MAGICA

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

D3.1 Report on Stock Taking and prioritisation of research and innovation needs and foreseen synergies

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Key takeaway messages

- Despite strong and ongoing investments in research at EU and national levels in Europe, the availability of climate knowledge to decision makers remains fragmented
- Based on the AR6 IPCC report, research gaps still remain in 4 main domains needed to transition to a climate neutral and resilient society:
    - Key climate processes, observations and modelling
    - Scientific underpinnings of GHG management and sustainable negative CO2-emissions
    - Scientific underpinnings of climate adaptation
    - Climate policy, finance and societal aspects
- Further research is needed in cross cutting domains particularly threatened by climate change impacts:
    - Polar regions, cryosphere and oceans
    - Cities and urban areas
    - African regions
- The future climate science SRIA must take into consideration the following recommendations:
    - continued support to basic climate research
    - integrated approach to mitigation and adaptation
    - recognition of benefits and challenges of inter- and trans-disciplinary research
    - positive communication on the co-benefits of the green transition that is not abstract, but connects to people's everyday lives and feelings

Summary

By 2050, Europe aims at transitioning to a climate neutral and resilient society, based on the best available science. To achieve this transformation, the European Union (EU) its Member States and associate countries have invested strongly in research and innovation as well as in advanced observation systems, including the Copernicus satellite systems. Environmental infrastructure developments such as the Integrated Carbon Observation System Research Infrastructure (ICOS) are also at the forefront of advanced analysis of greenhouse gas emissions (GHG) and removals. Horizon Europe (HEU) has responded through its Destinations programme and in its high-profile Missions and its plans for Partnerships. These are components of the wider policy environment including Green Deal, Climate Law and Climate Pact, and initiatives such as Destination Earth (DestinE). Through its members, Joint Programming Initiative (JPI Climate) “Connecting Climate Knowledge for Europe” has also invested in climate change research and in the development of systematic observations both collectively and at national levels. These are reported in their National Communications to the UNFCCC.

The project MAGICA aims at providing new momentum and mechanisms to bring the various initiatives together and ensure that European research is central to the provision of timely and authoritative knowledge for climate actions within Europe and globally.
Our objective is to establish a "single market" for such a climate science base for research policy through Developing a Strategic Research and Innovation Agenda (SRIA) for a number of priority research topics of high political and societal relevance for climate action. This SRIA will also address the issue of communication of science to policy and decision makers.

List of abbreviations

AAS	African Academy of Sciences
AC	Associated Country of the European Union
ACMAD	African Centre of Meteorological Applications for Development
AFDB	African Development Bank Group
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
AU-EU	African Union-European Union
BECCS	Bioenergy with carbon capture and storage
BOKU	University of Natural Resources and Life Sciences, Vienna
CCSE	Climate Change and Sustainable energy
CCU	Carbon Capture and Utilisation
CDR	Carbon Dioxide Reduction
CRD	Climate Resilient Development
CILSS	Permanent Interstate Committee for Drought Control in the Sahel
CMCC	Fondazione Centro Euro-Mediterraneo sui Cambiamenti Climatici
CMIP	Coupled Model Intercomparison Project
CNF	Climate Neutrality Forum
CNRS	French National Centre for Scientific Research
CO2	Carbon Dioxide
CRD	Climate Resilient Development
CS4RRA	Climate Services for Risk Reduction in Africa

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
ECOWAS	Economic Community of West African States
EPA	Irish Environment Protection Agency
ERA	European Research Area
ERA4CS	European Research Area for Climate Services
ESM	Earth System Models
EU	European Union
FACCE-JPI	Joint Programming Initiative on Agriculture, Food Security and Climate Change
FMI	Finnish Meteorological Institute
FORMAS	Swedish Research Council for Sustainable Development
GDP	Gross domestic product
GERICS	Climate Service Center Germany
GHG	Greenhouse Gas(es)
HEU	EU's Horizon Europe R&I programme
IAM	Integrated Assessment Model
ICLEI	Local Governments for Sustainability
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
LLHI	Low Likelihood-High Impact
MAGICA	Maximizing the synergy of European research Governance and Innovation for Climate Action

MS	Member State of the European Union
NDC	Nationally Determined Contribution
R&D	Research and Development
RCN	Research Council of Norway
SDG	Sustainable Development Goals
SHiFT	Social Sciences and Humanities for Transformation and Climate Resilience
SINCERE	Strengthening INternational Cooperation on climatE change Research
SLCF	Short-lived climate forcers
SRIA	Strategic Research and Innovation Agenda
SRM	Solar Radiation Management
UKRI	UK Research and Innovation
WCRP	World Climate Research Programme
WMO	World Meteorological Organisation

1 Introduction

A key context of this stock-taking exercise is the completion of the Sixth Assessment Report (AR6) of the Intergovernmental Panel on Climate Change (IPCC) (March 19th, 2023) which pin-points key issues related to future climate change, risks, and long-term responses. Continued greenhouse gas (GHG) emissions will lead to increasing global warming, and limits of 1,5°C or 2°C may be exceeded if no strong reduction of emissions can be achieved in the near term. Every increment of global warming will intensify multiple times and concurrent hazards (high confidence). Climatic and non-climatic risks will increasingly interact, creating compound and cascading risks that are more complex and difficult to manage (high confidence). Probability of low-likelihood outcomes associated with potentially very large adverse impacts increases with higher global warming levels (high confidence). If warming exceeds a specified level such as 1.5°C, it could gradually be reduced again by achieving and sustaining net negative global CO2 emissions. To face such issues, not only climate actions for adaptation and mitigation are required but also advanced scientific knowledge for better relevance and efficiency of those actions.

