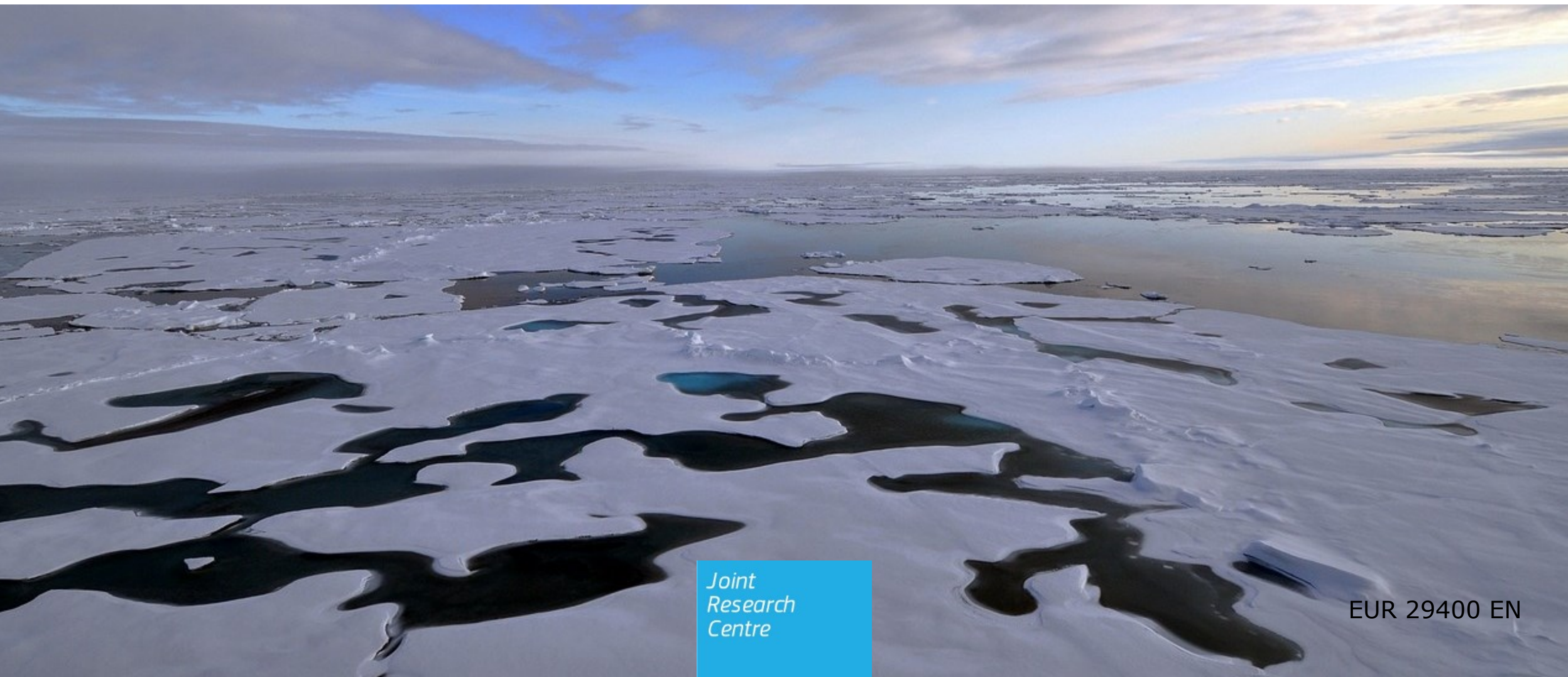
JRC SCIENCE FOR POLICY REPORT

Impact assessment study on societal benefits of Arctic observing systems

IMOBAR

Dobricic, S., Monforti Ferrario, F.,
Pozzoli, L., Wilson, J., Gambardella, A.,
Tilche, A.

2018



EUR 29400 EN

Contact information

Name: Srdan Dobricic
Address: European Commission, Joint Research Centre, Directorate C: Energy, Transport and Climate, Air and Climate Unit, via E. Fermi 2749, 21027 Ispra - Italy
Email: srdan.dobricic@ec.europa.eu
Tel.: +39 0332 786376

JRC Science Hub

https://ec.europa.eu/jrc

JRC113327

EUR 29400 EN

PDF ISBN 978-92-79-96697-2 ISSN 1831-9424 doi:10.2760/713084

Luxembourg: Publications Office of the European Union, 2018

How to cite this report: Dobricic S., Monforti Ferrario F., Pozzoli L., Wilson J., Gambardella A., Tilche A., *Impact assessment study on societal benefits of Arctic observing systems - IMOBAR*, EUR 29400 EN, Publication Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-96697-2, doi:10.2760/713084, JRC113327.

Impact assessment study on societal benefits of Arctic observing systems

The study compares costs and benefits of Arctic observation systems. Ten case studies show that annually economic benefits exceed by at least 50% investments. The analytical framework can be further developed for quantifying societal benefits from local to global scales.

Contents

Acknowledgements 3
Executive summary 4
1 Introduction 5
2 Methodology 8
  2.1 The conceptual framework linking observations to benefits 8
    2.1.1 Value Tree Analysis 8
    2.1.2 Intervention Logic 10
  2.2 Selection of case studies 11
  2.3 Assessing cost and benefits 11
    2.3.1 Costs of Observing Systems 12
    2.3.2 Evaluating Societal Benefits 12
3 Case studies: challenges, needs and objectives 14
  3.1 Permafrost and freezing/thawing of frozen ground 14
  3.2 Biodiversity 14
  3.3 Sea Level Rise 15
  3.4 Sea Ice 15
  3.5 Human Dimension to sea ice 16
4 Observing systems: Inputs, outputs and costs 17
5 Societal Benefit analysis 21
  5.1 Benefits from systematic observations of permafrost for infrastructure 21
  5.2 Benefits from systematic observations for forest management and logging 22
  5.3 Benefits from systematic observations for fisheries management 23
  5.4 Benefits from systematic observations for Port management 23
  5.5 Benefits from systematic observations for property insurance 23
  5.6 Benefits from systematic observations on ship routing and navigation 24
  5.7 Benefits from systematic observations for Offshore installations 24
  5.8 Benefits from systematic observations for Search and Rescue of vessels 24
  5.9 Benefits from systematic observations for Oil Spills 25
  5.10 Benefits from systematic observations for SmartICE 25
  5.11 Benefits for local communities 26
  5.12 Summary of the quantified economic benefits 26
6 Conclusions and recommendations 28
References 30
List of abbreviations and definitions 33
List of figures 34
List of tables 35

Annexes 36
  Annex 1. Value Tree Analysis and Intervention Logic for each case study 36

Acknowledgements

We would like to thank the Everis (Ines Ramos, Arnaud Berghmans, Ariadna Guell Sans, and Elena Goncearuc) and Deloitte teams (Patrick Wauters, Laura Doumbouya, Valentina Cilli, Elena Goncearuc, Katarina Bartz, Anna Siede, Elisa Lederer, Alana Gyszas). We are especially grateful to the experts participating in two workshops Tom Barry, Nicole Biebow, Jason Gallo, Jean-Claude Gascard, Ola Grabak, Thorsteinn Gunnarsson, Karinn Margaretha Husgard Larsen, Steven Lev, Linus Magnusson, David Miller, Ben Moat, Allen Pope, Lars Otto Reiersen, Antonio Reppucci, Paolo Ruti, Stein Sandven, Mikko Strahlendorff, Tazio Strozzi, Alberto Troccoli, Vito Vitale, Jeremy Wilkinson and Michael Zemp. We are grateful to Henrik Steen Andersen and Thibaud Delourme for providing EEA and Copernicus reports. We would like to thank the reviewers of the Deloitte (2018) report Nicole Biebow, Jason Gallo, Steven Lev and Lars Otto Reiseren, and the reviewers of this report Thomas Diehl, Joaquim Fortuny Guasch and Elisabetta Vignati.

Authors

Srdan Dobricic, Fabio Monforti Ferrario, Luca Pozzoli, Julian Wilson (European Commission, Joint Research Centre, Directorate C: Energy, Transport and Climate)

Attilio Gambardella, Andrea Tilche (European Commission, Directorate-General for Research and Innovation)

Executive summary

The goal of the IMOBAR study is to estimate and compare costs and benefits of Arctic observation systems as a contribution towards the "business case" for sustaining Arctic observations in the long-term and to support the decision-making process.

Accelerated warming and rapid environmental changes in the Arctic require development and implementation of a sustained, integrated and pan-Arctic observing system, capable of allowing timely access to information and data about the Arctic, capable of better-documenting processes within key sectors and capable of better-informing the decision-making processes. A diverse range of information is needed for managing, for planning, for developing adaptation solutions, and for designing sustainable development policies at local to planetary scales. Within this context, long-term perspective investments in research, operational infrastructure and logistical support services are essential.

The study proposes a new conceptual framework to link observations to benefits. The framework is based on well-established methodologies and builds on the extensive knowledge collected in the context of the *International Arctic Observations Assessment Framework* performed in 2017 (IDA-STPI and SAON, 2017). The IMOBAR study estimates the costs attributable to major observing systems in the Arctic, and for ten case studies develops the links between observing systems, their outcomes and impacts on twelve societal benefit areas and a partial quantification of economic benefits.

The results of the IMOBAR study show a positive return on investment for the considered case studies and for selected Arctic challenges. Observing systems in the Arctic strongly support the preservation of ecosystems, provide information for protecting human health and lives and reducing pollution, and provide savings by directly reducing losses in economic activities.

Even in a very conservative scenario, when the lowest identified total benefits are compared with highest identified total costs and considering the range of uncertainties and underestimates, it is possible to show that annual economic benefits exceed by at least 50% annual investments in Arctic observing systems. This demonstrates that investments in Arctic observing systems are fully justified by economic returns, even for the limited number of economic activities evaluated in the study.

Additional economic returns may be expected from other societal benefits including impacts on human health, ecosystem preservation, or global societal benefits like understanding and predicting global sea level rise or weather. Finally, the study focused mainly on local-to-regional benefits but the proposed analytical framework can be easily further developed for accounting for societal benefits of Arctic observing systems ranging from local to global scales.

1 Introduction

The Arctic is undergoing the most rapid changes in the climate system worldwide. This is demonstrated by the thinning and reduction of sea ice, the melting of ice sheets and glaciers, the progression in thawing of permafrost, and the triggering of more extreme weather events in particular in the northern latitudes. These changes are closely connected to the earth surface and ocean warming due to increased greenhouse gas concentration in the atmosphere (AMAP 2017).

While the role of these Arctic changes in increasing risks of extreme events remains a critical but hotly debated question, interlinked processes in the Arctic are expected to increase the risk from natural hazards such as increased erosion and icebergs break-off (AMAP 2017). Thawing of permafrost will release greenhouse gases that will further enhance the warming of the atmosphere and ocean (Schuur et al. 2015). This will have wide implications for the environment, ecosystems and communities in the Arctic and on the global scale (AMAP 2015). Environmental conditions in the Arctic may drastically change in the coming decades strongly influencing ecosystems and requiring adaptation measures by local communities (Arctic Council 2016). Arctic research and observation are essential to monitor and predict the evolution of these changes and its impacts on regional to global scales. In particular, observations in the Arctic bring information on ongoing changes, providing the basis for the theoretical understanding and prediction of complex environmental processes (Schlosser et al. 2016).

On the other hand, the warming of the Arctic will improve access to the Arctic and its resources, offering new opportunities for local communities and for economic development related to exploration of natural resources, transport, and other industries. Responding to these opportunities will require planning and decision-making based on scientific and economic assessments and predictions that rely on observations (AMAP 2017).

Observed environmental changes in the Arctic include large-scale near-surface warming, sea-ice, ice sheet and permafrost melting, changes in pollution loads and modifications of flora and fauna (AMAP 2017). Observational records of many important environmental parameters are however shorter than in other regions. This complicates the interpretation of tendencies and the distinction between natural climate and anthropogenic forcing of enhanced warming and environmental changes (AMAP 2017). Traditional knowledge[1] may represent in many cases the only source of information for the past environmental conditions in the Arctic (Schlosser et al. 2016).

