on direct and indirect costs and benefits of climate adaptation is essential for driving public support and investments. In addition, a better understanding of distributional impacts can ensure adaptation measures contribute to societal resilience while avoiding exacerbating existing vulnerabilities, reducing the risk of maladaptation. Research should therefore:

- Assess both direct costs (e.g. implementation, maintenance) and indirect costs (e.g. land-use change, opportunity costs, ecosystem impacts) of adaptation actions and identify alternative adaptation options (including risk mitigation and avoidance measures) to reduce these costs, while also considering potential synergies or trade-offs with mitigation and other sustainable development strategies;
- Develop methodologies to quantify and demonstrate adaptation benefits, including co-benefits such as improved public health, job creation, and economic opportunities, and incorporate the valuation of indirect and intangible impacts (e.g. biodiversity, aesthetics, cultural heritage) that are often excluded from traditional cost-benefit analyses;
- Explore distributional impacts of adaptation across different socio-economic groups, income levels, locations, ethnicities, gender, and other relevant social factors and investigate causal mechanisms that create or exacerbate inequalities within adaptation measures, and identify and demonstrate ways to reduce these;
- Support the development and updating of tools and frameworks for equitable decision-making and for monitoring and evaluating social outcomes over time.

Related to: SRC2 – CT1, CT2, CT3; SRC3 – CT4

B. Enhance the identification and sharing of successful adaptation

Sharing successful adaptation stories and studies is crucial for building support, accelerating learning and implementation, and guiding future climate resilience efforts. Co-designed case and learning studies that align climate adaptation with development goals may be especially effective. Research in this realm should:

- Identify and analyse successful adaptation actions across diverse contexts, sectors and scales, and synthesise knowledge for wider applicability across contexts;

Evaluate the effectiveness and transferability of adaptation success stories to inform wider resilience strategies;

- Explore and demonstrate methods for co-designing and co-developing case and learning studies with local stakeholders to ensure relevance and legitimacy and develop and demonstrate the potential for scaling these up;
- Enhance mechanisms for sharing and scaling learning studies, including through open platforms, storytelling, and practitioner networks.

Related to: SRC2 – CT2

CORE THEME 3:

Understanding Adaptation Bottlenecks and Enabling Conditions to Build Resilience

Identifying barriers and fostering enabling conditions is crucial for effective climate adaptation. Adaptation planning and implementation are often hindered by soft limits (institutional, financial, governance and societal barriers) and hard limits, as well as other context-specific challenges. As a result, adopted adaptation measures are often limited in their scale and scope (e.g. incremental adaptation based on retaining the status quo and simply recovery from shocks). Similarly, not effectively taking advantage of enabling conditions can also limit adaptation. To address these potential limiting factors, further knowledge is needed. Moreover, recognising the interconnections of these enablers and barriers with mitigation and other sustainable development goals will be essential to maximise synergies and avoid conflicts and unnecessary trade-offs. Additionally, enhancing pathways for engagement between research, policy and practice is vital to breaking adaptation barriers and strengthening enabling conditions.

A. Developing means of identifying and addressing barriers and strengthening enablers to enhance resilience

Effectively enhancing climate resilience requires identifying and addressing the wide range of barriers that constrain and limit action, as well as strengthening the enablers that support adaptation planning and implementation. Barriers and limits exist at multiple scales and include legal, technical, financial, political, behavioural and psychological challenges. These become more pronounced when deeper, systemic changes to the status quo are required, calling for cross- governance and cross-sector collaboration. To address these challenges, future research must:

- Investigate the diversity of barriers and limits (hard and soft) to adaptation, including transformational adaptation, across governance levels and contexts, and explore practical ways to overcome these barriers and address these limits;
- Examine societal, behavioural, and psychological factors (such as public perceptions, cognitive biases, and social resistance) that limit adaptation efforts and uptake, and explore how these challenges can be addressed;
- Identify key enablers (e.g. leadership, institutional capacity, financing mechanisms, and knowledge-sharing platforms) for effective adaptation, recognising their context-specific nature and variation across scales and examine how these enablers can be leveraged;
- Develop multidisciplinary and cross-sectorial frameworks, tools and guidance that support transformational adaptation planning and implementation. Here, the approach of “resilience by design” is to be considered more explicitly so that adaptation becomes an upfront effort to prevent plausible high-impact risks and losses when conceiving policies, investments and other measures;
- Engage with decision-makers, planners, practitioners, and other stakeholders to co-

develop practical tools to support the uptake and scaling of adaptation enablers, and facilitate the sharing of lessons learned to support mutual learning and capacity-building across different regions and sectors.

Related to: SRC2 – CT2; SRC3 – CT4

B. Identify means of increasing the effectiveness of financial mechanisms and insurance schemes for enhanced climate resilience

Finance – both from public and private sources – must substantially increase to meet the growing needs for climate adaptation. Finance and insurance schemes can be both barriers to, and enablers of enhanced climate resilience. Knowledge is needed to incentivise climate finance and to inform context-tailored insurance instruments to provide protection against the residual risks that even the most robust adaptation strategies cannot fully eliminate. Therefore, future research and innovation should:

- Identify and assess context-specific financial mechanisms and insurance schemes that support adaptation and climate resilience across diverse European settings;
- Co-evaluate recent pilot insurance mechanisms under varied conditions to test their effectiveness and adaptability, and explore insurance solutions tailored to evolving and compound climate risks;
- Investigate financial system resilience under compounding crises (climate shocks, pandemics, geopolitical conflict) as risks in climate finance;
- Investigate climate risk financing options, public-private partnerships, and incentive structures that can drive investment in adaptation;
- Examine regulatory and policy frameworks to enable the uptake of financial and insurance tools for resilience-building.

Related to: SRC2 – CT1

C. Enabling the production and use of regional and local adaptation scenarios to inform adaptation

Developing and using regional and local adaptation scenarios is vital for informing context-specific adaptation planning and implementation. Unlike general climate scenarios, adaptation scenarios must consider local socio-economic conditions, vulnerabilities, and adaptive capacities. These scenarios support decision-making and should be designed to help ensure adaptation actions are aligned with just transition principles. Therefore, further research and innovation is needed to:

- Develop and pilot methods for producing regional and local adaptation scenarios that reflect specific socio-economic and environmental contexts, and integrate local adaptive capacities, gaps, and limits to ensure scenarios are realistic and actionable;
- Develop usable and relevant adaptation pathways and scenarios that support systemic adaptation planning and implementation;
- Identify means to integrate adaptation more systematically into decision-making processes across sectors and governance levels;
- Enhance stakeholder engagement and just transition principles in scenario development, ensuring inclusive decision-making in developing adaptation pathways;
- Explore adaptation as a continuous, participatory learning process across diverse contexts and evaluate good practices across regions to support mutual learning.

Related to: SRC1 – CT3; SRC2 – CT3

CORE THEME 4:

Supporting Smarter and Systemic Policies and Practices, and Enabling Integrated Climate Adaptation and Mitigation

There is increasing need for integrated assessment and joint implementation of climate adaptation and mitigation measures. To facilitate the transition to smarter, systemic, coherent, and integrated climate adaptation and mitigation policies, research must address associated challenges and enable the joint evaluation of these policies in terms of their adequacy, coherence, and effectiveness. This approach requires recognising how and where poorly designed adaptation planning and implementation can lead to maladaptation, unsustainable mitigation, unintended negative socio-economic consequences, and harmful implications for achieving wider development goals. Assessing the intrinsic risks and unforeseen implications of both mitigation and adaptation actions will ultimately allow for the amendment or enhancement of measures to further improve their performance.

A. Informing the joint integration of adaptation and mitigation into climate action strategies, plans, and their implementation

Achieving the EU's climate ambitions will require integrating adaptation and mitigation strategies such that they become part of European and Member State long-term socio-economic planning and governance structures. Future research and innovation must support assessment of the intrinsic and often unforeseen risks towards better understanding the social, economic, and environmental implications of both climate mitigation and adaptation measures, including when integrated. Future research can contribute to this endeavour by:

- Supporting the development of integrated strategies and actions across sectors to ensure comprehensive and cohesive responses to climate change. This should include identifying synergies, trade-offs, and conflicts between adaptation and mitigation actions (e.g. social, economic, and environmental impacts), assessing the risks and unintended consequences of combined strategies, including potential for maladaptation or inequitable outcomes, and exploring context-specific limits (both hard and soft) to adaptation and the implications for mitigation planning;
- Facilitating the combination of mitigation and adaptation strategies at the urban scale to create cities that are both low-carbon and resilient to climate impacts;
- Supporting the development of monitoring, evaluation, and learning (MEL) frameworks to improve decision-making and enable adaptive management of climate strategies over time (see Topic B, below).

