EU-PolarNet

Co-ordinating and Co-designing the European Polar Research Area

European Polar Research Priorities

Photo: W. Kaszkin

Foreword

One of the most important tasks for EU-PolarNet 2 was to prioritise research topics in polar research. Based on the results of the previous work of the EU-PolarNet consortium, particularly the five White Papers and the European Polar Research Programme (EPRP), the priority topics for European Polar Research over the next 10 years have been identified through an extensive and inclusive process.

This document reports on the outcomes of this process. The introductory section provides an overview of how the overall result was achieved.

Photo: D. Mateev

Content

Introduction

Research prioritisation refers to the process of determining which research topics should be given the most attention and resources. Such a process is essential for effectively allocating limited resources, such as funding, time, and expertise, to the areas that will have the greatest impact or benefit.

The research prioritisation exercise that was performed within Work Package 3 ("Research Prioritisation") of EU-PolarNet 2, aimed at:
establishing and updating European and global Polar research questions and priorities, and contributing to the implementation of the European Polar Research Programme (EPRP) and the EU-PolarNet 1 White Papers.
From the outset, the intention was to create an open, transparent and inclusive process, similar to what had previously been done for developing the White Papers and the Integrated European Polar Research Programme (EPRP).

To ensure inclusiveness, the decision-making involved the participation and consultation of different levels of stakeholders and rightsholders: both scientific stakeholders from the EU-PolarNet 2 project consortium and the Polar Expert Group (PEG), a group of more than international 200 experts selected through a project internal nomination process[1] and the EU Polar Cluster Members and non-scientific stakeholders and rightholders (e.g. indigenous communities and industries). In addition, the Catalyst Platform, which has been implemented by EU-PolarNet 2 as a coordination platform, was used to share and discuss different opinions, perspectives and documents in a very efficient way.

A robust three-step-methodology was developed and implemented for the prioritisation process. It consisted of:

i) collecting the scientific input for the prioritisation process by considering several documents categories (e.g., national strategies and science plans of international organisations, research needs developed by indigenous organisations, outcomes of several workshops held with different kinds of stakeholders);
ii) implementing a systematic analysis both from a qualitative and a quantitative point of view;
iii) organising a retreat, where the PEG identified the critical future research needs in the Polar Regions based on a long list of priority topics arising from the work performed in step i) and ii). Their work was supported by a Priority Matrix prioritisation tool[2].

Figure 1 provides a graphical representation of the above three-step-methodology. The method used to prioritise the polar research topics is described in more detail in the Appendix.

The Process

[1]All the EU-PolarNet 2 Partners were invited to nominate experts for up to 11 different polar research disciplines, reflecting the European Polar research priorities. Partners were invited to nominate up to two experts per research field, one with Arctic expertise and the other with Antarctic expertise. In a second step a first shortlist of preferred candidates for each of the research themes was established by the EU-PolarNet 2 Executive Board and the responsible partners of WP3. The internal architecture of the PEG is organised as a twofold structure, consisting of an Executive PEG -ExPEG (29 members) surrounded by a larger group of experts consisting of 200 experts.

[2]The Priority Matrix is a more advanced version of the Eisenhower Matrix, which adds additional criteria for prioritisation. The matrix used is based on the definition of the PICK (Possible, Implement, Challenge, Keep Back) Chart, which can be customized to the scope under analysis [George, [2003]].

Research Prioritisation Process Workflow

Step 1 — Collect Inputs

1. EPRP (+ Background Docs Updates)
2. Call for Services Projects
3. Stakeholders' Workshops & Meetings
4. Survey within the EU Polar Cluster
5. Survey within the PEG

Step 2 — Systematic Analysis

Direct study and analysis of the main docs (in the Catalyst Platform)

in parallel:

Topics analysis by text mining methodology (T-LAB software)

Step 3 — Polar Expert Group (PEG) Retreat

PEG Retreat (San Servolo, Venice, June 2023)

Research Prioritisation Methodology
3 main tasks/steps:

1. Consolidation of the topic lists (per Research Need → Breakout group);
2. PICK chart analysis by online questionaries (google form on site);
3. Priority Topic description

Final Output
Priority List of Research Topics and Description

Figure 1: Methodology workflow adopted for the research prioritisation process. Step 1 and Step 2 were completed before the retreat, while Step 3 represents the culmination of the prioritisation process, which took place with the PEG retreat organised in San Servolo in the Venice Lagoon (June 2023).

Prioritised Research Topics

Photo: R. J. W. Visser

Understand Climate Change in the Polar Region

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The Arctic and Antarctic are connected to global climate through several feedback mechanisms. Several of these processes exhibit tipping points, which mean that once they are fully triggered, they can dramatically and irreversibly change the global climate on a human time-scale.

There is an urgency to increase predictability and reducing the uncertainty associated with key processes that affect climate change and people.

Ice sheets and interactions with ocean, atmosphere and solid Earth: unravelling instabilities, implications for future sea-level rise and climate scenarios

Scope

Observed accelerated trends in ice sheet mass loss directly impact global sea-level rise (SLR), atmospheric and oceanic circulation, and ultimately, global climate. According to geological evidence, collapses of large Antarctic regions are plausible in the near future, in response to climate changes. SLR responses may be up to m/century, however the magnitude, timing and rate are not yet constrained, nor the impact on deep water formation and global overturning circulation. Evaluating what fraction of future sea-level rise can be influenced by future anthropogenic forcing scenarios, identifying ice-sheet tipping points and potential cascading tipping points on ocean circulation are mandatory to better define crucial mitigation objectives and essential for designing efficient adaptation plans and avoid maladaptation. The proposed action aims at fostering a collaborative community effort in Europe, in conjunction with international initiatives (e.g. IASC[3], SCAR[4], ISMIP[5]), to address the challenges associated with ice sheet evolution, their interactions with the ocean, atmosphere and solid Earth, and improve projections of sea-level rise and ocean heat and carbon uptake.

This challenge should:

- Address knowledge gaps related to past and future ice sheets evolution and interactions with ocean and atmosphere, through the use of new and existing paleodata, direct measurements (including in-situ, ship, airborne and remote sensing), reanalysis, and numerical modeling;
- Unravel past to future instabilities within ice sheets, improve accuracy of hincasting and paleo simulation;
- Improve observing and modeling of ice shelf damage, calving and collapse, their trigger (including basal and surface melting) and the consequences for the ocean/sea-ice properties and associated ice-shelf melt feedback;
- Improve quantification of heat and salt transport to and from ice shelves cavities, freshwater fluxes at the shelf/fjord mouth, and the related impact on deep water formation;
- Improve quantification of surface mass balance evolution, impact of atmospheric rivers and extreme events on precipitation, change in surface melting and run-off, the ability of the firn layer to retain liquid water, the routing and pounding of surface melt-water;
- Improve understanding of bedrock properties, subglacial topography and hydrology impacts on glaciers sliding, water masses properties, circulation within cavities;

Expected impacts and outcomes

The research is expected to produce:

- Enhanced community effort in Europe in collaboration with international initiatives to bring together the latest advances in science including modelling, and paleo to present observations to tackle past to future ice sheet mass loss and impacts on sea-level rise and global climate;
- Address knowledge gaps on deep uncertainties related to past, present and future ice sheets behaviours, related contributions to IPCC[6];
- Improved understanding and model representation of interactions, links and feedbacks between atmosphere-ice sheets-ocean;
- Improved Earth System Models and physically-sound/better decadal to multi-centennial climate projections;
- Contributing to international observing and modeling initiatives (e.g. ISMIP7[7])
- Improved global, regional and local sea-level rise projections at different time scale (from decadal to millennial);
- Contributing to global, regional and local sea-level assessments in synergy with emerging European coastal climate services;
- Developing early warning systems anticipating ice-shelves collapse and decadal to multi-centennial mass loss and amplitude and rate of future sea-level rise prediction.

The proposal's outcomes will benefit:

European, and global society through providing improved knowledge and models of polar ice sheets and global climate. Society urgently needs improved projections of sea-level rise, and cascading effects of ice sheet mass loss to guide climate change mitigation and adaptation strategies.

[3] International Arctic Science Committee
[4] Scientific Committee on Antarctic Research
[5] Ice Sheet Model Intercomparison Project
[6] The Intergovernmental Panel on Climate Change
[7] Ice Sheet Model Intercomparison Project for CMIP7, where CMIP7 stands for Coupled Model Intercomparison Project – Phase 7 https://wcrp-cmip.org/cmip7/

Advancing Understanding of Polar Amplification and Climate Feedbacks: Addressing Key Uncertainties for Enhanced Knowledge of Future Climate and Weather

Scope

The polar regions play a critical role in the Earth's climate system and are experiencing amplified warming compared to the global average. Polar amplification involves a complex set of interactions between atmospheric and oceanic circulation patterns, teleconnections with lower latitudes, sea ice dynamics, clouds and aerosol particles, and other factors, which requires focused and coordinated interdisciplinary work to quantify. In addition, key feedback mechanisms specific for the polar regions, e.g. the ice-albedo feedback, water vapour feedback, cloud feedback, among others, play a crucial, yet uncertain, role in polar amplification. Improved regional and global climate projections are needed to plan for the extent of regional and global warming, including changes in weather and climate extremes such as storms, heat waves, and anomalous precipitation in the polar regions and beyond. However, the causes and mechanisms that drive polar amplification including regional climate feedback mechanisms and the functioning of polar amplification during past warm climates remain poorly quantified. Improved fundamental understanding from observations and models over different time scales that describe and quantify polar amplification for both poles are urgently needed to plan for climate adaptation and mitigation actions.

This challenge should be addressed through:

- Using new and existing measurements (ground based remote sensing and in situ data, aircraft campaigns, ship-based campaigns, satellite remote sensing), reanalyses, paleo reconstructions and model datasets in combination with new analysis methods, to advance the understanding of the complex interactions that drive polar amplification and feedbacks;
- Developing new measurement techniques;
- Using and improving numerical models, including high resolution and coupled models, to quantify and improve knowledge of polar amplification, teleconnections, and feedback mechanisms;
- Coordinating model experiments to quantify polar amplification including feedbacks and teleconnections;
- Coordinating and enhancing existing resources, including for the underrepresented dark months of the year.

Expected impacts and outcomes

The research is expected to produce:

- Quantification of how polar amplification controls polar and global weather and climate;
- Improved knowledge, quantification and model representation of key processes that control polar amplification, including how the atmosphere is controlled by ice, snow and ocean processes that drive polar amplification and related feedbacks;
- Improved understanding of differences in polar amplification and feedbacks between the poles, with a focus on understanding rapid Arctic amplification;
- Enhanced understanding and predictions of the respective role of short-lived and long-lived climate forcers (anthropogenic and natural) on polar amplification and feedback, including understanding how reductions in aerosols have unmasked polar warming;
- Improved understanding of how polar amplification and warming change weather systems, clouds, and precipitation, which are important for atmospheric controls on the cryosphere;
- Improved understanding of the role of teleconnections and large-scale atmospheric circulation patterns in modulating polar amplification and feedbacks;
- Public datasets and models accordance with Open and FAIR[8] science principles to inform climate and weather services;
- Significant contribution to IPCC assessments and polar specific climate assessments through addressing major knowledge gaps in and uncertainties specific to the poles within regional and global climate/Earth system models.

The proposal's outcomes will benefit:

- Arctic, European, and global society through providing improved knowledge and models of polar and global climate and weather. Society urgently needs regionally relevant amplitudes and magnitudes of change that show the most likely climate/weather conditions in the future (including uncertainties) in order to elaborate mitigation measures and prepare society to respond to climate change.