Within the 2021-2027 HEU programme, as much as 35 percent of the budget will contribute to climate action to achieve green change and sustainable value creation for companies, research institutions and public administration. However, roughly 1% (1b€) of HEU is dedicated to boost scientific knowledge on climate science itself, while some countries are investing more. Furthermore, this HEU budget (Cluster 5/Destination 1) represents only 10% of the efforts of European Countries, as 90% is managed at MS level with national, bilateral or multilateral instruments.

Such fragmented European Research Area (ERA) funds plead for a better coordination between the European Commission (EC), EU Member States (MS) and Associated Countries (AC) on climate science upstream of climate actions to boost R&I across the ERA on critical research and innovation challenges, including those pointed out by IPCC AR6 in a world where global warming is projected to overshoot warming of 1.5°C in the next decades unless immediate action to reduce GHG emissions is taken.

Against this backdrop, there is an urgent need to co-design and to invest efficiently in the further development of an integrated knowledge base as a sound basis for the strategies to achieve Europe's climate goals. The co-designed and co-production of knowledge is one way to ensure its uses by society at large. In addition to this approach there is a need to ensure inclusivity of decision-makers, managers and other society sectors in understanding challenges and outcomes of research. This 2025-2034 SRIA should not duplicate on-going efforts but work on the basis of identifying key knowledge bottlenecks that could be addressed in coming years/decade with transnational consortia across Europe and beyond. Below key issues are presented along proposed themes and sub-themes that should be prioritised in a subsequent phase of the SRIA elaboration in the coming year.

JPI Climate has been tasked by the EC to develop the 2025-2034 climate science SRIA, as part of the MAGICA project. This document, accompanied by an implementation plan, will guide JPI Climate activities for the next ten years. However, the SRIA is an open process, going far beyond the inner circle of JPI Climate and will only be successful if various actors are inspired by it to propose and participate in new projects and activities.

2 Stock-taking approach

2.1 Initial analysis

This stock-taking is based on the analysis of several documents such as the last IPCC AR6, World Climate Research Programme (WCRP) Future of Climate Modelling reports, and deliverables from previous EU funded projects involving MAGICA partners (e.g. CSA SINCERE and ERA-NET Co-fund ERA4CS). This analysis also builds on HEU initiatives, which address many climate knowledge gaps in different sectors, but in disconnected ways such as Horizon Europe Missions and Partnerships or CSA ClimatEurope. Finally, the analysis includes the outcomes from the last JPI Climate Scoping Forum Symposium (Dec. 2020), the two last European Climate Change Adaptation (ECCA) conferences (June 2021 and 2023), the first European Climate Neutrality Forum (CNF) (Sept. 2021), and the JPI Climate Action Group activities synthesising the

latest scientific knowledge and research gaps in critical domains for policy and action such as sea level rise, societal transformation for climate resilience and adaptation, climate modelling and prediction, sustainable finance or carbon dioxide removal.
Following discussion among MAGICA partners on this stock-taking exercise, the identified research gaps were categorized under 4 main themes, whose thematic focus should be prioritised in the context of MAGICA WP3 in terms of a SRIA. A fifth theme addressing cross-cutting issues in critical domains of interest for sectors particularly threatened by climate change was added subsequently.

2.2 Evidence gathering activities

The draft framework of the SRIA was presented at the MAGICA General Assembly in Lecce in late September 2023, giving the opportunity to all MAGICA partners to provide comments.
A workshop on research and innovation needs and foreseen synergies to finalize the structure of the draft SRIA was organised on 1st February 2024 in Brussels and online. The report from the workshop is available and the outcomes of this consultation on the stock-taking activity (milestone n°8) serves as a basis for the drafting this deliverable.

Experts involved in the stock-taking activity are listed below:
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The consultation of the wider climate science community, beyond the MAGICA network is planned to start after the submission of Deliverable 3.1. To this end, all WP3 partners have suggested names of scientific experts to be invited to participate in thematic working groups to develop the SRIA. Nonetheless, MAGICA WP3 preliminary work was presented at two occasions:

- SHiFT Cost Action Conference: Reflections on Transformation: Shaping the Future, Transcending Disciplinary Silos and Exploring 'Lived' Knowledge Systems, 18th-19th September 2023, University of Graz, Austria
- Science Conference of the WCRP in Session S33 on "Linking policy and climate information", Kigali, Rwanda and online from 23 to 27 October 2023

3 Gaps in research and knowledge

The former IPCC reports contain synthesis of the physical state of climate and climate mitigation and adaptation urgency but the work conducted in 2017-2022 was made with rather low-resolution models that needed to be post-processed by bias correction and other statistical means. The natural, meteorological and long-term climatic shift have not been possible to investigate in such detail as required by the decision and policy makers. Most of all, there is a lack of temporal resolution, including on climate events with Low Likelihood High Impact (LLHI). Current model generations are much improved, there are e.g., DestinE runs and there is a possibility to use artificial intelligence (AI) in more advanced ways to minimise the existing gaps. There is also more impact data openly available, including exposure and vulnerability issues at local and regional scales. Now it is time to investigate our near-term, mid-term and long-term future with these more sophisticated models, applications and datasets to improve understanding of the real future we are facing and not just the average world, which has been presented in the previous IPCC reports.