Due to the large area, remote position and harsh environmental conditions, the development of observing systems in the Arctic requires coordinated international efforts in order to maximise the impact of observations. The combination of observing system information with knowledge of local population may improve the understanding of current processes even in the absence of long-term observing records (Schlosser et al. 2016, AOS 2018).

Against this background and building on previous initiatives, the European Commission and the High Representative of the Union for Foreign Affairs and Security Policy adopted the Joint Communication to the European Parliament and the Council on "An Integrated EU Policy for the Arctic" (JOIN (2016) 21). The communication identifies three priority areas that are closely related to large environmental changes happening in the Arctic:

- *Climate change and safeguarding the Arctic environment;*
- *Sustainable development in and around the Arctic;*

---

[1] Traditional knowledge refers to the knowledge and practices of indigenous and local communities that have developed over centuries and are traditionally transferred from elders to young people in concrete working and life situations (https://www.arcticcentre.org/EN/communications/arcticregion/Arctic-Indigenous-Peoples/Traditional-knowledge).

— *International cooperation on Arctic issues.*

Research, science and innovation are key elements to tackle these priorities. In this sense, the EU has launched several initiatives to better understand the Arctic environment, under the 7th Framework Programme and Horizon 2020 (link to the EU Arctic research cluster https://www.eu-polarnet.eu/eu-arctic-cluster/). Amongst those research projects, some were devoted to observing systems (OS).

Key components of the EU Arctic policy are supporting Arctic observational systems to better understand climate change in, and environmental protection of, the Arctic, to underpin sustainable development in the region and international scientific cooperation in the continuing development of observational systems.

Today the challenge is to move toward a sustained, integrated and pan-Arctic observing system capable of better-informing the decision-making process and better-documenting processes within key sectors (e.g. local communities, shipping, tourism, fishing). The EU's strategies for the Arctic emphasise the need to implement monitoring programmes to underpin sustainable development in the region. To build and sustain an integrated system of many discipline-specific observing systems requires agreement among the major players from Europe, North America and Asia who can contribute to this system.

The EU is not acting alone in this respect. In 2016 over 450 delegates of the 3rd Biennial Arctic Observing Summit (AOS) from 30 countries discussed recommendations and a pathway toward the implementation of an internationally supported, pan-Arctic observing system that is considerate of and responsive to both local and global needs. They recommended to (Schlosser et al., 2016):

"Propose to the highest levels of government, the business case for a comprehensive pan-Arctic observing system. This proposal should assess the costs and demonstrate the benefits for society at various levels, including an Implementation Plan that builds upon the present system and past planning, and that identifies needed resources including infrastructure, instrumentation, human capacity, the pathways to financing, and a strategy for sustained financing." [2]

Later in 2016, at the first Arctic Science Ministerial Meeting in Washington on 28th September 2016 the Science ministers of the 8 Arctic states, 14 additional states (half of which are EU members) and the European Union, joined by Arctic indigenous representatives, asserted the importance of improving collaborative science efforts in the Arctic and committed to:

"the shared development of a science-driven, integrated Arctic-observing system that has mechanisms to maximize the potential of community-based observing and to draw on traditional and local knowledge; a design for sustained observations of vital variables and comprehensive studies of Arctic climate processes; technology development; and actions to provide enhanced and open access to data, products, and services. In this context, we see a critical role for the Sustaining Arctic Observing Networks (SAON) initiative—a joint responsibility of the Arctic Council and the International Arctic Science Committee—and encourage continued cooperation in other international science organizations that contribute to Arctic observing and data-sharing and building a network of community-based observation."[3]

As a response to these commitments, the Institute for Defense Analyses-Science and Technology Policy Institute (IDA-STPI) and SAON published the *International Arctic Observations Assessment Framework*, constructing a value tree analysis (VTA) for major Social Benefit Areas (SBAs) requiring observational capacity (IDA-STPI and SAON 2017). This value tree structure provides a comprehensive and consistent theoretical framework for the evaluation of possible benefits from Arctic observing systems. The framework can

---

[2] http://www.arcticobservingsummit.org/sites/arcticobservingsummit.org/files/AOS%20Conference%20Statement_Final_RELEASED-2016-03-23.pdf

[3] https://obamawhitehouse.archives.gov/the-press-office/2016/09/28/joint-statement-ministers

steer the work of SAON in its objective of the development of a "well-coordinated and sustained Arctic Observing Network that meets scientific and societal needs".

In 2018 participants from 26 countries of the 4th AOS stated (AOS 2018):

"expansion of observing activities will reduce vulnerability and build resilience of Arctic societies, environments and infrastructure. Not doing so increases the risk of greater impacts and associated costs." [4]

The present study builds on the extensive knowledge collected in this wide context and on the IDA-STPI and SAON (2017) findings. It is intended to be a contribution to the evidence base for the discussions and conclusions of the second Arctic Science Ministerial[5], taking place in Berlin on October 25-6th, 2018. By following and extending the VTA methodology, the study develops and applies a consistent and reproducible methodology to the study of individual "branches" of the value tree in several case studies, connecting SBAs to corresponding observing systems. The analysis further applies the intervention logic (IL) methodology, relates it to the VTA methodology and includes as much as possible, estimates of Arctic observing system costs and their economic benefits. Moreover, this study makes an effort to widen the stakeholders group and introduces work carried out by the JRC to reflect the view of local populations in the benefits analysis through social analysis.

Due to the limited time and resources, the study does not develop the full VTA analysis covering all societal benefits and observational costs. It selects several case studies covering as wide a variety as possible of different activities in the Arctic benefiting from observations. In this way, the study contributes to the understanding of how investments in observing systems respond to societal needs by covering as much as possible costs of existing observing systems and a wide spectrum of SBAs including the economic evaluation of selected benefits. Where benefits are evaluated economically, the study takes a doubly conservative approach, only looking at benefits accruing over the next 10 years and secondly, looking at the benefits directly accruing in the Arctic region, rather than worldwide.

By providing a synthesis of costs of producing observations in the Arctic and partly estimating observational contributions to the society, the study represents a unique attempt to understand the relationship between investments into Arctic observing systems and return in form of societal benefits.

This report represents a synthesis of several more detailed precursor reports (JRC 2017; Everis 2018; Deloitte 2018). The IMOBAR project provides a structured analysis of Arctic observing system costs and demonstrates their links to societal benefits. Finally, this report provides a list of findings and recommendations in support for future investments in Arctic observing systems.

---

[4] http://www.arcticobservingsummit.org/sites/arcticobservingsummit.org/files/AOS_Statement_Aug24_clean.pdf

[5] ttps://www.arcticscienceministerial.org/en/index.html

2 Methodology

The goal of the IMOBAR study is to estimate and compare costs and benefits of Arctic observation systems as a contribution towards the "business case" for sustaining Arctic observations in the long-term and to support the decision-making process.

In the first step of the study, observing systems have been identified and linkages between observing systems and their benefits have been established. This step required the design of a conceptual framework to link observing systems with societal benefits. The proposed framework combines two well-known methodologies: Value Tree Analysis and Intervention Logic. In Section 2.1 the proposed conceptual framework is described. In the second step, several case studies have been selected in order to provide a set of detailed analysis of societal benefits deriving from observing systems. Case studies have been selected in a way to cover as much as possible the spectra of existing observing systems and societal benefits. The selection of the case studies is described in Section 2.2. Finally, the costs of observing systems have been defined and their quantifiable and non-quantifiable benefits have been assessed. Description of the assessment of costs and quantifiable benefits and evaluation of non-quantifiable benefits is given in Section 2.3.

2.1 The conceptual framework linking observations to benefits

Observing systems in the Arctic have been identified by using information from previous publications (e.g. EU-PolarNet 2016) and all other available information on positions of observing systems like the World Meteorological Organization (WMO) tables or information from Copernicus Web pages dedicated to the observational data download.

The next two subsections briefly describe the two methodologies that are used to design the conceptual framework to link the information produced by observations to societal benefits and their relevance for the study.

Table 1. List of SBAs developed by IDA-STPI and SAON.

Societal Benefits Area
1. Disaster Preparedness
2. Environmental Quality
3. Food Security
4. Fundamental Understanding of Arctic Systems
5. Human Health
6. Infrastructure and Operations
7. Marine and Coastal Ecosystems and Processes
8. Natural Resource
9. Resilient Communities
10. Sociocultural Services
11. Terrestrial and Freshwater Ecosystems and Processes
12. Weather and Climate

2.1.1 Value Tree Analysis

Value Tree Analysis (VTA) was developed in the IDA-STPI and SAON (2017) report to link observing systems to Societal Benefit Areas (SBAs). The VTA methodology relies on the expert domain knowledge. Experts connect Observing Systems (OS) to Key Products, Services and Outcomes (KPSOs), which further link to Key Objectives (KO). KOs are connected to societal benefit sub-areas that form Societal Benefit Areas (SBAs). In the Arctic, experts have defined 12 SBAs listed in Table 1. The SBAs are associated with four focus areas: Economy, Environment, People and Climate. Each SBA contains a number of key sub-areas, which in turn contain a number of KOs and these are further divided into KPSOs. The idea is that each KPSO has observational systems requirements and when these are identified, the societal benefits accruing from any observational system can be evaluated and compared by integrating their potential contributions over the twelve SBAs.

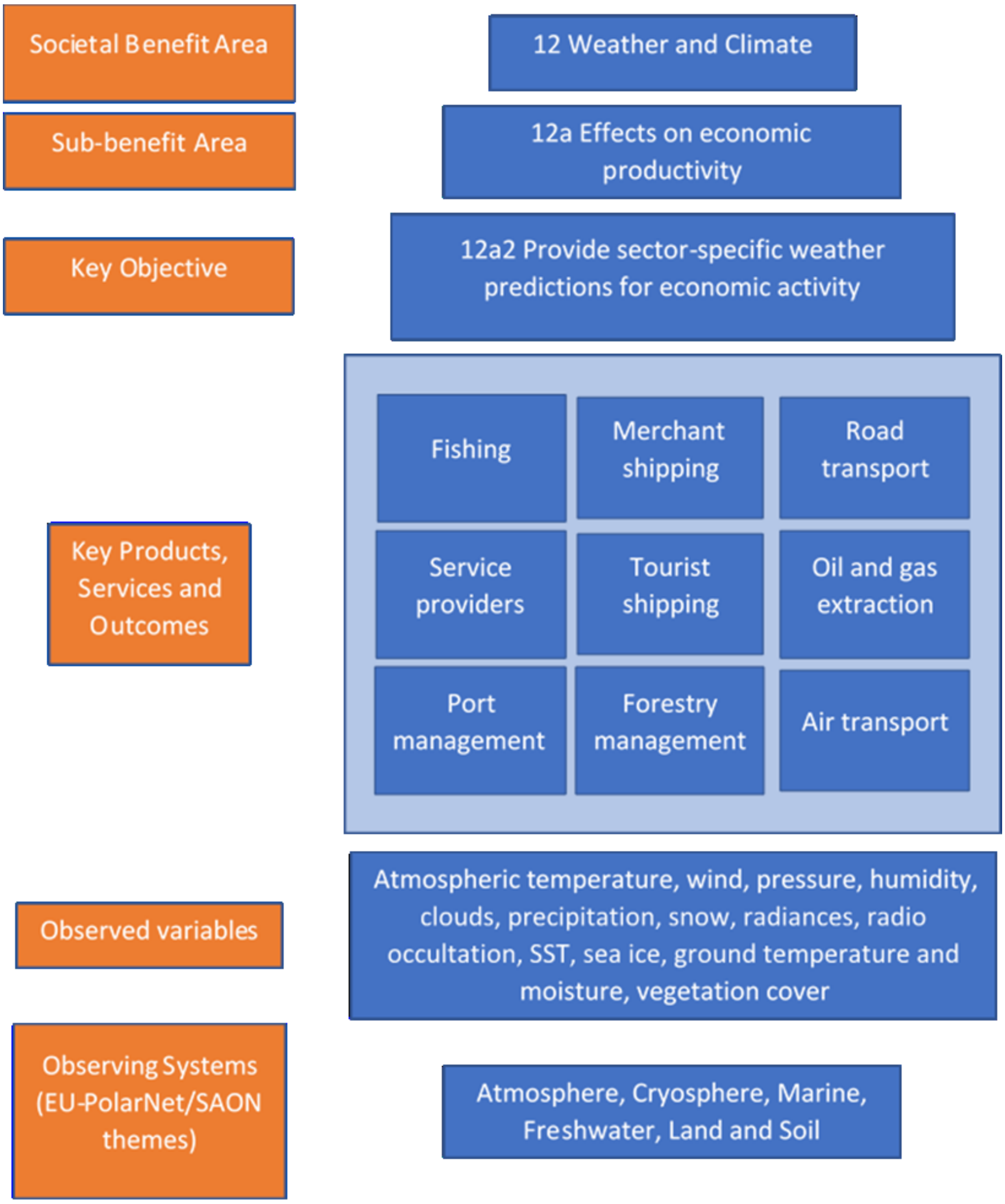


Figure 1. Value Tree analysis of the key objective "Provide sector-specific weather predictions for economic activity" in relation to the Societal Benefit Area "Weather and Climate"