[8] Findability, Accessibility, Interoperability, and Reuse of digital assets

Ocean-sea ice controls of polar climate variability, feedback mechanisms and impacts on global climate

Scope

Changes in the polar oceans and sea ice are affecting global climate through interconnections with the ocean and atmospheric circulations, the major global physical and biogeochemical cycles, including the ocean sinks of heat and anthropogenic carbon, and large-scale terrestrial systems, including the Greenland and Antarctic ice sheets. Since the nutrient-rich waters of the polar oceans feed some of the most productive ecosystems on the planet, these changes have already had severe impacts on all socio-ecological systems. It is vital to better understand the distribution, underlying mechanisms and impacts of polar ocean-sea ice changes to reduce uncertainties on projected future changes in (i) large-scale ocean circulation and transports, including possible tipping points and collapse of the overturning circulations, (ii) regional and global climate and weather systems, including extreme events and mid-latitude weather, and (iii) ocean fluxes to and from the Greenland and Antarctic ice sheets.

Current knowledge gaps include:

- Lack of baseline information and understanding on the functioning and evolution of the physical environment of the polar oceans and sea ice;
- Limited knowledge on the variability and trends of the Atlantic/Arctic and Southern Ocean overturning circulations and the AMOC[9] in relation to polar oceans;
- Limited knowledge on the coupling between ocean volume transports/ocean mixing and fluxes of carbon and nutrients.

The research should lead to enhanced understanding of:

- Polar ocean and sea ice dynamics and their seasonality, their connections to ocean stratification, ventilation and vertical fluxes, freshwater storage and pathways, heat content changes and air-sea ice-ocean interactions;
- Sensitivity of polar ocean-sea ice systems to atmospheric and terrestrial forcing under past, present and future climate change, including possible tipping points linked to collapse of the winter Arctic Sea ice, ventilation shifts in the subpolar North Atlantic and AMOC response to Greenland freshwater fluxes;
- Poorly understood (mostly occurring at fine scales) ocean-sea ice processes: ocean convection, internal mixing, eddies, slope currents, coastal polynyas, fluxes to and from ice shelf cavities;
- Physical drivers of ocean carbon and nutrient fluxes in the polar oceans;

[9] Atlantic meridional overturning circulation

Photo: S. Hendricks

Photo: R. J. W. Visser

- Polar ocean-sea ice connectivity to the global ocean and large-scale atmospheric variability;

These challenges should be addressed through:

- Enhanced process studies though dedicated observation programs, both in-situ and remote sensing combined with new model developments, novel instrumentation and reconstructions;
- Coordinated monitoring networks at key polar ocean gateways in relation to existing ocean arrays and global ocean simulations;
- Improved representation of polar ocean-sea ice processes and feedback in Earth System models;
- Joint physical and biogeochemical observations and modelling.

Expected impacts and outcomes

The research is expected to produce:

- New knowledge on the functioning of the polar oceans and sea ice covers, including their mutual interaction with, impact on and vulnerability to, current and future changes in the other components of the regional and global climate systems;
- Improved quantification of the impacts of polar ocean changes on the global ocean circulation and their future role in anthropogenic CO_2 uptake and regulation of global warming;
- Reduced uncertainties on future decadal to millennial climate projections through improved representation of the ocean-sea ice component in Earth System Models;
- Knowledge-based recommendations for ocean monitoring systems to optimize the collection of information on future polar ocean changes and their relation to global changes;
- Enhanced space borne information on polar oceans and sea ice through enhanced algorithms, ground-truth and understanding of ocean and sea ice properties;
- Better informed planning of marine resources and services, including ocean-based solutions for management of the polar regions and adaptation strategies.

The European research community has a long-lasting experience in polar ocean research, observation and infrastructure and data sharing. It is now ready to build on the outcomes of past and ongoing Polar Cluster projects and take advantage of existing Arctic Ocean observation networks, outcomes of recent major international large scale initiatives, strong international coordination fostered by the UN Decade of Ocean Science initiative and the associated polar Action Plans, and European and international collaboration currently developing on polar ocean observation from space (e.g. ESA CCI Sea Ice project) and operational system developments (e.g. CMEMS[10]).

[10] Copernicus Marine Service

Land-coast-ocean continuum dynamics as a key component of freshwater and carbon fluxes

Scope

Rapid changes are ongoing in precipitation and freshwater discharge to the Arctic and permafrost is thawing and releasing increased sediment, contaminants, organic matter and nutrients into the Arctic. These will affect ocean currents, increase contaminant influx affecting the ocean food web, including fisheries, with unknown impacts on human health, contribute to increased coastal erosion with impacts on infrastructure and local and Indigenous communities. There is also an urgent need to quantify permafrost contribution to remaining carbon budgets under policy relevant pathways, especially in coming decades and in the context of overshoot scenarios.
Tackling these challenges will lead to improved predictions and better planning for adaptation measures. There is a need for quantification of freshwater and sediment fluxes from land (run off, rivers) and coasts (fjords, coastal currents) to the ocean, understanding their pathways and their impact on water masses, currents, stratification and the mass balance of the Greenland ice sheet. A better understanding of sub-sea permafrost, a major unknown concerning methane release and the ground ice distribution inland, is key for improving Earth System Models.

Particular points to be considered are:

- Quantification of freshwater fluxes from land (run off, rivers) and coasts (fjords, coastal currents) to the ocean. As well as how this will impact water masses, currents and the mass balance of the Greenland ice sheet;
- Quantifying and understanding sediment pathways, including fluxes of nutrients, carbon and pollutants related to freshwater and estimate/understand their impact on ecosystems;
- Quantifying how an increase freshwater-induced changes will affect ocean stratification, convection primary production and life in the ocean;
- Characterizing and quantifying inland ground ice and its potential for degradation, and unfrozen ground of permafrost;
- Characterizing sub-sea permafrost and assess its current and future contribution to methane release in different climate change scenarios;
- Assessment of poorly understood tipping elements or irreversible Earth System changes, such as subsea permafrost thaw, abrupt thaw and coastal erosion.

Expected impacts and outcomes

The research is expected to produce:

- Improved mapping of circumarctic ground ice, allowing for better understanding permafrost degradation pathways and their implications for land, ocean and atmosphere;
- Quantification of fluxes from the land and coast to the ocean. Understanding of the processes driving these fluxes and their impact on the ocean;
- Increased process understanding of water masses, ocean currents and living conditions in the ocean, including conditions of occurrence and impacts of extreme events such as marine heat waves;
- Better understanding of subsea permafrost distribution, characteristics and impacts on the climate system;
- Improved accuracy of model predictions through improved parameterizations;
- Improved advice on (marine) weather forecasts, management of fisheries, invasive species, food-safety and one health;
- Improved management of terrestrial and marine ecosystems, including Marine Protected Areas;
- Improved management of infrastructure, including exposure to hazards, across the Arctic;
- Quantification of the permafrost carbon feedback contribution to future Arctic climate change.

The proposal's outcomes will benefit:

The scientific community thanks to increasing fundamental understanding of processes and then providing significant contributions to the modelling community and finally to better predictions and projections. These will be useful to IPCC with improved model parameterization and predictions and to policy makers from local to national and European level providing a more solid base for decision making. The action will be beneficial for local communities providing improved advice for food security, infrastructure management, transports, and ecosystem services management.

Long-term carbon dioxide and biogeochemical cycle dynamics and their feedback in polar regions. Unravelling the climatic significance and future implications.

Scope

Polar regions act as sensitive indicators and amplifiers of global climate change, but their rapid warming has profound implications for the entire planet. Understanding past biogeochemical cycles recorded in polar ice and sediments and estimating their present and future role in feedback mechanisms will shed light on key processes governing Earth's climate. This will illuminate the role of the important greenhouse gases CO_2, CH_4, and N_2O and other forcings on future climate, and on the fate of polar ice and oceans.

The benefits of this research include:

- Improved understanding of the carbon and other biogeochemical cycles as recorded in polar regions, leading to more accurate climate projections and predictions;
- Enhanced ability to assess the sensitivity of polar regions including stores of carbon and ice, to climate change, enabling better-informed policy decisions;
- Insights into past climatic conditions and their linkages to present-day and future changes, aiding in the identification of effective mitigation and adaptation strategies.

The topic involves investigating the interactions between various components of Earth's climate system, such as ice, atmosphere, ocean, and ecosystems, and their role in regulating various biogeochemical fluxes, including carbon, between different reservoirs, and corresponding feedback mechanisms.
Existing studies are often limited in spatial and temporal coverage, hindering a comprehensive understanding of these cycles and their interactions with climate change.

The knowledge gaps include:

- Limited understanding of the long-term trends in carbon cycle and climate dynamics under an extended range of climates, including the Mid Pleistocene Transition, which can be addressed through the analysis and robust synchronisation of marine sediments, ice cores, and other paleoclimate archives. The project will contribute to the generation of new data on greenhouse gas and aerosol forcing and related biogeochemical cycles, global climate and global ice coverage, as for example obtained in the frame of deep drilling ice core project BeyondEPICA and correlated to paleoclimatic data obtained from terrestrial and marine geological records;

Photo: @PNRA/IPEV

- Insufficient knowledge of the complex feedback mechanisms and interactions between different components of the Earth system (in particular between climate and polar regions), which can be investigated using new paleo data and advanced modeling approaches.
- Poor knowledge of the past extent of the East Antarctic Ice Sheet (EAIS), which could be a neglected part of the sea level budget.

Overall, the scope of this research topic is to:

- Conduct interdisciplinary research to improve our understanding of the carbon dioxide and biogeochemical cycle dynamics through new observations in polar regions, establishing links to observations in mid- to low-latitudes, establishing links to observations in mid- to low-latitudes, and modelling exercises;
- Utilize, new and existing paleoclimate archives, and other available datasets to reconstruct past climate conditions and carbon cycle dynamics and assess their climatic significance in relevant periods of time in which frequency and intensity of forcing factors changed considerably. This includes assessment of the past stability of the neglected EAIS;
- Develop and refine models that better capture the past interactions between different components of Earth and in particular the polar regions and evaluate their future implications under different climate scenarios.

Expected Impacts and Outcomes

The research is expected to yield the following outcomes:

- Enhanced understanding of the carbon and other biogeochemical cycles and in particular the role of biogeochemical processes in polar regions, leading to more accurate climate models and future projections;
- Reconstruction of past climate conditions (forcing and responses) and identification of key climatic drivers, providing insights into the present and future climate sensitivity of polar regions;
- Improved understanding of the feedback mechanisms and interactions between polar components, allowing for better predictions of future climate change impacts;
- Assessment of when the EAIS attained its present extent last, contributing to discussion about thresholds for worst case scenarios of the future.

The significance of this work lies in its potential to:

- Improve the accuracy of climate models and projections, leading to more reliable assessments of future climate change impacts at regional and global scales;
- Inform policy decisions related to climate change mitigation and adaptation strategies, with specific relevance to polar regions and their implications for the entire planet.
- This proposal directly addresses the questions raised by conducting interdisciplinary research, utilising various data sources, including new observations, analyses of paleo archives and developing advanced computational models.

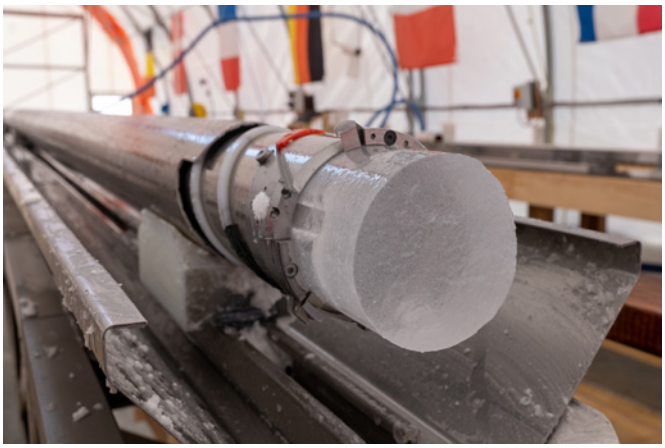

Photo: Mulvaney@PNRA/IPEV

The proposal's outcomes will benefit:

- Scientists and researchers working in the field of climate science, enabling them to expand their knowledge and contribute to ongoing efforts in understanding and addressing climate change;
- Policymakers and governmental bodies involved in formulating climate change policies and strategies, providing them with scientifically robust information to guide decision-making;
- Society at large, as the research outcomes will contribute to a better understanding of climate change impacts, fostering awareness and promoting sustainable practices.

