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CONNECTING SCIENCE WITH SOCIETY

Deliverable 2. 1
Report on prioritised objectives in Polar Research

Submission of Deliverable

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Executive Summary

Polar issues have been rising up the political agenda across Europe over the past decade since the rapid changes occurring in the Polar Regions are significantly influencing global climate with consequences for global society. The European Union and its executive body, the European Commission (EC), attribute an increasing importance to science and innovation in the high latitudes for a variety of reasons.

In this framework, EC has launched a five-year coordination and support action "EU-PolarNet – Connecting Science with Society", which will work in close cooperation with the EC in shaping Europe's polar research and policy agenda. EU-PolarNet will establish an ongoing dialogue between policymakers, business and industry leaders, local communities and scientists to increase mutual understanding and identify new ways of working that will deliver economic and societal benefits. The results of this dialogue will be brought together in a plan for an Integrated European Research Programme for the Antarctic and the Arctic that will be co-designed with all relevant stakeholders and coordinated with the activities of many other polar research nations beyond Europe.

As a first step, the project consortium has been tasked to compile a set of European research priorities for the Polar Regions, which shall serve as a basis for the upcoming research planning process in EU-PolarNet. These priorities have been identified by a desk study based on publications of national Polar strategies, international consortia and major scientific clusters. The list of the consulted documents is reported in the Annex.

Through a complex step-by-step process, all polar research strategic documents have been analysed. A huge amount of relevant information has been extracted, processed, harmonized and synthetized into **ten overarching topics**. Each topic includes several **key-questions, which are summarizing the hundreds of key questions and priorities of the background documents**. A paragraph describing the relevant **Societal Challenges** connected to each scientific topic has been added in order to match research priorities and societal needs.

Based on this work, an on-line consultation has been launched in order to integrate the Science Community's input into the compilation of research priorities and related societal challenges. Through this consultation, it has been possible to verify the completeness of the original compilation and the related societal relevance.

1. Introduction

Among the major overarching actions towards a future European scientific strategy in Polar regions, the Horizon 2020 EU-PolarNet project plays a crucial role. EU-PolarNet is looking at the identification of key questions in polar research and their prioritization. A major target of this process is the establishment of a multi-expertise forum to discuss polar research issues and provide opportunities for different interested groups, and not just scientists, to give their views.

In this framework, the Deliverable 2.1 of EU-PolarNet deals with the identification of the key questions in polar research and their prioritisation.

In the last five years many Polar and Polar related relevant publications have been produced by scientific clusters and International Organizations such as the IASC, SCAR and national science plans. These publications aim specifically at highlighting relevant scientific priorities able to fit the main societal needs and to achieve a sustainable development, respectful of the environment.

In order to identify Europe's-relevant key questions in Polar Regions, a desk study based on publications of the major scientific clusters has been carried out to collate the range of research questions emerging from relevant and authoritative scientific documents.
The general target has been **to harvest the most topical national and international priorities from existing documents, extract, summarize and prioritize all the key questions** and launch a public consultation on the EU-PolarNet website to get feedback from the relevant communities and stakeholders.
As a second stage, based upon the results of the desk study, an on-line consultation has been launched in order to get the Science Community's input into the compilation of research priorities and related societal challenges. Through this consultation, it has been possible to verify the completeness of the original compilation and its societal relevance.
This process will result in a set of conclusions and recommendations addressing Polar related issues, which will be the basis for the first EU-PolarNet Townhall meeting hosting representatives from all the key scientific communities as well as representatives from relevant international programmes such as ArcticNet, ASP, SEARCH, IPA, CliC and WCRP, bodies such as the Belmont Forum and longer-term initiatives, such as Future Earth.
Conclusion and recommendations will be synthesized into a Report that will also provide essential inputs to a series of six White Papers on the six top-research priorities looking forward to the development of an Integrated European Polar Research Programme for Europe.

2. The Desk Study: Identifying Priorities and Key-Questions

Going into details of the Desk Study, a comprehensive work has been carried out by extracting research priorities and questions from a large number of polar research strategies, national science plans and other relevant documents. The list of the documents is reported in the Annex 2.
Based on these documents, polar topics linked to climate change and other key issues relevant to Arctic and Antarctic marine and terrestrial environment and surrounding atmosphere and space have been carefully considered and extracted. In some documents phenomena affecting the whole Planet, such as sea level rise, changes in marine ecosystems, climate change and ocean acidification, were addressed by a global-scale point of view: these phenomena clearly concerned also the Polar Regions.

Topics related to technological and methodological issues as well as Human and Social Sciences, (health, well-being, adaptation and mitigation, policy and international cooperation, etc.) have also been considered. It is worth mentioning that Social Sciences and Humanities issues have been additionally and extensively addressed and summarized during and after the meeting held in Venice in January 2016
According to the Partners' resolutions taken in Berlin in September 2015, the huge amount of information extracted from the polar research strategic documents has been processed, harmonized and synthesized through a complex step-by-step process, into twelve overarching topics (Fig. 2).
The key-questions extracting phase resulted in a Matrix made of ten overarching Topics, thirty Sub-topics (two-three Sub-topics for each overarching topic, on average) and hundreds of key-questions distributed among the Sub-topics.
As for the analysed documents, the resulting Matrix was also affected by a high rate of heterogeneity and the Partners have been asked to contribute to fill some existing gaps. The Matrix has been circulated for further comments and improvements, especially related to the additional merging of topics/questions and to the prioritization of questions.

The comments from Partners provided the Matrix with a crucial added value. From a general point of view the inputs can be clustered in three main groups:

- Group 1: (clustering the majority of Partners): improvement of the Matrix (integration/redefinition of some Topics, Sub-topics and questions), basically keeping the general structure, as it was proposed.
- Group 2: (primarily proposed by Norwegian Partners): improvement of the Matrix with the reduction of Topics and Sub-topics and re-packaging of questions
- Group 3: (mainly proposed by Human and Social Scientists): reorientation of the Matrix in terms of the connection between science and relevant social issues.

In this framework, the following process was adopted:

- Step1: integrating and rationalizing (eliminating overlapping and homogenizing the style) the current Matrix with all contributions coming from the first group of contributors. This step resulted in the new improved **Matrix _1**.
- Step2: merging the improved **Matrix_1** into the proposed Norwegian structure. This step resulted in a new matrix, **Matrix _2.**

The scheme of the process is shown in Figure 1.