The VTA developed by IDA-STPI and SAON (2017) represents a first attempt to systematically link observing systems to societal benefits in the Arctic. For each specific practical benefit, or KO, the KPSOs involved are identified and linked through the key observables to the relevant OSs. Going back up the value tree, they can be also linked to one or more SBAs. For example, **Figure 1** shows that a large number of OSs measuring a wide variety of parameters may be linked to the SBA named “Weather and Climate”

(**Table 1**), through effects on the economic productivity, providing weather predictions which are fundamental in several economic sectors, such as shipping, fishing and aviation. This is achieved by first linking those OSs to observed variables and evaluating how information on the state of each variable may contribute to possible activities in the Arctic. These activities are then divided into different KPSOs that may contribute to KOs and finally to sub-areas and SBAs.

While ideally the complete value tree for the whole Arctic should be evaluated, in this study a subset of value tree branches have been analysed. Several reasons are behind this choice: The study was performed with limited resources and time constraints, there was a need not to duplicate work performed elsewhere and, given that this is the first time that such an analysis has been attempted for the Arctic, it has been necessary to invest resources in developing a robust, comprehensive and consistent methodology that is reproducible, giving quantitative cost and benefit analyses where possible.

2.1.2 Intervention Logic

Since 2016, the European Commission has been pursuing the "Better Regulation" (BRG) concept, in EU policy-making. BRG is supported by the Better Regulation Toolbox which includes the Intervention Logic (IL) methodology.

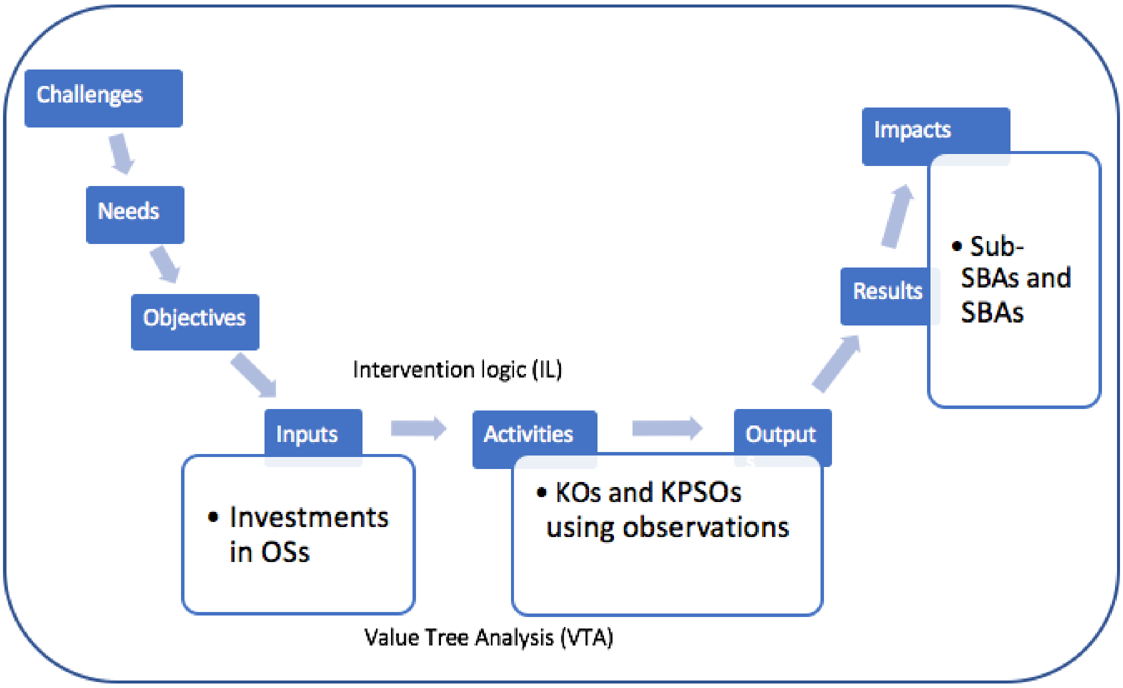


Figure 2. Correspondences between VTA and IL. VTA connects OSs with KPSOs and KOs and finally to societal sub-SBAs and SBAs. IL instead starts from a longer logical chain that evaluates Challenges, Needs and Objectives that provide the motivation for Inputs, Activities and Outputs, producing Results and Impacts. Inputs are investments that correspond to OSs in VTA. Activities and Outputs correspond to KOs and KPSOs benefiting from observations, while Impacts and Results are closely related to sub-SBAs and SBAs in VTA. Challenges, Needs and Objectives are not present in VTA. They represent the general set-up requiring intervention. In each selected case studies they may represent specific environmental conditions that may require responses by producing observations.

IL builds a logical link between the problem that needs to be tackled, or the objective that needs to be pursued, the underlying drivers of the problem and the action (e.g. the policy) to address the problem and achieve the objective. It consists of eight sequential steps: Challenges, Needs, Objectives, Inputs, Activities, Outputs, Results and Impacts. In this context inputs are the consequence of the previous requirements and they may produce activities and outputs that further may contribute to results and impacts. By applying IL it is possible to plan, organize and evaluate impacts that should meet the initial challenges and needs. In the IL context investments in OSs correspond to Inputs. The Activities and Outputs are improved products using observations like more accurate weather forecasts, corresponding to KOs and KPSOs, while SBAs arise from the Results and Impacts that follow from Outputs (Figure 2).

In IL investments in observations can be represented by inputs and Societal benefits by results and impacts. While VTA provides a consistent approach to evaluation of societal benefits across the 12 SBAs, IL complements this with descriptions of other steps in the policy process. The additional components are represented by challenges, needs and objectives that motivate investments into observing systems. These steps may, for example, represent environmental pressures due to climate change in the Arctic. Unlike VTA which does not consider the motivation for developing a value tree, IL may logically explain how investments in OSs respond to these pressures by contributing to societal benefits. The present study combines the two approaches. Definitions and descriptions of case studies given in Section 3 represent challenges, needs and objectives in the IL framework. Then estimation of observing systems in Section 4 and benefits in Section 5 use both VTA and IL methods. Future iterations of this study may thus take advantage of both VTA and IL to link observing systems to societal benefits.

2.2 Selection of case studies

The case studies considered by the study were identified by experts from the Arctic science community and Arctic stakeholders during a workshop in November 2017. Ten case studies, distributed across five wider domains that met the criteria of:

- *relevance and sensitivity to climate change in the Arctic;*
- *capable of producing quantifiable and non-quantifiable benefits;*
- *cover a wide spectrum of different observing systems;*
- *and taken together they produce benefits in all of the twelve Arctic SBAs.*

In each of the case studies, relevant KPSOs were logically connected with one or more SBAs to which they are known to be beneficial (Table 2 in Section 4). At the same time, on the other side of the Value Tree, the main OSs relevant for the case studies were identified (Table 4 in Section 4). Additional information on observing systems and societal benefits arising in selected case studies were obtained by extensive literature review (e.g. EARSC and The Green Land BV., 2016; Melvin et al., 2017), structured interviews and surveys addressing stakeholders and experts.

2.3 Assessing cost and benefits

The quantitative estimate of costs and benefits has been the core of the last step of the IMOBAR study. Two different types of challenges had to be faced. In the case of costs, comprehensive information concerning the overall OS costs is not readily available, while available information is not always reported consistently. Moreover, several of the OSs considered are not specifically designed only for Arctic, so it is necessary to determine the share of their costs that refers specifically to the Arctic. Secondly, only a limited number of societal and environmental benefits could be readily expressed in monetary form and it was also difficult to estimate the fraction of these benefits that can be attributed to observational systems. The practical approach requires assumptions for economic benefits that, in a conservative manner, frequently assume lower benefits than really available for economic activities.

Although in general, cost-benefit evaluations are limited to the activities that have measurable monetary benefits, such an approach would have risked ignoring important societal and environmental benefits that are difficult to measure in monetary terms. For this reason, non-quantified benefits have been also summarised in the analyses. Important non-quantified benefits include the benefits of observations as perceived by the peoples of the Arctic, which were investigated via a complementary social science research activity that focused on the Arctic population and local communities (Romero Manrique et al., 2018).

2.3.1 Costs of Observing Systems

In order to quantify the costs a two-fold approach has been used. First, the cost of the whole observing system was estimated by applying a top-down approach without evaluating their relative contributions to specific KPSOs. Then, in a bottom-up approach, observing systems contributing to each case study were identified separately. The two approaches are complementary: on the basis of the top-down approach, it is possible to give estimates of the costs of observing systems in the Arctic, while the bottom-up approach provides qualitative insights into the links between OSs and SBAs analysing their relevance in relation to the different case studies.

In practice, costs include capital investments (CAPEX) and operating costs (OPEX). CAPEX comprises costs of the research, design, production and installation of the observing system. OPEX accounts for costs of operation, maintenance and personnel costs, including costs of data elaboration, storage and provision, that cover the life span of observing systems. The actual life span is often longer than the predicted life expectancy and it differs significantly between observing systems. Some observing system costs were available only as the annual values. In these cases CAPEX and OPEX were not estimated.

Costs of OSs operating beyond the Arctic, like those associated to polar orbiting satellites, have been rescaled on a geographical base, using the ratio between the Arctic and the total areas covered by the observing system. Estimates of observing system costs for the Arctic are thus highly sensitive to the geographical definition of the Arctic used in the study. Data have been obtained from literature, reports (e.g. Zeug 2011; Eyre and Reid 2014; JERICO 2014; Everis 2018; Deloitte 2018) and interviews with experts.

2.3.2 Evaluating Societal Benefits

Whenever it has been feasible, the analysis of societal benefits arising from observing systems was quantified. In these cases, the current economic activity related to the case study is estimated and its possible future evolution predicted. For each case study, three scenarios are defined: The first is conservative assuming the slow-down of economic activities, the second is central assuming the most probable growth rate of activities, while the third assumes that economic growth in the Arctic is faster than currently expected.

In several of the case studies, potential economic savings by reducing costs and losses due to unexpected environmental conditions, are estimated for each selected economic activity (Deloitte 2018). These estimates are produced considering tangible savings provided by relevant information on current and future environmental conditions to specific human activities. This information is partly based on observations originating from Arctic observing systems. The percentage of observing system impacts on savings is estimated for each specific case on the basis of the available literature describing similar studies, interviews with stakeholders and expert opinions. Given the overall economic turnover of the activity, the percentage reduction in economic losses attributable to observing systems is then translated into net monetary benefits. As an example, in the case of sea ice monitoring, the OSs provide a tangible benefit by allowing a better optimisation of ship's travel time across the Arctic. Such a benefit is evaluated in terms of overall cost savings under the previously cited hypotheses. This approach is similar to methodologies applied in other studies on economic benefits arising from environmental information (e.g. Booz & co 2011; PWC 2016; PWC 2017).

In the specific case of permafrost thawing, a different approach is used where regional estimates of the costs to the community of adapting and not adapting to permafrost loss in one area (for example Alaska) are extrapolated to the entire Arctic by estimating the proportion of the economic value of infrastructure in that area with respect to the whole Arctic. The same approach is used for the forest management case study which is based on a case study made for Sweden (EARSC and The Green Land BV., 2016). Average annual estimates of possible economic savings are produced for the period from 2018 to 2028.