Related to: SRC1 – CT3; SRC2 – CT3

B. Enhancing the effectiveness and use of Monitoring, Evaluation and Learning Frameworks towards optimising and scaling climate adaptation

To effectively address the needs for climate action, it is crucial to enhance the effectiveness, usefulness, and applicability of existing Monitoring, Evaluation and Learning MEL) frameworks and tools. This will contribute to making assessments and monitoring more robust, consistent, and comparable, fostering mutual learning from diverse contexts.

Future research and innovation can support this process across the following key areas:

- Evaluating how current frameworks and tools define targets and ambitions for joint climate adaptation and mitigation. This includes understanding their relevance across different contexts and sectors and their ability to address nexus issues of multiple sectors, e.g. water-food-energy-ecosystem;
- Co-designing and co-evaluating short- and long-term monitoring schemes to support the evaluation of climate actions at different levels, identifying deficits, gaps and areas where priority actions are needed. This should include developing consistent and comparable metrics and indicators and transparent and objective methods (including for measuring social, economic, and environmental performance of climate change adaptation solutions), facilitating measuring adaptation success relative to ambitions and supporting prioritisation and continuous learning and improvement;
- Understanding and bringing into adaptation assessments consideration of the limits (hard and soft), as well as potential for scaling up, risks (including the context-specific potential for maladaptation), synergies and trade-offs associated with proposed adaptation responses;
- Co-developing and co-evaluating frameworks and methodologies that support and demonstrate the value of integration of alternative knowledge sources (such as indigenous and local knowledge and citizen science) into adaptation decision-making and implementation processes.

Related to: SRC2 – CT3; SRC3 – CT1

C. Harnessing nature-based solutions in achieving climate resilience through systemic adaptation

- There is growing interest in nature-based solutions (NbS) as means of reducing climate risks, especially at the local level. There is however a need for enhanced evidence as to the effectiveness, sustainability, scalability, and resilience (see MEL frameworks under Topic B) of the different NbS under consideration. The research should consider:
- Exploring and demonstrating monitoring systems to estimate the effectiveness and sustainability of specific solutions, including the benefits and limitations of combined grey-green solutions;
- Identify means of considering both the direct impacts and co-benefits of NbS, including identifying the impacts and risks, as well as the costs and benefits of implementing NbS as means of achieving climate adaptation and mitigation, as well as biodiversity goals;
- Integration of the assessment and evaluation of NbS with other types of adaptation measures to provide a consistent assessment and evaluation process. Assessment should include understanding how and to what extent NbS can be scaled up and their overall impact on resilience ambitions.

Related to: SRC2 – CT3

3.4 Strategic Research Challenge 4: Scientific Underpinnings of Greenhouse Gas Management and Carbon Dioxide Removal

Global and European climate mitigation policy is focused on limiting global warming to well below 2°C and making efforts to limit warming to 1.5°C in line with the PA temperature goal. Many NDCs are informed by emissions pathways that are "aligned" with warming of 1.5°C. In general, this requires that CO_2 emissions should reach net-zero before 2050, with large scale reductions in non-CO_2 greenhouse gases (GHG) emissions. Residual emissions of these gases will need to be "balanced" by CO_2 removals by 2050 in order to reach net-zero CO_2 emissions. Accurate data and information on emissions and removals of GHG and short-lived climate forcers (SLCF) are required to create effective climate policies, set emission reduction targets, and measure progress. Such data and information enhance transparency regarding emission trends and the proportions of emission levels of individual countries of origin. In general terms, advanced GHG management systems, including integrated and operational systems to monitor GHG fluxes and carbon stocks, provide everyone a means to make better choices in terms of reducing emissions and enhancing removals.

Given the limited progress in reducing global GHG emissions, there is an increasing likelihood that global warming will exceed 1.5°C in the coming decades. This is termed a temperature "overshoot". In such a scenario, global warming would only be limited to 1.5°C if the concentration of atmospheric GHGs concentrations, specifically CO_2, was rapidly reduced. In this context, carbon dioxide removal (CDR) from the atmosphere and its long-term storage, including its management and governance, has become a critical area of research and policy.

Yet, CDR methods remain technologically immature, costly, or environmentally uncertain. The potential for adverse social and ecological effects, high investment requirements, and insufficient regulatory frameworks present additional hurdles. Ethical concerns persist, particularly the risk of complacency or misuse to delay meaningful GHG emission reductions.

This strategic challenge outlines the considerations on interdisciplinary research necessary to advance the effective, equitable, and responsible deployment and governance of CDR. It is structured by three Core Themes on 1) Monitoring, Reporting, and Verification (MRV) for GHG management and removals; 2) Enabling a Portfolio of Negative CO_2-Emission Approaches; and 3) Investigating Market Development and Governance.

CORE THEME 1:

Supporting and Enhancing Inventories of Climate Forcers and Monitoring, Reporting, and Verification (MRV) Frameworks for GHG Management and Removals

Robust monitoring of the levels of GHGs such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O) levels allows one to see emission trends and tell how much GHGs are, or have been, contributing to global warming in a given time frame. There are increasing requirements for more spatially and temporally detailed information on GHG emissions and removals. Establishing robust Monitoring, Reporting, and Verification (MRV) frameworks is therefore critical for both the success of GHG management as agreed by international treaties as well as the effective implementation of CDR. Ensuring transparency, permanence, and accuracy in carbon removal measurements will create trust in certification, accountability between nations and allow for companies to invest and markets to develop. Research must address challenges such as double accounting, verification costs, liability questions and the long- term durability of stored carbon across methods and (voluntary) standards. Additionally, integrated policy modelling efforts should bridge gaps between scientific advancements and governance structures to facilitate regulatory alignment.

A. Support the development of National Emission Inventories

National emissions inventories of climate relevant emissions and removals are central to the PA Transparency framework and the implementation of NDCs. To support their development and their links to related policy areas, it will be crucial (in addition to points mentioned under SRC1 – CT2) to:

- Enhance the use of climate observation across inventory development, information and management support systems;
- Enhance the use of inventory data and reporting tools and systems for use at sub-national, regional and local levels including disaggregation and localisation of data;
- Develop systems and tools to integrate observational data (remote and in-situ) to support mitigation actions including addressing hot spots and distributed emissions;
- Develop means to reliably differentiate between natural and anthropogenic effects and influences in emissions and removals.

Other long-lived GHGs are also impacting on the climate system and other areas addressed under Multilateral Environmental Agreements (MEAs) such as the Montreal Protocol or the Vienna Convention. Research should:

- Enhance the use of observations to support inventory development, attribution studies, and fingerprinting of emissions sources of industrial gases which have a small but increasing contribution to radiative forcing as potent GHGs.

The impact of SLCFs and precursor gases on the climate system needs to be further understood, also with a view on annual reporting requirements under the Convention on Long-Range Transboundary Air Pollution (CLRTAP) in Europe. This area would focus on:

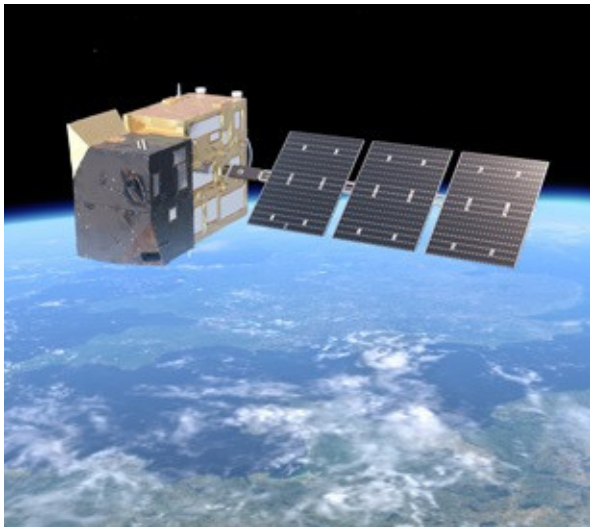
- Enhancing the use of observations to support inventory development, source attribution studies, and fingerprinting of GHG emission sources.