The research infrastructure needed includes access to ice, sediment, paleoclimate data repositories, advanced modeling tools, and interdisciplinary collaboration platforms.
The time scale of funding needed will depend on the specific research activities proposed, but a six-year funding commitment is necessary to achieve meaningful results.
The impact of this research is expected to be long-lasting, as it will contribute to a deeper understanding of the carbon and biogeochemical cycles in polar regions, with implications for climate change projections and policy decisions for years to come.

Polar climate extremes: Quantifying and projecting hazards, feedbacks, risks, and impacts for improved resilience

Scope

The polar regions are experiencing unique, rapid and unprecedented changes, including more frequent and intense climatic extremes and extreme events. These changes have regional and global implications for ecosystems, communities, and the global climate system. Understanding and projecting future polar climate extremes, such as heatwaves, extreme or unusual precipitation, wildfires, air pollution, ice melt, permafrost thaw, and their interconnected climate risks and impacts, is critically important to build polar and global climate resilience. Knowledge of how climate extremes have formed and propagated in the past, better constraints for the associated processes, and improved quantification of uncertainties in their future projections, are needed to develop climate adaptation strategies and European risk assessments, to ensure ecosystem sustainability, and to build resilient communities. The challenge is to provide improved understanding of the mechanisms that control polar region and polar regulated climate extremes, enhance the detection of extremes by observations (ground based, satellite, etc.), use existing global and high-resolution models and data to quantify extremes, and enhance models (including climate, Earth system, high-resolution and impact models) ability to correctly represent these extremes. This will result in improved ability to identify climate hazards and their associated natural and community vulnerabilities, improved quantification of the impacts on natural and human systems, and improved ability to quantify polar feedbacks on the broader climate system. Polar extremes can be unique to the Arctic and Antarctic regions, but may also trigger rapid, accelerated, and potentially irreversible, further changes at the poles or in other parts of the Earth. Quantifying the Earth system response(s) to Polar climate conditions and extreme events is therefore an urgent research need to understand and adapt to the future conditions within the Polar regions and beyond.

Photo: E. Horvath

Expected Impacts and Outcomes

The research is expected to yield the following outcomes:

- Improved knowledge of the processes that govern and control polar climate extremes and extreme events in the past, present, and future;
- Quantification of the impacts, hazards and risks associated with polar climate extremes including events;
- Improved models, including high resolution models, that accurately represent polar climate extremes;
- Improved future projections that provide a more complete understanding of uncertainties in climate extremes including, for example, event frequency;
- Improved understanding of how polar climate extremes, including extreme events, result in impacts and risks elsewhere on the planet;
- Improved ability to use climate information and projections to recommend pathways towards resilience;
- Contributing to IPCC assessments and polar specific climate assessments;
- Informing climate and weather services that provide information on extremes events and/or hazard alerts.

The proposal's outcomes will benefit:

- Society, policymakers and governmental bodies that are planning for how to adapt to and polar climate extremes and events.

Photo: M. Frost Arndal

Polar Biodiversity and Socio-Ecological System

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Understanding the changes in structure, functioning, and biodiversity of polar ecosystems in the Arctic and Antarctic poses common challenges due to their remoteness and limited infrastructure. Both regions have been significantly impacted by human activities such as industrial fishing and whaling, necessitating ongoing monitoring and conservation efforts. The concept of socio-ecological systems highlights that human societies are integral to polar ecosystems and that resilience, vulnerability, and adaptive capacity are critical for managing these rapidly changing environments.

Consequences of changing species distributions in the polar regions

Scope

Climate change causes poleward shifts of aquatic and terrestrial species. Evidence of this process has been presented in empirical studies and review papers. However, a huge knowledge gap exists concerning the potential impacts of climate-induced biodiversity changes on polar food webs and ecosystem functioning. We have only seen the beginning of poleward species shifts into and within the polar regions. In the near future large societal implications can be expected with respect to, e.g., fisheries, traditional livelihoods, tourism, conservation and management. Robust new scientific knowledge on ecological and socio-economic consequences of the expected large changes in biodiversity will facilitate risk assessment and policy-making as it allows early warning/preparedness for both positive and negative aspects of changing species distributions. New species could give rise to socio-economic gains or losses by providing new or larger harvests, competing with native species, disrupting food webs, modifying habitats, and spreading diseases/parasites to animals and humans. Policymaking is not keeping up with the fast changes in species distributions caused by climate change in the polar regions and needs increased knowledge input on the potential consequences to make informed management decisions.

Photo: Ademollo©PNRA

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This challenge should:

- Cover potential crucial changes in food webs and ecosystem functioning and their consequences for ecosystem management, animal and human health (e.g., diseases), subsistence of local communities (e.g., hunting, fishing), and industries (e.g., fishing), caused by changing species distributions in the polar aquatic and terrestrial ecosystems.

Expected impacts and outcomes

The research is expected to produce:

- Evaluation of the potential modifications of food webs, habitats, ecosystem productivity, ecosystem functioning, ecosystem services, and animal and human health in the polar regions caused by climate-induced biodiversity changes;
- New understanding of the potential ecological and socio-economic consequences caused by climate-induced biodiversity changes as a basis for effective management and conservation strategies for the polar ecosystems.

The proposal's outcomes will benefit:

- The EU in international discussions, negotiations, and cooperation for conservation and sustainable management of the polar regions;
- Policy- and decision-makers and conservation organisations through new evidence-based scientific knowledge in developing and adapting strategies for managing and protecting the polar ecosystems;
- Local communities in protecting and/or expanding their livelihoods (reindeer-herding, fishing, hunting);
- Industries working in polar areas (fishing, tourism, shipping) in streamlining their operations;
- Scientists in building a new knowledge base for further research.

Changing water cycle: effects on biodiversity, ecosystem productivity and human subsistence in the polar areas

Scope

Water is key for life. With accelerating climate change the natural water cycle in the terrestrial-marine boundary layer is modified through, e.g., changes in precipitation, thawing permafrost, increased freshwater discharges to the ocean, changing ocean circulation, flood hazards, ground-water changes, glacier melt, sea-ice melt, and sea-level rise. Evidence of this existing knowledge is presented in empirical studies and review papers. However, a huge knowledge gap exists on how these processes in combination can change living conditions for polar organisms and ecosystem services through changes in biodiversity and ecosystem productivity, and ultimately affect human subsistence. For example, it is unknown how water-cycle changes will affect the marine and terrestrial flora and fauna, local communities and operations in the terrestrial-marine boundary layer. In the polar regions the water cycle depends on particular components that are lacking in other areas - frozen land, frozen water and extreme seasonality - and is thus more complicated than elsewhere. Policymaking is not keeping up with the fast changes in the water cycle caused by climate change in the polar regions and needs increased knowledge input on the potential consequences to make informed management decisions.

This challenge should:

- Cover potential consequences of the complexity of changing interactions between the water-cycle processes for the terrestrial and marine ecosystems, including the coastal boundary layer between them. Examples of unknown processes are biodiversity and productivity changes on land and in the sea with freshening of coastal areas, water and food security and associated risks for the human population.

Photo: Barbaro@PRA

Photo: R. J. W. Visser

Expected impacts and outcomes

The research is expected to produce:

- New knowledge on the consequences of climate-induced modifications of the water cycle with respect to biodiversity, ecosystem productivity, food-web interactions, ecosystem services, societal prosperity, and human and animal health. Mediators are, e.g., changes in freshwater balance, nutrient dynamics, timing and duration of the growing season, supporting ecosystem services, water resources necessary for human well-being;
- Crucial understanding of the consequences of changes in the water cycle for effective management and conservation strategies for the polar ecosystems and improvement of climate scenarios.

The proposal's outcomes will benefit:

- The EU in international discussions, negotiations, and cooperation for conservation and sustainable management of the polar regions;
- Policy- and decision-makers and conservation organisations through new evidence-based scientific knowledge in developing and adapting strategies for managing and protecting the polar ecosystems;
- Local communities in protecting and/or expanding their livelihoods (reindeer-herding, fishing, hunting);
- Industries working in polar areas (fishing, tourism, shipping) in streamlining their operations;
- Scientists in building a new knowledge base for further research.

Cumulative impacts of climate change on biodiversity structure and functions in polar ecosystems

Scope

The polar aquatic and terrestrial ecosystems face multifaceted environmental change with climate warming. Simultaneous changes in physical and chemical stressors, as well as directly human-generated stressors such as habitat destruction and pollutants, are expected to have cumulative impacts on biodiversity, productivity and ecosystem functioning, which may have major socio-economic impacts. Evidence that such impacts are often cumulative has been presented in empirical studies and review papers from geographical areas outside the polar regions. There is an urgent need to integrate polar field data with experimental results using polar organisms in ecological modelling to understand cumulative impacts of climate change and increased accessibility for human activities on ecosystem restructuring and possible cascades. Robust new scientific knowledge, including new data collection, modelling, and forecasting, will facilitate assessments of ecosystem vulnerability and assist decision-making in development, implementation and evaluation of risk assessment and policy.

This challenge should:

- Collect new data on cumulative effects of interacting environmental parameters and human stressors typical for the polar aquatic and terrestrial ecosystems;
- Analyse interaction processes of cumulative impacts of climate change on polar organisms by combining field and experimental data, modelling ecosystem responses such as nutrient cycling, energy flow, food-web dynamics, and regional to global predictions of the consequences for polar ecosystem services.

Photo: LoGiudice@PRA

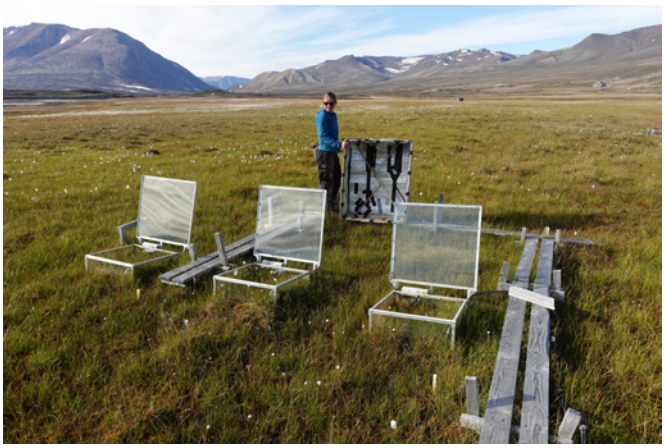

Photo: M. Frost Arndal

Expected impacts and outcomes

The research is expected to produce:

- Understanding of the consequences of cumulative impacts of climate change on biodiversity structure, function and supporting ecosystem services in polar ecosystems, mediated by direct climate change impacts (temperature, salinity, nutrients, oxygen, etc.) and increased accessibility of the polar areas (shipping, fishing, hunting, contaminants, etc.);
- Identification of those cumulative impacts of climate change and increased accessibility that are crucial for effective management and conservation strategies for the polar aquatic and terrestrial ecosystems.

The proposal's outcomes will benefit:

- The EU in international discussions, negotiations, and cooperation for conservation and sustainable management of the polar regions;
- Policy and decision-makers and conservation organisations through new evidence-based scientific knowledge to identify possible – previously unknown – risks so that effective adaptive management approaches can be developed for protecting the polar ecosystems ion the best possible ways;
- Scientists in building a new knowledge base for further research.