It is clear that this methodology provides estimates of avoided losses where decisions on performing economic activities in the Arctic have already been made. This approach leads to a structural underestimation of the actual benefits of the existing observing systems: In reality, even the decision to perform economic activities in the Arctic often implicitly assumes the availability of environmental observations. The existence of observing systems is, therefore, crucial for making decisions on performing many economic activities. By limiting the economic impact of observing systems only to a percentage of economic savings in existing activities in the Arctic, the study underestimates monetary benefits.

Finally, it is also worth underlining that the estimates contained in this report only concern the human activities taking place in the Arctic and do not involve in any respect the contribution from observing systems to the preservation of the Artic environment per se. Several methods are available in the literature for associating monetary values to environmental goods and ecosystems (Costanza et al, 2014). In principle, it could be possible to extend the analysis to include a quantitative estimate of the monetary value of the degradation of the Arctic environment and eventually quantify the role of observations in reducing environmental degradation. Such an analysis is out of the scope of the IMOBAR study, but it would certainly further increase the value of the actual benefits provided by observing systems.

Some of the benefits are nevertheless not possible to evaluate in quantitative terms for various reasons ranging from the lack of reliable data to their intrinsic non-monetary nature. For some of these, indicative estimates of benefits are possible by making a series of additional assumptions, which make them much more uncertain. While these are discussed in chapter 5, they are not included in the final evaluation of economic benefits.

A part of the study (Section 5.11) includes social research engaging actors relevant for observation systems in Lapland. The main objective is to understand how people living in the Arctic access and use different sources of environmental information to create strategies for adaptation to environmental change and how scientific information is interwoven with traditional knowledge (Romero Manrique et al. 2018).

3 Case studies: challenges, needs and objectives

As discussed in Section 2.2 within the five observational domains 10 case studies, each addressing one or more key objectives from the value tree analysis, were selected by experts and stakeholders at the November 2017 workshop (Everis, 2018). According to these criteria five broad topics/domains relevant for the Arctic were selected: **Permafrost and freezing/thawing of frozen ground; Biodiversity; Sea level rise; Sea ice; and Human dimension to sea ice**. Examples of value trees for the five selected domains were developed by expert and stakeholders. For each domain, four to six KPSOs were identified finding several direct links to the 12 high-level SBAs (Everis, 2018). Among all the cases identified during the workshop a reduced number of case studies was selected and they are summarised in the following sections.

3.1 Permafrost and freezing/thawing of frozen ground

Permafrost is ground and bedrock both onshore and offshore that remains permanently frozen for at least two years (e.g. US Geological Survey, 1993). Climate-change induced thawing of permafrost initially creates settling and subsequently subsidence. Entire layers of ground can detach from the underlying permafrost provoking land-slumps, slides, holes, slope failures and coastal erosion.

— *Case study: Impact on infrastructure of thawing permafrost*

The resulting geomorphic and land-use products highlight areas at risk of permafrost thaw and over what timeframe. Infrastructure at risk includes buildings and their foundations, drainage systems, roads, railways and airstrips, and pipelines. It is necessary to support the strategic planning and location of future infrastructures in remaining permafrost areas, strategic planning of future infrastructures in non-permafrost conditions and the identification of adequate and timely adaptation or remediation strategies for existing infrastructures.

— *Case study: Forest management and logging*

The definition of Arctic region used in this study includes large areas of the northernmost Boreal forests. Today, these forests have lower growth rates than more southerly Boreal forests, but under nearly all climate change scenarios, they become comparable to the currently more productive southern Boreal regions, within a century. One issue is the fraction of the year that the forest ground remains frozen and can support mechanical logging equipment. This represents a significant opportunity for the economic development of Arctic communities, which needs to be planned and managed carefully.

3.2 Biodiversity

Biodiversity is a unique asset in the Arctic, both in terms of culture, aesthetics, and spirituality, but also in terms of science, ecology and economy. Biodiversity is at the centre of local communities' traditions and livelihoods since thousands of years, while it is also leveraged in both local and global economies, notably in the tourism industry as well as in fisheries (CAFF 2018). More than 21 thousand cold-adapted species living in the Arctic are key actors in the marine and terrestrial ecosystems, in which the functional significance of different groups is not well understood (CAFF 2013).

— *Case study: Fisheries management*

Marine fish are exploited commercially and represent a key element for many local economies. The wider Arctic is one of the world's larger marine fish sources with over 10% of global catches (CAFF 2013). With the sea ice reduction the region is becoming more accessible, with increasing primary production over large areas. In 2017 nine nations and the European Union agreed on a moratorium on commercial fishing in the Central Arctic Ocean for the next 16 years, giving scientists time to develop an evidence-based sustainable fishery plan. Climate change and economic activities represent an important stressor of the aquatic ecosystems. Consequences include the northward shift of fish stocks, introduction of new species and ecosystem damage due to new fishing practices (European Parliament 2015). This requires the development of effective ecosystem-based management and planning strategies for Arctic fisheries underpinning the precautionary approach of sustainable fisheries management.

3.3 Sea Level Rise

The rate of temperature increase in the Arctic has been about twice as high as the global increase rate (AMAP 2017). One of the most serious consequences is the melting of Arctic land ice and its contribution to sea level rise. In the Arctic, the Greenland Ice Sheet and other frozen land areas—mountain glaciers and ice caps—in places like Iceland, the Canadian and Russian Arctic, Alaska and Norway's Svalbard Islands, pose the greatest risk for ocean levels because melting land ice is one of the main cause of rising sea levels and most of the Arctic's land ice is still locked up. In addition to simply adding water to the ocean, thawing Arctic land ice can raise sea levels even more via a mechanism called thermal expansion[6] (IPCC AR5, 2013).

— *Case study: Port management*

It is very important for port authorities to be able to assess and predict potential impacts from sea level rise and develop procedures to incorporate the financial and other risks into their investment decision making processes. Globally higher sea levels are expected to cause more frequent and severe flooding of port facilities and restrict the passage of ships under bridges. In the coastal areas of the Arctic region, any improvements and building of new infrastructure, such as port facilities and support stations should consider the future change of sea level.

— *Case study: Property Insurance*

Sea-level rise is the main determinant of the frequency and severity of coastal flooding events. Property insurance is considered one important factor that could alleviate economic hardships and the loss of livelihoods. Without observing systems, insurance companies may not have accurate enough information to calculate risks and assess damages. Although no insurance company commented on the exact use of data generated by observing systems, it is safe to assume that incomplete information could result in insurance costs that do not reflect actual risks.

3.4 Sea Ice

The reduction of the sea-ice coverage in the Arctic during the last two decades provides more favourable conditions for shipping and development of offshore installations in the region. In recent summers, as much as 40% of the Central Arctic Ocean has been open water, mostly north of Alaska and Russia, over the Chukchi Plateau (Hoag, 2017). An integrated or interoperable Arctic marine monitoring system would bring benefits to the shipping and offshore installation industry, while improved data collection will upgrade the assessment and prediction capacity and the cost-effectiveness of data collection.

— *Case study Ship Routing and Navigation*

Observations provide information improving safety and reducing environmental impacts of navigation. Estimated economic savings in the ship routing and navigation depend on fuel costs, navigation fees, navigation periods and take-up of high-technological developments.

— *Case study: Search and Rescue of vessels*

The success of search and rescue operations on the sea with the presence of sea ice strongly depends on analysis and predictions of weather and ocean conditions based on

---

[6] As the ocean warms, the density decreases and thus even at constant mass the volume of the ocean increases and is one of the major contributors to sea level changes during the 20th and 21st centuries.

observations. Several factors influence economic savings, which further depend on the point in time considered as well as the scenario used.

— *Case study: Offshore installations*

Oil and gas offshore installations represent an important economic sector in the Arctic. Benefits are obtained during exploration, transportation and distribution of extracted resources and decommissioning of platforms in the harsh Arctic environment, by providing important information for safe and sustainable activities.

— *Case study: Oil Spills*

It is assumed that observing systems can significantly improve the reaction to oil spills, as they can help improve the response time and mitigation efficiency, for example by supporting the identification and location of spill and predicting its spread.

Addition benefits from avoided oil spills due reduced risks of accidents during transportation of oil.

3.5 Human Dimension to sea ice

The following example of observing systems provides direct benefits to individuals and communities in the Arctic. The sea ice loss observed in recent decades in the Coastal Zones of the Arctic Ocean makes it more difficult for local communities to predict ice thickness and distribution by traditional methods, making ice travelling, mainly for food provision and collecting fuel for heating, more dangerous. Today, hunters and fisherman are faced with unreliable ice conditions and need to find new, sometimes more expensive ways such as drones, to monitor the ice thickness. In turn, reindeer herders have difficulties to feed their animals because of challenging food provision and navigation. Routes traditionally known as safe are becoming less reliable, particularly in periods of ice freeze-up in autumn and break-up in spring.

— *Case study: SmartICE application*

SmartICE Sea Ice Monitoring and Information Inc, a spin-off of the Memorial University of Newfoundland (Canada) has been working on the SmartICE App since 2013, with the support of academia, industry, government and community[7]. It is built on three pillars comprising Inuit knowledge, sea-ice observations and production of sea-ice maps. Key observed variables are ice thickness, concentration and roughness.

The system relies on two main types of observing systems to record data: in-situ sensors (stationary and mobile carried on sledges) and Synthetic Aperture Radar (SAR) satellite imaginary systems. SmartICE improves the predictability of sea-ice in the Arctic, thereby safeguarding traditional livelihoods and improving the safety of on-ice travel and tourism.

---

[7] https://www.smartice.org/technology/

4 Observing systems: Inputs, outputs and costs

Detailed lists of in-situ observing stations and systems can be found for example in NRC (2006) that provides a list of satellite missions observing the most important Arctic variables. EU-PolarNet (2016) provides an inventory of more than 500 observing systems in the Arctic classified by *observing theme* into Atmosphere, Cryosphere, Marine, Freshwater, Land and Soil, Ecosystem and Human dimension.

There are two main types of OS:

- **Remote sensing.** OS collecting data through a satellite. This means that they usually collect data from different world regions and are not exclusively monitoring the Arctic. Remote sensing includes both **global** and **polar satellites**, as well as **airborne** (aircrafts and unmanned aerial vehicles, UAVs) and **marine coastal radar** measurements.
- **In-situ**. OS collecting data through devices, sensors and other monitoring tools on terrestrial ground, sea and air. It usually involves land stations, sensors, vessels or other data collection mechanisms directly located in the place where the data is produced. This OS type may include research **icebreakers**, and instruments on ships, **underwater** observations with buoys or gliders, **atmospheric** observations for meteorological parameters and atmospheric composition, or **direct measurements** over land like drill holes.

Due to difficult environmental conditions in the Arctic, in-situ observational networks of physical and biogeochemical variables are sparse in comparison to nearby geographical areas and long-term monitoring is less frequent. Remote sensing by satellites is therefore necessary for continuously monitoring the whole Arctic. On the other hand, in-situ observations are essential for obtaining accurate unbiased observations. Satellite observations are also limited to atmosphere, ice, snow, land and ocean surface, while the ocean interior or deeper soil layers may be observed only by in-situ observations.

Table 2. OS types needed for each case study as described in Deloitte (2018)

Domains	Case studies	Global Satellites	Polar Satellites	Airborne	Marine (coastal radars)	Icebreakers	Underwater	Atmospheric	Direct measurements
Permafrost	Forest Management	●	●	●					●
	Infrastructures on frozen ground	●	●					●	●
Biodiversity	Species maps	●			●	●	●		
Sea Level Rise	Port Management	●	●	●	●		●	●	
	Property Insurance	●		●	●		●	●	
Sea Ice	Shipping	●	●	●	●	●	●	●	●
	Offshore	●	●	●	●	●	●	●	●
	Search and Rescue (S&R)	●	●	●	●	●	●	●	●
	Oil spills	●	●	●	●	●	●	●	●
Human Dimension	SmartICE	●	●				●		●

One OS can generate products and services relevant to several topics and eventually SBAs depending on its capacity to measure several parameters or variables that are transversal to more than one topic (Everis, 2018). In this section we focus only on those OSs which contribute to the KPSOs identified during the case study selection (Sections 2.2 and 3). **Table 2** summarises the type of OSs which contribute to each case study, showing the need for a large number of different types of observations to obtain a group of KPSOs needed for a specific objective and SBA in the Arctic (Deloitte, 2018). Some examples of KPSOs obtained from the OS indicated in **Table 2** for each case study are listed below:

Forest management: Vegetation maps; Wildlife habitat and migration maps; Depth of frozen ground; Projections of forest evolution.