Related to: SRC1 – CT2; SRC2 CT1

B. Development of MRV Standard Protocols and Methodologies

Accurate measurement and verification of CO_2 removal are critical for trust and market development. Research should help to:

- Assess the permanence of carbon storage across conventional and novel CDR approaches and address the temporal asymmetry in CO_2 emissions and removals, balancing natural and technological processes;
- Improve independent knowledge base on durability and reversibility of carbon storage and set (voluntary) standards for long-term durability of stored carbon across methods;
- Propose standardised MRV protocols that prevent double accounting and ensure durability of sequestration;
- Reconcile definitional and methodological discrepancies between top-down (model-based) and bottom-up (national inventory-based) accounting of anthropogenic versus natural CO_2 removals, and examine emerging accounting benchmarks such as Geological Net Zero, to ensure that reported progress towards net-zero targets accurately reflects genuine reductions in fossil carbon;
- Develop cost-effective and transparent verification tools with well understood measurement accuracy and uncertainties in technologies and software;
- Link MRV standards with integrated GHG monitoring frameworks (see section above);
- Propose guidelines for international governance, liability, and options to integrate MRV systems in CDR markets;
- Bridge gaps between scientific advancements and governance structures through integrated policy modelling efforts to facilitate regulatory alignment.



Related to: SRC1 – CT2

CORE THEME 2:

Enabling a Portfolio of Sustainable Negative CO_2 Emission Approaches and Methodologies

Once feasibility is proven and risks managed, CDR technologies will have to be rapidly developed and deployed to meet the EU climate targets. To this end, research must target feasibility and risk assessments, conditioning the advancement of scalable prototypes and of field demonstrations at increasing scales, and ensuring environmental and social sustainability of a broad portfolio of technologies.

3

A. Enhancing and Diversifying Technologies and Innovations

Fundamental research should lay the ground for improving efficiency and cost-effectiveness in existing methodologies such as Direct Air Capture (DAC) or Bioenergy with Carbon Capture and Storage (BECCS), alongside fostering entirely new and innovative CDR technologies that remain under-explored to diversify the portfolio of environmentally and socially sustainable technologies. This includes:

- Exploring physical, chemical, and biological processes that could improve permanent CO_2 sequestration methods beyond traditional land-filling and non-permanent Carbon Capture and Utilisation (CCU);
- Investigating alternative storage methods on land and in oceans to diversify long-term storage solutions (including Nature-based Solutions).

Related to: SRC2 – CT1

B. Interactions in Co-Deployment of CDR Methods

A systemic approach is needed to understand interactions between different deployed CDR strategies and their social and environmental sustainability. Research should therefore:

- Analyse the combined impact of afforestation, wetland and other nature restoration, biochar and soil carbon sequestration, as well as other conventional CDR methods for climate and biodiversity goals;
- Identify additional benefits and potential limitations of co-deployment of CDR methods to optimise land use and address land use conflicts (see Topic C, below);
- Address trade-offs between CDR and other sustainability goals within a nexus approach;
- Address the regional dimension of feasibility, scalability, and risk assessments to ensure that CDR methods account for local constraints, opportunities, and context-specific conditions.

Related to: SRC1 – CT1; SRC2 – CT3

C. Research on Feasibility, Scalability, and Risks

Assessing the effectiveness and risks of CDR methods requires field trials and pilot projects that focus on the scalability potential of CDR technologies. Research should:

- Explicitly assess synergies and trade-offs, including in particular competition with agricultural and forestry production, and other land use conflicts;
- Establish international collaborative frameworks for joint experiments and assessments of CDR deployment and scalability potentials;
- Develop life cycle assessments, economic viability models, and social impact assessments for emerging CDR approaches including distributional effects and aspects of equity and social vulnerability (e. g. in regions of the Global South);
- Address implications of disruptive risks and crisis conditions such as wars, large-scale accidents, and natural or technological disasters for CDR feasibility and sustainability;
- Conduct studies on public acceptance and transparent policy communication to enhance deployment feasibility.

Related to: SRC1 – CT1; SRC2 – CT1; SRC3 – CT1

D. Advancing Carbon Accounting and Policy Modelling

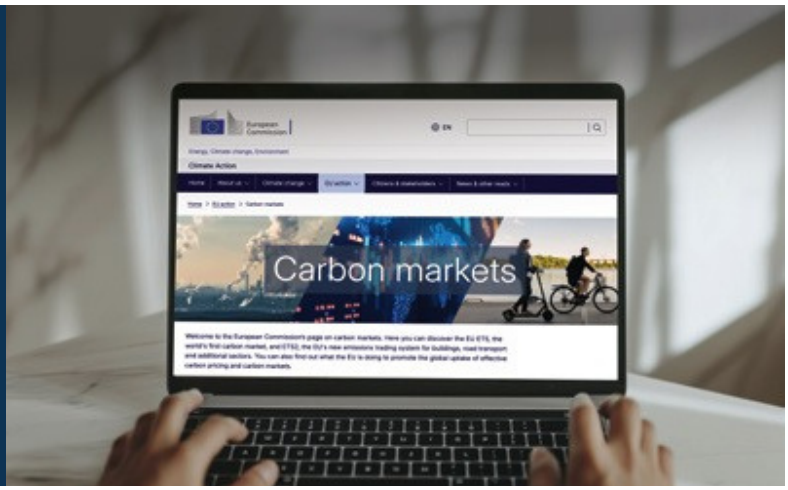
To integrate CDR into policy and regulatory frameworks, robust Earth System Models (ESMs) and Integrated Assessment Models (IAMs) must be refined to:

- Accurately represent CDR methods and their effects on biodiversity, land management, forestry or agriculture;
- Support science-based carbon accounting and align CDR with broader climate mitigation and adaptation strategies;
- Improve transparency and open-source access to IAM assumptions and data.

Related to: SRC 1 – CT3

CORE THEME 3:

Investigating Market Development and Governance for Sustainable Negative CO_2 Emissions



Economic and governance research is necessary to accelerate market development for CDR solutions. Technology, governance, market structures as well as Monitoring, Reporting, and Verification (MRV) frameworks must be developed in parallel and aligned to avoid delays in implementation. Addressing these challenges in an integrated and strategic manner will be essential for achieving net-zero emissions targets and ensuring a sustainable future. Studies should focus on institutional frameworks, policy incentives, and financial mechanisms that can drive market development and support large- scale adoption.

3

A. Institutional and Policy Frameworks for Market Development

The transition from research to large-scale CDR deployment requires well-designed policy mixes, strong institutions, and effective governance mechanisms, based on a common ethical framework. To facilitate investment in CDR technologies, a robust regulatory framework with effective incentive structures is needed. Research in this realm should help to:

- Identify suitable policy instruments to accelerate technology adoption and market creation;
- Develop governance structures that integrate voluntary efforts, legal requirements, and market mechanisms;
- Assess the effectiveness of current and future policy mixes by conducting stress-tests under various exogenous and endogenous conditions, carbon leakage effects, and potential interaction effects between different policies (for example rebound effects);
- Ensure a reliable carbon pricing structure that incentivises private sector engagement over time;
- Develop robust MRV systems for accountability (see Core Theme 1 above);
- Address supporting insurance concepts and schemes.

Related to: SRC2 – CT1

B. Economic and Social Implications of CDR Markets

CDR will have wide-ranging impacts on economies and labour markets. Research should therefore also make specific contributions to:

- Assess the effects of a CDR economy on employment, industrial growth, and value creation;
- Analyse the balance between private and public investments, including subsidy mechanisms;
- Explore socially just land-based CDR implementation strategies to mitigate conflicts over land use.