Adaptation of conservation measures for the polar ecosystems

Scope

There is a critical need to update and customise conservation measures for the rapidly changing polar aquatic and terrestrial ecosystems in the face of climate change, increasing human pressures and shifts in global geopolitics. These adaptations should take into account the uniqueness of the polar ecosystems and be based on the latest scientific knowledge. Ecosystem-Based Management (EBM) is endorsed at the highest level, including UN bodies and states, but unachievable for the polar areas due to gaps in fundamental knowledge on ecosystem functioning and services. At the same time, the IPCC reports show that the polar regions have major environmental protection issues to solve due to high vulnerability to disturbances, high levels of endemism and extinction risks of biodiversity, high needs for ensuring resilience of terrestrial and marine ecosystems, not least with respect to subsistence of indigenous and local communities. The polar regions have gained geopolitical importance due to their natural resources, potential shipping routes, and strategic significance. As countries and stakeholders compete for access and influence in these regions it is crucial to have access to operable conservation measures that align with these changes. By developing new scientific knowledge on how to design appropriate conservation measures for the polar areas the EU can significantly contribute to mitigating the impacts of climate change and protecting vulnerable species and habitats, and thereby fulfil its obligations for international agreements and frameworks for the conservation of the polar regions.

This challenge should:

- Address the existing knowledge gaps on polar ecosystem services, the extent of habitat loss, the potential for ecological shifts and disruptions, cumulative impacts of increasing human activities, socioeconomic aspects, and indigenous and local perspectives related to the necessary adaptations of conservation needs and measures for the polar areas;
- Evaluate the existing governance, policy frameworks, and monitoring and assessment for polar conservation and how they could be adapted to the ongoing changes.

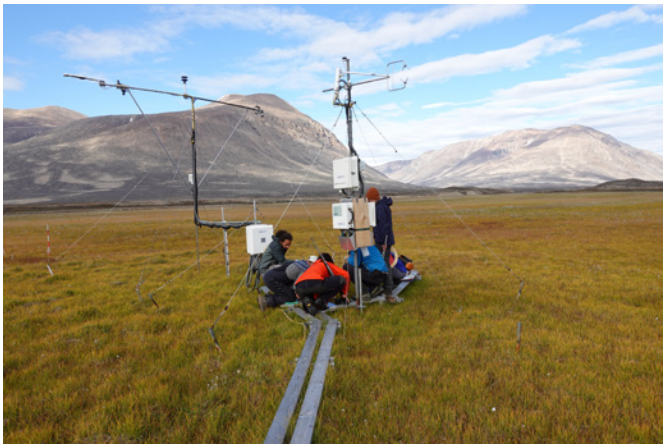

Photo: M. Frost Arndal

Expected impacts and outcomes

The research is expected to produce:

- Conservation strategies for the polar ecosystems built on the latest scientific knowledge;
- Updated conservation measures, which will help to manage and regulate emerging activities (e.g., tourism, shipping, resource extraction and fishing), and minimise negative impacts on the fragile polar ecosystems;
- Comprehensive analyses of the currently applied conservation measures and how they could be adapted to the ongoing changes;
- Identification of emerging key challenges, vulnerabilities, and other areas of concern that require immediate attention.

The proposal's outcomes will benefit:

- The EU in international discussions, negotiations, and cooperation for conservation and sustainable management of the polar regions;
- National governance as well as the international body (BBNJ) for the high seas will be able to unite common efforts with respect to existing and new human activities;
- Growing industries in the polar areas (tourism, shipping, fisheries, etc.) can adapt their activities;
- Local citizens will benefit through protected areas adjacent to their fishing and hunting areas.

"Polar System of Systems": an integrated biological-chemical-physical long-term observing system

Scope

Development of an ecological observing system for the polar areas is critically important to identify long-term trends, assess ecosystem health and resilience, and to provide reliable data and services to EU decision-makers and citizens. Development of a "Polar System of Systems" allows for accurate monitoring of ecological indicators through integrated and standardised data collection. This contributes to improved understanding of climate change processes, reliable climate models and projections, and feeds into different levels of decision-making. Ecosystem analyses focus on interactions between physical, chemical and biological parameters, superimposed by human-generated pressures, such as shipping, hunting, fishing and pollution. However, integration between disciplines and spatial-temporal data coverage are lacking for the polar ecosystems. Collection of biological data, such as biodiversity, productivity and energy flows in the polar aquatic and terrestrial ecosystems, has only just begun: existing data are still scarce for most of the polar ecosystems, not collected systematically, and often with different methods. Disharmony in ecological data collection between countries, regions and research projects is an additional widespread problem for ecosystem analyses at both poles. Input of non-harmonised data hampers the value of model outputs and comparisons between different model outputs. This emphasises the urgent need for internationally agreed ecological measurements and indicators for the polar areas, as well as for standard data and metadata formats, to ensure that the data are reliable and enable comparisons within and between ecosystems.

This challenge should:

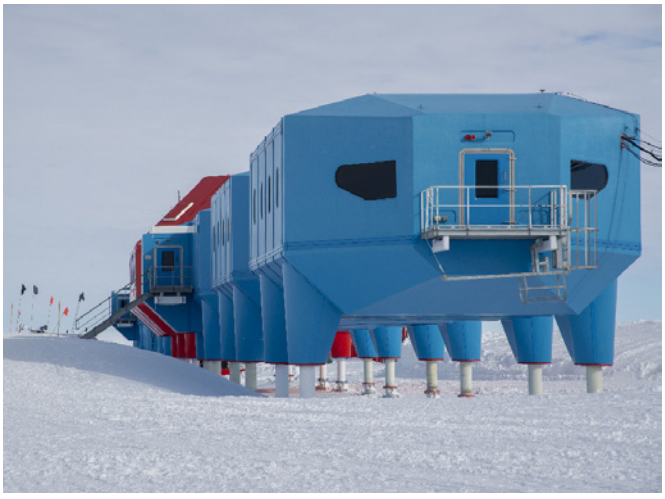

Photo: P. Bucktrout

- Ensure that the "Polar System of Systems" is a robust science-based fundament for long-term sustainable management and conservation of the polar ecosystems that be used to assess specific impacts as well as to detect long-term trends;
- Align existing observing efforts by engaging relevant actors and stakeholders from local to global scales into the process;
- Develop standardisation of methods and indicators for ecosystem analysis, data and metadata formats relevant for modelling, in collaboration with international actors;
- Select relevant observations and data from monitoring networks, marine and terrestrial infrastructures, sensor networks, data management systems, remote sensing and geospatial technologies, data analysis and modelling tools, platforms for collaboration and networking.

Expected impacts and outcomes

The research is expected to produce:

- A comprehensive "Polar System of Systems" integrating long-term ecological observations, covering actors across scales and geographical regions, and feeding into global earth observing efforts such as GEOSS[11];
- Alignment of existing observing efforts by engaging relevant actors and stakeholders from local to global scales into the process;
- Standardisation of methods and indicators for ecosystem analysis, data and metadata formats relevant for modelling.

The proposal's outcomes will benefit:

- The EU in international discussions, negotiations, and cooperation for conservation and long-term sustainable management of the polar regions;
- The UN by addressing a range of 2030 SDGs (e.g., 2, 6, 11, 13, 14, 15) and associated targets and helps formulate future goals and targets beyond that;
- International research and monitoring programmes, e.g., the EU's international research collaboration on Antarctica, the Joint Programme for Scientific Research and Monitoring (JPSRM) of the Central Arctic Ocean Fisheries Agreement (CAOFA) signed by the EU, the scientist-driven international Synoptic Arctic Survey (SAS) collaboration, the International Polar Year (IPY), etc.

[11] Global Earth Observation System of Systems.

Photo: J. Dahl

Human Impacts on Polar System

Contributors

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The EU aims to develop a research framework to support safe, sustainable, and just operations in the Polar Regions. Increased activities in these areas, driven by climate change and development, will create both challenges and opportunities for local communities and operators. Sustainable operations are crucial, with companies investing significantly in research and development to understand the costs and challenges involved.

Essential indicators for assessing the state and change of the polar environment

Scope

Polar regions are facing a rapidly changing environment and increasing human activities. A set of robust environmental indicators designed especially for the unique polar regions is needed to support a sustainable development and green transition. These essential indicators can be used to assess the state of the environment (including the impacts of polar operations) and for long-term monitoring. Observations inform actions in the face of these changes, but the design of the existing observing systems and coordination approaches are not sufficiently developed. Requirements for observing systems are more demanding in the polar regions, not only because logistics and operating conditions are more challenging, but also due to a greater need for cross-disciplinary and cross-sector prioritisation and extrapolations from local to regional (pan-Arctic, pan-Antarctic) scale. The indicators need to cover a high variability of (partly frozen) habitats in marine, coastal and terrestrial ecosystems. Understanding the environmental changes in these regions is crucial not only for the EU but also at global scale, as the polar conditions directly influence the climate and environment world-wide. For increasing capacity and understanding the impacts of polar environmental change and human activities in the remote Arctic and Antarctic, indicators must also be harmonised and fed into high resolution Earth System models, such as the Destination Earth (DestinE) digital twin. This is urgent as processes of global and regional change already affect both polar regions.

This challenge should:

- Improve and integrate observing systems and monitoring programmes that presently are not in place in large parts of the Antarctic continent and surrounding oceans as well as in the Arctic Ocean and surrounding land areas;
- Establish and sustain baseline observations and develop essential indicators affecting Arctic and Antarctic ecosystems to understand the current state, change and impacts of climate change, accumulation of chemicals and human activities on the environment (food web structure, biodiversity, ecosystems, biogeochemistry);
- Increase capacity and close gaps in the existing monitoring of chemicals and climate change such as those conducted under the Arctic Monitoring and Assessment Program (AMAP). A similar approach has also been approved for Antarctica (AnMAP[12]) and should be developed further and encouraged by the EU and its member states;
- Upscale best practice examples from local monitoring pro-

[12] The Antarctic Monitoring and Assessment Programme

Photo: M. Meredith

Photo: P. Verzone

grammes to similar monitoring and assessment programmes for larger areas/regions, using internationally agreed essential indicators and variables of relevance for the DestinE model;
- Design an optimal pan-Arctic and pan-Antarctic observing network of key variables that can directly be fed into Earth System models, ensuring open access to the observations and results for all stakeholders and decision makers;
- Explore the possibility to involve indigenous communities to gather additional scientific information on polar environment and to let the population more aware about the actual changes taking place through a citizen in science approach.

Expected impacts and outcomes

The research is expected to produce:
- Essential indicators for long-term monitoring in the polar regions that can assess the impacts of polar change and operations and can guide governance responses and establish adequate political urgency to take mitigation or adaptation measures;
- An identification of existing monitoring programmes and existing gaps in monitoring;
- Best practice guidelines for how Earth Observation could be used to reduce the impact of polar operations, by developing operational monitoring services to support safe science and operations in polar regions;
- Key variables and indicators for long term monitoring and observations that are essential to understanding the changes and feed into high resolution Earth System models such as the Destination Earth (DestinE) model.

The proposal's outcomes will support:
- The European Commission's Green Deal and Digital Strategy in achieving the objectives of the twin transition;
- Multinational participation and improved access to data, field stations and ship-based logistics and research infrastructure;
- Interdisciplinary collaboration by facilitating collaboration between ecologists, climatologists, chemists, biologists, social scientists, and policy experts to ensure a holistic assessment of the cumulative impacts and change in the Arctic and Antarctic;
- The Antarctic Treaty Committee for Environmental Protection's decision in June 2023 to start discussions on the development of a framework for environmental monitoring (including indicators);
- The further development and EU support for establishing an integrated Arctic observing system and the role that the EU can take by stimulating international cooperation and a European contribution to monitoring in Antarctica.