This part presents a comprehensive although non-exhaustive list of research gaps in climate science, inspired by, but not limited to, the conclusions of the 6th assessment cycle of the IPCC. It means to provide the basis for the identification and selection of research priorities for a future climate science SRIA. The order of presentation is random, with no prioritisation between or within themes. As our aim is not to duplicate on-going efforts but to work in synergy, a list of relevant existing initiatives is provided at the end of each section.

3.1 Key climate processes, observations and modelling

Advances in understanding the Earth system are essential to assess how climate may change in the future, understand regional impacts, and formulate effective adaptation and mitigation strategies. A better understanding of the key processes and feedback of the climate system as well as our ability to model and

observe them requires an understanding of past and present changes in the climate system and the study of future scenarios. In particular, the following research needs were identified:

3.1.1 Improve process understanding of the climate system

- Investigate the role of climate variability in setting near-term climate extremes (i.e. global warming overshoot within the next 10 years)
- Improve understanding and constraints of processes involved in setting the higher bound of the climate sensitivities.
- Assess cloud feedback mechanisms in the climate system and their dependence on the climate state
- Understand and quantify near-surface fluxes of heat, moisture and momentum, particularly over the ocean
- Reduce uncertainties around the roles of short-lived climate forcers on climate in particular the aerosol impacts and explore synergies with actions to address air quality
- Improve analysis of the changes in the upper atmosphere including the ozone layer stability, and increased levels of water vapour
- Understand the Earth system response to declining and net zero emissions of CO2 and other GHGs
- Extend high-resolution proxy reconstructions with a focus on the mid-Holocene
- Explore regional changes in climate and extreme weather (incl. HILL): local vs. dynamical responses; changes in regional aerosol forcing and its climate impacts; time of emergence
- Improve observations and understanding of processes behind extreme events, internal variability;
- Better quantify future precipitation changes at local and regional spatial scales, especially in relation to monsoon systems
- Improve the detection and attribution of anthropogenic influence (aerosols, land-use, etc) at regional scales and on climate-responsive extremes events and their impacts (storms, fire, etc.)
- Explore Solar Radiation Management (SRM) and other climate intervention methods: physical processes, regional responses, risks of side effects, portfolio of SRM methods and optimization of regional impacts
- Improve understanding of tipping points: climatic and impact thresholds, early warning signals, assessment of irreversibility and possible risks; non-linear, abrupt response of hydrological systems; interactions between abrupt changes; e.g. AMOC; Arctic permafrost, ice melt; instability of marine ice shelves.
- Improve observation and modelling of ecosystem and biodiversity functions and processes (including soil and below ground processes, closely linked to theme 3)

- Integrate research across key conventions that address atmospheric protection issues including UNFCCC, Vienna Convention/Montreal Protocol and UNECE CLRTAP

3.1.2 Data collection and management

- Close gaps in systematic observation and data availability as well as coordinated activities for long-term data collection and management (including data recovery, digitization, analysis, archiving and availability) and open data sharing/open access to data products
- Improve data assimilation (e.g. slowly evolving snow and water reservoirs over land)

3.1.3 Methodological development for modelling and scenarios

- Develop novel approaches to produce future projections for a wider range of climatic impacts drivers [1]
- Improve performance, development and application of regional and sub-regional climate models and other downscaling for the understanding of local climate risks, making use of advanced computational techniques, machine learning and artificial intelligence.
- Improve representation of multiple forcers in scenarios and regional climate models, notably different GHGs, aerosol types, land use and feedbacks
- Improve quantification of overarching uncertainties in Earth system models (ESM), e.g. due to nonlinear processes, parameter uncertainties or, resolution and unrepresented climate-relevant processes
- Develop new and modify current impact assessment models (IAM) and tools to serve robust user-centred assessments of different climate policy (mitigation and adaptation) solutions and their impacts and interaction with other (sustainability) policy goals
- Translate new climate results into more understandable concepts and wording for people outside of the scientific community (e.g. scenario range instead uncertainty).

Links: IPCC Working Group I, Copernicus Climate Data Store, Open Science Europe (Open AIRE), The European Data Act, Inter-Sectoral Impact Model Intercomparison Project (ISIMIP), EURO-CORDEX, WCRP Coupled Model Intercomparison Project (CMIP), DestinE, Horizon Europe Cluster 5 Destination 1, WCRP

[1] Some of these novel approaches need to provide input to develop new and modify current IAMs and tools to serve robust user-centred assessments

3.2 Scientific underpinnings of GHG management and sustainable negative CO2-emissions

Monitoring progress in stabilising global temperature is crucial for guiding climate policy and requires capacity to carefully assess and monitor natural and artificial sources and sinks of GHGs, processes and feedback, and associated carbon budgets. As net zero targets come closer, we also need to better understand how the Earth system responds to zero CO2 emissions/GHG emissions. However, with reductions in GHG emissions progressing too slow, global warming is expected to exceed 1.5°C next decade (IPCC AR6). Thus, there is an urgent need to better understand i) the risks associated with temperature overshoot scenarios on carbon sinks provided by biosphere, soil and ocean, and ii) the feasibility and impact of large-scale carbon dioxide removal (CDR) needed to reduce both CO2 and temperatures and, iii) more generally, the implications for mitigation and adaptation strategies.