Infrastructures on frozen ground: Ground temperature; Depth of frozen ground and distribution of layers; Changes in land cover; Land use maps; Fauna and flora composition and characteristics;

Species maps: Evolutive fisheries maps; Taxonomic inventories; Fish stock models.

Port Management: Improved maps of the ocean floor; Real-time reports, Short term forecasts and longer-term predictions of ice conditions and weather; Maps and real-time monitoring ocean currents;

Property Insurance: Flood maps; Coastline changes; Database on coastal vulnerability and exposure; Improved climate models.

Shipping: Improved maps of the ocean floor; Real-time reports, short term forecasts and longer-term predictions of ice conditions and weather; Maps and real-time monitoring ocean currents; Navigation charts.

Offshore installations: Seabed, seawater and sea ice observations (exploration phase); Weather forecasts.

Search and Rescue: Real-time information on the weather condition; Ice thickness maps; Icebergs in the area; Near-real-time wind, currents or waves.

Oil spills: Icebergs and sea ice real-time and forecast; Canada's Integrated Satellite Tracking of Pollution (ISTOP); Maritime Patrol Aircraft (MPA); Oil trajectory modelling.

SmartICE: Monitoring of ice in near real time.

Structured interviews with representatives of local communities confirmed that observing systems include also traditional observations of environmental change impacts on peoples’ livelihoods including fishing, agriculture, forestry and reindeer herding. Traditional observational capacity is used to augment data and information from the technological tools through the creation of local observer networks (Okey and Brubaker, 2017). With environmental changes being rapid and unpredictable, local people are increasingly combining the uses of their traditional knowledge and technological observational systems.

The full list of OS for each group type included in the analysis of the costs is given in Table 3. As explained in Section 2.3.1, we used a top-down approach. The main efforts were made to gather data on the capital expenditure (CAPEX), operational expenditure (OPEX), and life expectancy of the OS. Overall, the availability of data on observing system costs is limited and variable. Information on CAPEX and OPEX of some global satellites used in the Arctic, like Landsat 5 and 8, Sentinel 2 and SMOS, was not found, while information for NovaSAR-S and RCM is based on planned estimates. For many observing systems, information has only been identified either on their one-off set up costs or annual operating costs (Table 41 in Deloitte, 2018). In a nutshell, the study identified 41 systems (**Table 3**). For 21 systems both CAPEX and OPEX could be identified, for 9 systems only CAPEX and for 8 systems only OPEX were identified, while for the remaining systems only the annual costs, implicitly including OPEX and CAPEX, were available.

Table 3. List of OS identified during the case studies selection.

OS types	Observing Systems
Global Satellite	TerraSAR-X; RADARSAT Constellation Mission (RCM); TanDEM-X; Envisat; Twin Sentinel 1 (Sentinel 1A and 1B); Sentinel 3; AISSat-1; Metop-A, Metop-B, Metop-C; NOAA 15-19; NovaSAR-S; EOS-Aqua; EOS-Terra; Suomi; DMSP-F16.
Polar Satellite	CryoSat-2
Airborne	Aircraft and helicopters (surveillance/photography); Light Detection and Ranging (LIDAR); Radio sensor; Infrared (IR); Ground Penetrating Radar (GPR); Unmanned Aerial Vehicle (UAV)
Marine	Marine Radar (open array); Shore-Based Marine Radar.
Icebreakers	Sikuliaq (US); Kronprins Haakon (Norway); Polarstern (Germany); MV Xue Long (China).
Underwater	Moored buoys; Drifting Buoys; Autonomous Underwater Vehicles (AUVs)/ Submarines; Fixed Moorings; Wave Gliders for Arctic MIZ Surface Observations and Navigation Support; Argo floats; Instruments on ships.
Atmospheric (non-satellite)	SYNOP-SHIP-METAR; EMEP; AERONET; ICOS.
Direct measurements	Drill holes; Satellite Tracked Drifting Buoys; SmartICE devices.

In order to make a comprehensive cost-and-benefit analysis of Arctic observing systems, the **fraction of the costs of observing systems** that relate to the Arctic area and, ideally, that refer specifically to information that is used for the purpose of the human activities that are carried out as part of each of the cases examined would need to be determined.

As a single OS in Table 3 may contribute to different case studies and SBAs, we present the results of the cost analysis as the overall costs of the OS in the Arctic. The following table gives a summary overview of the data that have been identified in relation to the different types of observing systems studied. It includes ranges and median of CAPEX and OPEX costs for each type / group of systems. The median CAPEX and OPEX costs are used to estimate the **Arctic annualised costs** taking into account **life span** and estimated **minimum and maximum Arctic coverage** of the systems.

These estimates have limitations: it was not possible to identify robust data in relation to all types of observing systems and data points needed, which is why it was necessary to work with estimates and median costs. In addition, the figure does not provide a complete picture; it was not possible to include data on costs in relation to all relevant systems. As it is even more difficult to allocate cost fractions to specific SBAs linked to observing systems, this evaluation has not been performed in the study.

The study did not evaluate the possible production of environmental information from activities that were not intended for observations. For example, in situ observations of temperature and winds, Global Navigation Satellite System (GNSS) observations of drifts of aircrafts and ships, like observations by the Galileo programme with the global coverage (reference), may provide in situ information on atmospheric and oceanographic parameters, while GNSS radio occultation may indirectly produce observations of atmospheric temperature profiles. As these systems are implemented for very different purposes than providing environmental observations for general purposes, it was difficult to estimate the fraction of their costs related to environmental observations.

The estimated overall costs per year (excluding airborne sensors and drones as well as direct measurements) associated to the OS contributing to KPSOs in the selected 10 case studies ranges between **70 and 135 MEUR/yr**. The main contributions to the total costs derive from **global satellite observation, 23-54 MEUR/yr**, and **icebreakers (research vessels), 22-39 MEUR/yr**.

Table 4. Estimates of overall annualised costs from all relevant observing systems relating to the Arctic for ten selected case studies.

Type of observing system	Annualised costs (global in MEUR)	Assumed share of the observations that refer to the Arctic		Annualised costs (Arctic, for all systems identified) (in MEUR)	
		Min.	Max.	Min.	Max.
Global satellite (e.g. Envisat, Sentinel 1)	770	3%	7%	23	54
Polar satellite (CryoSat)	19	50%	70%	9	13
Airborne (aircraft and helicopters)	13	20%	70%	3	9
Marine (coastal radars)	2	25%	45%	1	1
Atmospheric observation systems (non-satellite) / atmospheric composition (e.g. SYNOP-SHIP-METAR, EMEP)	3.5-10[8]	100%[9]		3.5	10
Icebreakers (research vessels)	88	25%	45%	22	39
Underwater (coastal buoys, drifting buoys, wave gliders, Argo, instruments installed on vessels)	9	100%[8]		9	9
Estimated overall Arctic costs per year				**70**	**135**

---

[8] The uncertainty range depends on the definition of the Arctic geographic area.

[9] Only stations/systems located in the Arctic (Latitude above 60°N) are considered (Deloitte, 2018)

5 Societal Benefit analysis

Scientific experts and stakeholders in the Arctic selected five domains and a large number of observing systems and key products, services and outcomes that could be linked to a considerable number of key objectives, covering all the societal benefit areas of the VTA (Everis, 2018). Ten selected cases from this first pool of observing system and key products are analysed in more detail through the VTA and IL (see Annex 1 and Deloitte, 2018). We present a summary of the main benefits of the observing systems that have been identified in relation to each of the selected case studies. Table 5 shows the SBAs found for each case study, either for quantified (highlighted in red) or non-quantified economic benefits. Explanations of how we came to the individual estimates of the monetary benefits as well as presentations of the non-quantified benefits are presented in the next sections (Deloitte 2018). In Section 5.12 we present a summary table of the quantified economic benefits.

Table 5. Contribution to the SBAs associated to the selected case studies relevant to the Arctic. Black dots indicate non-quantified SBAs, red dots quantified SBAs.

Case studies	Disaster preparedness	Environmental Quality	Food security	Fundamental Understanding	Human Health	Infrastructure & Operations	Marine Ecosystems	Natural Resource	Resilient Communities	Sociocultural Services	Terrestrial/freshwater Ecosystems	Weather and Climate	Quantified SBAs	Total SBAs linked
5.1 Infrastructures	●	●	●	●	●	🔴			●				1	7
5.2 Forest Management		●	●	●		🔴		🔴	●	●	●	●	2	9
5.3 Fisheries Management		●	●	●	●		●		●		●		-	7
5.4 Port Management	🔴		●	●		🔴			●			●	2	6
5.5 Property Insurance	🔴					🔴			●				2	3
5.6 Shipping	🔴	●	●		●	🔴	●	🔴					3	7
5.7 Offshore	🔴	●				🔴							2	3
5.8 Search and Rescue	🔴				●								1	2
5.9 Oil spills	🔴	●	●		●		●						1	5
5.10 SmartICE	●		●		●				●	●			-	5

5.1 Benefits from systematic observations of permafrost for infrastructure

Quantifiable benefits of observing systems under the infrastructure and operations SBA can be determined by estimating the fraction of costs from damage to infrastructure that can be expected to be avoided by timely adaptation in the Arctic infrastructure sector (Figure 3 in Annex 1). A 2017 study of the costs of damage, reconstruction and repair of public infrastructure in Alaska between now and the end of the century estimated cumulative cost of between 3.6-4.2 BEUR[10] without adaptation measures and 1.9-2.4 BEUR with adaptation measures depending on the climate scenario (Melvin et al., 2017).

Savings are estimated by taking the difference between cases with and without adaptation cases, extrapolating these figures to the entire Arctic (Section 2.3.2) and assuming that costs increase exponentially between 2015 and 2099. Average savings in annual infrastructure damage, reconstruction and repair costs for the whole of the Arctic due to successful adaptation measures for the period 2015-2030 appear to be between 39-76 MEUR/yr. Adaptation strategies to avoid damage and repair costs or to propose reconstruction, necessitate a thorough understanding of the local permafrost and its evolution, for which observation products are essential. The potential impact of observation systems on avoiding costs is thus significant and our analysis assumes 60-80%[11] of the annual benefits can be attributed to using observation products, giving an average annual benefit of 23—61 MEUR/yr (Deloitte, 2018).

Additional societal benefits that are not quantified arise under the Human Health (avoided loss of life), Resilient Communities (continuity, wellbeing, avoided relocation), Environmental quality (species migration), Disaster preparedness (landslides and coastal erosion), Fundamental understanding of the Arctic System, and Food Security SBAs.

5.2 Benefits from systematic observations for forest management and logging

Quantifiable benefits of observing systems for forest management and logging also fall under the infrastructure and operations SBA, as well as natural resources and terrestrial and freshwater ecosystems and services SBAs (Figure 4 in Annex 1). In Sweden, the Swedish Forest Agency (SFA) is responsible for ensuring the effective implementation of forest management policy (SFA, 2015). Using satellite derived maps, the SFA monitors whether logging is performed as authorised and whether landowners are compliant with land management practices. While the SFA spends approximately 0.5 MEUR/yr to purchase and use the imagery, this forest management system has registered large direct and indirect benefits, quantified between 16-21.6 MEUR/yr. Such benefits include higher timber productivity, reduced organisational costs for the agency, increased compliance, re-use of data produced (published as open data) and better intra-agency cooperation (Persson ,2016; EARSC and The Green Land BV., 2016).