Cumulative impacts of human activities on the polar environment and ecosystem services

Scope

Polar operations, such as cargo transport, tourism, fishing, mining and renewable energy production, increase with ongoing global climate change. Polar terrestrial and marine ecosystems thus become more exposed to the impacts of human activities, following the decline of permanent glaciers and sea ice. The EU is an important player in the Arctic and Antarctic regions with EU member states contributing to the environmental footprints, with activities such as habitat destruction and contaminant levels. New commercial opportunities represent increased pressures on the environment, biodiversity and ecosystem functioning with consequences for regulating, supporting and maintaining ecosystem services. Responsible behaviour and environmental regulations are indispensable to assure sustainability in all polar operations. However, crucial knowledge gaps exist with respect to the cumulative impacts of the increased local and regional activity levels. Of special interest is to understand the impact of multiple pressures on local hot spots and the availability of living resources to European societies. New methodologies and tools to understand the cumulative direct and indirect impacts from tourism and industrial activities are needed as well as long-term observations combined with indigenous and local knowledge. Integrated pan-Arctic and pan-Antarctic studies are needed that build on existing national local and regional distributed observations.

This challenge should:

- Develop new methodologies for understanding the increasing pressures from polar operations and how to protect and restore ecosystems to maintain their ability to deliver ecosystem services;
- Analyse the complexity of the multifaceted interactions between humans and the polar environment with focus on scientific issues related to indirect and cumulative impacts of increased human activity levels in vulnerable areas;
- Especially address the cumulative impacts and risks of human activities and climate change on polar ecosystems, the environment and (in the Arctic) indigenous people and local communities, and to what extent existing legal regimes and regulations are effective in addressing these risks/impacts;
- Increase knowledge on human disturbance of Arctic species and their habitats from wind farms, hydropower production and (also in Antarctica) tourism;
- Present a toolbox on how to implement technological, spatial, temporal, and regulatory actions that can minimise the environmental impacts of operations in the polar regions caused by shipping, tourism and other industrial operations.

Expected impacts and outcomes

The research is expected to produce:

- A comprehensive scientific report detailing with the cumulative impacts and risks of human activities on the polar environment, ecosystem functioning and ecosystem services. This should build on essential biodiversity and ecosystem health indices and deliver practical guidelines for sustainable operations;
- Predictive models to simulate the cumulative impacts of different human activities, allowing for scenario analysis and projection of potential outcomes;
- Methods to predict the impact of new and increasing investments in future economic and environmental scenario development;
- Recommendations on how the new knowledge can be incorporated into national and international policies, with guidelines for sustainable development of the polar regions, co-produced with governmental, public and industrial stakeholders to gather insights and foster cooperation for sustainable practices;
- Increased public awareness within the EU about the importance of responsible human operations in the polar regions;
- A significant step forward towards understanding the intricate relationships between human activities (including indigenous and local people), environmental change and ecosystem services in the most fragile and vital regions on Earth.

The proposal's outcomes will benefit:

- The EU in international relations for sustainable management of the polar regions;
- National policy- and decision-makers and conservation organisations through new evidence-based scientific knowledge in developing strategies for managing polar operations and protecting polar ecosystems;
- Local communities and indigenous people in protecting and/or expanding their livelihoods (reindeer-herding, fishing, hunting);
- Industries working in polar areas (fishing, tourism, shipping, energy or insurance companies) in streamlining their operations;
- Scientists in building a new knowledge base for further research.

Sustainable economic development and environmental management in the Arctic

Scope

Sustainable social and economic development is needed in the Arctic region to improve the livelihood of its inhabitants. As the Arctic becomes more accessible for new commercial activities, an ecosystem-based management approach and new scientific knowledge is needed to secure healthy ecosystems and ecosystem services for the benefit of Arctic and European societies. Balancing increasing economic activities with protection of the environment is mandatory and involves all relevant stakeholders. The co-existence of various interests and users of land and ocean areas need to be sustainably managed in a socially fair way. Measures must be taken to render environmentally sustainable economic development in line with the framework set by the EU Taxonomy, the EU Green Deal and the UN SDGs[13]. The Arctic marine, coastal and terrestrial ecosystems are complex and sensitive to the impacts of climate change and human activities. Sustainable ecosystem-based management needs to be precautionary and requires in-depth understanding of the drivers of change and the barriers for critical factors that challenge a sustainable economic transition. Conflicting interests and new economic developments strongly require legal and fair regulatory frameworks that enable best practice environmental management.

This challenge should:

- Identify governance systems that can regulate and enable responsible industrial operations and other activities to play a key role in the economic development and sustainable green transition of the Arctic, through an open dialogue between diverse stakeholders in establishing a knowledge-based and sustainable balance between use and protection;
- Contribute to manage co-existing industrial activities and nature conservation in the Arctic according to sustainability criteria that enable coastal indigenous and local communities to develop their social and economic activities in line with the UN SDGs and a sustainable green transition. Identify the various legal, social, technological, political, economic, and environmental characteristics of the transition;
- Establish new research and alliances that can guide societies and industrial actors in polar areas to operate sustainably and environmentally friendly, thus also becoming more attractive for young people and more competitive in attracting higher investments in line with the EU Green Deal;
- Develop best-practice environmental and ecosystem-based management plans and governance systems for sustainable co-existence of commercial activities. Investigate how national and international law and policy frameworks, region-specific regulations and new precautionary management approaches can support a sustainable development of operations in vulnerable and productive Arctic areas (technological, spatial, temporal, regulatory, monitoring);
- Analyse global economic drivers and geopolitical trends and factors that influence and govern the sustainable development of Arctic commercial and industrial activities;
- Address important risks and uncertainties related to climate scenarios and the growing impact of contaminants, initiating case studies in hot-spot areas and developing in-situ and space-based observation systems.

[13] United Nation Sustainable Development Goals

Photo: P. Prokosch

Photo: L. Bakken

Expected impacts and outcomes

The research is expected to produce:

- Improved ecosystem-based management plans for polar marine, coastal and terrestrial areas in support of the EU Green Deal, EU Taxonomy and the UN 2030 Agenda;
- Better understanding of the global economic, technological and geopolitical drivers and factors that influence the management and development of Arctic commercial and industrial activities;
- Regulatory frameworks and governance systems in line with the goals of the EU Arctic Strategy that contribute to increase the competitiveness and environmental responsibility of companies and operators;
- Promotion of peaceful and sustainable economic development on the basis of the best available environmental, societal, technological, political and economic scientific knowledge;
- Reduced overall human footprint and conflicting interests of social and economic activities in the Arctic.

The proposal's outcomes will benefit:

- The EU in international relations for economic development, conservation and sustainable management of the Arctic region;
- National policy- and decision-makers and conservation organisations through new evidence-based scientific knowledge in developing and adapting ecosystem-based management strategies for the Arctic;
- Local Arctic communities and indigenous people in protecting and/or expanding their livelihoods (reindeer-herding, fishing, hunting);
- Industries with commercial interests in the Arctic (fishing, tourism, shipping, energy, extractive industries, insurance companies etc.) in streamlining their operations;
- Scientists in building a new knowledge base for further research.

Photo: P. Prokosch

Improving international and national law and governance systems for environmental protection and peaceful cooperation in the Arctic and the Antarctic

Scope

Polar areas are rapidly changing due to climate change and new geopolitical turbulence. There is an urgent need to understand how national and international law, agreements and governance systems can be improved and implemented to secure a continued peaceful cooperation between nations in the Arctic and the Antarctic. Relevant agreements are those that form part of the Antarctic Treaty System (ATS) and the (soft law) Arctic Council cooperation. Also, other international, regional and national laws and governance systems exist of which the UN Convention on the Law of the Sea (UNCLOS) is especially important for rule-based cooperation in the Arctic. Many of the ecological and social concerns in the polar regions are already subject to one or more of these legal instruments. Experience shows that solving problems and achieving the objectives of the legal regimes can prove to be very challenging, e.g., related to the conservation of ecosystem health and services, marine protected areas, and fisheries management. There is a gap in scientific multidimensional analysis of the full landscape of all the regulations, their implementations and evaluation of their impacts. Scientific analyses of the functioning and impacts of current law and governance systems are therefore needed to identify which existing regulations are effective or not, and what would be necessary to improve them to achieve better functionality with respect to environmental issues.

This challenge should:

- Evaluate international law and agreements applicable to the polar regions, relating to conservation and management of marine, coastal and terrestrial ecosystems, including their implementation and effectiveness. This includes assessments of the domestic implementation of international agreements between the countries involved to better analyse whether the sum of the efforts of the countries realises the agreed objectives;
- Improve knowledge on the complex interrelationships between all valid legal regimes to reduce fragmentation, as research is often only focused on single regimes such as e.g., the ATS, including their contribution to a peaceful and prosperous development in the polar areas;
- Identify new challenges that are not or are insufficiently addressed in the current legal systems, in light of the rapid regional and global environmental changes (e.g., climate change, biodiversity losses, accumulation of legacy and emerging chemicals) and geopolitical changes.

Photo: G. Pellegrino

Photo: P. Prokosch

- Prioritise general issues such as:
  - the implementation of obligations on (strategic) environmental impact assessment under legal regimes applicable to the polar regions and the extent of international cooperation on this issue;
  - the extent to which the legal regimes take account/adapt to global environmental change, such as climate change;
  - the implementation of obligations on environmental monitoring and reporting under legal regimes applicable to the polar regions;
  - the effectiveness of obligations and approaches within the law and governance systems to address cumulative impacts in the Polar Regions;
  - the need of and ability to protect inviolate areas as reference areas for scientific research;
  - best practices in strengthening supervision and enforcement of international agreements applicable to the Polar Regions.

- Prioritise specific legal regimes applicable to the polar regions:
  - the operation of the Arctic Council and its working groups;
  - the implementation of UNCLOS in relation to the Polar Regions;
  - the implementation of the IMO[14] Polar Code and the need to develop additional rules (e.g., for non-SOLAS[15] vessels);
  - current and future challenges for ensuring comprehensive environmental protection in Antarctica in accordance with Article 2 of the Protocol on Environmental Protection to the Antarctic Treaty, particularly in light of cumulative impacts caused by the increase of research stations and tourism;
  - the effectiveness of ecosystem-based management in the framework of the CAMLR[16] Convention in times of climate change and continued intensive fishing.

Expected impacts and outcomes:

The research is expected to produce:

- A new analysis that provides a better overview of the implementation and effectiveness of existing international law and conventions, soft law agreements and governance systems in the polar regions;
- Recommendations of possible improvements and additional law and governance measures that would be necessary to address current and particularly also future challenges;
- Improved law, governance and monitoring systems that better address future polar challenges, such as a worsening of the geopolitical environment, and the knowledge needed to understand how climate change, human activities and possible new types of polar operations can potentially challenge the functioning of the legal systems.

The proposal's outcomes will benefit:

- The EU and/or Member States in their international relations discussing international cooperation on conservation and sustainable management of the polar regions;
- The EU and/or Member States in receiving scientific evidence-based information on the effectiveness of the objectives of the agreements that they have signed;
- Future EU policies and involvement in Antarctica and the Arctic;
- Scientists in building a new knowledge base for further research.

[14] International Maritime Organization
[15] International Convention for the Safety of Life at Sea
[16] Commission for the Conservation of Antarctic Marine Living Resources

Photo: R. J. W. Visser

Prospering Communities in the Arctic

Contributors

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Ongoing climate changes increased human activity, and growing geopolitical interest profoundly impact Polar Regions, with the most significant effects still forthcoming. Arctic communities face unique challenges from urbanisation, migration, and the diverse needs of their populations, necessitating a nuanced understanding of gender, age, and cultural differences. Sustainable community development in the Arctic requires residents to have the knowledge and resources to innovate and address these emerging challenges effectively.

Food and water security in the Arctic

Scope

The availability, accessibility and safety of food and water for humans and animals in the Arctic are under threat. Besides the consequences of climate change in the Arctic, such as changing weather and ice conditions, permafrost thaw, increasing natural disasters and wildfires; the Arctic environment suffers from different traces of human-induced pollution – from soot to plastics, methane to pesticides and radioactive fallout, made worse by use of wood combustion and oil and gas flaring.

On top of that, a shift in food production from mid and southern latitudes towards the Poles is expected, making parts of the Arctic and also the Southern Ocean possible future food suppliers to the rest of the World.