3.2.1 Observation-based monitoring of GHG emissions

- Integrate monitoring, observation and modelling for verification of GHG inventories and management.
- Quantify regional and global GHG fluxes by country, region, sector, over time - for CO2, CH4 and N2O.
- Quantify anthropogenic and natural GHG fluxes (e.g. permafrost regions, intermediate and deep ocean); pre-industrial ozone levels.
- Assess carbon cycle status/quantification of clathrates (esp. methane hydrates), CH4 emissions (esp. wetlands and permafrost); improve monitoring of soil CO2 balance.
- Improve emissions accounting for Agroforestry, Forestry and Other Land Use (AFOLU)
- GHG emissions in food systems; dynamics of dietary change (behavioural patterns, interaction with human health)
- Actively link bottom up analysis of GHG emissions and removals with analysis being provided by global and regional models, including IAMs and ESMs.
- Improve *in situ* observations of concentrations of short-lived climate forcers (SLCFs).

3.2.2 Develop operational systems for integrated GHG monitoring

- Supplement national inventory reports with observation-based monitoring of GHG emissions.
- Reveal over- and underestimations of sources and sinks as well as regional hotspots and thus reduce uncertainties.

- Differentiate natural and anthropogenic contributions and a quantification of diffuse sources and sinks of GHGs, such as in the AFOLU sector as well as in transport.
- Enable the evaluation and further development of monitoring strategies as well as transboundary cooperation on this topic.

3.2.3 Enable a portfolio of sustainable negative CO2-emission approaches and methodologies

- Develop technologies and innovations towards prototypes and scalability that could be implemented by various sectors (industry, agriculture, forestry, blue economy, etc)
- Improve known technology areas as well as technology-open basic research on CDR technologies (incl. physical, chemical and biological) that have not yet been researched much or on alternative permanent forms of CO2 storage to usual landfilling and CO2 storage in products (Carbon Capture and Utilisation/CCU)
- Improve co-deployment / synergies: from single-technology considerations towards portfolio analysis including synergies of simultaneous deployment on the same area (e.g. afforestation and soil carbon sequestration); magnitude of additional benefits or perhaps other problems caused by co-deployment that in turn limit individual potentials
- Develop R&I regarding technological effectiveness, feasibility, acceptability and scalability as well as risks of a portfolio of land- and ocean-based CDR approaches and methodologies, including technologies like bioenergy with carbon capture and storage (BECCS), Direct Air Capture (DAC), artificial photosynthesis enhanced weathering, biochar, carbon storage products
- Improve process optimization, demonstration, as well as upscaling of methods, field experiments and pilots
- Facilitate life cycle emissions and costs analyses, circular economy, material efficiency and availability, as well as environmental impact assessments
- Develop joint international scenario assessments for coordinated potential analyses and feasibility evaluations
- Support scientific exchange and research on acceptance, transparency and suitable forms of public dialogue (both from the research perspective and for government action)
- Solve issues related to implementing CDR in the EU and globally by developing ESMs and ecosystem (including agroecosystems) models to:
    - better represent a portfolio of relevant CDR methods and various forest and agricultural land management actions to quantify sequestered carbon and its permanence by different methods

    - inform policies for science-based carbon accounting of CDR methods and land management in general
- Explore a wider range of mitigation options by developing IAMs to include realistic use of CDR methods (considering issues related to land-use, social acceptability, financing); role of the financial sector; feedback of climate damages on economy, particularly to mitigation activities; inclusion of behavioural measures and lifestyle changes; better material efficiency and circular economy in modelling; consideration of bottom-up studies; interlinking national-level and regional models. Moreover, the transparency of IAMs needs to be improved with better documentation of assumptions and underlying data, and/or open-source publishing of the models.

3.2.4 Investigate market development for sustainable negative CO2-emissions:

- Investigate what institutions are needed to accelerate technology and market development and to steer them. Which policy instruments are suitable?
- Explore solutions for socially and economically just implementation of land-based measures considering land conflicts
- Investigate economic effects of CDR: what are the expected effects of a CDR market on labour markets and jobs, growth and value creation, and what is the relationship between private and public investment (potential magnitude industry, level of subsidy)?
- Develop a regulatory framework for business and market development, structure and incentive structure for industry buy-in and investment
- Develop governance of fragmented global markets
- Embed in wider infrastructure considerations including finance and investment perspective
- Develop common methodological bases and standards for monitoring, reporting and independent verification of the permanence of the removal of carbon from the atmosphere (link to integrated GHG monitoring)
- Address asymmetry of the temporal response of the climate-carbon cycle to CO2 emissions and removals and balancing assessment with nature-based processes

Links: Joint Programming Initiative on Agriculture, Food Security and Climate Change (FACCE-JPI), ICOS, Global Carbon Project, IPCC Methodology Report on Carbon Dioxide Removal Technologies, Carbon Capture Utilization and Storage in this cycle, Chapter 9 of the State of CDR

3.3 Scientific underpinnings of climate adaptation

With increasing warming, impacts, vulnerabilities and risks are becoming stronger, more complex and more difficult to control. Continued warming beyond 1.5°C will further disrupt the global water cycle, affecting variability, monsoon rainfall, river flows, seasonality, and very wet conditions and extreme drought. Prioritising equality, social justice, inclusion and fairness will promote change and supports ambitious climate policy by building consensus and social trust.