Related to: SRC2 – CT1

C. Coordination of Global and Regional Markets

Given the fragmented nature of international carbon markets, research should:

- Explore global coordination in CDR governance and assess its current limitations to help design more robust and integrated mechanisms;
- Assess the alignment of CDR market structures with existing EU policies, including the Carbon Removal Certification Framework (CRCF) and EU Emissions Trading System (ETS);
- Investigate financial sector engagement in long-term investment for CDR deployment.

Related to: SRC2 – CT1, CT4

4

Enabling Conditions and Relevant Stakeholders for Impactful Climate Research

Interdisciplinary and transdisciplinary collaboration is essential for all four Strategic Research Challenges (see also Section 7.3). To be efficient and impactful, climate research must combine expertise from diverse scientific fields to ensure well-grounded, high-quality research informing how to effectively enable the transformation towards climate neutrality and climate resilience. This requires sufficient research funding allowing for the integration of different scientific disciplines as well as for stakeholder engagement to ensure lasting societal impact (see Section 6.1).

Research actions should be tailored to establishing constant two-way dialogues between researchers, decision-makers, and practitioners to allow for iterations between scientific findings and learnings from experimentation and practical experience.

Such coupled research approaches, fostering engagement between science and practice throughout the research and innovation cycle, are vital to support societal and policy uptake, making outcomes of climate research actionable. Relevant actors include stakeholders from all levels of governance and government – local, regional, national, and international – as well as the business sector, sectoral trade unions, civil society organisations, and grassroots collectives. Support from transnational bodies such as the European Committee of the Regions and networks of local governments, such as Covenant of Mayors - Europe, will be vital in amplifying impact and fostering knowledge exchange.

Critical to the effectiveness of sustained two-way communication and collaboration between researchers, practitioners, and policymakers, are platforms for facilitating exchange, along with MEL frameworks, databases, and repositories to track and communicate mitigation and adaptation effectiveness over time. Databases and repositories are essential to support continuous learning and improvement which is critical for enhancing climate mitigation and adaptation. In addition, facilitating the uptake of scientific evidence into policy implementation (e.g. via HEU Missions) or recurring policy assessments such as the European Climate Risk Assessment (EUCRA) is critical to enable iterative policy improvements.

Europe has a long tradition of scientific cooperation between Member States, Associated Countries and the European institutions, in particular the European Commission, as well as collaboration between strong research organisations at European and national level. For example, several major infrastructures, projects, and programmes[8], funded by the EU or individual countries, are critical enablers of efficient climate research, while cross-sectoral collaborative partnerships such as the European Climate and Health Observatory provide valuable expertise for policy-making. This ecosystem requires enhanced funding in order to strengthen Europe's strategic autonomy against geopolitical changes.

While the topic of CDR is still relatively new, some European countries are already promoting major research programmes. CDR research should aim to complement and strengthen existing EU mitigation frameworks, particularly the EU Emissions Trading System (ETS) to incorporate verifiable CDR credits, the Carbon Removal Certification Framework (CRCF) to standardise certification processes, and legal instruments under the European Climate Law.

For research on the climate system per se, large-scale, internationally coordinated programmes, in particular via the World Climate Research Programme (WCRP), are critical structures ensuring efficient coordination of top-level research, and as such require continued support in particular in an era of large geopolitical uncertainties. This anchoring in existing research institutions and networks is an important enabling condition for the implementation of the SRIA.
Furthermore, continued investment in high-performance and quantum computing is essential to support high-resolution climate modelling, advanced data integration, and the implementation of AI-driven tools for improved simulations of Earth system processes, without neglecting sustainability goals. Sustained funding for long-term climate observation programmes is equally critical to ensure continuous data collection, particularly in under-sampled regions such as the polar areas, the African continent, and deep oceans. Open-access data policies and progress of AI-based techniques for data recovery can enhance collaboration, unlock insights from historical records, and improve climate change detection.

(8) Such as the Copernicus Programme, the Destination Earth (DestinE) European flagship initiative, European Centre for Medium-Range Weather Forecasts (EC-MWF), the Integrated Carbon Observation System (ICOS), In-service Aircraft for a Global Observing System (IAGOS), Aerosol, Clouds and Trace Gases Research Infrastructure (ACTRIS), the European Climate Research Alliance (ECRA), ESA missions such as Sentinel-5P and the upcoming CO2M, or the Emissions Database for Global Atmospheric Research (EDGAR).

5

Added Value of European Collaboration

Enabling societal transformation for climate action is central to meeting the EU's climate goals, as outlined in the European Green Deal, the Fit for 55 package, and the European Climate Law. With Europe warming faster than any other continent, there is an urgent need to rethink how we govern, organise, and mobilise societies for change. Achieving climate neutrality and climate resilience requires more than technological solutions – it calls for shifts in governance, institutions, and values. Research and innovation are key to enabling these transformations, helping align climate policy with societal needs and capacities.

Joint action across the ERA is vital to this effort. Cross-country studies, knowledge exchange, and coordinated policy research can reveal what works across diverse contexts. This can support more coherent, Europe-wide incentive structures and avoid fragmented or ineffective national responses.

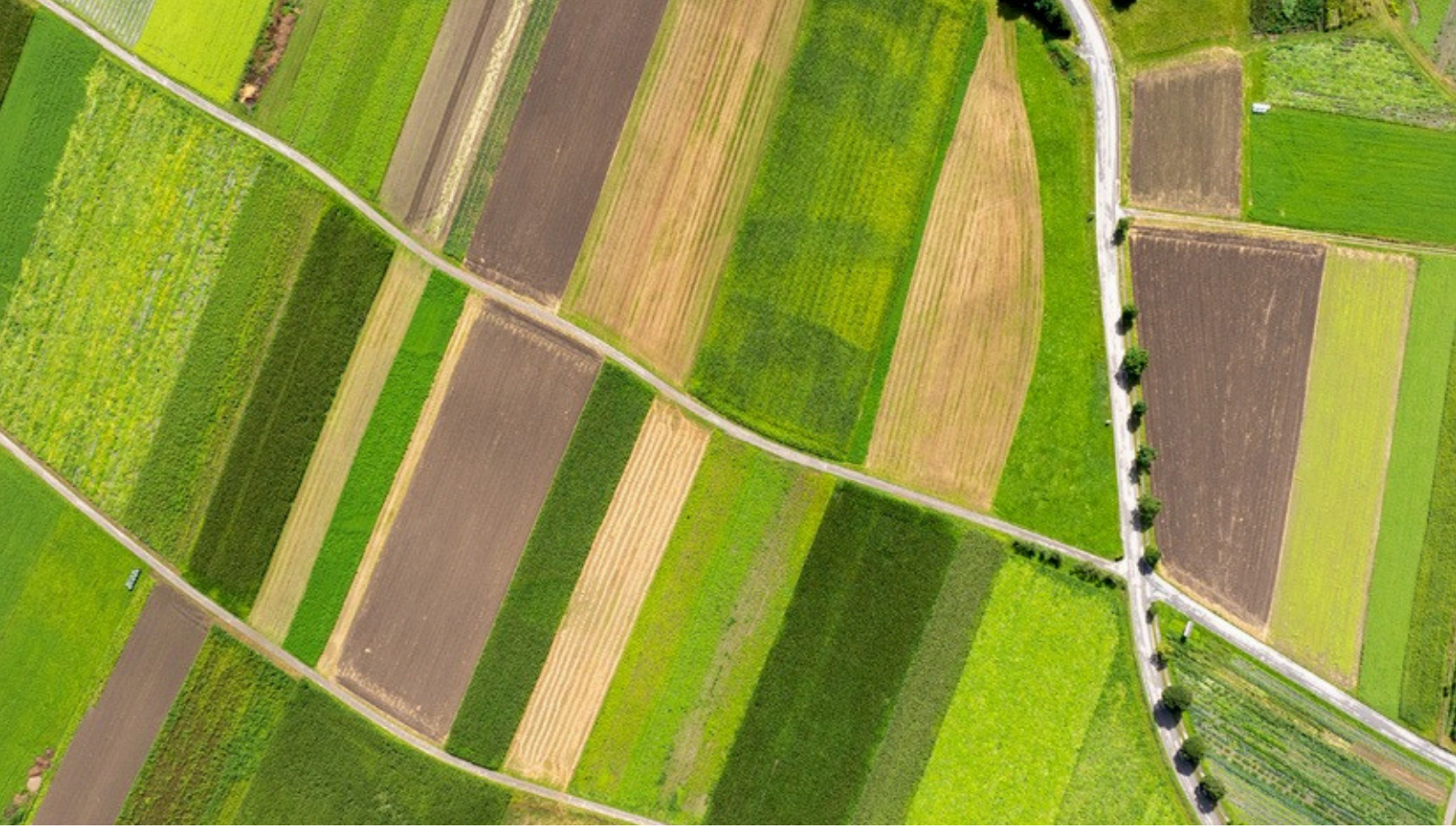
Particularly in climate mitigation and adaptation research, European cooperation will not only allow to reinforce strategic resilience, but also to drive equitable and sustainable development across Europe.