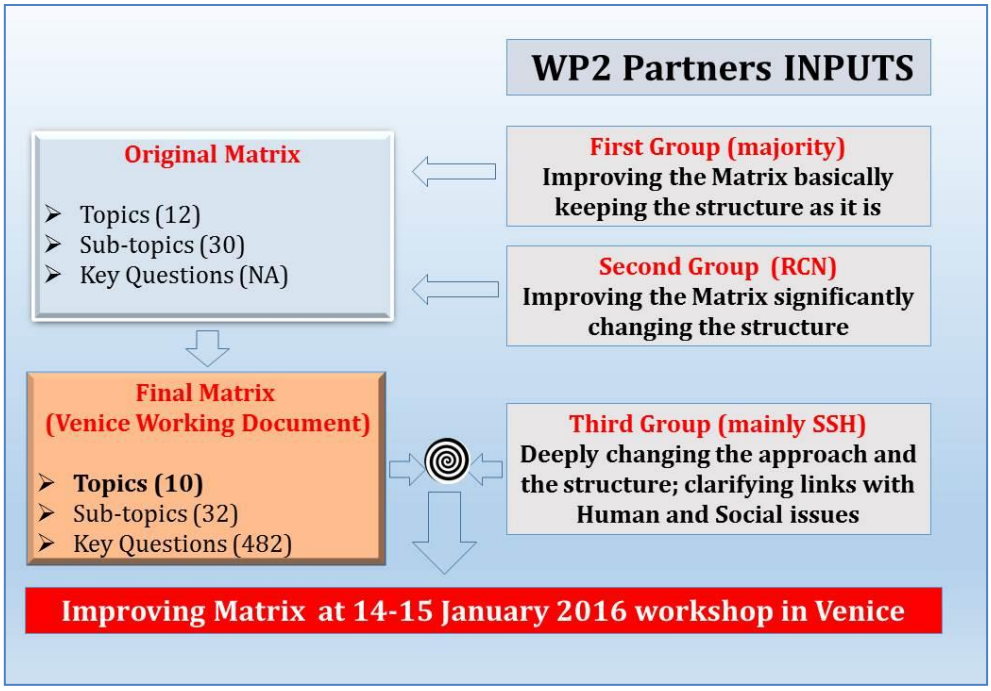

Figure 1: Scheme of the prioritization process

Topics	Sub-topics	Questions
1. Polar Climate System	4	63
2. Cryosphere and Sea Level	4	42
3. Geodynamics and Mineral Resources	4	43
4. Paleoclimate and Paleo-environment	2	43
5. Pollution and Greenhouse Gases	5	45
6. Understanding Ecosystem Changes and Preserving Biodiversity	5	115
7. Astronomy, Astrophysics and Space	3	13
8. Sustainable social and economic development, Healthy People and Resilient Communities	3	65
9. New Technologies and Methodologies	3	61
10. Strategy, Policy and Cooperation	3	35
total	36	525

Figure 2: Final Matrix used as working document at the meeting in Venice (January 2016)

The resulting list of Topics is shown Figure 2. In this scheme the Sub-topics and key-questions included in each Sub-topic are not shown extensively: the total amount of Sub-topics and key-questions is shown in the right part of the figure. The Matrix of Figure 2 has been adopted as Working Document at the WP2 meeting in Venice on January 14-15, 2016.

3. Further processing: Meeting in Venice, January 2016

During the workshop in Venice the WP2 partners examined and discussed extensively the draft Matrix of topics, sub topics and questions provided as working document. The group was composed by (alphabetic order) Roberto Azzolini (IDPA, Italy), Carlo Barbante (IDPA, Italy), Renuka Bahde (EPB, The Netherlands), Nicole Biebow (AWI, Germany), Johan Etourneau (CNRS, France), Jon Børre Ørbæk (RCN, Norway), Antonio Quesada (MINECO, Spain), Denis-Didier Rousseau (CNRS, France), Søren Rysgaard (Aarhus University, Denmark) /Greenland, Annette Scheepstra (RUG, The Netherlands), Gertrude Saxinger (University Wien, Austria), David G. Vaughan (BAS, UK). Three Working Groups have been established to analyses the Matrix.

3.1 Improving the Matrix

The original overarching Topics have been redrafted so as to better represent the major scientific priorities of crucial importance for societal needs for the coming years.
The original Sub-topics and Questions were carefully analysed and clustered in a reduced number of Questions capable of condensing the previous array in a more synthetic but also exhaustive way. The Matrix's Sub-topics (36) and Questions (525) have been left out and new Questions replaced the former Sub-topics, including also the huge amount of the original questions.

This process has resulted in a new array consisting of two levels (Topics and Questions) instead of the former three levels (Topics, Sub-topics and Questions). In this new array, the Questions have replaced

the previous Sub-topics by extending their content and wording in order to represent in a most comprehensive way all the original questions.
As an additional crucial step for improving the Matrix's representativeness and significance, the importance and priority of Human and Social Sciences has been addressed through an extensive and detailed discussion. The discussion resulted in providing guidelines for integrating such priorities in the natural sciences priorities and in establishing a Working Group to expand and deepen the integration between the two frameworks of Natural and Human and Social Sciences in the Matrix's scheme.

Moreover, having in mind the need for a more "solution-oriented" research, as repeatedly emphasized by authoritative researchers, major funding agencies and Arctic residents, an additional effort has been made to enhance the relevance and key priorities of Human and Social Sciences.
In this framework a set of "Boxes" describing the relevant Societal Challenges connected to each scientific priority question has been introduced in the Matrix for each Topic, in order to meet the need of highlighting the relations and interconnections between Natural Sciences priorities and Human and Social Science priorities. As an example, the Topic Polar Climate Systems, will include societal challenges boxes highlighting the societal relevance of global sea-level rise; safe marine operations; weather and sea-ice forecasting. This solution meets two targets: first, to summarize a clear set of priority topics to be addressed in Polar Sciences, which will serve to build future strategic actions for Europe in Polar Regions; second, to clarify the crucial role of science to provide relevant knowledge and solutions societal needs and relevant political and economic issues related to sustainable development of Polar Regions.

4. The Key-Questions and their societal relevance

Based on the information extracted from the polar research strategic documents (see Annex 2) and on the comprehensive analysis and synthesis carried out in the above described process, a final Matrix made of 12 overarching Topics and 44 Key-Questions has been developed. The Working Team is confident to represent the best possible approximation of the large number of scientific priorities found in the reference documents. A paragraph describing the relevant Societal Challenges connected to each scientific topic has been added in order to highlight the match of the research priorities with the societal needs.
The resulting Overarching Topics are shown below. The new Matrix, made of 12 Overarching Topics, 44 Key-Questions and 12 Societal Challenges boxes relevant to the Key-Questions has been made available on the web for a public consultation from February 16th to March 7th, 2016 until March 9th 2016.

1. Polar Climate Systems (includes 5 Key-Questions and Societal Challenges)
2. Cryosphere (includes 3 Key-Questions and Societal Challenges)
3. Solid earth and its interactions (includes 3 Key-Questions and Societal Challenges)
4. Palaeoclimate and Palaeoenvironment (includes 3 Key-Questions and Societal Challenges)
5. Astronomy, Astrophysics and Space (includes 3 Key-Questions and Societal Challenges)
6. Human impacts (includes 3 Key-Questions and Societal Challenges)
7. Polar ecosystems and biodiversity (includes 4 Key-Questions and Societal Challenges)
8. Sustainable management of resources (includes 5 Key-Questions and Societal Challenges)
9. People, Societies and Cultures (includes 5 Key-Questions and Societal Challenges)
10. Human health and Wellbeing (includes 3 Key-Questions and Societal Challenges)

11. International relations and legal dimension (includes 3 Key-Questions and Societal Challenges)
12. New technologies (includes 4 Key-Questions and Societal Challenges)

5. Online consultations

On February 16th, 2016 a public online consultation was launched within the international scientific community. The EU-PolarNet consortium asked for the input to a limited number of questions in order to check whether the compilation of priorities was complete and the societal relevance well addressed. The public consultation was open until March 9th, 2016. The questionnaire has been completely anonymous. The recipients have been provided with the European research objectives in polar research and the list of reference. EU-PolarNet online Questionnaire was structured as follows:

1) ANOYMOUS DEMOGRAPHIC DATA
   a. Professional background
   b. Main area of interest (Arctic, Antarctic, Both Poles)
   c. Country of current residence
   d. Years of professional experience
   e. Gender
2) EUROPEAN POLAR RESEARCH PRIORITIES
   a. "Are your national priorities for polar research reflected in our summary? (Well, Fair, Poor)"
   b. "Do you feel there is a societal challenge that has not been addressed in our document? (Yes, No) If yes, please indicate, which societal challenge is missing."
   c. "What are the most important topics for European Polar Research that should be the subject of strategic discussions with stakeholders, in order to develop future funding priorities? Sustainable and safe management of the Polar regions with major concern to the Arctic Population wellbeing; Climatic connection between high and middle latitudes"
   d. "Have we missed looking at any important document? (Yes, No) If yes, please indicate which document(s) is/are missing and the web link to access it/them or a full reference."
   e. "Any further comments"

5.1 Online questionnaire outcomes

The EU-PolarNet online consultation was open for three weeks from February 16th until March 9th 2016. The online questionnaire was very well received from the public. Two hundred thirty six persons, mainly scientists, from all over Europe have participated. Some results are presented herein, based on the outcome of the online questionnaire and on further contributions from EU-PolarNet partners.
The following two tables show the area of application (Arctic, Antarctic, both poles) and the nationality of the contributors.