3.3.1 Cascading hazards, vulnerabilities, risks and impacts

- Better understand compound risks and cascading impacts under a global warming beyond 1.5°C
- Better understand responses and vulnerability of fauna and flora (changes in geographical ranges of species; resilience of plants and their adaptation potentials; paleo-ecology).
- Highlight risk assessments from the combined influence of multiple anthropogenic and natural influences, such as GHGs, aerosols, land use, and internal climate variability, and their distinct societal connections (e.g. air quality)
- Improve scenarios for detection, attribution and – if possible – prediction of climate change at the regional level (e.g. coastal or polar regions), including short-term climate change and long onset events, as well as extreme events and low likelihood / high impact (LLHI) outcomes
- Develop disaster risk reduction and related early warning systems
- Identify sectoral risks or cascading risks in the food, energy, transport, telecommunications, water, cultural heritage and banking and finance sectors; social cost/damage functions.
- Enable the monitoring of health risks in different socio-economic development paths
- Explore the role of globalisation in transmitting climate-related risks across sectors and borders, for example through trade, finance, health, food and ecosystems
- Better understand cascading risks in global society: diminishing livelihoods impacting migration movements and security aspects
- Consider population response and coastal adaptation strategies in the face of rising sea levels

3.3.2 Understand socio-economic impacts of climate change

- Explore the interaction between climate change and food security, freshwater availability, health and well-being, security, infrastructure security and development, trade, migration…
- Investigate causal mechanisms of different dimensions of inequality such as income, socio-economic, spatial, socio-cultural as well as ethnicity and gender

- Include cascading and mutually reinforcing impacts in integrated assessments
- Develop citizen science and indigenous knowledge about risks, mitigation and adaptation strategies
- Analyse efficient regional integrated governance systems (structures/methods)
- Better understand socio-cognitive (behavioural) factors and endogeneity problems
- Explore loss and damage of LLHI events as well as of slow-onset events, such as sea-level rise and persistent water scarcity.
- Investigate land use change/land use competition; feasibility of planned resettlements; relocation and migration.

3.3.3 Integrate life sciences to humanities to break adaptation bottlenecks

- Identify and address gaps in climate change science and resources available to support systemic adaptation
- Improve understanding of the effectiveness of ecosystem-based adaptation.
- Explore, identify and find solutions for technical and societal barriers to effective and timely adaptation action as a basis for enabling adaptation and communicate them
- Explore the transformational adaptation, including the processes, enablers and barriers, towards enabling an effective transition
- Enable the monitoring (short- and long-term) and evaluation of adaptation actions at the national and systemic levels to identify the adaptation deficit and where further actions are needed.
- Enable the production and use of adaptation scenarios.
- Consider the integration of management, resilience and adaptation to reduce climate hazards' potential damage from climate change (including climate justice)
- Enable the exchange of knowledge and data to support adaptation action and policy (relevant, usable, accessible and legitimate knowledge and data), including enhancing pathways from R&I and adaptation policy and practice that support societal, policy and market uptake
- Identify barriers to adaptation at a psychological, collective and political level.

3.3.4 Support smarter, systemic and coherent mitigation and adaptation policies

- Assess adaptation effectiveness under a different mitigation scenario, incl. adaptation limits or maladaptation
- Develop a long-term monitoring framework of adaptation measures

- Improve understanding of the synergies and/or competition of ecosystem services for adaptation and mitigation (sustainable land use, afforestation-deforestation, soil fertility, biodiversity).
- Enable effective integrated climate action - adaptation and mitigation - based on a stronger understanding of potential synergies, complementarities and conflicts as part of an effective means to address climate change.
- Develop methods and tools to assess different adaptation solutions and their performance in multi-target policy framework, including SDGs and geopolitical context.
- Understand the social, economic and environmental implications of both mitigation and adaptation measures - assessment of the risks of implementation as well as the monitoring and evaluation of these risks as a basis for amending or enhancing measures.
- Understand the role of fear and the challenge of transforming systems for joint adaptation and mitigation and address it
- Explore the opportunities and risks of AI transformation in adaptation and mitigation

Links: IPCC Working Group II, Disaster risk reduction groups, International Network of Boundary Organizations on Adaptation, SHIFT Cost Action, Fridays for future, International Climate Councils Network (ICCN), ClimaLex, Biodiversa+ Partnership, Water4All Partnership, European Citizen Science Association

3.4 Climate policy, finance and societal aspects

Harmful climate effects, anticipated risks and vulnerability increase the need to promote Climate Resilient Development, combining strong emission reductions and climate adaptation. Humans and natural systems increasingly face adaptive limits, making adaptation measures ineffective in reducing risks and protecting against adverse consequences. To tackle these issues, further research is needed in the following areas.

3.4.1 Climate Resilient Development (CRD)

- Conduct population and lifestyle analyses in parallel with housing policy, traffic and transport policy, energy policy as well as education policy analyses. Are climate strategies, their communications and their implementations are understandable and on the right track?
- Create impact on many levels to reach out and help in finding the focus of future talent. What should be done? What kind of labour do we need? How can we in EU do to be more self-sufficient

and better prepared to face various kinds of impacts - be they just weather related (future extremes) or transport chain, food related, health sector (viruses, medicine etc.) related, or rescue and recovery related (do we have enough experts in these critical sectors that can help the vulnerable when acute situations emerge?)?