Fundamental climate research aiming at improving our understanding and projections of the Earth's Climate System has always been carried out in collaboration at the European level. Monitoring of climate change, ambitious field campaigns to recover extremely valuable paleoclimate records in hostile and remote environments, coordinated numerical experiments for useful climate projections, and many other fundamental climate research activities, are by essence international. European research funding needs efficient coordination at the European level to be and remain relevant.

In the field of GHG management and CDR strategies, the width of required and intended investments demonstrates the ambition of Europe to be and to remain a global leader. The deployment of these investments depends largely on the capacity of European actors to collaborate and coordinate their efforts. Research can be instrumental in identifying best practices for EU-wide coordination in funding and regulatory frameworks for CDR. EU-funded research or other alignment mechanisms such as Joint Programming can help developing ERA-wide programmes and infrastructure investments to scale up CDR technologies.

More generally, Europe has a key role in fostering international coordination, harmonising standards, and incentivising public and private sector investment. For this, coordinated high-quality climate research can contribute to strengthen Europe's position within the international climate policy and research community, including in assessments such as the IPCC and related international negotiations. By pooling resources, fostering collaboration, and sharing results, Europe can maintain and enhance the scale, quality, efficiency, and relevance of climate research, thereby acting as a reliable custodian of global climate data enabling access for all.

Furthermore, enhanced coordination at the European level is a means of making the ERA's research system more resilient against geopolitical shocks and changes. These efforts will strengthen the EU's strategic autonomy, resilience, and competitiveness and ultimately ensure a just, effective, and sustainable climate-resilient transformation across Europe.



6

Recommendations for Implementing the SRIA

The SRIA identifies strategic priorities for climate research, and offers practical recommendations for implementation. These aim at guiding both research funders and providers across Europe and at all levels, including the next EU Framework Programme (FP10). The following general recommendations outline foundational actions needed:

1. Support Fundamental and Frontier Research: As climate impacts intensify in a world warming beyond 1.5°C, continued investment in rigorous fundamental climate science is essential. Collaborative approaches must complement curiosity-driven and breakthrough research, particularly those that deepen understanding and predictability of extreme events and local impacts while contributing to reducing uncertainty of projections in general.

2. Integrate Climate Mitigation and Adaptation: Research should no longer treat mitigation and adaptation as separate endeavours. Accordingly, this SRIA identifies areas where integrated research strategies on mitigation and adaptation pathways are needed to maximise impact, reveal co-benefits, and enhance the overall effectiveness of climate action.

3. Embrace Inter- and Transdisciplinarity: Delivering transformative change requires integrating diverse perspectives, knowledges, and disciplines, especially those from the social sciences and humanities (SSH). Supporting social science-led research and fostering diversity in teams can ensure climate solutions are more inclusive, just, and system-transformative. This can ultimately favour policy and societal uptake and allows to adequately embrace climate-related nexus aspects, such as water resilience, biodiversity protection, or energy and food security. Realising this in practice requires embedding co-creation and justice requirements throughout the research process, alongside

systematic monitoring and evaluation of transformative impact beyond individual projects.

4. Improve Climate Science Communication: Scientific knowledge must be translated into accessible, relatable language to inform and empower non-expert audiences with user-friendly evidence. Emphasising co-benefits – such as improved health outcomes or economic resilience – can contribute to building broader support for climate action. Climate science communication efforts should, where possible, draw on established frameworks, such as the One Health approach, in order to align messaging and ensure complementarity.

5. Ensure SRIA Remains Actionable: The SRIA should be reviewed and updated regularly to reflect evolving scientific knowledge and emerging research and policy priorities. Regular reassessment is key to maintaining its relevance and effectiveness.

6. Enhance collaboration at the funding level: Enhancement of collaboration among research funding organisations, from the regional to the European level, is needed to favour synergies and complementarities in climate research in the ERA.

Building on these general actions, the specific recommendations focus on practical steps for implementation, emphasising stakeholder engagement, access to research infrastructures and capacity building, and knowledge communication. An Implementation Proposal (see annex to the SRIA; Section 9.1) suggests further implementation options, involving both EU and national research programming.

6.1 Accelerating the Generation and Transfer of Knowledge from Science to Climate Policy and Action

To implement the SRIA, a robust and dynamic implementation mechanism is essential. This mechanism must prioritise accelerating the generation of climate knowledge and enhancing its transfer into effective policy and societal action, while facilitating implementation at scale.

The Equinox Process: A Strategic Mechanism for Generating Actionable Knowledge

Beyond assessments, delivering on the SRIA requires systemic support for transferring and translating scientific knowledge into climate policy and practice. One strategic mechanism for this is the Equinox Process – an innovative initiative designed to advance climate knowledge for policy and action. The biennial European Scientific Assessment and Stocktaking Process was created by JPI Climate to overcome the limitations of the slower IPCC cycles and to focus on European needs, offering more timely and targeted updates on climate research for decision-makers. The Equinox Process is stakeholder-driven and actively involves researchers, policymakers, and practitioners to ensure that scientific outputs are relevant and actionable.

Facilitating Two-Way Dialogue for Enhanced Policy and Societal Utility of Climate Research

To scale up transitions, collaboration amongst stakeholders from science, policy, and society is critical. Engaging with governments, practitioners, and civil society helps identify and bridge research and policy gaps in the climate realm. Furthermore, targeted engagement at the science-society-policy interface also enables the co-design of research, specifically tailoring scientific inquiry to the needs of political and societal stakeholders. Sustained two-way dialogue between researchers and societal actors (such as decision-makers and practitioners) allows for iterations between scientific findings and learnings from experimentation and experience from practice. This, for example, can involve the co-design and co-development of climate scenarios and tools and guidance for decision-making. More effectively connecting science and the intended users may ultimately facilitate the uptake of evidence-based policy solutions, making outcomes of climate research actionable (see also Section 7.3).
An Implementation Proposal (annex to the SRIA; Section 9.1) suggests further

implementation options to address the SRIA's research and innovation priorities, involving EU-level and national research programming, joint research calls, mechanisms for more structured cooperation across the ERA, as well as Living Labs and Knowledge Hubs tailored to accelerating context-specific climate solutions.

6.2 Research Infrastructures and Capacity Building

Europe hosts world-class research infrastructures (RIs) for climate science, such as the Copernicus Programme, ICOS, INTERACT, Euro-Argo, and the Copernicus Atmosphere Monitoring Service (CAMS) and Copernicus Climate Change Service (C3S), both hosted by the European Centre for Medium-Range Weather Forecasts (ECMWF). ECMWF, together with ESA (European Space Agency) and EUMETSAT, delivers the EU flagship initiative Destination Earth (DestinE), which develops digital twins of the Earth. Europe also hosts the distributed e-infrastructure of the European Network for Earth System Modelling (ENES), which serves as a platform for distributing and analysing climate model data, and sharing expertise on developing and using community tools. Sustained investment in the maintenance, expansion, and accessibility of these RIs is vital to ensure robust, continuous observations that underpin accurate climate modelling and extreme event attribution. Enhancing and expanding databases and observatories for tracking and monitoring adaptation effectiveness will also be required.

Strengthening such platforms and the coordination between them will improve data quality and usability for both researchers and policy-makers. Given growing geopolitical uncertainties, it is crucial to assess vulnerabilities in observational networks and develop strategies to ensure data resilience. A coordinated European approach is essential to maintain climate data integrity. Long-term, openly accessible data remain fundamental for climate simulations and monitoring. European investment must prioritise data recovery, digitisation, and accessibility, positioning Europe as a reliable custodian of global climate data.