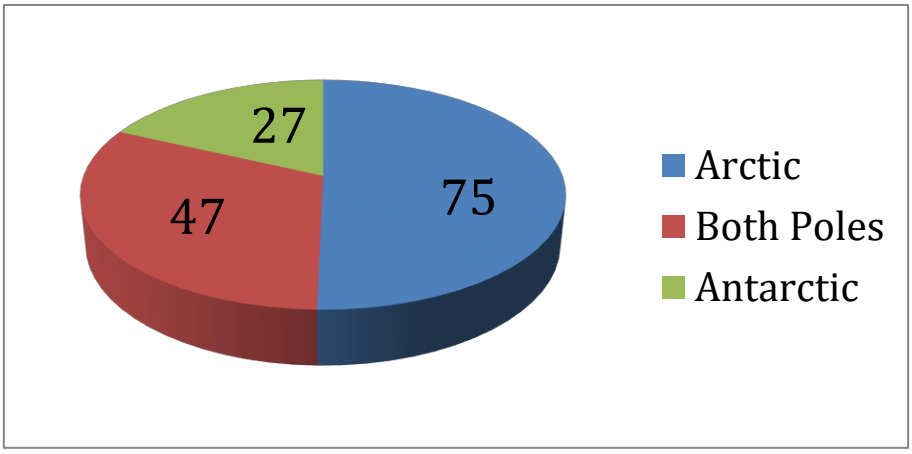

Figure 3: Area of application (Arctic, Antarctic, both poles) of the contributors

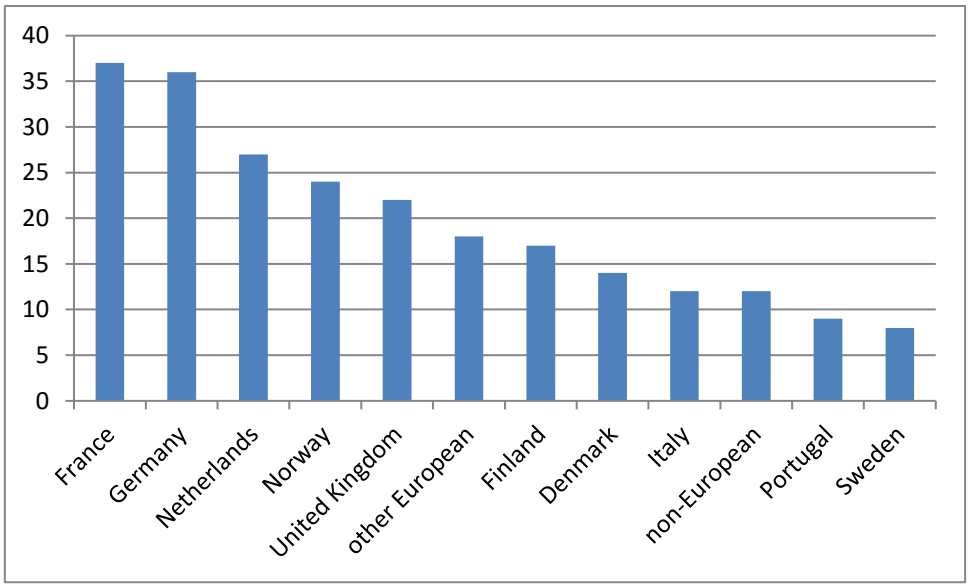

Figure 4: Nationality of the contributors

The following three figures show the result of the quality of the provided documents supporting the European National Polar priorities (Figure 4), the missing of relevant documents (Figure 5) and the missing of relevant societal challenges (Figure 6).

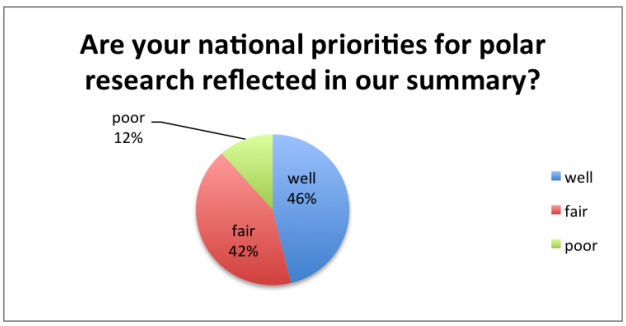

Figure 5: Evaluation of the scientific documents

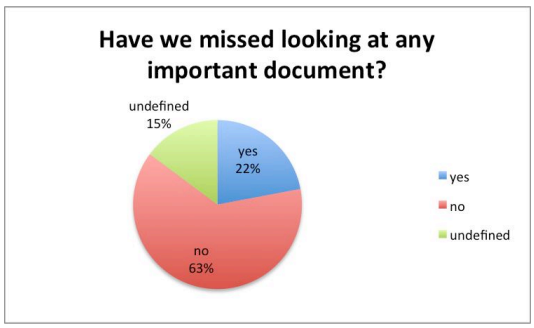

Figure 6: Relevant documents missed

The provided scientific documents supporting the European Polar Research Priorities have been largely considered to be comprehensive and representative of the European National Polar Priorities, being the ranking well and fair equal to 88% of the answers; just a minor part of the contributors (12%) considered the documents not completely representative of all their national Polar Priorities. This result is consistent with the figure 6, where a minority of the contributors (22%) consider that in the priorities analysis some relevant documents have not been considered.

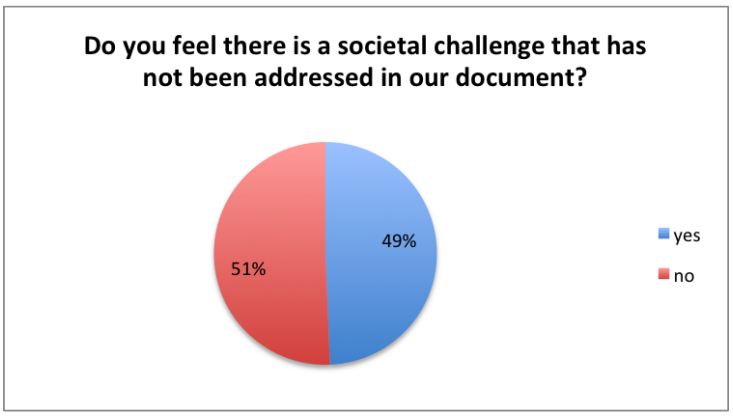

Figure 7: Perception of the completeness of the addressed societal challenges

On the other side, the majority of the contributors (51%) did not consider the provided societal challenges covering all the potential societal needs and suggested additional societal challenges to integrate the already identified ones.