These complex and rapid changes call for more knowledge on what might help develop more resilient and sustainable food production in the Arctic, with innovative and sustainable use of living resources. Innovations will also be needed to ensure water security and develop infrastructures to enable food production, including hydroponics for production of local food products. These developments cannot be seen separately from economical questions, regarding costs, accessibility and access to global markets.

With most food being transported into the Arctic, a better understanding of regional and global food systems, health risks, and water availability and safety in order to achieve what has been termed "food and water sovereignty" for Indigenous and northern communities is required. Threats to Indigenous livelihoods, people's rights and access to safe food and water in northern communities needs to be better understood to find ways for a sustainable and just transition in food production with food and water security. We need to better understand how climate change and pollution are affecting the availability of traditional foods such as reindeer and sea mammals, how dependence on imported food impacts societal vulnerability and how this relates to new local and global economic developments.

With a significant amount of clean water coming from ground sources, there is a need to research water security (including the influence of climate change or sabotage) in Arctic communities, to improve contaminant exposure estimates and reduce uncertainties in health risk estimates. Research on indicators of availability, on accessibility and safety of food and of water should be central. Community-based monitoring of modern diets and dietary transitions in Arctic Indigenous Peoples should be co-designed and are required to improve estimates of health effects.

Photo: L. Hislop

This challenge should:

- Research the feasibility and desirability of infrastructures that enable sustainable and resilient food production in the Arctic, innovative and sustainable use of living resources, including hydroponics or re-use of industrial materials for production of local food;
- Improve the understanding of food systems, health risks, water availability and safety in order to obtain food and water sovereignty for all Arctic communities;
- Improve the understanding of threats to Indigenous livelihoods, people's rights, and access to safe food and water;
- Improve the understanding of how climate change is affecting the availability of traditional food, thereby affecting not only food and water security, but also more generally the health and well-being of Arctic communities;
- Improve the understanding of water security in Arctic communities especially in relation to contaminants and impacts on the health of affected communities;
- Identify appropriate and co-developed indicators on availability, accessibility and safety of food and of water;
- Enable Arctic Indigenous Peoples to co-design and monitor diets and dietary transitions to improve estimates of health effects and exposure.

Expected impacts and outcomes:

Climate change brings threats and opportunities to food production and use of natural resources with enhanced possibilities to export these to other parts of the globe.

- The research is expected to produce and contribute to a:
- Sustainable use of resources, development of methods and infrastructures including hydroponics for production of local food products, and the possible need for new legislation to make this possible;
- Improvement of sustainability and efficiency through possible re-use of resources for the production of local food products using 'waste' from industry, such as heat from data centres or repurposed mines;
- Development of new technology for improvement, monitoring and handling of food production by local communities and new locally led emerging businesses;
- Co-designed holistic approach with local and Indigenous Peoples collating influences of climate change on agriculture, fishing and hunting;
- Necessary holistic perspective with production of co-knowledge with Indigenous Peoples using a system approach, not a subset of fragmented parts;

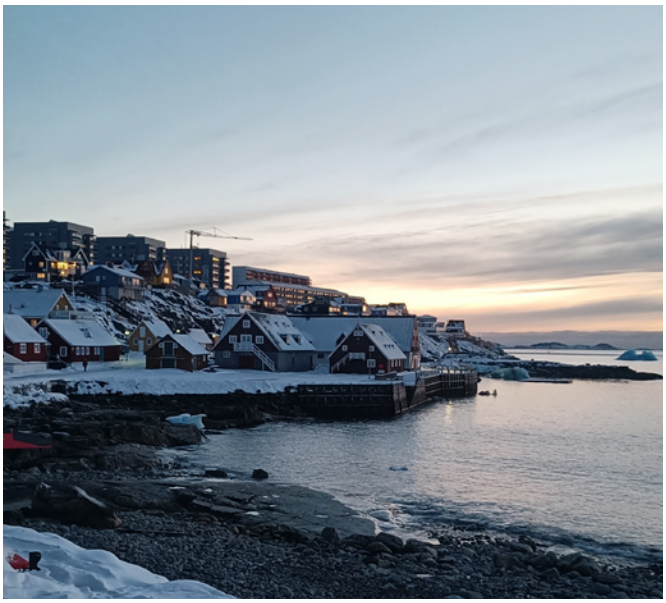

Photo: K. Latola

- Multidisciplinary approach including local, regional and global perspectives which will meet the challenges of the current situation and the even greater impacts expected in the near future;
- Reductionistic quantitative indicator is needed for initiating comparable food and water security monitoring. This will give accurate information on ongoing changes and will be able to project future changes in food and water security.

The proposal's outcomes will benefit:

- Indigenous peoples, northern communities, European and global societies will benefit, through sustainable food production in the Arctic. This will be via innovative and sustainable uses of living resources, innovative and sustainable re-use of resources from industry for food production, e.g., hydroponics or greenhouses heated e.g., with waste heat from data centres, for the production of local food products.

Permafrost thaw and One Health

Scope

As stated in the EU Arctic policy there is an urgent need to address the adverse effects of thawing permafrost and the associated gas hydrates, which present a clear danger to the Arctic environment and its people, and which will have wider repercussions beyond the Arctic as well.

Studies have also shown the ability of ancient microbes (bacteria, viruses and more recently, multicellular organisms) to remain infectious after long periods of freezing in deep permafrost. Even though it is not threatened by immediate thawing, infections are feared during large-scale extraction from open-pit mining operations that are made easier by global warming. Exposing large concentrations of workers to the unknown microbial flora of deep permafrost layers entails a health risk that is difficult to estimate, and is of a completely different nature to simply extending the perimeter of known diseases. It is particularly desirable that a monitoring network be set up at the level of Arctic industrial activities, for which specific recommendations will have to be issued.

On a global scale, the majority of emerging diseases are zoonoses. To be better prepared for dealing with emerging diseases, there is a need for systematic surveys and reporting across nations, including monitoring how host species are on the move. The world should learn from the past pandemic and be better prepared for a next pandemic and be more proactive rather than reactive. There are emerging infections and there is severe lack of harmonization of pan-Arctic or pan-EU data, a lack of multidisciplinary analysis from different institutions, and authorities etc. The paradigms governing this study area are still heavily anthropocentric, neglecting interactions and the intersectionality between micro-organisms, animals and humans.

There is a need for developing a methodology that integrates One Health, rights of nature and environmental law. There is a need to create citizen/community science monitoring methodologies to document ecosystems and emerging microbes together with contaminants released during permafrost thaw. Public health data has to be harmonised on a European level.

This challenge should:

- Develop methodologies for citizen science, develop community-based monitoring systems for documenting ecosystems, to finally monitor emerging microbes and contaminants released from permafrost thaw.

Photo: P. Prokosch

Expected impacts and outcomes

The research is expected to produce:

- Standardized procedures of sampling/monitoring at a European level;
- Harmonized systems for domestic and wild animals (also relevant in Antarctica). Species will move towards the poles due to climate change, spreading infectious diseases, >75% of emerging diseases are zoonotic;
- New methodologies that integrate One Health, rights of nature and environmental law, together with a harmonization and integration of data on infections in humans, animals and the environment in European countries. This data will be gathered in open access databases, reflecting the dynamic processes that are ongoing in nature. These will for example help the development of Public Health, and could even give us the possibility to predict future pandemics;
- Awareness among industrial players of the health risks associated with the possible reactivation of various pathogens (bacteria, viruses, fungi, worms, etc.) preserved in deep (and therefore ancient) permafrost layers.

The proposal's outcomes will benefit:

This has the potential to benefit everyone, because in case of newly emerging diseases, there is the potential for a pandemic, and all the citizens around the globe will be impacted. Thus, by being able to monitor and predict newly emerging diseases and contaminants, global society can benefit, by being better prepared to save lives. There is a need to co-create methodologies for community-based monitoring with a component of citizen science-based monitoring, and documentation of ecosystems for emerging microbes and contaminants released during permafrost thaw. Monitoring can be managed by local research infrastructures, benefiting the communities in the area.

Indigenous societies, governance and rights

Scope

EU Arctic policy is to support the inclusive and sustainable development of the Arctic regions, to the benefit of its inhabitants and future generations, focusing on the needs of Indigenous Peoples, including women and youth. Accelerated changes due to climate change and other pressures such as the green transition are affecting people's health and wellbeing. Understanding and addressing issues faced by Indigenous societies is crucial for achieving social justice, equality, and sustainable development in the EU. The proposed research aims to investigate historical, cultural, and socio-political dimensions of the different Arctic Indigenous peoples. With this knowledge it seeks to understand the current challenges they face, assess the effectiveness of existing policies, and explore avenues for improving Indigenous rights. It will do this by enhancing participation in decision-making, and the development of inclusive and culturally sensitive knowledge-generation and governance models that uphold Indigenous rights. It also aims to enable the preservation of Indigenous knowledge, languages, and practices, which contribute to biodiversity conservation, and sustainable resource management.

There is a need to generate co-produced knowledge for prospering Indigenous societies as well as new tools and data to meet the policy goals. Arctic Indigenous Peoples are specifically affected by climate change, but also past and present colonialism, impacting their communities and wellbeing. Gaps in knowledge persist, with Indigenous communities facing land dispossession, green colonialism, loss of heritage, poverty, and limited access to education and health services. In the near future, specific studies on the impacts of the energy transition are needed. Bridging these gaps and advancing collaborative research are essential. There is a need for the study of Indigenous data, governance and sovereignty, Indigenous Knowledge and use of Artificial Intelligence. There is a need to ensure ethical AI design, to bridge the digital divide in a way that contributes to a more inclusive and equitable approach to AI development. Cultural and ethical protocols for documenting Indigenous knowledge and Indigenous languages (documentation, systematization) need to be developed and employed. Studies on Indigenous societal structures, mental health and advancement of Indigenous wellbeing, including developing educational programs to address mental health of children are also required.

This challenge should:

- Improve the understanding of the challenges Arctic Indigenous peoples face, and assess the effectiveness of existing policies;
- Explore avenues for improving Indigenous rights, participation in decision-making, and the development of inclusive and culturally sensitive governance models that uphold Indigenous rights;
- Study impacts of the green energy transition on Indigenous communities, their cultures and livelihoods;
- Study Indigenous data governance and sovereignty, Indigenous Knowledge and Artificial Intelligence for inclusive and equitable approach to AI development;
- Develop and employ cultural and ethical protocols for documenting Indigenous knowledge and Indigenous languages (documentation, systematization);
- Co-produce studies of Indigenous societal structures, mental health and advancement of Indigenous wellbeing. It should include the development of educational programs to address the mental health of children.

Expected impacts and outcomes:

The impacts will be a comprehensive understanding of Indigenous societies, governance, and rights within the EU, yielding insights into the challenges faced by Indigenous communities and identifying effective policy approaches to a just energy transition. The empowerment of Indigenous communities, informing policies for social justice, cultural diversity, and human rights. The advancement of interdisciplinary examination of historical, cultural, and socio-political dimensions of Indigenous communities. Indigenous communities will get new avenues for implementing Indigenous rights.

The proposal's outcomes will benefit:

Policymakers will receive co-produced and evidence-based recommendations for more inclusive, just policies. Academia will better understand Indigenous societies, their rights and the need for just transitions. Civil society organizations will have a better understanding of Indigenous issues, facilitating advocacy and support. The general public will benefit from increased awareness, intercultural understanding, and a more inclusive society. Research impacts can lead to long-lasting systemic change through policy influence, cultural diversity promotion, and Indigenous rights advocacy.