This analysis covers all Sweden, by interpolating from all Sweden to the boreal forests of the Swedish Arctic, as defined in the study and then extrapolating from the Swedish Arctic forests to all Arctic forests (Sweden was responsible for just over 5% of Arctic wood production in 2002, Deloitte, 2018) and further taking into account that Arctic boreal forests are under-exploited relative to the sub-Arctic southern boreal forests we estimate annual benefit from forest observations of 20-40 MEUR/yr for the Arctic as a whole. These benefits do not include those of predicting when a forest is waterlogged and cannot support mechanical operations and are thus an underestimate of the true infrastructure and operations benefits.

The additional societal benefits that are not quantified arise under the Environmental Quality, Fundamental understanding of the Arctic System, Resilient Communities, Sociocultural Services, Weather and Climate and Food Security SBAs.

---

[10] Discounted to 2015 assuming 3% inflation.

[11] The estimates of percentages of benefits attributable to the observing systems in this and other case studies are based on assumptions about the expected contributions of the observing systems, taking into account the findings from the desk research and stakeholder consultations (Section 2.3.2 and Deloitte 2018).

5.3 Benefits from systematic observations for fisheries management

We did not find examples of the quantification of benefits of observations underpinning fisheries management on which to base an assessment for the Arctic. Nevertheless, observations bring non-quantified benefits to the Food Security, Marine and coastal ecosystems and processes, Terrestrial and freshwater ecosystems and processes and environmental quality SBAs (Figure 5 in Annex 1).

5.4 Benefits from systematic observations for Port management

Benefits for port management from observations fall primarily under the infrastructure and operations SBA and are predominantly costs avoided by adaptive measures (Figure 6 in Annex 1). No direct estimates could be made either for the Arctic or for the role of observations due to a lack of suitable base cases. For example, the FP7 project Climate Cost on the economics of climate change and adaptation excluded ports from consideration of sea level rise (Brown et al., 2011). Another study looked at the costs of adapting US ports for future sea level rise (53-75 BEUR), but not the costs of taking no action (Hippe et al., 2015).

If benefits are restricted to the Arctic, indicative benefits from improved observations can be estimated by assuming that the infrastructure of the port sector is no more than five times the combined airport and railway sectors in the Alaskan study referred to in Section 5.1 (Deloitte, 2018). Together these two sectors are responsible for 1.5% of infrastructure damage, reconstruction and repair costs with and without adaptation, which would imply annual average benefits for the entire Arctic of the order of 3-5 MEUR for the period 2015-30.

In addition to the infrastructure and operations SBA, observations for port management also generate additional non-quantified benefits under the fundamental understanding of Arctic systems, weather and climate, food security and disaster preparedness SBAs.

5.5 Benefits from systematic observations for property insurance

In addition to the sea level rise observational products described in Section 4, products describing flood risk in coastal areas, as well as the projected evolution of this risk with rising sea levels are required to inform insurers of current and future risks so that premiums may be set accordingly.

Benefits for property insurance from observations fall primarily under the infrastructure and operations and resilient communities SBAs (Figure 7 in Annex 1). If benefits are restricted to the Arctic, indicative benefits from improved observations are inevitably a very small fraction of the global total and of the order of 1-2 MEUR/yr averaged over the period 2015-2028, taking into account the coastal Arctic building stock at risk, the overall market penetration for flood insurance in Arctic states is between 20-40% (OECD 2016), and an indicative saving for insurers of 10-20 euro per policy per year.

As sea level rise is a global issue and approximately 40% of global sea level rise to 2100 is estimated to be attributable to melting Arctic land ice (AMAP 2017), it makes sense to also evaluate the global impact. A recent study for Europe (Mokretch et al. 2015) suggest that for the business as usual case and no flood protection in excess of 18 million Europeans are at risk of coastal floods at least once by 2100, but that with flood protection measure these numbers can be reduced by half. As the losses in the no flood protection case for Europe could total 236 BEUR by 2100, the benefits for the insurance industry, will be commensurately larger than those in the Arctic. A more recent study (Vousdoukas et al. 2018) suggests that without increased investment in coastal adaptation, the expected annual damage caused by coastal floods in Europe could increase from €1.25 billion today to between €93 billion and €961 billion by the end of the century.

In addition to the infrastructure and operations SBA, observations for property insurance also generate additional non-quantified benefits under the fundamental understanding of Arctic systems, weather and climate and disaster preparedness SBAs.

5.6 Benefits from systematic observations on ship routing and navigation

Currently, the Arctic navigation season is too short, and sea ice conditions are difficult to predict. Challenges include high operational costs, limited infrastructure, navigation safety and the environmental impact of shipping. Nevertheless, the loss of Arctic sea ice is making new trade routes increasingly feasible, fostering the possibility of economical trans-Arctic shipping, as well as greater access to regional resources. This may also stimulate the local shipping industry, both for natural resource extraction and cruising as part of tourism (Figure 8 in Annex 1).

Observations are conservatively assumed to be responsible for 15-20% of the cost savings (Deloitte, 2018) calculated for three scenarios for the evolution of commercial traffic in the Arctic based on current shipping recorded in the Arctic growth rates for the shipping industry worldwide assuming variously a 50% lower (conservative), current (central) and 25% faster (speculative) growth rates for Arctic shipping. Total annual savings by 2028 are of the order of 920 – 1168 MEUR, consequently the benefits form observations are between 138 and 234 MEUR/yr by 2028 (Deloitte, 2018).

Ship routing has a strong connection with the Natural Resources SBA, as well as the Disaster preparedness, Weather and climate, Marine and coastal ecosystems and processes, Environmental quality and Food security SBAs, but these additional benefits are not quantified.

5.7 Benefits from systematic observations for Offshore installations

The main impacts for offshore installations are safer operations and transport, including the prevention of accidents with the loss of lives and harmful impacts of the environment respecting natural ecosystems and the presence of local communities (Figure 9 in Annex 1).

Economic benefits due to the prevention of accidents account for the reduction of economic losses in equipment and reduced activity. Depending on the price of oil and gas, there is a strong uncertainty on the evolution of offshore installations in the Arctic in the next decade. Assuming different scenarios, the study finds that annually 8-14 MEUR may be saved by avoiding accidents (Deloitte, 2018). It is assumed that only a fraction of this saving may be attributed to observations and the savings do not contribute significantly to overall economic benefits from observing systems in the Arctic. The study does not account for the value of eventually saving human lives that in the Arctic may reach 11 MEUR annually (Deloitte, 2018). It also does not account for the impact of observations on the sustainable exploration and use of natural resources in the Arctic. In addition, observations with respect to activities on offshore installations contribute to SBA Maintenance of Environmental quality.

5.8 Benefits from systematic observations for Search and Rescue of vessels

Improvements and innovations in observing and communication systems, leading to better navigation charts and accurate information on meteorological and oceanographic conditions, can lead to more efficient and therefore less costly S&R operations (Figure 10 in Annex 1). We consider three scenarios to estimate the economic benefits associated to observations use in S&R operations: Conservative (no efficiency gain); Central (limited efficiency gain); Speculative (greater efficiency gain). Common assumptions for the three scenarios are:

- the number of incidents requiring S&R operations is expected to increase by about 16% during the decade, 2018-2029, which reflects the expected increase in human activity in the Arctic;
- The costs for S&R operations are considered to range from EUR 70,000 (for 'small' operations) to EUR 500,000 (for 'medium-sized' operations) to EUR 850,000 (for 'large' operations);
- The average annual cost of S&R operations is estimated as a weighted average of small, medium and large S&R operations, representing respectively 50%, 40% and 10% of the total S&R operations carried out in one year (Deloitte, 2018).

In the conservative scenario, costs are expected to increase in line with the increase in human activity, i.e. by about 16%. The central and speculative scenarios are expected to lead to a 5.3% and 17.6% decrease in the costs of S&R operations compared to the conservative scenario. On this basis, the estimated annual monetary benefits from observing systems are in the EUR 0.5-1 million range for the speculative scenario in 2028, possibly in the 20-25% range (Deloitte, 2018). We note that these estimates are very conservative. It is also possible e.g. that the location of a lost ship or airplane might only be found due to observing systems. In such cases, the benefits could thus be significantly higher. The economic benefits in terms of saved human lives are not quantified. The synergies between environmental and GNSS observations (e.g. UN 2018) provided in S&R activities, such as Galileo S&R[12], are also not evaluated.

5.9 Benefits from systematic observations for Oil Spills

Oil spills may strongly harm marine ecosystems requiring long recovery. They may impact human physical health by direct contact with crude oil, inhalation of vapours or consumption of contaminated seafood. Local economies like the fisheries, aquaculture, and tourism may suffer for long time after the oil spill. The reduction of oil spill accidents and the increased efficiency of cleaning the pollution after the accident may, therefore, strongly reduce negative impacts on the society. The response to an oil spill in a remote area like the Arctic is complex and costly (Figure 11 in Annex 1).

Improving the efficiency of the oil spill response creates savings that can be measured by economic terms. In the next decade, assuming an accident similar to Exxon Valdez[13], the study estimates that savings due to improved efficiency of oil spill response activities are between 110 and 420 MEUR. It is further estimated that 10% of these savings are due to better use of observations. Assuming one accident per decade, the study estimates that 1 to 4 MEUR are saved annually by the presence of observing systems in the Arctic. This a very conservative estimate, because the study does not monetarize impacts on the ecosystems and human health, and it does not account for the reduced probability of oil spill accidents due to the presence of observations in the Arctic (Deloitte, 2018).

Non-quantified social benefits of reduced number of oil spills and improved oil spill response belong to SBAs: Environmental quality; Food security; and Human Health.

5.10 Benefits from systematic observations for SmartICE

The main direct benefit of SmartICE is enhanced safety on sea ice routes reducing the number of accidents due to ice-related hazards and collisions. This leads to a series of other positive impacts for local communities and all Arctic stakeholders. Optimisation of operations on sea ice allows for informed decision-making across a wide area. Emergency rescue services can be optimised increasing public safety. In addition SmartICE, as a

---

[12] https://www.gsa.europa.eu/european-gnss/galileo/services/galileo-search-and-rescue-sar-service

[13] On 4 March 1989, oil tanker Exxon Valdez was en route to Long Beach, California (US), when it struck the Bligh Reef in the Prince William Sound region of Alaska. It was carrying about 204 million litres of oil. The accident caused the rupture of 8 of its 11 cargo tanks, releasing 42 million litres of crude oil into the waters of Prince William Sound in the following days, contaminating over 2,000 km of coastline. The Exxon Valdez is the largest oil spill ever to have occurred in the Arctic region.

community activity, safeguards traditional livelihoods, uses and knowledge of sea ice, and expands local employment and training opportunities (Figure 12 in Annex 1).

All these impacts link to societal benefits covered by SBAs: Enhanced infrastructure and operations; Fundamental understanding of Arctic systems; Increased disaster preparedness; Monitoring of impacts on environmental quality; Sociocultural Services; and Resilient communities. Assuming that the main impact of the study is to safeguarding the traditional lifestyle of local communities, benefits were not quantified.

5.11 Benefits for local communities

Structured interviews performed in a separate JRC study in Lapland (Romero Manrique 2018) provided a dynamic picture of the Arctic communities and of their relationships with environmental data. Arctic people are experiencing and observing an increasing variability and unpredictability of the weather and seasonal climatic patterns, as well as changes in the sea ice and the health of wildlife. Interviews suggest that observing system benefits for local communities are closely linked and translated into main traditional activities that depend on environmental conditions. They see "food security" as a secured access to fishing activities and the smooth continuation of reindeer and caribou herding. With environmental changes being rapid and unpredictable, local people are increasingly combining the uses of their traditional knowledge and technological observational systems, such as satellite data, and mappings resulting from GIS elaboration, becoming more and more involved in active use of scientific data. Moreover, they are more and more making use of other scientific or technological data, where they increasingly play an active role: for instance, hunters, herders or gatherers, support their activities actively monitoring herd movement through unmanned aerial vehicles (drones).