To sustain and enhance Europe's climate leadership, targeted training and capacity building for climate research must be prioritised over the next decade. Strengthening human capital, especially early-career researchers (e.g. via existing programmes such as Marie Skłodowska-Curie Actions), requires structured support across disciplines. Future training and career development should also foster and incentivise interdisciplinary and transdisciplinary approaches to break disciplinary silos and enable collaboration with societal stakeholders.

In addition, training in specific areas such as advanced computing and climate modelling, GHG mitigation, adaptation, carbon removal, or climate litigation should be complemented by skills in ethics and reflexivity, enabling climate researchers to critically examine their assumptions and methods. As such, capacity building should bridge technical excellence with inclusive and ethical approaches to climate action.

Finally, helping climate researchers to become effective agents of change demands more than aspiration: it requires consistent investment, supportive structures, and realistic expectations. Not every scientist will be a public communicator, but targeted training and collaboration with communication professionals can improve societal impact and policy engagement. IPCC tools, such as Principles for effective communication and public engagement on climate change, should be streamlined in climate research training.

6.3 Climate Change Communication, Education, and Public Awareness

Effective climate change communication, education, and public awareness are essential to drive meaningful climate action. Embedding climate science across all levels of education can support societal learning, equipping citizens to engage critically and constructively with climate change and climate action. Education and awareness-raising campaigns must highlight the co-benefits of climate action, such as improved health, biodiversity protection, and social equity, linking climate goals with broader societal challenges. Importantly, climate change communication should be provided through tangible, concrete messages that relate to people's daily lives.

To counter misinformation and disinformation, collaboration with public administrations at all levels is needed to ensure consistent, evidence-based messaging and enhance climate literacy of the general public. Targeted training in science communication is vital to help researchers convey findings confidently, clearly and accessibly (see Section 6.2). Providing communicators, influencers, knowledge brokers, and other knowledge multipliers with accurate, up-to-date climate information may also strengthen outreach efforts. Empowering these actors may broaden public understanding and support for climate policies, fostering a more informed and resilient society. It is critical to develop specific methods and frameworks to monitor, evaluate, and eventually enhance the effectiveness of such tailored communication, education, and awareness initiatives (see SRC 2 – Core Theme 2).

Finally, more effective dissemination and exploitation of climate knowledge is needed to advance climate action. Climate change communication should therefore focus on clear, practical information that helps governments, organisations, and people take meaningful steps toward climate neutrality and resilience. Highlighting successful climate mitigation and adaptation stories makes it easier for different communities and sectors to learn from what already works and apply it in their own contexts.

7

Guiding Principles of the SRIA

The SRIA is guided by key principles designed to ensure climate research is open, inclusive, ethical, and impactful. These principles emphasise responsible research practices, Open Science, inter- and transdisciplinary collaboration, and multi-level cooperation. Together, they aim to foster transparency, fairness, and scientific excellence, while enhancing societal relevance and global impact. By aligning with these principles, this SRIA supports the development of climate solutions that are not only effective and innovative but also equitable and aligned with European values.

7.1 Responsible Climate Research Practices

Ensuring climate research is inclusive, fair, and equitable requires a commitment to responsible research and innovation practices. By promoting reflection, inclusion, anticipation, and responsiveness, the SRIA aims at guiding future climate research to develop solutions that are both scientifically sound, and socially and environmentally responsible. It is acknowledged that applying such practices requires adequate research training and support (Section 6.2).

The principle of reflection encourages researchers to critically examine the motivations and values underpinning their work, fostering more ethically grounded outcomes. Inclusion means involving a wide range of societal actors – especially those most affected by climate change – early and throughout the research process. This supports co-creation and ensures that diverse perspectives shape research goals, processes, and outcomes. Anticipation urges

researchers to consider both the intended and unintended consequences of their work, across environmental, social, and economic dimensions, and requires appropriate safeguarding mechanisms. Responsiveness requires an openness to learning, adapting, and aligning research with evolving societal needs and values.

Specifically for research on SRM (see SRC1 – CT 1) and other possible maladaptive responses to climate change, these principles for responsible research, in particular reflection and anticipation, must be respected. Such research should fully comply with ethical guidelines defined in high-level advice such as the Commission's Scientific Advice Mechanism on SRM (2024), and by national academies. Any research and innovation on CDR (see SRC4 – CT2) should also closely follow such guidance to address potential ethical concerns, for example the risk that CDR may be misused to delay meaningful emission reductions.

7.2 Open Science and Research

The proposed research across the four Strategic Research Challenges (Chapter 3) should be conducted in compliance with the highest standards of transparency and openness. An Open Science (OS) approach involves making scientific knowledge, research findings, data, code, and methodologies freely available, without restrictions such as paywalls or copyright limitations. OS aims to democratise the research process, promote reproducibility, enhance credibility, and accelerate scientific progress by fostering a culture of openness and inclusivity. Research outputs and data should be managed in compliance with the FAIR principles (Findable, Accessible, Interoperable, Reusable) to enhance their impact. Key OS principles include:

1. **Open Access Publishing**: Making scholarly articles and research findings freely accessible, typically through online platforms or repositories. This model removes barriers to accessing scientific literature and maximises the dissemination and impact of research. Plan S, an initiative supported by the European Commission, mandates that scientific publications funded by public grants must be published in open access journals or platforms, increasing accessibility of climate science publications.
2. **Open Data**: Sharing research data openly to allow reuse, replication, extension, and further analysis, following FAIR principles. By sharing raw data, code, and supplementary materials, researchers enhance the transparency and reproducibility of their work while facilitating collaboration, innovation, and the extension of existing data (e.g. time series). Here, the use of the European Open Science Cloud (EOSC) should be promoted to foster and accelerate Open Science across Europe.
3. **Open Methodologies**: Sharing research methods, protocols, codes, and workflows openly and encouraging collaborative approaches to research, such as crowdsourcing, citizen science, and interdisciplinary collaborations to foster credibility, inclusivity, innovation, and impact (see below, Section 7.3).
4. **Open Science Recognition and Capacity**: Research assessment should also value open datasets, software, and public engagement, while OS training should be embedded in career development (see Section 6.2). Equitable international participation, especially for lower-resource research communities, should underpin this openness (see also Section 7.4).

7.3 Inter- and Transdisciplinarity to Increase the Quality and Impact of Climate Research

The SRIA promotes integrated, inter- and transdisciplinary research approaches that transcend disciplinary, sectoral, and geographical boundaries. This is essential to improving the quality, relevance, and impact of this research in terms of its potential contribution to societal change and transformation. It is acknowledged that engaging in inter- and transdisciplinary research requires adequate training and capacity building (Section 6.2).

Climate change presents multifaceted challenges that cannot be addressed through singular disciplinary lenses. Natural sciences provide crucial insights into physical and environmental processes, bio-medical sciences contribute essential understanding of climate-related impacts on human and animal health, while SSH offer perspectives on societal impacts, behaviours, governance, and ethical considerations. Integrating these diverse approaches enables a holistic understanding of climate risks and those linked with the transformation to climate neutrality and resilience, and supports the design of solutions that are both scientifically sound and socially acceptable.

Embedding societal readiness within research projects promotes inclusiveness, anticipates unintended consequences, and encourages adaptability. This can help innovations deliver positive social, environmental, and economic outcomes while avoiding real and perceived harm. The early and sustained engagement across scientific disciplines throughout project and programme design and implementation is vital.

Transdisciplinary approaches further expand this by actively involving non-academic stakeholders (such as decision-makers, communities, and industry) from the outset. For example, co-designing the scope of and inputs to assessment models with relevant political and societal stakeholders is essential to ensure research aligns with public needs, capabilities, and values. An inclusive, participatory approach can increase societal readiness, and can also contribute to strengthening trust and fostering coalitions for change to eventually facilitate the uptake of results (see also Section 6.1).