- Develop agile roadmaps for sustainable and climate neutral lifestyles and really aim at transforming societies to become more resilient for the future. Develop sharing of good practises, interaction and facilitating skills. This means involving more than just science, it is about practice, presentations, workshops, dreaming, criticising, etc. The economic analyses will support finding economically sustainable pathways
- Investigate interactions of climate change with other anthropogenic factors in the context of sustainable development
- Explore limits and conflict of objectives of gradual system transitions to achieve CRD in a timeframe that reflects the urgency of the Paris Agreement and the Sustainable Development Goals (SDGs)
- Investigate indicators of e. g. employment and productivity gains, legal and regulatory acceptability, transparency and accountability, social and regional inclusiveness, benefits for gender equality, intergenerational equity.
- Develop a set of realistic options for the implementation of SDGs in relation with other climate-relevant SDGs
- Invest more resources into bridging the gap between science and society (e.g. citizen science initiatives) to address the increasing scepticism towards science in society
- Better understand the acceptability of actions; decision-making (influence of power relations, politics and institutional culture, and ecosystem services) and the role of (climate) services to enhance actions and CRD
- Explore technological change and innovation (including its limits), and evidence on the speed of transitions
- Highlight trade-offs related to e.g. land use, non-carbon climate effects (e.g. albedo changes), water use, and food production and security.

3.4.2 Assessing mitigation and development pathways (including CRD pathways)

- Investigate dynamic interactions between individuals, social and structural drivers of change; transformation of urban systems; tools and mechanisms to accelerate the transition to sustainable and healthy food systems

- Explore the role of urbanisation and migration
- Support the application of ethical parameters to enrich many existing quantitative frameworks to assess the fairness and ambition of Nationally Determined Contributions (NDC)
- Develop metrics to measure actual human well-being beyond GDP's
- Develop material substitution; indicators for material efficiency and circular economy
- Assess the strengths of low-emission innovation systems and impacts of decarbonisation policy instruments on innovation
- Study the impact of disruptive demand and supply side technologies and designs on GHG emissions; explore climate impacts of the digital economy
- Enhance the scope, impact, effectiveness and quality of development cooperation
- Assess the growing role of upcoming and resource-rich economies in particular in African, Asian and South American countries
- Address inequalities and negative direct and indirect effects of green capitalism

3.4.3 Economics of climate change

- Conduct ex-ante and ex-post analysis of effectiveness and efficiency of mitigation and adaptation policies, including economic and social impacts as well as equity
- Consider the costs of possible climate damage and vs costs of adaptation and climate protection and the associated savings
- Assess investment strategies, private/public financing, effectiveness of policy measures
- Investigate the limits of the capitalist system to absorb the demand for green products
- Explore the adaptation market, innovation pathways and means of developing a viable adaptation market
- Explore alternative economic systems, including the possibilities to scale up sustainable lifestyle structures
- Explore demand-side climate protection measures, policies and incentives
- Model behavioural change; reduce potential trade-offs; support disruptive innovations, technologies and design; enhance acceptance and participation.
- Study the impact of the global financial system on sustainability by channelling financial flows into sustainable activities, explore the potential of the financial sector to make the economy and society environmentally friendly and climate-neutral, thereby contributing to the achievement of international climate and sustainability goals
- Develop sustainable financial products and instruments, processes and market mechanisms and their effects

- Better understand needs, acceptance and behaviour of financial market players for a market transition towards sustainability: the role of financial service providers, investors and private customers
- Develop data availability, quality and analysis.

Links: Net zero lawyers alliance, Covenant of Mayors, EU Mission Adaptation to Climate Change, World Economic Forum, European Association of Environmental and Resource Economists (EAERE), Civil Society Networks, BSR (Business Transformation for a Just and Sustainable World (BSR)

3.5 Cross-cutting domains

During the stock-taking exercise, the following cross-cutting domains were identified:

3.5.1 Polar regions, ocean & cryosphere

As stated in the IPCC special report on the ocean and cryosphere in a changing climate, despite recent progress, large uncertainties remain on the likelihood, timing, and amplitude of abrupt and irreversible changes projected on ocean and cryosphere responses to past and present anthropogenic GHG emissions and current global warming. The following research needs were identified:

- Assess comprehensive trends and risks for future changes in the polar regions including its role in climate changes and socio-economic impacts
- Observe/measure data on ocean acidification, especially in winter and in the Southern Ocean; heat and carbon storage; oxygen deficiency, carbonate chemistry
- Quantify blue carbon stocks and assess future changes and mitigation potential; marine ecosystem (components) (e.g. deep-sea floor, viruses and protists)
- Understand permafrost conditions and outgassing; glacier dynamics
- Explore polar regions as indicators of rapid change and advance warning for regional or global tipping points
- Assess indigenous and new knowledge, behaviours and investments required for sustainable resilience and adaptation
- Increase international cooperation beyond Europe

Links: EU-PolarNet 2, PolarRES, Arctic Summit, JPI Oceans, SEA'TIES Ocean & Climate Platform, EU Mission Restore our Ocean and Waters by 2030

3.5.2 Cities and urban areas

When it comes to systemic change, cities emerge as key players in mitigation and adaptation measures and as important factors for people's well-being. This is why, further research is needed to:

- Explore microclimate in cities and in interaction with the environment, risks and adaptation
- Support disruptive innovations, technologies, design, infrastructure, mobility and construction, behavioural change
- Improve the growth of large informal settlements in marginal areas linked to the climate-related push-factors in rural areas
- Improve policy integration of climate adaptation and mitigation, disaster risk reduction, poverty alleviation, sustainable water management; health care.
- Explore the role of mega-cities in climate change (e.g. emissions, mobility patterns, energy consumption, food distribution) and human well-being
- Take urban transition and demographic changes (including migration) into account

Links: Driving Urban Transitions (DUT) Partnership, Local Governments for Sustainability (ICLEI), United Cities and Local Governments (UCLG), C40 Cities, IPCC Special report on Climate Change and Cities, EU Mission 100 Climate-Neutral and Smart Cities by 2030

3.5.3 African regions

African countries are among the most vulnerable to negative climate change impacts, having contributed less than 10% of global GHG[2]. This puts these countries amidst those around the world facing many shared challenges, which require sustainable solutions. To strengthen climate resilience in Africa, the following research needs have been identified:

- Increase international cooperation between European Union and African Union to develop a long-term partnership for climate risk reduction, resilience and adaptation
- Improve early warning systems (observations, models, data access)
- Develop climate and environmental services for water excess management (urban, coastal, rural)

[2] https://www.cdp.net/en/research/global-reports/africa-report

- Support climate-smart agriculture, indigenous crops and sustainable landscapes to face and improve the local climate
- Investigate climate impacts and resilience under present and future scenario of hazards, exposures and socio-economic vulnerabilities
- Contribute to climate justice efforts by supporting operationalisation efforts of the loss and damage fund
- Support development trajectories, including, climate justice and adaptation measures
- Defragment and scale-up multilateral programmes for African regions, from climate science to local actions for risk reduction
- Support long lasting African capacities beyond projects of scientists, scholars and practitioners, including local practices, indigenous knowledge and decision-making.

Links: African Union-European Union (AU-EU) Partnership on Climate Change and Sustainable Energy (CCSE), AU-EU Innovation Agenda, Climate Services for Risk Reduction in Africa (CS4RRA), World Meteorological Organisation (WMO), African Development Bank Group (AFDB), Economic Community of West African States (ECOWAS), Permanent Interstate Committee for Drought Control in the Sahel (CILSS), African Centre of Meteorological Applications for Development (ACMAD), African Academy of Sciences (AAS), European Organisation for the Exploitation of Meteorological Satellites (EUMETSAT)

4 Next steps and recommendations

4.1 Thematic working groups and consultations

After the completion of the stock-taking exercise and the publication of this deliverable, the MAGICA WP3 team will consult the climate science community to focus priorities for the next decade among the identified research gaps. To achieve these consultations, thematic working groups will be established around the main themes of the framework presented above. As of now, three working groups have been constituted:

- Key climate processes, observations and modelling Working Group, led by ANR and FMI. In particular, the activities of this group will consider the work of the CMIP community[3].

[3] EGUsphere - Bringing it all together: Science and modelling priorities to support international climate policy (copernicus.org)

- Sustainable negative CO2- emissions Working Group, led by DLR. The activities of this group will rely on conclusions of the workshop on the Role of R&D and Policy for advancing CDR in the EU[4] which took place in August 2023 in Brussels and the CNF
- Societal transformation in the face of climate change Working Group, led by RCN and BOKU. The activities of this working group will focus on social sciences and humanities and encompass several themes of the framework.

A fourth working group on climate adaptation and risks is yet to be established, with a strong involvement of GERICS and CMCC. The activities of this group will take advantage of the organisation of the ECCA 2025 conference to engage with the private sector in terms prioritisation of research needs.

Consultations on the cross-cutting domains will be conducted in interaction with:

- the EU-Polar Net 2 consortium for polar regions and cryosphere, JPI Oceans and the Knowledge Hub on Sea Level Rise in Europe
- DUT Partnership for cities and urban areas
- Climate Services for Risk Reduction in Africa (CS4RRA) initiative for African regions, including defragmentation between MS and EU/FP.

Experts from leading European and international initiatives and projects will be invited to take part in the working groups. Particular attention will be paid to transdisciplinarity and the inclusion of social sciences and humanities and stakeholders in all themes and cross-cutting domains. In addition to these working groups, MAGICA WP3 partners will organise consultations at major events in the course of the next two years such as ECCA 25, the CNF, the Equinox Summit, and science-policy events organised by MAGICA WP4.

4.2 Conclusions and recommendations

Despite strong investments by EU/FP and MS, more research is needed to deepen the understanding and predictability of extreme climate events and their cascading impacts at local levels, facilitate informed decision-making and transformative action.
In addition, the following are recommendations based on reflections and insights arising from the stock-taking exercise and first consultations, for consideration for the delivery of the future climate science SRIA:

[4] The Role of R&D and Policy for advancing Carbon Dioxide Removal (CDR) in the EU – JPI Climate (jpi-climate.eu)

Recommendation 1: There is a need to continue supporting basic collaborative climate research in addition to applied research, as the world enters next decade a global warming beyond 1.5°C where expected and unexpected events will happen. Frontier research is necessary to allow the emergence of breakthrough and novel scientific ideas.

Recommendation 2: Mitigation and adaptation strategies have historically been, and continue to be, developed separately. As the urgency to step up climate action mounts, it is fundamental to also adopt a more integrated approach to mitigation and adaptation interventions where such an approach can maximise their overall effectiveness.