5.2 Missing societal challenges

Question 2b asks if there are any societal challenges that have not been addressed in the European Polar Priorities. Should there be any, the contributors are requested to indicate, which societal challenge is missing.

Within this section, inputs have been provided for each of the 12 Overarching Topics of the European Polar Key-Questions. Based on the analysis of the 49% of the answers which considers the provided societal challenges not covering enough all the potential societal needs, a list of 32 Core Topics of societal relevance have been extracted and grouped in five groups:

1. **Climate change and related impact**. including global changes, climate changes, impacts, ecosystems, biodiversity, global warming, atmospheric changes, ocean processes, earth system changes, interactions; This group includes Polar Climate Systems, Solid earth and its interactions, Polar ecosystems and biodiversity, Palaeoclimate and Palaeoenvironment
2. **Cryosphere and sea-level,** including sea-ice, sea-level, ice and snow distribution, ice melting; This group includes Cryosphere, New technologies (cross-cutting)
3. **Policy and Society:** including funding, European policy, support, international cooperation, weather forecast for targeted users, stakeholders, human issues, communities; This group includes People, Societies and Cultures, Human health and Wellbeing, International relations and legal dimension, Astronomy, Astrophysics and Space,
4. **Resources, sustainability**: including resources, sustainable development, industrial (including resources) management; this group includes Sustainable management of resources, Human impacts (includes 3 key-questions and Societal challenges), New technologies (cross-cutting)
5. **Predictions, monitoring, data policy**: including data, future scenarios, monitoring. This group includes also relevant aspects of New Technologies.

Figure 8 shows the distribution in percentage of the main Societal Challenges that have been highlighted by the contributors.

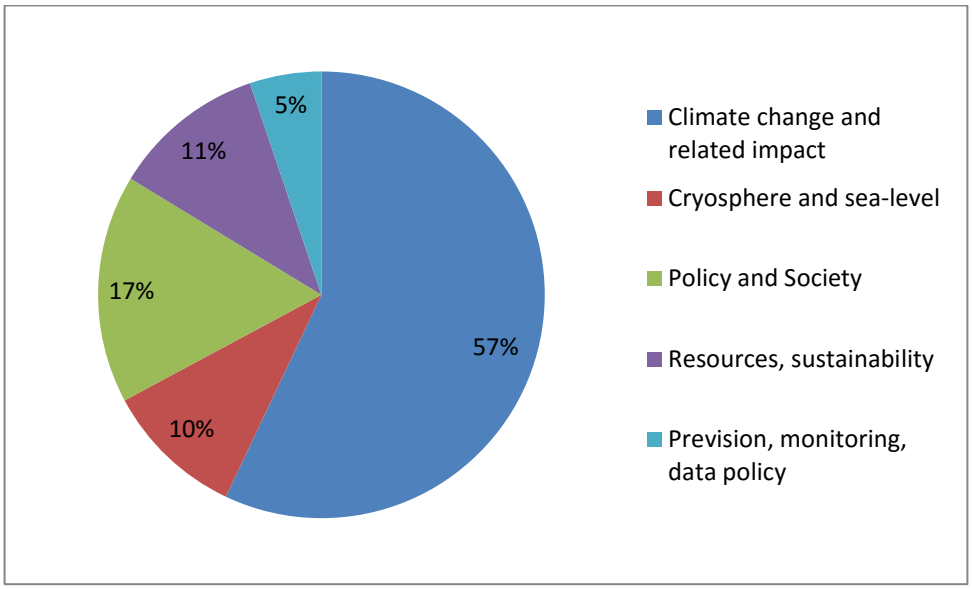

Figure 8: Distribution in percentage of societal challenges areas suggested by contributors.

This result must be carefully analysed in order to highlight more clearly the Societal Challenges that have not been satisfactorily expressed or missed. However, some general advice and concerns raised from the online consultation can be mentioned:

- The provided European Polar Priorities focus too much on marine impacts and issues;
- There is very little about infrastructure building and potential for business;
- The Societal challenges focus on the Arctic and should also refer to Antarctic issues related to sub-sea permafrost, environmental pollution, terrestrial environments and other issues of concern;
- Aerosols and atmospheric alterations seem to receive more relevance than other pollutants of societal relevance;
- The word "snow" is absent from this document, although it is the most obvious and societal relevant feature of the cryosphere;
- No mention of the carbon sink in the Southern Ocean, nothing on biogeochemistry. Both are key processes within Polar Climate and Ecosystems;
- It is very weird to have separated ecosystems and biodiversity from Climate and to have ignored biogeochemistry;
- There is too much emphasis on sustainability of biodiversity use (i.e., exploitation) and insufficient attention to outright protection of wildlife, fish and marine invertebrates;
- A strategic approach to understand and find mechanisms to mitigate the influences of the Polar regions on the outside regions should be encouraged: not purely thinking of the Polar Regions in isolation.

5.3 Topics for discussion with stakeholders

Question 2c asks what the most important topics are for European Polar Research that should be the subject of strategic discussions with stakeholders.

Almost all contributors answered this question. Using the same approach as for the Societal Challenges, a list of 32 more recurrent Topics have been extracted by the contributions and grouped into the same groups of the Societal Challenges.
Figure 9 show the distribution in percentage of the fields of the most important Topics to be discussed with stakeholders that have been highlighted by the contributors.

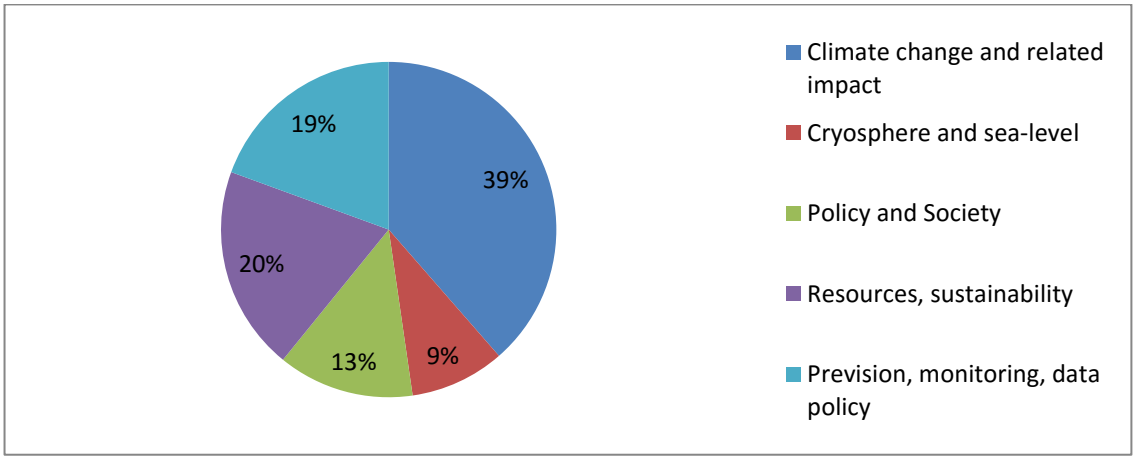

Figure 9: Distribution in percentage of the fields of the most important topics to be discussed with stakeholders.