7.4 Multi-level Cooperation for Climate Change Knowledge

Climate change is a complex, global challenge that affects regions, sectors, and societies in varied and interconnected ways. A coordinated approach helps align research and innovation agendas and fosters the development of joint innovation pathways, especially in areas that require scale, such as climate mitigation and resilience strategies.

Collaboration across borders and governance levels allows for sharing context-specific solutions, resources, data, and expertise. Effective climate research must therefore be rooted in multi-level cooperation, linking local, national, European, and international actors and different knowledge sources to ensure the relevance and impact of knowledge generation.

Finally, climate change demands strategic international cooperation. European research contributes significantly to major global assessments, such as those of the IPCC. A clear, principled approach to international partnerships and global climate data is essential to ensure scientific excellence and equitable and open data access while safeguarding European strategic interests.

8

Complementarity with other Climate Research Initiatives

To effectively and efficiently advance climate research, it is crucial to build complementarities and synergies with existing initiatives, programmes, and infrastructures while avoiding duplication of efforts. Coordinated action across the ERA will maximise the impact of research and innovation funding, ensure coherent progress, and accelerate the delivery of transformative climate solutions.

The research priorities identified in this SRIA should therefore be pursued in close collaboration with ongoing national and EU-funded research schemes, innovation ecosystems, and international networks. Leveraging existing platforms, partnerships, and infrastructures will facilitate knowledge exchange, foster innovation, and support the uptake of science into policy and practice. This coordinated approach is essential not only for addressing the complexity of the climate challenge, but also for strengthening Europe's global leadership in climate science and action.

Relevant initiatives with which synergies should be actively pursued include:

- Established and emerging HEU Partnerships (e.g. Social Transformations and Resilience, Resilient Cultural Heritage, Biodiversa+, Water4All, DUT)
- HEU Missions (e.g. Adaptation to Climate Change, Climate-Neutral and Smart Cities, Restore our Ocean and Waters, A Soil Deal for Europe)
- Flagship initiative under the Strategy for European Life Sciences to implement the Strategic Research and Innovation Agenda on Health and Climate Change
- HEU CSAs (e.g. CLIMAAX, Pathways2Resilience, Climateurope2, MAIA, TransformAr, Valorada, EU-Polar-Net2, Adaptation Hubs)
- COST action SHiFT
- Destination Earth (DestinE)
- European Scientific Advisory Board on Climate Change (ESABCC)
- The EU LIFE Programme
- Knowledge and Innovation Communities initiated by the European Institute of Innovation and Technology's (EIT) (such as Climate-KIC, InnoEnergy, etc.)
- Other JPIs such as JPI Oceans and JPI Cultural Heritage, including joint initiatives such as the Knowledge Hub on Sea Level Rise (KH-SLR)
- Covenant of Mayors – Europe
- ESFRI (European Strategy Forum on Research Infrastructures) Landmarks and Projects including ICOS, ACTRIS, etc.
- Copernicus and the European Space Agency
- Intergovernmental Panel on Climate Change (IPCC)
- Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)
- International research initiatives and networks, such as: Future Earth, Belmont Forum, World Climate Research Programme (WCRP), World Adaptation Science Programme (WASP), Global Carbon Project (GCP)

9

Annexes

9.1 Implementation Proposal

1. Purpose and Vision

The Strategic Research and Innovation Agenda (SRIA) for Climate Change Science proposes a decade-long programme to advance knowledge, innovation, and policy and practical solutions for climate action in Europe and beyond. The SRIA intends to act as an inspirational document for Research Funding Organisations (RFOs) and Research Performing Organisations across the European Research Area (ERA) and offers a joint reference framework for climate research. Its implementation requires a flexible coordinating mechanism to ensure that research investments across the ERA are aligned, impactful, and efficiently delivered.

2. Implementation Approach

JPI Climate in collaboration with its members and the European Commission will work towards alignment of national and EU research activities addressing the SRIA's four Strategic Research Challenges, building on its coordinating role and the Equinox Process.

Instruments for SRIA Implementation

SRIA implementation may draw on a broad instrument portfolio, combining national, multilateral, and EU-level mechanisms:

Instrument	Scope & Purpose	Governance & Funding
National Research Programmes	Implement national priorities related to the 4 SRCs, build domestic capacity	Managed by national ministries / RFOs; funded from national budgets
Multilateral / Joint Calls	Pool national funds to launch joint research calls to address common topics related to the 4 SRCs	Coordinated by JPI Climate in collaboration with other Joint Programming Initiatives; co-funded by participating states (and potentially EC)
Knowledge Hubs & Platforms	Coordinate and exchange knowledge, align agendas, build networks for science-policy-society engagement	Thematic hubs / platforms (such as under the Equinox Process, on the example of the joint JPI Climate / Oceans Knowledge Hub on Sea Level Rise and the Assessment work on AMOC in focus); supported via national level and by the EU Research and Innovation Framework programmes
European Partnerships & Missions	Large-scale, structured cooperation across EU to tackle the 4 SRCs and to onboard a larger number of countries	Co-programmed and co-funded (MS + EC)
Living Labs, Action Research, Pilots & Demonstrators	Co-create and test solutions related to the 4 SRCs in real-world environments	Public-private collaboration; mix of EU, national, and regional funding
Research Infrastructures & Capacity Building	Provide shared facilities, data, services for long-term research, training and career development	Jointly governed by MS with EU support

9.2 Methodology of SRIA Development

Workflow Summary and Timeline of SRIA Development

The development process of the SRIA followed a structured, iterative methodology:

1. **Stock-Taking Phase 1**: Comprehensive evidence gathering, synthesis of existing knowledge, and identification of research gaps.
2. **Prioritisation**: WG-led evaluation of research and knowledge gaps, development of thematic R&I proposals, and iterative drafting of the SRIA.
3. **Consultations**: Multi-level engagement with stakeholders to validate and refine priorities.
4. **Analysis & Integration**: Systematic synthesis of feedback and incorporation into revised drafts.
5. **Stock-Taking Phase 2**: Comprehensive evidence gathering, synthesis of existing knowledge, and identification of research gaps based on MAGICA and JPI Climate activities, as well as Equinox events.
6. **Final Drafting**: Consolidation into a coherent, actionable SRIA for 2026-2035.

1. Stock-Taking Phase 1

The SRIA development process began with a comprehensive stock-taking exercise, identifying and synthesising existing knowledge, research outcomes, and policy-relevant insights. This analysis was informed by multiple sources, including:

- The IPCC Sixth Assessment Report (AR6)
- World Climate Research Programme (WCRP) reports on the future of climate modelling
- Deliverables from previous EU-funded projects involving MAGICA partners (CSA SINCERE, ERA4CS)
- Horizon Europe Missions and Partnerships addressing climate knowledge gaps
- Outputs from key climate events: JPI Climate Scoping Forum Symposium (2020), European Climate Change Adaptation (ECCA) Conferences (2021, 2023), and the European Climate Neutrality Forum (2021)

MAGICA partners identified key research and innovation gaps, which were structured into four main themes, with an additional cross-cutting theme addressing issues relevant for sectors particularly threatened by climate change. These gaps formed the basis of the first SRIA framework.

The draft SRIA framework was presented at the MAGICA General Assembly (Lecce, September 2023) to gather partner feedback. A dedicated workshop on research and innovation needs was held in February 2024 (Brussels and online), producing a detailed report that served as the foundation for drafting Deliverable D3.1.

Engagement with the wider scientific community included contributions from the SHiFT Cost Action Conference (University of Graz, September 2023) and the WCRP Science Conference (Kigali, October 2023), which provided additional input on knowledge gaps and priorities.

2. Prioritisation of Knowledge Gaps and Development of 1st Draft

Based on the stock-taking outcomes,four thematic Working Groups (WGs) were established in December 2024 / January 2025:

1. **WG 1: Key climate processes, observations and modelling** (leads: Gerhard Krinner, CNRS; Joonas Merikanto, FMI)
2. **WG 2: Scientific underpinnings of GHG management and sustainable negative CO_2-emissions** (leads: Gregor Laumann, DLR; Frank McGovern, EPA)
3. **WG 3: Scientific underpinnings of climate adaptation** (leads: Roger Street, CMCC; Lola Kotova, GERICS)
4. **WG 4: Scientific underpinnings of societal transformation for climate action**(leads: Karina Standal, CICERO; Johannes Wagner, ANR)

Each WG was constituted of core members, selected on a voluntary basis, from science, policy, and practitioner communities within the climate realm. WG size ranged from five to 13 members.