Recommendation 3: Benefits and challenges of inter- and trans-disciplinary research should be recognized. In particular research projects led by social scientists should be further encouraged. There is also a need to embrace creativity and diversity in climate change science research. It is the only way to foster a culture of innovation, which is inclusive and empowering. It will allow the development of adaptive solutions that are appropriate, just, and capable of transforming systems and behaviours to meet the challenges of climate change.

Recommendation 4: Climate knowledge/data and transforming adaptation/mitigation measures should be communicated into issues/things the everyday person really cares about to make it more usable and less abstract. An emphasis should be put on the positive aspects and the co-benefits that a green transition would bring to their lives.

5 References

Axelsson K., Adams B., Wagner A., Clements M., Polkinghorne K., Lezak S., Ives M., Jenkins S., McConnell A., Allen M., Fuss S., McGovern F., Tovoni M., Fry E., Parr A., Barbrook Johnson P. (2021). Sensitive Intervention Points for Achieving Climate Neutrality: Summary Report for the Climate Neutrality Forum. Climate Neutrality Forum, 8 - 9 September 2021 - Net Zero Climate

BiodivERsA and JPI Climate. (2022). BiodivERsA & JPI Climate Strategic workshop report. BiodivERsA & JPI Climate Strategic workshop report – JPI Climate (jpi-climate.eu)

Bougeault P., Alterio I., Dumitrache N., Bley D., Galluccio G., Manderscheid P., Fernandes A., Malnaca M., Doblas- Reyes F., Ruiz-Ramos M, Cortekar J., Street R. (2020). Report of the Scoping Workshop "Future research needs in support of Climate Services". ERA4CS-D7-6-workshop-report-final.pdf (jpi-climate.eu)

Bylund J., Gollner C., Jäger M., Klaming G., Noll M., Riegler J., Rodenstedt A., Wallsten B. (2022). Driving Urban Transitions to a Sustainable Future Roadmap. DUT Roadmap 2022 (dutpartnership.eu)

De Jong F., Malnaca M., Manderscheid P. (2021). Streamlining ECCA2021 Webinars and High-level event key findings and messages for next talks (CoP26). Strengthening INternational Cooperation on climatE change REsearch | SINCERE | Project | Results | H2020 | CORDIS | European Commission (europa.eu)

European Commission. (2021). 100 Climate-Neutral and Smart Cities by 2030 Mission Implementation Plan. Implementation Plan - master copy 19 05 (europa.eu)

European Commission. (2021). A Soil Deal for Europe Mission Implementation Plan. soil_mission_implementation_plan_final_for_publication.pdf (europa.eu)

European Commission. (2021). Climate Change Adaptation Mission Implementation Plan. climat_mission_implementation_plan_final_for_publication.pdf (europa.eu)

European Commission. (2021). Restore our Ocean and Waters by 2030 Mission Implementation Plan https://research-and-innovation.ec.europa.eu/document/download/d6162cbd-6d09-48fd-b5b4-d7d2be69972c_en?filename=ocean_and_waters_implementation_plan_final.pdf

European Commission. (2023). Horizon Europe - Work Programme 2023-2024. Horizon Europe work programmes - European Commission (europa.eu)

European Commission. (2024). The Next Frontier for Climate Change Science. The next frontier for climate change science - Publications Office of the EU (europa.eu)

European Environment Agency. (2024). European Climate Risk Assessment. European Climate Risk Assessment — European Environment Agency (europa.eu)
IPCC. (2023). AR6 Synthesis Report: Climate Change 2023. AR6 Synthesis Report: Climate Change 2023 — IPCC

Joussaume S., Guglielmo F., Bessembinder J., Djurdjevic V., Doblas Reyes F., Garrett N., Hewitt C., Jiménez I., Kjellström E., Krzic A., St. Clair A., Máñez M. (2019). Recommendations to Horizon Europe on research needs for Climate Modelling and Climate Services. Recommendations to Horizon Europe on research needs for Climate Modelling and Climate Services | climateurope

JPI Climate and FACCE-JPI (2021). Report of the joint workshop on "Land-based greenhouse gas (GHG) emissions/removals and analysis systems". Report of the joint JPI Climate & FACCE-JPI workshop "Land-based greenhouse gas (GHG) emissions/removals and analysis systems" – JPI Climate (jpi-climate.eu)

JPI Climate and German Aerospace Center – Project Management Agency. (2020). Providing Knowledge for a climate neutral and resilient Europe. Report from the 2nd JPI Climate Scoping Forum Symposium. 2nd JPI Climate Scoping Forum Symposium 2020 report: Providing Knowledge for a climate neutral and resilient Europe – JPI Climate (jpi-climate.eu)

JPI Cultural Heritage & JPI Climate (2022) Cultural Heritage and Climate Change: New Challenges and Perspectives for Research. [White Paper] Cultural Heritage and Climate Change: New Challenges and Perspectives for Research | Heritage Research Hub (heritageresearch-hub.eu)

Water4All Partnership. (2022). Water4All's Strategic Research and Innovation Agenda (SRIA): 2022-2025. Strategic Research and Innovation Agenda | European Partnership Water4All (water4all-partnership.eu)

West J., Worliczek E. (2019). Operationalising knowledge on and for societal transformations in the face of climate change. Operationalising knowledge on and for societal transformations in the face of climate change (jpi-climate.eu)

World Health Organization. (2021). Climate change and health research: current trends, gaps and perspectives for the future. Climate change and health research: Current trends, gaps and perspectives for the future (who.int)

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