Sustainable economic development and energy transition

Scope

The central challenge of the EU´s energy transition lies in finding a way to rapidly and equitably extend these advantages to all citizens, while bolstering competitiveness, fostering the creation of future jobs, and effectively mitigating the costs and consequences associated with the transition. There is need for a better understanding of and improved policy pertaining to the EU's "Just Transition" mechanism to avoid risking Indigenous communities' livelihoods and cultures, particularly Sámi reindeer herding. Research is needed to comprehensively assess the social, cultural, economic, and health impacts of energy transition initiatives on Indigenous communities, including understanding the potential disruptions caused by large-scale renewable energy projects, such as wind farms or hydroelectric dams, on Indigenous lands and livelihoods. Some segments of society are or will be more extensively and negatively impacted by the rapid energy transition and several knowledge gaps remain in terms of implementing the Just Transition framework. There are gaps such as: Are there environmentally responsible methods to extract critical minerals which are deemed necessary for the electrification of Europe? How can negative impacts of the energy transition be minimized? How can the EU's "Just Transition" mechanism be implemented in a way that takes into consideration Indigenous rights and regional and cultural specificities?

There is a need to develop innovative adaptation measures to climate-related changes affecting fisheries and hunting: such as the distribution and accessibility of fish and animals, while creating new economic activities. We need to study the environmental and social impacts of past and present resource extraction, including the impacts of the energy transition and decarbonization on Indigenous Peoples, communities and rights. Global economic drivers need to be identified for the industrial development of the Arctic. What geopolitical trends and factors affect tourism, mining and processing, fish farming and forestry and their effects on the development of Arctic cities or urban centres. Research on infrastructure needs to be carried out (what sort of infrastructure – see the kind of work being done by https://infranorth.eu/) that considers the SDGs and Arctic specific SDGs are needed.

This challenge should:

- Assess the social, cultural, economic, and health impacts of energy transition initiatives on Indigenous communities, including understanding the potential disruptions caused by large-scale renewable energy projects, such as wind farms or hydroelectric dams, on Indigenous lands and livelihoods;
- Answer the following questions: Are there environmentally and socially responsible methods to extract critical minerals? How can the negative impacts of energy transition be

Photo: Henning Lorenz

Photo: J. Dahl

minimized? How can the EU's Just Transition mechanism be implemented in a way that takes into consideration Indigenous rights and regional and cultural specificities?;
- Develop innovative adaptation measures to climate-related changes affecting fisheries and hunting: such as distribution and accessibility of fish and animals and create new economic activities such as local food production;
- Study the environmental and social impacts of past and present resource extraction, including impacts of the energy transition and decarbonization on Indigenous Peoples, communities and rights;
- Identify global economic drivers for the industrial development of the Arctic. What geopolitical trends and factors affect tourism, mining and processing, fish farming and forestry and their effect on the development of Arctic cities or urban centres;
- Research on infrastructure that considers the SDGs, the development of Arctic specific SDGs is needed, such as a qualified "life on indigenous land" SDG for example;
- Examine existing legal and policy frameworks concerning the energy transition and indigenous rights. This involves evaluating the effectiveness of current regulations in safeguarding Indigenous rights, land tenure, and resource ownership in the context of renewable energy development.

Expected impacts and outcomes

The research is expected to produce:
- Understanding of global economic drivers for the industrial development of the Arctic;
- Understanding on what geopolitical trends and factors affect tourism, mining and processing, fish farming and forestry and their effect on the development of Arctic cities or urban centres;
- Innovative adaptation measures to climate-related changes, which will benefit fisheries and hunting, and create new economic activities.

The proposal's outcomes will benefit:
Identifying gaps and developing appropriate legal and policy mechanisms can help ensure the protection of Indigenous rights throughout the energy transition. The research impact can lead to long-lasting systemic change through policy influence, and Indigenous rights advocacy.

Demography and migration, equality

Scope

Climate change is threatening to displace millions of people, creating new migrant flows, within and across international borders. The EU has a leading role in reducing global warming, mitigating its effects, improving knowledge about the consequences for vulnerable populations, and to build resilience. Success depends not just on adopting forward-looking strategies, but also on adequate resources and effective implementation. Understanding the how's and the why´s of migration flows to, within and from the Arctic is needed in order to co-develop possible adaptation strategies and ensure resilience in the Indigenous communities. Research shows that migration patterns are different between men and women. There is a need for equality: by stratification of all demographic data according to age and gender, in order to implement the existing recommendations regarding research and innovation. The policy report produced by the EU funded H2020 expert group on 'Gendered Innovations' provided researchers and innovators with methodological tools for sex, gender and intersectional analysis. Impacts of climate and labour migration on Arctic societies and Indigenous cultures and languages need to be understood. We need to better understand migration flows to, within and from the Arctic, looking at inward and outward migration, accelerating urbanisation, and growing geopolitical interest in the region. Settler's adaptation to Arctic conditions needs to be investigated, and resources, both material and virtual (including health, remoteness etc) need to be improved. We need understanding of the impacts of remoteness on the delivery and implementation of education, health care and other important aspects of society and how to address these impacts. What cultural and economic opportunities and investment programmes could meet youth aspirations and improve the attractiveness of Arctic Communities.

This challenge should:

- Improve understanding of demographic profiles within the Arctic in order to identify, and map, growing and shrinking communities over the long term on a very fine scale;
- Improve understanding of migration flows to and from the Arctic to ensure resilience of the Indigenous communities and adaptation for the settlers' populations;
- Produce stratification of all demographic data according to age and gender to implement the existing recommendation regarding research and innovation;
- Investigate settler's adaptation to Arctic conditions and resources, both materially and virtually (including health, remoteness etc);
- Improve understanding of the impacts of remoteness on education, health care and other important aspects of society and how to address these impacts;
- Identify what cultural and economic factors could meet youth aspirations and improve the attractiveness of Arctic Communities.

Expected impacts and outcomes

The research is expected to produce:

- Better understanding of migration flows to and from Arctic Communities: Inward and outward migration, accelerating urbanisation versus depopulation, and growing geopolitical interest in the region;
- Understanding the impacts of remoteness on education, health care and other important aspects of society and how to address these impacts;
- Understanding what cultural and economic factors could meet youth aspirations and improve the attractiveness of Arctic Communities.

The proposal's outcomes will benefit:

The impact of climate and labour migration on Arctic societies and Indigenous cultures and languages will be understood. Investigations of settler's adaptation to Arctic conditions (including health, remoteness etc) will enable better support for individuals and new policies to be developed. The whole society, the people who migrate to the North and Arctic and those who already live there will be impacted.

Photo: P. Prokosch

Appendix: Prioritisation Methodology

STEP 1: Collecting the Input

The intent was to use the most complete set of documents for the research prioritisation. Updated national or international science plans and bottom-up contribution from the scientific community and stakeholders, have been collected and used for the research prioritisation process:

1. Integrated European Polar Research Programme (EPRP) and several background documents: The purpose was to start this process from the achievements of the previous work, mainly the EPRP. The structure of the EPRP made of 6 research needs and several key questions has been adapted. In addition, relevant documents for the prioritisation process (e.g., updated national and international strategies etc.) were collected. The aim was to start from these achievements, to keep their structure (Research Needs and Key Questions) and to look for gaps and needs in order to identify critical future research needs in the Polar Regions.

2. Call for Services projects (output of Task 3.3 "Provision of seed money for the preparation of pre-studies for European Polar research actions"):
Two projects related to the EPRP Research Needs 4 ("Prospering Communities in the Arctic") & 6 ("Inclusive creation, access, and usage of knowledge") contributed to the research prioritisation process.

These are:

i) "ArcticXchange - Exchanging knowledge and co-producing climate services with reindeer herders and Arctic communities"
ii) "CO-CREATE - comprehensive Policy Brief to the EU Commission - A roadmap to decolonial Arctic research".

Three projects related to the EPRP Research Needs 1 ("Better understanding climate change in the Polar Regions and its links to lower latitudes") & 2 ("Informed weather and climate action") were still ongoing during the prioritisation process. It was later verified that the main outcomes of these projects were reflected in the outputs of the prioritisation process.

iv) "EA-MISI - East Antarctic Marine Ice Sheet Instability. exchange and disseminate knowledge on Ice-Ocean-Lithosphere Interplay – ICEOLIA new European Research Council synergy project preparation"
v) "COLDwater - Does climate change represent a challenge for polar Communities by Limiting their access to Drinking water? – COLDwater"
vi) "HILDAE - HIgh Latitude Dust in a changing Arctic Environment focussed on supporting coordination and harmonization of activities in relation to HLD (High Latitude Dust) in the Arctic".

3. Stake- and rightsholder' workshops & meetings performed in EU-PolarNet 2 and related resources:

- The Sámi Arctic Strategy (2019)
- ASSW 2021: Online Co-creation Workshop
- ICASS 2021: Online Workshop Co-creating Knowledge
- ASSW 2022: Online Co-creation Workshop
- EU PolarNet 2 visit to Kautokeino, August 2022
- EU PolarNet 2 workshop during SMM – International Maritime Trade Fair" (6-9 September 2022 – Hamburg, Germany)
- EU PolarNet 2 Workshop, Nuuk, Greenland, 7-11 November 2022

4. Consultation within the EU Polar Cluster community: The EU Polar Cluster projects were asked to answer the question "What do you think are the potential gaps and future needs that should be addressed based on the expected outcome of your research?" We received valuable feedback from 8 projects out of 25.

5. Consultation within the Polar Expert Group (PEG): PEG members were asked to answer the following questions "Have any of the six Key Questions of the EPRP been addressed in previous or ongoing national or international research projects during the last years that you know of? If yes, please send us links to these projects" and "Are there any gaps in the Research Needs/Key Questions defined by EU-PolarNet1 based on new information that has emerged during the last years? Please, define new Research Needs/Key Questions." For this consultation the valuable contribution of around 20% of PEG members fed the process.

Other inputs that have been considered in the process were:

- ESA Polar Science Collocation Meeting ESA/ESRIN (Frascati) – November 2022.
- ASSW23 sessions on "EU-PolarNet 2: advancing European Polar research strategies" and "EU Polar Cluster Community Meeting".
- Policy briefing event (Brussels, 3rd of May 2023) titled "Recent changes in the Antarctic and their impacts on Europe", jointly organised by the Horizon2020-funded EU Polar Cluster projects: EU-PolarNet 2 and SO-CHIC, with TiPACCs and PROTECT.

STEP 2: Performing a systematic analysis

Step 2 consisted of two sub steps:

i) Directly studying and analysing the main input documents (reported in Step 1) and harmonising them to align with the structure of the EPRP. This was a qualitative analysis of the texts.
ii) Performing topic analysis using a text mining methodology. This is a quantitative analysis.

For the second sub step (ii) different tools were investigated to extract the information needed from the documents collected and analysed in Step 1. The intention was to be as objective as possible while preparing the basic working documents for the retreat (Step 3).

For our scope the T-LAB textual & statistical analysis software was used to perform a systematic analysis. The support of the software developer was also provided.
In Figure 2, the T-LAB workflow is shown. The main goal of T-LAB was to group text segments into thematic clusters (i.e., elementary contexts) and select for each cluster a set of text segments which best describes its thematic content, from which a preliminary list of priority topics has been extracted to feed Step 3.

T-LAB analysis consists of two main phases:

a) A Natural Language Processing (NLP) process, which is implemented by transforming the texts into database tables.
b) Topic analysis, which is performed by multivariate and comparative methods.