5.12 Summary of the quantified economic benefits

Quantifiable benefits were estimated for several case studies in a conservative way (Section 2.3.2). In the first approach, the study included benefits that may be directly quantified starting from economic values of savings for each activity (Section 2.3.2). This was done in case studies on Oil spill, Search and rescue, and Offshore activities. In the second approach, benefits were estimated starting from economic estimates made globally, for other similar geographical regions or Arctic sub-regions (Section 2.3.2). This approach was applied in estimating benefits for Infrastructures and Forest management. The third approach combined the first two approaches. It was used in estimating benefits for Shipping.

Table 6 summarizes economic benefits of observing systems providing the overall estimate of annual economic savings between 183 and 341 MEUR (for more details see also Tables 42 and 43 in Deloitte, 2018). These numbers may account for only a fraction of all economic benefits. For example, in the Oil spill case study the evaluation assumes that observations contribute only to additional savings in the future and have no impact on savings in current cleaning activities. Economic impacts can be further assessed, for example, on improving predictions of global sea level rise due to the ice sheet melting in the Arctic, or on more accurately and timely forecasting severe cold weather intrusions into the mid-latitudes. The assessment for a limited number of activities in the Arctic indicates an average of 250 MEUR of economic benefits, while the inclusion of other economic activities and global impacts may result in several times larger numbers.

Table 6. Economic benefits for each case study.

Case	**Unit of analysis**	**Overall monetary effects in MEUR**		**Estimated share of effects relating to observing systems**		**Annual monetary benefits from observing systems in MEUR**	
		Min.	**Max.**	**Min.**	**Max.**	**Min.**	**Max.**
Sea ice							
Ship routing	Expected cost savings relating to shipping in the Arctic	919	1,168	15%	20%	138	234
Search and rescue	Benefits of observing systems relate to a potential reduction of the costs for S&R activities	2	5	20%	25%	0.5	1
Oil spills	Savings relating to the clean-up savings for a fictive oil spill similar to that of the *Exxon Valdez every 10 years*	100	330	10-15%		1	4
Sea level rise							
Property insurance	Estimated benefit of data from the Copernicus program for intermediate users in the insurance and (re)insurance industry in 2016, with the potential to grow by 64% per year	0.5	1	100%		0.5	1
Permafrost							
Infrastructure	Costs savings due to timely infrastructure adaptation measures	39	76	60%	80%	23	61
Forest management	Estimated revenue generated based on data generated by observing systems in relation to forest management in 2020	20	40	100%		20	40
Estimated overall savings relating to the data points identified						**183**	**341**

6 Conclusions and recommendations

Observing systems in the Arctic may provide essential information to a number of societal benefit areas in the Arctic and at the global scale. On the other hand, observing in the Arctic may require high investment costs due to difficult environmental conditions. This study applied Value Tree Analysis (VTA) and Intervention Logic (IL) methodologies to link observing systems in the Arctic to societal benefits. VTA links observing systems to societal benefit areas through a value tree that includes key products and objectives, while IL adds the logical part of the policy development corresponding to societal challenges, needs and objectives anticipating a policy.

By using analytical structured methodologies for the first time the study estimated costs of Arctic observing systems and partly quantified their societal benefits.

The total cost of maintaining observing systems identified in the study ranges between 70 and 135 million Euros per year. This is probably an underestimate of the total cost, but as most of observing systems are included in the study, costs of additional systems should not significantly increase this estimate.

The evaluation of benefits using expert opinions was based on the assessment of case studies covering a large number of activities and environmental processes in the Arctic. In the ten case studies, observing systems are linked to all twelve societal benefit areas identified previously for the Arctic, demonstrating a large span of societal benefits originating from information provided by observing systems.

When identifying societal benefits the study assumed fast and efficient use of all available information originating from observing systems. Many case studies contained applications that require either continuous information flow or emergency response situations. The most successful achievement of societal benefits requires collaboration at the regional and global level including the participation by local communities. This effort should increasingly lead to continuous and reliable implementation of observing systems with standardized quality and communication methods and rapidly accessible data.

In several case studies, it was possible to assess parts of economic benefits that can be directly linked to observations. The total amount of identified economic benefits due to the use of information originating from observing systems amounts to a range of 183 to 341 million of Euros per year. Most likely, by conservatively applying the economic analysis only to the most accessible economic estimates, the study identified only a fraction of total economic benefits that can be several times larger than the maximum identified value here.

By comparing the lowest identified total benefits with highest identified total costs and considering the range of uncertainties and underestimates, it can be concluded that annual economic benefits exceed by at least 50% annual investments in Arctic observing systems. The results of this study show for the first time that costs associated to Arctic observing systems are widely compensated by their economic benefits and this represents a key finding towards the "business case" for sustaining Arctic observations.

Rapid environmental changes in the Arctic will likely lead to a strong increase of human activities and pressures to Arctic communities and environment that were not assumed in the study. Responding to these challenges may also require increased investments in observing systems. On the other hand, we may expect that benefits in environmentally changed conditions in the Arctic will become even increasingly more significant and future studies using the same or similar structured approaches may demonstrate even higher rates of return from larger investments in observing systems.

A full justification of long-term investments in Arctic observing systems is still necessary and further resources should be devoted to complete the cost-benefits analysis and to reduce uncertainties. The structured approach applied here provides means for a reproducible and expandable evolution of the study to other activities and observing systems. For example, it can evaluate the impacts of the future evolvement of sustained observing systems in the Arctic including the assessment of synergies with GNSS. It can also be expanded to quantify benefits in other case studies covering additional branches of the full value tree in the Arctic. Moreover, this study focused mainly on benefits in the Arctic region. The proposed analytical framework should also be further developed to estimate the economic benefits of Arctic observing systems at global scale.

References

AMAP, *Methane as an Arctic climate forcer*, Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway. vii + 139 pp, 2015.

AMAP, *Snow, Water, Ice and Permafrost in the Arctic (SWIPA) 2017*, Arctic Monitoring and Assessment Programme (AMAP), Oslo, Norway, xiv + 269 pp, 2017.

AOS, 2018. Arctic Observing Summit (AOS) 2018 Statement and Call to Action August 24, 2018. (http://www.arcticobservingsummit.org/sites/arcticobservingsummit.org/files/AOS_Statement_Aug24_clean.pdf).

Arctic Council (2016). Arctic Resilience Report. M. Carson and G. Peterson (eds). Stockholm Environment Institute and Stockholm Resilience Centre, Stockholm. (http://www.arctic-council.org/arr).

Booz & co (2011) Cost-Benefit Analysis for GMES, 244 pp, available at Copernicus: http://www.copernicus.eu/sites/default/files/library/ec_gmes_cba_final_en.pdf

Brown S, Nicholls RJ, Vafeidis A, Hinkel J, and Watkiss P (2011). The Impacts and Economic Costs of Sea-Level Rise in Europe and the Costs and Benefits of Adaptation. Summary of Results from the EC RTD ClimateCost Project. In Watkiss, P (Editor), 2011. The ClimateCost Project. Final Report. Volume 1: Europe. Published by the Stockholm Environment Institute, Sweden, 2011. ISBN 978-91-86125-35-6.

CAFF, 2013. Arctic biodiversity assessment – Synthesis; https://www.caff.is/assessment-series/arctic-biodiversity-assessment/232-arctic-biodiversity-assessment-2013-synthesis.

CAFF, 2018. Arctic Biodiveristy Assessment – Indigenous peoples and biodiversity in the Arctic (https://www.arcticbiodiversity.is/index.php/the-report/chapters/indigenous-peoples-and-biodiversity-in-the-arctic)

Costanza, de Groot, Sutton, van der Ploeg, J. Anderson, Kubiszewski, Farber, Turner, Changes in the global value of ecosystem services, Global Environmental Change, Volume 26, 2014, Pages 152-158, ISSN 0959-3780, (https://doi.org/10.1016/j.gloenvcha.2014.04.002).

Deloitte, 2018. Impact Assessment Study on Societal Benefits of Arctic Observing Systems: Evaluation of costs and benefits. Final report. 15 June 2018. (Available upon request. Contact: Srdan Dobricic at the European Commission's Joint Research Centre, srdan.dobricic@ec.europa.eu)

EARSC (European Association of Remote Sensing Companies) & The Green Land BV. (2016). Copernicus Sentinels' Products Economic Value: A Case Study of Forest Management in Sweden; (https://esamultimedia.esa.int/docs/EarthObservation/case_report_forest_management_in_sweden_final.pdf)

Everis, 2018. Impact assessment study on societal benefits of Arctic observing systems. Final report. 31 January 2018. (Available upon request. Contact: Srdan Dobricic at the Joint Research Center, srdan.dobricic@ec.europa.eu)

Eyre, J. and R. Reid, *Cost-benefit studies for observing systems*, Forecasting Research Technical Report No: 593, Met Office, Exeter, 11 pp, 2014, available at (https://www.metoffice.gov.uk/binaries/content/assets/mohippo/pdf/k/n/frtr593.pdf)

European Parliament. (2015). Fisheries management and the Arctic in the context of climate change; (http://www.europarl.europa.eu/RegData/etudes/STUD/2015/563380/IPOL_STU(2015)563380_EN.pdf)

GROOM, 2014, Report describing costs to build and operate the glider observatory infrastructure, FP7 Project GROOM, 52 pp, available at: (http://www.groom-fp7.eu/doku.php?id=public:deliverables).

EU-PolarNet, 2016, Inventory of existing monitoring and modelling programmes, 17 pp (https://www.eu-polarnet.eu/fileadmin/user_upload/www.eu-polarnet.eu/Members_documents/Deliverables/WP2/D2_3_Inventory_of_existing_monitoring_and_modelling_programmes.pdf) Inventory available at: https://www.arcticobserving.org/images/pdf/Committees/CON/EUPolarNet/Inventory_monitoring_26SEP2016.xls).

Hippe et al. (2015). Estimation of Cost Required to Elevate US Ports in Response to Climate Change: A Thought Exercise for Climate Critical Resources. CIFE Working Paper #WP138, Stanford University, December 2015

Hoag, 2017. Nations agree to ban fishing in Arctic Ocean for at least 16 years (http://www.sciencemag.org/news/2017/12/nations-agree-ban-fishing-arctic-ocean-least-16-years)

IDA-STPI and SAON. 2017. International Arctic Observations Assessment Framework. IDA Science and Technology Policy Institute, Washington, DC, U.S.A., and Sustaining Arctic Observing Networks, Oslo, Norway, 73 pp.

JERICO, *Running costs of coastal observatories*, FP7 JERICO project report, 141 pp, 2014, available at (http://www.jerico-ri.eu/previous-project/deliverables/d4-5-running-costs-of-coastal-observatories/)

JOIN(2106)21, JOINT COMMUNICATION TO THE EUROPEAN PARLIAMENT AND THE COUNCIL, An integrated European Union policy for the Arctic. (https://eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52016JC0021&from=EN)

Melvin, A. et al. (2017). Climate change damages to Alaska public infrastructure and the economics of proactive adaptation; http://www.pnas.org/content/114/2/E122

Mokrech et al. (2015): An integrated approach for assessing flood impacts due to future climate and socio-economic conditions and the scope of adaptation in Europe. In: Climatic Change, (128) 245. (https://doi.org/10.1007/s10584-014-1298-6)

National Research Council (NRC), 2006, Toward an Integrated Arctic Observing Network, ISBN: 0-309-65484-X, 128 pages

National Research Council (NRC), 2009. Science at Sea: Meeting Future Oceanographic Goals with a Robust Academic Research Fleet. Washington, DC: The National Academies Press. (https://doi.org/10.17226/12775).

OECD (2016): Financial Management of Flood Risk. (http://www.oecd.org/daf/fin/insurance/Financial-Management-of-Flood-Risk.pdf)

Okey, T. A., & Brubaker, M. Y. (2017). The Local Environmental Observer (LEO) Network: Collaborative environmental surveillance, adaptation decision making, and integration of monitoring programs.

Persson, A. (2016). Sustainable forest management in Sweden with the support of satellite imagery; (https://www.eurisy.org/good-practice-forest-management-in-sweden-with-the-support-of-satellite-imagery_199)

PWC (2016) Study to examine the socio-economic impact of Copernicus in the EU - Report on The socio-economic impact of the Copernicus programme, Report prepared by PwC for the European Commission, EU Publications, 55 pp, doi:10.2873/01661

PWC (2017) Copernicus ex- ante societal impact assessment, Report prepared by PwC for the European Commission, 343 pp, available at: (http://copernicus.eu/sites/default/files/documents/News/Copernicus-Ex-Ante-Final-Report.pdf).