Comparing the missing Societal Challenges (question 2b) with the most important Topics to be discussed with stakeholders (question 2c), it could be noticed that Climate Change and its impact is largely the top field for both questions. This preliminary result is not surprising and indicates that Climate Change entails a huge amount of Societal Challenges, greater than the ones that have been represented in the online questionnaire. On the other hand, the impact of Climate Change in every field is a major concern to be discussed with stakeholders, including Policy Makers.
In a second position, missing societal challenges are indicated in the Policy and Society fields. These fields include, among the others, issues related to relation between users (including indigenous populations), scientists and policy makers, in terms of supporting population needs, establishing appropriate juridical frames, protecting environment and wellbeing. Instead, the second position among the most important topics to discuss with stakeholders field includes issues related to resources exploitation and management and sustainable development. The field of prevision and monitoring is considered at the same high level of importance to be discussed with stakeholders, since the capacity to invest in the future lies in the understanding of future environmental and societal conditions.

6. Further contributions from the Partners

The analysis of the responses to the online consultation may be integrated with some relevant suggestions addressed from the Partners at the General Assembly of EU-Polarnet (Fairbanks 13 March 2016). The suggestions concern some important research topics that should be better highlighted in the list of scientific priorities for Europe. These topics can be summarized as follows:

Cryosphere: This Topic is basically focused on the Arctic and should also address Antarctic issues related to the dynamics of terrestrial and sub-sea permafrost and to the indicators and spatio-temporal impacts of permafrost degradation on the environment. The European Priorities have been integrated accordingly.

Solid earth and its interactions: It is widely agreed that understanding the Antarctic tectonics is a key issue to understand the global tectonic of our planet. Understanding the geodynamics of Arctic and Antarctic regions, particularly the interaction of the Antarctic plate tectonics with several other tectonic units, is an important Societal Challenge that needs to be addressed in this topic. The European Priorities have been integrated accordingly.

Palaeoclimate and Palaeoenvironment: Several researchers are examining the response of ecosystems to past climate conditions during the Holocene. As an example, the PAGES-Antarctic group is preparing two scientific papers on the climate variability in Antarctica (temperature, precipitation) during the last 2,000 years. A reference to the Holocene climate variability is missing in this topic. An additional question on the differences in system-scale changes between the current warming, that in the mid 20th century, and that of earlier periods in the Holocene, and in the more distant past (i.e., mid-Pliocene) has been added.

Human Impacts: A question addressing the link between increasing bioavailability and bioaccumulation of trace metals and metalloids and food webs, and related processes in polar areas, needs to be included in this topic with similar emphasis as that given to the greenhouse gases and aerosols, and acidification in order to achieve greater balance within the major questions to be addressed in the future. These contaminants are also a major concern in the Arctic as well as in the Antarctic areas. Therefore, a question has been added accordingly to the European Polar Priorities list.

Identifying resilience in biological systems to contamination is also an important issue, still with several gaps, and fundamental as background for the other questions already presented within this Topic. An additional question addressing the biological and genetic adaptation strategies of organisms to contamination, to provide resilience to polar terrestrial, limnic and marine biological systems has been added**.**

Polar ecosystems and biodiversity: The Topic 7**,** "Polar ecosystems and biodiversity, is based on a huge amount of documents and related priorities. The four overarching Key-Questions of this topic try to summarize at the best the major topics addressed in the original documents. However, there are still major gaps in fundamental knowledge on ecosystem functioning and biodiversity in Polar areas which should be acknowledged and addressed.

There are several important aspects in terms of improving the knowledge on the Polar Biology that should be enhanced in the provided European Polar Priorities. Low emphasis is given to the terrestrial Polar ecosystems in comparison to ocean ecosystems. The urgent need for new knowledge on the dynamics of Polar biological communities (from microbes to top predators) and the integrations between them and adaptations to the extreme environment conditions must be further stressed. In fact, this fundamental knowledge is essential to cover topic 6 "Human impacts", topic 8 "Sustainable management of resources" and the Bioprospecting aspect highlighted in topic 12 "New Technologies". A broader Biological Topic 7 (e.g. Polar Biology, Ecology and Biodiversity) could give more emphasis to terrestrial polar ecosystems, to the urgent needs of new knowledge on polar biological communities and to the interactions between them and with the environments.

As for the invasive species**,** many references on invasive species have been found in the scientific reports and assessments which have been used for compiling the key-questions. Although this

important topic has been mentioned in the European Polar Priorities, a stronger emphasis has been recommended in the final Report. Therefore, a Key Question has been added accordingly.

In conclusion, the very wide spectrum of important topics falling into this section require to include more questions in Topic 7 in order to better represent this vast biological compartment and eventually relocate some of the current questions. Consequently, two Key Question have been added to the European Polar Priorities list, addressing the fundamental biological processes from the organism to community level in Polar regions and the major threats and implications of changing biodiversity in Polar regions.

International relations and legal dimension: Even if the current Key-questions already address the Conservation issue in different sections, this topic must be emphasized within the European priorities, also taking into consideration the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) tasks and the IPBES Stakeholder Days, 20-21 February 2016 feedbacks. Conservation related issues could be properly represented in Topic 7, but Topic 11 may also allocate properly this issue because of its strong connection to international cooperation and regulations. In this Topic, two further Key question have been added, addressing how can management measures be assessed and strategies determined that best promote conservation of the biodiversity and how effective are Antarctic and Southern Ocean conservation measures for preserving evolutionary potential.

7. Major cross cutting themes:

When finalising the compilation of the European Research Priorities, the working group decided to remove the former themes 11 International relations and legal dimension and 12 New Technologies from the list. The reason for this was, that both themes are so overarching and cross-cutting with all the other themes that they should be applied to most of the research questions. The final list of the European Research Priorities with 10 research themes is available in Annex 1.

7.1 International relations and legal dimension

By international standards, both the Polar Regions have been leaders by constantly pushing the edges of governance innovation, in particular manifested through the international cooperation - through the Arctic Council in the north, and the Antarctic Treaty System for the south.
There is an increased interest in the Arctic from businesses and governments, due to the sometimes-called “scramble for Arctic riches”. Some Arctic governments have been increasingly active in asserting their rights and claims, in turn encouraging a number of non-Arctic states to assert their own claim to a role in charting the future of the Arctic. The involvement of the armed forces, particularly the Navy, in the search and rescue operations has increased with Navies themselves increasingly investing in research activities.
Critical questions include how existing resource management regimes will be able to cope with the changing distribution and magnitude of commercially important fish stocks and how the Law of the Sea can accommodate the environmental changes taking place, including an increased access to mineral and petroleum resources.
It is important to note that the forcing factors related to international politics, economy and security issues in general originate from outside the Polar Regions. Thus, the scientific questions and social science challenges are not in themselves specifically polar in nature.

Both Polar Regions experience some similar developments, in particular unprecedented levels of human activities, including research, tourism and new forms of resource extraction, such as the expansion of mineral and fuel extraction into the Arctic Ocean or krill fishery in the Southern Ocean. Considering that environmental, economic and social changes now occur at a greater speed and scale than ever before, and in increasingly interconnected ways, residents and stakeholders in circumpolar regions rely on applied and detailed knowledge on a range of key issues as stated above.
These issues need further research to inform judicious decision-making:

- How do political developments on different scales influence the Polar Regions?
- How can the international resource management regimes cope with the changing conditions?
- How can we better understand the governance that influences the Polar Regions?
- How can international cooperation strengthen polar research and observing systems?
- How can management measures be assessed and strategies determined that best promote conservation of the biodiversity?
- How effective are Antarctic and Southern Ocean conservation measures for preserving evolutionary potential?