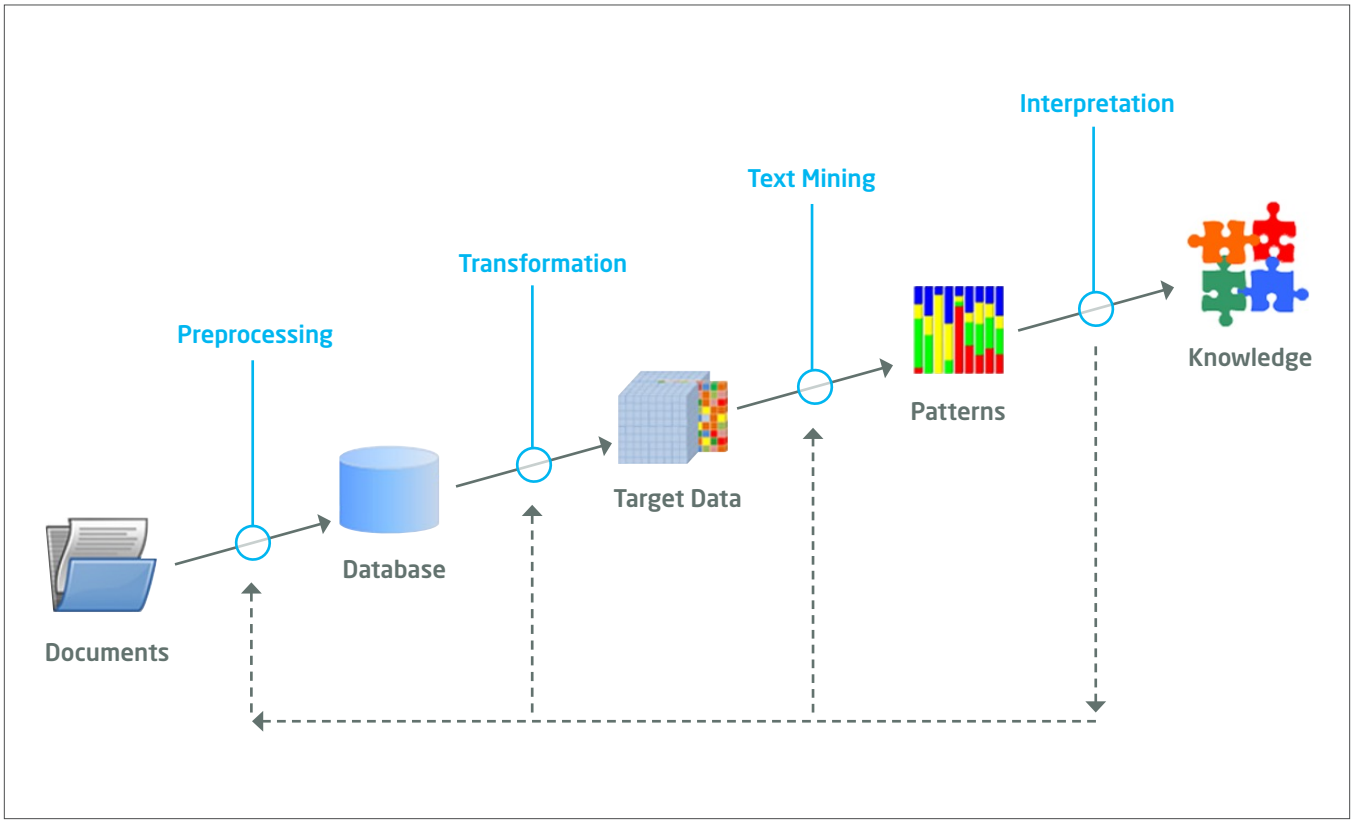

Figure 2: T-LAB software workflow

To convert "unstructured data" (i.e., texts) into 'structured information' (i.e. a database), T-LAB performs various steps which, as they are transparent, can be customised by the user. In our case, an eight-step-procedure was carried out (see D 3.5 for details). Based on this procedure, a preliminary list of priority topics has been extracted to feed Step 3.

To support the retreat and streamline the process, it was decided to limit the number of priorities per research need. Furthermore, instead of merely providing titles, we developed complete and comprehensive descriptions for each priority topic, using the templates and guidelines reported below. Based on this information the outputs from T-Lab are as follows (Examples from Need 4, prospering communities in the Arctic):
T-Lab generates a number of outputs to assist in the construction of various key questions. Cluster analysis gave rise to a set of keywords based on their frequency in the text.

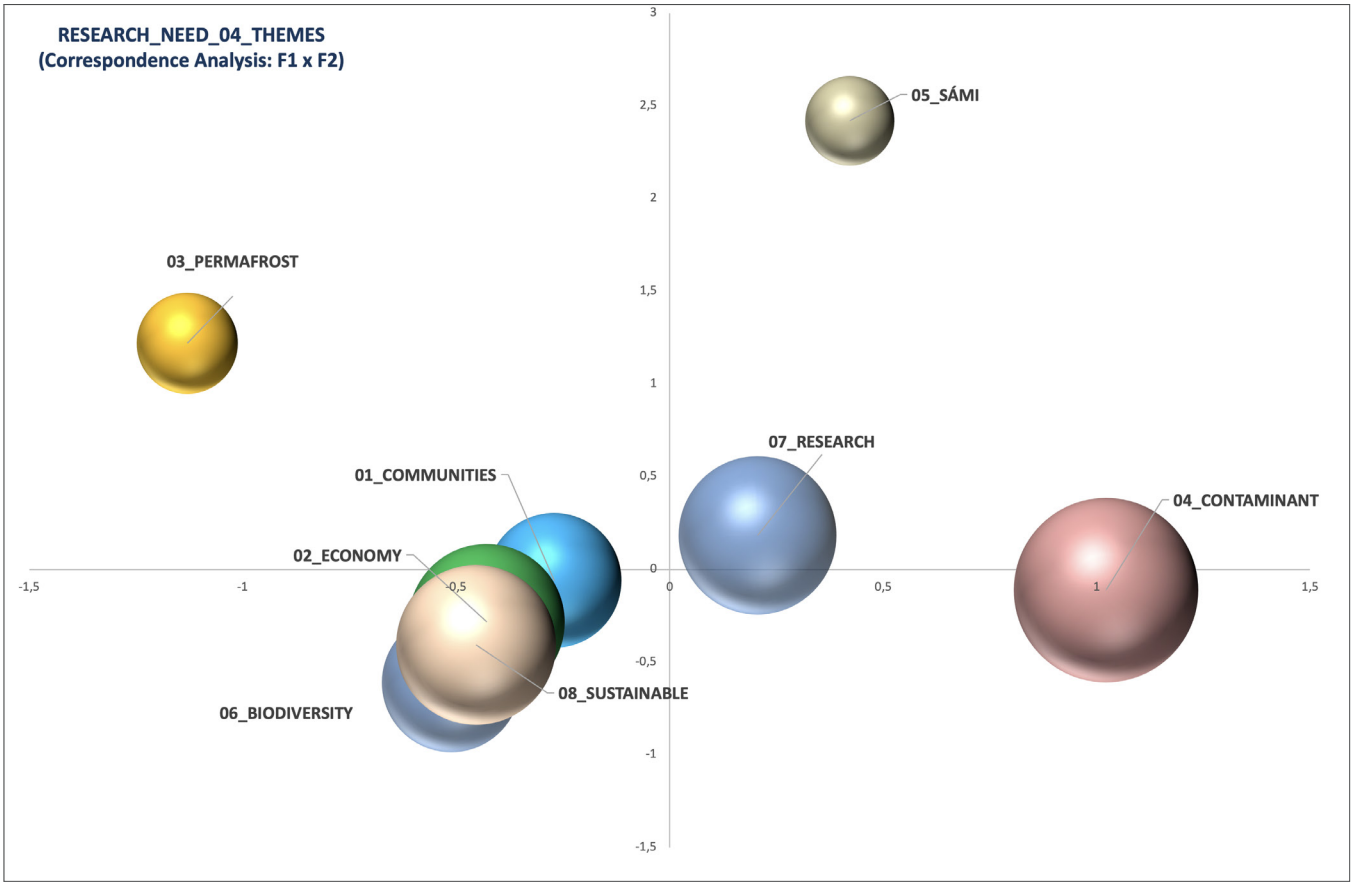

Figure 3: Outputs from T-Lab for Research Need 4, "Prospering communities in the Arctic". Cluster analysis gave rise to a set of keywords based on their frequency in the text.

As an example, those keywords also have words associated with them with a score like in the table below (transforming the texts into database tables). See Annex 4 of Deliverable 3.5.
The output of Step 2 is a preliminary list of priority topics for each research need and key questions (between 40 to 70 for each Research Need). See Annex 5 of Deliverable 3.5.

STEP3: PEG Retreat

The retreat was the culmination of the process with which the research prioritisation was completed. The PEG retreat took place in San Servolo (Venice Lagoon) from 12th to 16th June 2023. 34 experts participated in the event of which: 16 from the Executive PEG, 15 from the project consortium, 1 international partner from ESA and 2 representatives from two EU Polar Cluster projects.

The participants were divided into 4 working groups, which refer to the research needs of the EPRP:

1) Breakout Group 1: Polar Climate System (referring to Research Need 1 and 2)
2) Breakout Group 2: Polar Biodiversity (referring to Research Need 3)
3) Breakout Group 3: Human Impacts on Polar System (referring to Research Need 5)
4) Breakout Group 4: Prospering Communities in the Arctic (referring to Research Need 4)

No specific Breakout Group was created for Research Need 6, as it was considered cross-cutting and was discussed in all Breakout Groups.
The main consecutive tasks/steps performed during the retreat were:

1. Consolidation of the List of Topics provided by Step 2: this activity consisted in the revision of the initial list of topics with the aim to reduce them by proper integration, combination, or cancellation of topics.
2. PICK chart through online questionnaires collecting values from experts (Scales from 1 to 5) on the following two parameters for each topic: Importance (representing the x-axis of the matrix), Difficulty (representing the y-axis of the matrix).

The importance parameter has been defined on the basis of the criteria reported below. The definition and relative weight are provided as well.

Criteria for importance

Criteria	Definition	Weight
Scientific Relevance	Evaluate the scientific relevance, novelty of the research question, including its potential contribution to closing knowledge gaps and its relevance to current scientific inquiries. Consider the project's methodology, data collection techniques, and analysis procedures to ensure the production of high-quality reliable data.	1
Collaboration	Assess the potential for collaboration with local communities, other research institutions, and international partners to enhance the project's effectiveness, ensure cultural sensitivity, and promote knowledge co-production.	0.7
Societal relevance and Impact	Evaluate the potential societal relevance and impact of the research question, including its contribution to conservation efforts, sustainable development, policymaking, urgency and public awareness/engagement.	1
Interdisciplinary Approach	Encourage an interdisciplinary approach by integrating multiple scientific disciplines, such as biology, geology, climate science, oceanography, and social sciences, to provide a comprehensive understanding of polar regions.	0.7

The difficulty parameter is defined based on the criteria reported below. The definition and relative weight are provided as well.

Criteria for difficulty

Criteria	Definition	Weight
Feasibility	Consider the practical feasibility of answering the research question at a reasonable time scale. This includes technical development, accessibility, methods and data availability or if new development of methods/instruments is necessary.	1
Safety	Prioritise the safety of the research team and any indigenous communities or wildlife in the polar regions, considering the harsh and unpredictable environmental conditions, extreme temperatures, and potential risks associated with fieldwork.	0.7
Resources	This includes availability of financial resources, personnel, and Research Infrastructures in the given timeline.	1
International collaboration and permits	Conducting research in polar regions often requires collaboration with international partners, obtaining permits from relevant national authorities, and adhering to international regulations. Navigating these bureaucratic processes can add complexity and increase the time and effort required.	0.7

Each expert gave a score from 1 to 5 to each of the above-mentioned criteria for each of the two parameters for each Topic.
In the table below the qualitative descriptors associated with the SCORE scale for "Importance" and "Difficulty" are reported.

Criteria	Evaluation
5	exceptional urgency/ relevance extremely difficult
4	Very strong urgency/relevance Very difficult
3	Strong urgency/relevance Difficult
2	Some urgency/relevance Somehow difficult
1	Little urgency/ relevance Not difficult

Conclusion

Acknowledgements

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- The Work Package 3 team
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- The Executive Polar Expert Group, https://eu-polarnet.eu/polar-expert-group/
- The EU Polar Cluster members, https://polarcluster.eu/
- The Call for Service projects, https://eu-polarnet.eu/services/
- Indigenous rights-holders and industry stakeholders

EU-PolarNet

Co-ordinating and Co-designing
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Photo: Mulvaney@PNRA/IPEV

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