Each WG was tasked with prioritising research gaps to develop intermediate strategic R&I proposals for the SRIA. A set of guidelines was used to ensure systematic prioritisation, considering:

- Impact: relevance for climate science, policy, and societal resilience;
- Scale: extent and urgency of the knowledge gap;
- Timing: sequencing of priorities for maximum leverage;
- Stakeholders and funding: potential funders and enablers.

Each knowledge gap was rated using a traffic light system as Low, Medium, or High priority. Medium and High ratings required justification, including scientific importance, societal impact, and potential for progress within the next decade. This allowed for the identification of strategic research priorities.

By March 2025, each WG delivered a thematic R&I proposal identifying up to five core themes, providing rationales, and outlining specific research topics. These proposals were consolidated during an in-person workshop in Paris (March 2025), shaping SRIA Version 0 (May 2025). Successive drafts (V.1 in June 2025, V.2 in September 2025) incorporated iterative refinements.

3. Consultations to Gather Stakeholder Feedback

During September and October 2025, targeted stakeholder consultations were conducted to validate and refine the draft SRIA V.2. The process was also tailored to identify missing priorities or underrepresented perspectives, and ensure alignment with societal needs and national and European policy goals. Participants included: JPI Climate members and other Research Funding Organisations (RFOs) within the European Research Area; European Commission (DG RTD, DG CLIMA, DG SANTE, DG ENV); the wider climwate research community; policy-makers, practitioners, civil society representatives, and private sector actors.

Stakeholder feedback was systematically recorded to ensure transparency. Preliminary findings were presented at major events such as EGU 2025 and ECCA 2025, enabling wider engagement. Key feedback sources included:

- 33 participants providing input on SRC1 - Climate Observations (EGU 2025);
- 46 participants providing input to SRC3 - Adaptation (ECCA 2025).

As part of the broader consultation phase on SRIA draft V.2, over 140 organisations across Europe were invited to contribute, ensuring geographic and sectoral diversity. A total of 64 organisations from 27 countries and at EU-level have contributed their written feedback (see list of organisations and countries, below).

4. Analysis of Stakeholder Feedback and Final Drafting of SRIA

Following consultations, feedback was synthesised and analysed to identify common themes, gaps, and divergent views. The WGs refined their thematic priorities and rationales accordingly, ensuring that the SRIA reflects and incorporates stakeholder needs and priorities revealed during consultations.

The final drafting phase focused on harmonising the structure across thematic chapters, and integrating cross-cutting themes consistently; strengthening links to national, European, and international policy frameworks; providing clear recommendations for research funders and policymakers.

5. Stock-Taking Phase 2

The SRIA was further updated based on the results of MAGICA and JPI Climate activities, as well as Equinox events. In particular, it drew on the following deliverables and reports (see https://magica-project.eu/ for the complete list of documents).

MAGICA Deliverables: D2.2 An Action Plan on the Future Role of Climate Science in the Implementation of EU Policies and Legislation and Recommendations for the Design of Corresponding Scientific and Institutional Structures, D2.3 Report on Equinox Summit 2023, D2.4 Presentation of the Equinox Process at the Meeting of the Network of EU Climate Ambassadors, D3.4 Recommendations to Strengthen an Open Science Framework for European Climate Science, D4.1 Report on European Climate Change Adaptation Conference 2023, D4.2 Report on European Climate Change Adaptation Conference 2025, D4.3 Sea Level Rise Event Series Dissemination Activities for the 1st Assessment Report of the Knowledge Hub on Sea Level Rise, D4.4 Report on Climate Neutrality Forum 2024, D4.5 Report on Climate Neutrality Forum 2026, D4.6 Report

on Lessons Learnt for Enabling Societal transformation from Social Science and Humanities in the Face of Climate Change, D4.7 Recommendations to Research Funders Advancing Societal Transformation for Climate Action: How Future Funding Can Address Identified Research Gaps;

Other reports, including those from events organized under the Equinox Process: Global Climate Observation Systems Stocktake Workshop Summary Report, 10 Years After the Paris Agreement - Keeping 1.5°C in Reach Report, Equinox Workshop on Societal Transformation in the Face of Climate Change Summary Report, Summary of the JPI Climate and CTNTE dialogue supported by the MAGICA project "Equinox Dialogue on Modelling the Economics of Climate Change", Science for policy – How to engage with policy makers? Session Brief, the White Paper Cultural Heritage and Climate Change: New Challenges and Perspectives for Research.

The update was intended to be additive and not subtractive, complementing the insights collected through the dedicated SRIA development pathway with the knowledge generated throughout the MAGICA project. This step was carried out on an iterative basis.

6. Organisations that Contributed Written Feedback to SRIA V.2

Country	Organisation
Austria	BOKU – Universität für Bodenkultur Wien
	Climate Change Centre Austria (CCCA)
	International Commission for Protection of the Alps (CIPRA)
Belgium	Belgian Science Policy Office (BELSPO)
	Fund for Scientific Research (FNRS)
Bulgaria	Bulgarian National Science Fund (BNSF)
	Department of Climatology, Hydrology and Geomorphology at Sofia University
Croatia	Croatian Science Foundation (HRZZ)
Estonia	Estonian Research Council (ETAg)
EU	Climate-KIC
	DG CLIMA
	DG ENV
	DG RTD
	DG SANTE
	European Environment Agency (EEA)
	Science Europe
Finland	Finnish Meteorological Institute (FMI)
	Ministry of Transport and Communications
France	University of Lille
	Agence de programme Climat, biodiversité et sociétés durables
	Centre Européen de Recherche et de Formation Avancée en Calcul Scientifique (CERFAS)
	CNRS
	Électricité de France
	Haut Conseil pour le Climat
	Institut Pierre Simon Laplace
	Ministry of Education and Science
	Ministry of Environment
	TEC Consultants, Marseille
	WCRP Joint Scientific Committee
Georgia	Shota Rustaveli National Science Foundation of Georgia (SRNSFG)
Germany	Climate Service Center Germany (GERICS)
	DLR
	University of Hamburg

Country	Organisation
Greece	Green Fund Greece
Hungary	National Research, Development and Innovation Office (NKIFH)
Ireland	Irish Environmental Protection Agency (EPA)
	University College Cork
Italy	CMCC
	Consiglio Nazionale delle Ricerche (CNR)
	Institute of Atmospheric Sciences and Climate of the National Research Council
	Ministry of Higher Education and Research
Latvia	Latvian Science Council (LZP)
Malta	Malta Council for Science and Technology - Xjenza Malta
Netherlands	Wageningen University and Research (WUR)
Norway	CICERO
	Confederation of Norwegian Enterprise (NHO)
	NBIM/University of Oslo
	Research Council of Norway (RCN)
Poland	National Centre for Research and Development (NCBR)
	National Science Centre (NCN)
Portugal	Universidade Nova de Lisboa
Romania	Executive Agency for Higher Education, Research, Development and Innovation Funding (UEFISCDI)
Slovakia	SAS Institute of Forest Ecology
	Slovak Academy of Sciences
Spain	Basque Centre for Climate Change
	Spanish State Research Agency (AEI)
Turkey	The Scientific and Technological Research Council of Turkey (Tübitak)
	TÜBİTAK Marmara Research Center
Ukraine	National Research Foundation of Ukraine (NRFU)
United Kingdom	Met Office UK
	National Centre for Atmospheric Science, University of Reading
	Natural Environment Research Council – NERC (UKRI)
	University of Leeds
USA	George Mason University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Contact

https://www.magica-project.eu/contact
Giulia Galluccio, Coordinator of MAGICA
Euro-Mediterranean Center on Climate Change (CMCC)
Via Marco Biagi, 5 - 73100 Lecce, Italy

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TOGETHER AND GROUNDED IN SCIENCE,
EUROPE CAN ACHIEVE THE TRANSFORMATION
TO CLIMATE NEUTRALITY AND CLIMATE RESILIENCE