7.2 New technologies

The harsh conditions of the Polar Regions provide an ideal benchmark for developing and improving technology for extreme environments like space or the deep-sea. Additionally, the Polar Regions are an ideal location to investigate human health under extreme conditions (both physiological and psychological studies). Bioprospecting for active compounds and organisms important for pharmacology, medicine, materials technology, and industrial processing and the food industry are other important topics for global society. As an example, the expression of genes involved in the implementation of thermogenic mechanisms during the growth of polar animals, is a unique model for activation of natural systems to adapt to extreme conditions. These regulatory mechanisms are well known and can apply to the survival in extreme conditions. Polar areas are highly sensitive to human influence and hence innovation in reducing the footprint of the humans living and working in these areas, including research and industry, is of high importance. This ranges from improving alternative energies to reducing the noise impact of vessels working and crewing in the polar marine areas.
These issues need further research to inform judicious decision-making:

- Propose the development of new technologies and the improvement of present ones for sustainable operations in the harsh polar environments such as autonomous systems, miniaturised sensors, drilling technology for sediment and ice-coring and noise reduction of vessels.
- Can technologies and infrastructures be developed that reduce the energy consumption (alternative energies, building materials) and footprint of the research and local community?
- How can we develop and further improve communication and data transfer in Polar areas?
- How can we transfer technology and knowledge to society by cooperation with relevant businesses?

8. Conclusions

The online consultation has provided a substantial amount of input that will strengthen the understanding on the European Polar priorities for the coming years. The comprehensiveness of the documents that have been taken into account for the analysis of the European Polar Priorities, and the consultation with a very significant amount of polar scientists with long-term and wide-ranging

expertise will result in the most robust and comprehensive assessment of the European Polar Priorities, capable of providing Policy Makers and relevant Stakeholders with improved strategic guidelines for future actions.

The evaluation and prioritization of European key questions in polar research establish a bridge connecting Scientist, Policy Makers, Stakeholders and Users for understanding, implementing and managing of actions in Polar regions that will be beneficial for end users and society.

Annex 1: European Polar Research Priorities

1. Polar Climate Systems

Many of the natural physical processes occurring in the polar atmosphere and oceans are of profound significance in controlling conditions across the globe and affecting lives and livelihoods across the world. The great ocean current "conveyor belt" originates in the Arctic and Antarctic, it ventilates the deepest portions of the world's oceans, and feeds the atmospheric and ocean current systems that shape the climate in Europe. Future changes in climate mean that many of these processes may be modified in intensity or effect, and the impacts will induce changes across the planet. These effects are not confined to the distant future, as it is clear that the inclusion of Polar Regions in forecast models has greatly improved regional weather prediction. The residents and operators in the Polar Regions are the most directly affected by climate change, but such changes have global importance. Understanding the polar processes in a global context will benefit the people, policy, ecosystem management, and businesses well beyond the Polar Regions.

Therefore the main objectives would address:

- Natural processes in the Polar Regions that influence or control conditions across the globe
- Changes in Polar Regions that have global importance for people, policy and businesses well beyond the Polar Regions.

Key questions:

- What are the key physical and chemical processes in the ocean?
- What are the key physical and chemical processes in the atmosphere?
- What are the key ocean-atmosphere-ice-land interactions? [Cross-cuts to 2. Cryosphere]
- How do we improve forecasting and projections of future polar and global climate and its impact on Polar marine and terrestrial areas?
- How do the changing polar climate systems affect lower latitudes through ocean and atmospheric circulation?

2. Cryosphere

The great ice sheets of Antarctica and Greenland, together with the smaller glacier systems across the Arctic and on the Antarctic and Sub-Antarctic Islands, hold sufficient water to significantly raise global sea-level over coming centuries. The uncertain stability of these glacier systems, many of which are in areas of recent, rapid climate change make them uniquely vulnerable to both atmospheric warming and changes in ocean temperature and circulation. This is also reflected through the uncertain projections of future global sea-level rise. Improving our understanding of these systems poses particular challenges to science, but is essential to manage the risks to coastal communities, precious coastal ecosystems and major capital assets across the globe. Governments, businesses and individuals who own, or are charged with protecting these assets, need to work more with science to inform their decisions on investment in and management of coastal regions.

Understanding the Antarctic terrestrial and sub-sea permafrost and the consequences of its degradation is also a crucial issue. Terrestrial and sub-sea permafrost is susceptible to climate change, directly impacting the infrastructure and landscape, in the Canadian and Alaskan Arctic in particular, where vulnerability to coastal erosion is increasing. In Russia, major infrastructure is at risk of damage from thawing permafrost. The indirect impacts on climate through the potential release of greenhouse gases will add to those resulting from anthropogenic sources. Patterns and rates of permafrost change are poorly measured in all areas of the Arctic, and improved understanding of such changes is urgently needed.

Sea ice and icebergs present hazards to shipping and marines structures, depending on the location within the Polar Regions. Improvements in monitoring of these would reduce risks for shipping and other ocean operations and activities.

Therefore the main objectives would address:

- Factors associated with or contributing to the instability of ice sheets and global sea-level rise.
- Risks to coastal communities, coastal ecosystems and assets.
- Impact of terrestrial and sub-sea thawing permafrost on infrastructure and landscape
- Release of greenhouse gases, especially carbon and methane, from thawing permafrost.
- Risk assessment methodology to estimate/map sea ice and icebergs impacts on shipping and marines structures.

Key research questions:

- What are the processes controlling the stability and equilibrium of polar glaciers and ice sheets and how will they affect future global sea level?
- How is Arctic and Antarctic terrestrial and subsea permafrost changing in the context of global climate change?
- How does/will changing floating ice (sea ice and icebergs) impact with the physical and chemical exchanges within the polar climate system?
- What are the indicators and spatio-temporal impacts of permafrost degradation on the environment

3. Palaeoclimate and Palaeoenvironment

Future climate scenarios strongly benefit from paleo-reconstructions conducted in both Polar Regions as they allow a better understanding of how the climate system worked both regionally and globally during abrupt climatic transitions and under warmer or colder than present-day conditions. Paleo-records from ice and sediment cores provide key insights into changes in both physical and biochemical parameters within the ocean, atmosphere, terrestrial and cryosphere components under natural and anthropogenic forcing, which is increasingly impacting local Arctic communities and ecosystems in the context of global warming. Past volcanic activity and its environmental impacts, evolution of greenhouse gases (e.g. CO_2, CH_4…) in the past, ice sheet and related sea level changes can also be investigated thanks to well-dated high-resolution proxy records combined with better constrained model simulations which help to significantly better assess and project climate and environmental changes within the next centuries.

Therefore the main objectives would address:

- The use of paleo-reconstructions, including volcanic events, for projecting future climate scenarios
- How paleo-records can provide key insight into changes under natural and anthropogenic forcing
- Understanding the transition from 40ka cycles to 100ka cycles as crucial topic to understand current climate

Key research questions:

- What do the paleo-records tell us about polar climate and environmental conditions prior to the instrumental period?
- How can we best use modelling and records of past conditions (e.g. proxies) to understand ocean-atmosphere-ice-land interactions and global teleconnections?

- How do polar records of key geological periods (e.g., interglacial intervals, Pliocene) provide insight into present global climate change and improve projections?
- What are the differences in system-scale changes between the current warming, that in the mid-20th century, and that of earlier periods in the Holocene, and in the more distant past (i.e., mid-Pliocene)?
- Why did we have the Mid-Pleistocene Transition (MPT) around 1Ma ago and why do we now live in a 100 ka world?

4. Polar Biology, Ecology and Biodiversity

The biological diversity in Polar Regions has long been thought as generally simple, species poor and isolated. A very different picture is now emerging, demonstrating that some marine or terrestrial polar ecosystems are highly diverse and that regional and global connectivity is greater than supposed. Nonetheless, polar areas remain extremely stressful to organisms: the polar species, most of them exhibiting a high degree of endemism, are often close to their threshold of growth and have developed highly sophisticated adaptations which make them more vulnerable to rapid environmental changes. The direct effect of climate change on organisms is combined with those of human impacts, including, local pollution, and invasion of non-native species or infectious diseases. These drivers directly affect the survival of populations already weakened by climate change and initiate new trophic links which fundamentally modify the structure and functioning of these ecosystems. However, the complex interactions among these drivers are rarely addressed. For instance, we don't really know how alien invasive species combined with temperature changes will affect marine and terrestrial biodiversity and ecosystems.

As for terrestrial ecosystems, enormous changes in vegetation are happening across the Arctic and these changes will have important impacts both at the ecosystem level, but also at the global climate level, due to the changing nature of biogeochemical fluxes

The potential wealth of information hidden in unidentified polar species, especially marine microorganisms, includes the possibility of providing new active compounds and processes relevant for new and improved biotechnological and biomedical applications.

The polar oceans in their ice-covered state in winter are known to be quite data poor, and much effort is underway to remedy that. Polar waters are also thought to be among the regions that will be most affected by ocean acidification. Amongst other things, acidification disrupts the formation of protective carbonate exoskeletons in many marine dwellers, disrupting and potentially changing the marine food web. This would directly affect living resources and commercially important species. Harvesting of living resources by fisheries, hunting, etc., is also vulnerable to direct human influence and their sustainability is crucial to maintain the ecological functioning in both oceans and terrestrial ecosystems and ensure future resource availability.

Conservation of these terrestrial and marine ecosystems remains a key issue and management policy highly depends on our knowledge of their threats and their capacity to cope with them.

Therefore the main objectives would address

- Threats to highly specialised and adapted polar species from climate-related changes in ecosystems.
- Methods to identify and track the occurrence of invasive species and their impacts on ecosystems.
- Methods to identify novel active compounds and processes for biotechnological and biomedical applications (bioprospectation).
- The occurrence, severity, and impacts of ocean acidification.

- The potential for changes in marine food webs that may directly affect living resources and commercially important species
- Limnic ecosystems in polar areas
- Conservation management issues

Key research questions:

- What the long term changes are occurring in polar food webs?
- How can the polar organisms and ecosystems adapt to future climate changes?
- How resilient are polar ecosystems?
- How vulnerable are polar ecosystems to combined human and natural influences?
- How do we manage polar marine and terrestrial living resources in a sustainable way?
- What are the specialised, polar-related fundamental biological processes from the organism to community level in Polar regions?
- What are the major threats and implications of changing biodiversity in Polar Regions?
- How will invasive species and range shifts of indigenous species change Polar ecosystems?
- How can management measures be assessed and strategies determined that best promote conservation of the biodiversity?

5. Human impacts

Long-range transported pollutants and bioaccumulation of contaminants in polar food chains represent major challenges for both ecosystems and human health. Due to the increase in maritime operations and transport in the Arctic, a larger risk of oil spills and environmental pollution is expected in ice-covered seas. Arctic and indigenous communities are experiencing large impacts of climate change and pollution on food and water security and the availability of traditional food due to bioaccumulation of environmental contaminants, changed migration patterns of animals and difficult hunting conditions as the climate changes and sea ice retreats. Pollutants and atmospheric aerosols are transported by ocean and air currents and deposited in polar terrestrial and aquatic environments. Aerosols of natural origin (erupting volcanoes) and from human industrial and agricultural activities (black carbon) scatter light and directly modify the atmospheric radiation balance and temperature. Indirectly, the Earth's climate is influenced by aerosols modifying cloud properties, i.e. the way clouds reflect and absorb light, thus changing the Earth’s energy budget.

Stratospheric ozone depletion, with a large springtime decrease in ozone around both Polar Regions, has been a major challenge to polar ecosystems and people. The resulting increased levels of harmful ultraviolet radiation passing through the Earth’s atmosphere have created worldwide concern for a variety of biological consequences such as increases in sunburn, skin cancer, cataracts, damage to plants, and changes in plankton populations in the ocean's euphotic zone. Although on the path to recovery as a result of the Montreal Protocol, continuous monitoring of stratospheric ozone and its atmospheric chemistry are still needed as new substances with ozone-depleting potential maybe used by industry.

Further, there is a potential for political struggle due to the large economic, environmental, political and social consequences, and the intense media attention that may occur in climate-change degraded areas on Earth.

Therefore the main objectives would address

- Effects of long-range transport of pollutants and their bioaccumulation in polar food chains.
- Influence of aerosols on the Earth's climate
- Stratospheric ozone depletion and its effects on ecosystems and people in the Arctic and Antarctic
- Increased economic activity and related hazards.

Key research questions:

- How do natural and anthropogenic pollutants and contaminants currently affect Polar Regions and what are future scenarios?
- What are the sources, sinks, dynamics and impacts of greenhouse gases, Short Lived Climate Pollutants and aerosols in the Polar Regions? [Cross-cuts to 1. Polar climate]
- How does ocean acidification affect polar marine and coastal ecosystems? [Cross-cuts to 6. Ecosystems]
- What are the sources, sinks, dynamics and impacts of increased bioavailability of natural and anthropogenic pollutants?
- Are there any biological and genetic adaptation strategies of organisms to environmental contaminants that may provide resilience in polar terrestrial, limnic and marine biological systems to the accumulation of trace metals and metalloids and persistent organic contaminants in marine food webs in Polar Regions? *(revised by AMAP)*

6. Solid earth and its interactions

There is already significant strategic and commercial interest in the marine and terrestrial geological and geothermal resources in the Arctic. An improved understanding of the distribution of these resources, would benefit both residents and stakeholders alike. In Antarctica, it is intended that the Antarctic Treaty and its Protocol on environmental protection will continue to prevent exploitation of mineral resources in future decades.

Additionally, the Arctic basins are a result of a long history that involves continental blocks and ocean basins whose physiographic interpretation will support the definition of the exclusive economic zone of the Arctic countries.

Therefore the main objectives would address

- Strategic and commercial interest in Polar resources (mainly Arctic)
- Scientific support the definition of the exclusive economic zone in the Arctic

Key research questions:

- How have geodynamical and geothermal processes shaped the Polar Regions?
- How does the Antarctic tectonic plate interact with other tectonic units?
- What is the geological history of the Polar Regions and the distribution of key minerals?
- How does volcanic activity affect the global atmosphere and the stability of cryospheric components, particularly glaciers and ice sheets?

7. Sustainable management of resources

Recent studies suggest that about 20 to 30 percent of the untapped global petroleum resources may be found in the high North. In addition, significant fisheries resources, forests and mineral resources are found in the region, and the effects of global warming would provide a better access to these resources. This has significantly increased the interest in the region, by Arctic and non-Arctic states and international businesses. Reduced sea-ice opens the possibility for greater ship transport and facilitates exploitation of resources. The environmental, economic and societal impacts of mineral and petroleum extraction need to be addressed in terms of the boom and bust nature of the extractive industry, the impact on traditional industries such as reindeer herding, and pollution risks and risks to water supply. The Arctic Ocean holds several fisheries of global significance (both natural and through aquaculture) that will likely be impacted by an increase in maritime operations, along with a warmer and more acidic ocean and the resulting marine ecosystem changes. In the North Atlantic,

commercially important species such as mackerel and cod are experiencing a northward shift, potentially challenging the international management regimes of these resources. Further, the recognition of the value and significance of traditional and local knowledge is increasingly seen as important for operating in the Arctic in terms of resource use, monitoring and in handling the consequences of resources extraction and environmental engineering. Infrastructure and (maritime) safety issues are complex in these remote places.

By contrast, human presence in the Antarctic is comparatively recent and governed by the Antarctic Treaty System, an international regime dedicated to promoting peace, science, collaboration and, more recently, environmental protection in the Antarctic continent and surrounding seas south of 60° southern latitude. The Southern Ocean itself is a large marine resource capable of supplying up to 7% of the world's fish resources, but remains threatened by the effects of climate change, including acidification, and changes in species diversity.

Therefore the main objectives would address

- The feasibility, challenges and impact of exploitation of Arctic petroleum resources (20 to 30 percent of the untapped global petroleum).
- Sustainable use of fisheries, forests and mineral resources in the Arctic
- Impact of reduced sea-ice in relation to exploitation of Arctic oil and gas reserves.
- Impact of increased human/industrial activity on traditional lifestyles such as reindeer herding.
- Pollution risks and risks to safe food and water supply.
- Impact of increased maritime operations on fisheries.
- Recognition of the value and significance of traditional and local knowledge in relation to scientific research and monitoring activities

Key research questions:

- How can use and management of natural resources in the Polar Regions be made sustainable and safe in the context of a changing climate and increased human activity? [Cross-cuts 6. Ecosystems]
- What are the consequences of a changing environment for local and global food sources and food security in the Arctic? [Cross-cuts to 6. Ecosystems]
- What are the drivers, conditions, requirements and consequences of Polar mineral and petroleum extractive industrial activities?
- What steps need to be taken so that maritime operations can be conducted safely in the Polar Regions?
- How can the Polar Regions contribute to blue growth and a low carbon energy transition?

8. People, Societies and Cultures

About 4 million people live in the Arctic, of which about 10 % are indigenous. A number of rapid societal and environmental changes confront Arctic residents, local communities and socioeconomic sectors and challenge their livelihoods and well-being. Important trends are demographic shifts and urbanization, changing livelihoods and lifestyles, economic dependence on the primary sector and public transfers, the increasing role of education and research, empowerment and increasing complexity of governance. These changes are impacting the composition of Arctic populations in respect of gender, age, health and ethnic composition. For indigenous communities, changes in lifestyle bring about a cultural transformation, including alterations in family structure, values and cultural forms of expression. These can lead to positive developments, e.g. the increasing role of women in society, and negative ones, e.g. barriers to intergenerational knowledge transmission or loss of indigenous languages. Natural resource dependent communities and industries, throughout the Arctic are experiencing direct and indirect impacts of climate change. Many questions remain about

how they will be affected, how they can adapt and what resources are needed for strengthening adaptive capacities and ensuring adaptation.

Cultural heritage management in the Polar Regions is an increasingly challenging endeavour as management authorities face impacts from climate and environmental change as well as increasing human activity such as oil and gas extraction and tourism.

There is a growing recognition of the importance of local and traditional knowledge to these societies.

Therefore the main objectives would address

- Changes in lifestyle of indigenous communities.
- Alterations in family structure, values and cultural forms of expression.
- increasing role of women in society
- Barriers to intergenerational knowledge transmission or loss of indigenous languages.
- Cultural heritage management.

Key research questions:

- How can social and cultural viability and heritage be sustained in Polar Regions?
- How can a sustainable socio-economic future be achieved and what is the role of the educational system in this respect?
- How does increased globalisation and recognition of indigenous peoples' rights influence Arctic communities?
- What are the adaptation challenges and possible strategies facing Arctic communities in relation to rapid changes in the social-ecological systems and those associated with climate change?
- How can we better evaluate and understand the changing importance of the polar regions to the globe – economically, environmentally and politically? [cross-cuts most topics]

9. Human health and Wellbeing

Health and wellbeing is highly diverse with respect to the proportion of people living in urban areas in the different countries, income levels and general health status. They are both the result of complex interactions among genetic, economic, social, cultural, political and environmental factors. Changes in lifestyle, in combination with environmental and societal changes, have major impacts on the health and wellbeing of indigenous communities, while urban populations may be less affected. In general, three aspects considered to be prominent features of wellbeing have been identified, particularly pertaining to rural indigenous and non-indigenous communities, but with some relevance for urban communities: Fate control, guiding one's own destiny; cultural vitality, belonging to a viable local culture; and contact with nature, interacting closely with the natural world.

In addition, soft-security is of crucial importance: food, water and energy. All three are compromised by climate and other environmental changes and globalization.

In terms of health, there is special concern in some Arctic counties over increases in cancer and other lifestyle-related diseases, sexually transmitted diseases, suicides and alcoholism

Therefore the main objectives would address

- Changes in lifestyle impacting the health and wellbeing of indigenous communities
- Impact of climate change and socio-economic changes on food, water and energy security
- Changes in the rates of cancer and other lifestyle-related diseases, sexually transmitted diseases, suicides and alcoholism

Key research questions:

- How can the health of Arctic residents be safeguarded in times of change?
- What are current and projected future health impacts of contaminants on the Arctic communities?
- How can the mental wellbeing of Arctic residents be enhanced in order to reduce societal and medico-psychological problems?

10. Astronomy, Astrophysics and Space

The Polar Regions provide an ideal platform from which to study the Earth's upper atmosphere, the solar system and outer space, to improve understanding of sun-earth connections and space-weather, and answer fundamental questions such as the origin of the universe. The unique features of the polar environment mean that these areas provide astronomers and other scientists with a unique window on our universe, and environmental analogues that allow the prototyping and testing of equipment destined for space use. Similarly, space agencies have long understood the similarity of the isolation, lack of day-night cycles, and extreme environmental conditions to which polar communities are subject, and those that humans engaged in space flight must endure. These agencies can benefit significantly from the use of polar platforms and the medical and technical advances which can be made in these areas.

At another scale, severe space weather event arise from occasional massive ejections of material and energy from the Sun. These events pose risks to satellites and key infrastructure on the ground (e.g., power systems). Better understanding of the likelihood of damaging events and the ability to forecast their occurrence would provide satellite operators, and those who manage terrestrial infrastructure, better tools with which to build resilience into their systems and an opportunity to take protective measures against specific events. The location of the Polar Regions with respect to the Earth's geomagnetic field means that these are the favoured sites for many instruments used to observe and understand the interactions of our atmosphere and the solar flux.

Therefore the main objectives would address

- Development of an ideal platform to study outer space.
- Development of prototypes and testing of equipment destined for space use.
- Forecast space weather.
- Identification of useful sites for observing Sun-Earth interactions

Key research questions:

- How can we quantify, forecast and manage the risk of severe space weather events to satellite, airborne and terrestrial assets?
- What can be learned about the origin and evolution of our solar system and the universe from records and observations that exist in the Polar Regions (e.g. meteorites)?
- What is the role of the sun in controlling processes in the Earth's atmosphere, and how does this influence weather and climate?

Annex 2: National and international Polar strategies which have been consulted by EU-PolarNet

1_European National priorities

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- Belgium_ResearchOverview.pdf

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