Romero Manrique D., Völker T., Zoghbi J., Guimarães Pereira Â., Arctic: Traditional Knowledge, Livelihoods and Community Engagement Setting the Scene – volume 01, EUR 29293 EN, Publications Office of the European Union, Luxembourg, 2018, ISBN 978-92-79-90170-6, doi:10.2760/61611, JRC112270.

Schlosser, P. et al. A 5˚ C Arctic in a 2° C World. Challenges and recommendations for immediate action from the July 21-22, 2016 Workshop: Briefing Paper for Arctic Science Ministerial, September 20, 2016. Available at: (https://eprints.uni-kiel.de/39117/1/5C_Arctic_final_pages.pdf)

Schuur, E. A. G. et al., *Climate change and the permafrost carbon feedback*, Nature, 520, 171-179, doi:10.1038/nature14338, 2015.

SFA, 2015. Royal Swedish Academy of Agriculture and Forestry. Forests and forestry in Sweden. (https://www.skogsstyrelsen.se/globalassets/in-english/forests-and-forestry-in-sweden_2015.pdf).

UN 2018. European Global Navigation Satellite System and Copernicus: Supporting the Sustainable Development Goals. Building Blocks towards the 2030 Agenda". ST/SPACE/71, 2018-01-29, STSC 55th session.

US Geological Survey. (1993). Permafrost. (Publication n° 1993-356-619). (https://pubs.usgs.gov/gip/70039262/report.pdf).

Vousdoukas M. I., Mentaschi L., Voukouvalas E., Bianchi A., Dottori F., Feyen L. Climatic and socioeconomic controls of future coastal flood risk in Europe. *Nature Climate Change*, 2018; doi:10.1038/s41558-018-0260-4

Zeug, G., *GMES in situ cost assessment - 2011 update*, GMES in situ Coordination (GISC) internal project report, European Environment Agency (EEA), Copenhagen, 62 pp, 2011.

List of abbreviations and definitions

AMAP	Arctic Monitoring and Assessment Programme
AOS	Arctic Observing Summit
BEUR	Billions of Euro
BRG	Better Regulation Guidelines
CAFF	The Conservation of Arctic Flora and Fauna
CAPEX	Capital expenditure
EARSC	European Association of Remote Sensing Companies
EU	European Union
FP7	7th Framework Program
GIS	Geographic Information System
GNSS	Global Navigation Satellite System
IDA-STPI	Institute for Defense Analyses-Science and Technology Policy Institute
IL	Intervention Logic
IMOBAR	Impact assessment study on societal benefits of Arctic observing systems
IPCC AR5	Intergovernmental Panel on Climate Change 5th Assessment Report
ISTOP	Integrated Satellite Tracking of Pollution
KO	Key Objective
KPSO	Key product, service and outcome
MEUR	Millions of Euro
MPA	Maritime Patrol Aircraft
NRC	National Research Council
OECD	Organisation for Economic Co-operation and Development
OPEX	Operational expenditure
OS	Observing System
S&R	Search and Rescue
SAON	Sustaining Arctic Observing Networks
SAR	Synthetic Aperture Radar
SBA	Societal benefit area
SFA	Swedish Forest Agency
SWIPA	Snow, Water, Ice, Permafrost in the Arctic
UAV	Unmanned Aerial Vehicle
UN	United Nations
US	United States
VTA	Value Tree Analysis
YR	Year
WMO	World Meteorological Organization

List of figures

Figure 1. Value Tree analysis of the key objective "Provide sector-specific weather predictions for economic activity" in relation to the Societal Benefit Area "Weather and Climate" 9

Figure 2. Correspondences between VTA and IL. VTA connects OSs with KPSOs and KOs and finally to societal sub-SBAs and SBAs. IL instead starts from a longer logical chain that evaluates Challenges, Needs and Objectives that provide the motivation for Inputs, Activities and Outputs, producing Results and Impacts. Inputs are investments that correspond to OSs in VTA. Activities and Outputs correspond to KOs and KPSOs benefiting from observations, while Impacts and Results are closely related to sub-SBAs and SBAs in VTA. Challenges, Needs and Objectives are not present in VTA. They represent the general set-up requiring intervention. In each selected case studies they may represent specific environmental conditions that may require responses by producing observations. 10

Figure 3. Value Tree Analysis and Intervention logic for Future infrastructure on thawing permafrost 36

Figure 4. Value Tree Analysis and Intervention logic for forest management 37

Figure 5. Value Tree Analysis and Intervention logic for fisheries........ 38

Figure 6. Value Tree Analysis and Intervention logic for Port Management........ 39

Figure 7. Value Tree Analysis and Intervention logic for Property insurance. 40

Figure 8. Value Tree Analysis and Intervention logic for shipping. 41

Figure 9. Value Tree Analysis and Intervention logic for Offshore installations........ 42

Figure 10. Value Tree Analysis and Intervention logic for Search and Rescue........ 43

Figure 11. Value Tree Analysis and Intervention logic for Oil spills........ 44

Figure 12. Value Tree Analysis and Intervention logic for SmartICE. 45

List of tables

Table 1. List of SBAs developed by IDA-STPI and SAON. 8

Table 2. OS types needed for each case study as described in Deloitte (2018) 17

Table 3. List of OS identified during the case studies selection. 19

Table 4. Estimates of overall annualised costs from all relevant observing systems relating to the Arctic for ten selected case studies. 20

Table 5. Contribution to the SBAs associated to the selected case studies relevant to the Arctic. Black dots indicate non-quantified SBAs, red dots quantified SBAs. 21

Table 6. Economic benefits for each case study. 27

Annexes

Annex 1. Value Tree Analysis and Intervention Logic for each case study

Future infrastructure on thawing permafrost

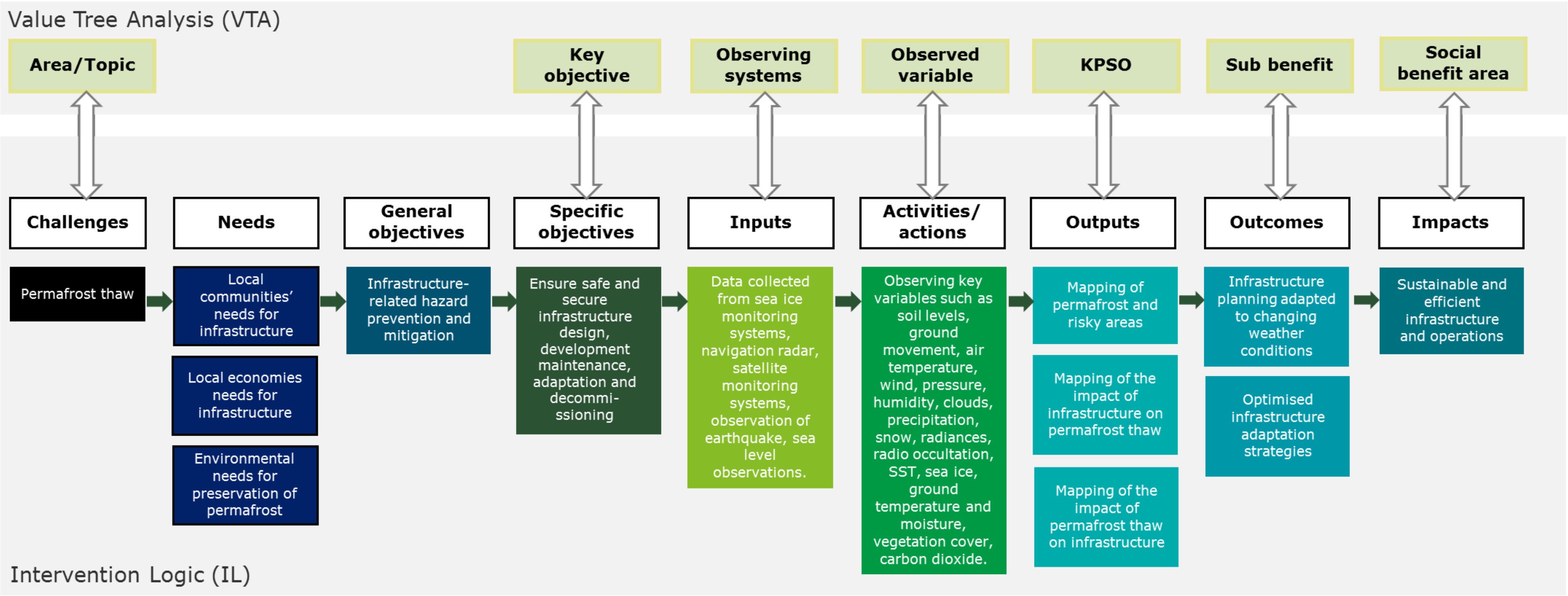


Figure 3. Value Tree Analysis and Intervention logic for Future infrastructure on thawing permafrost

Forest management

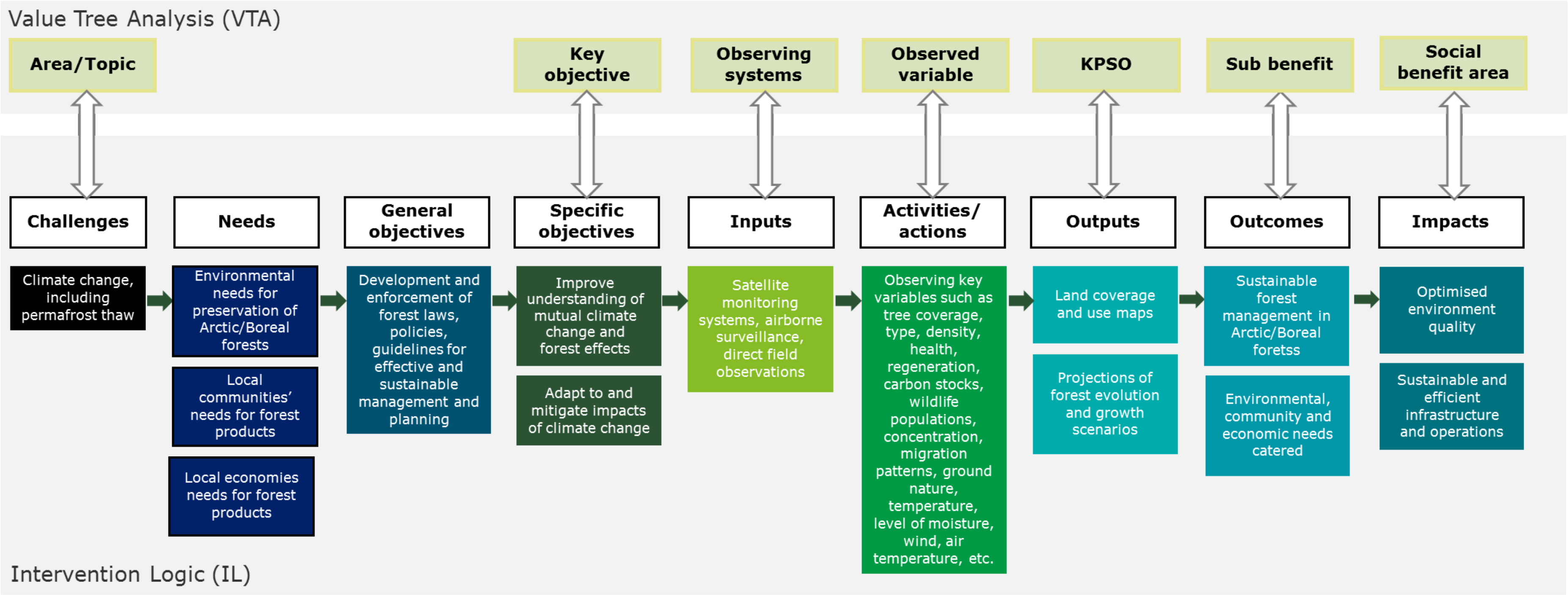


Figure 4. Value Tree Analysis and Intervention logic for forest management

Fisheries

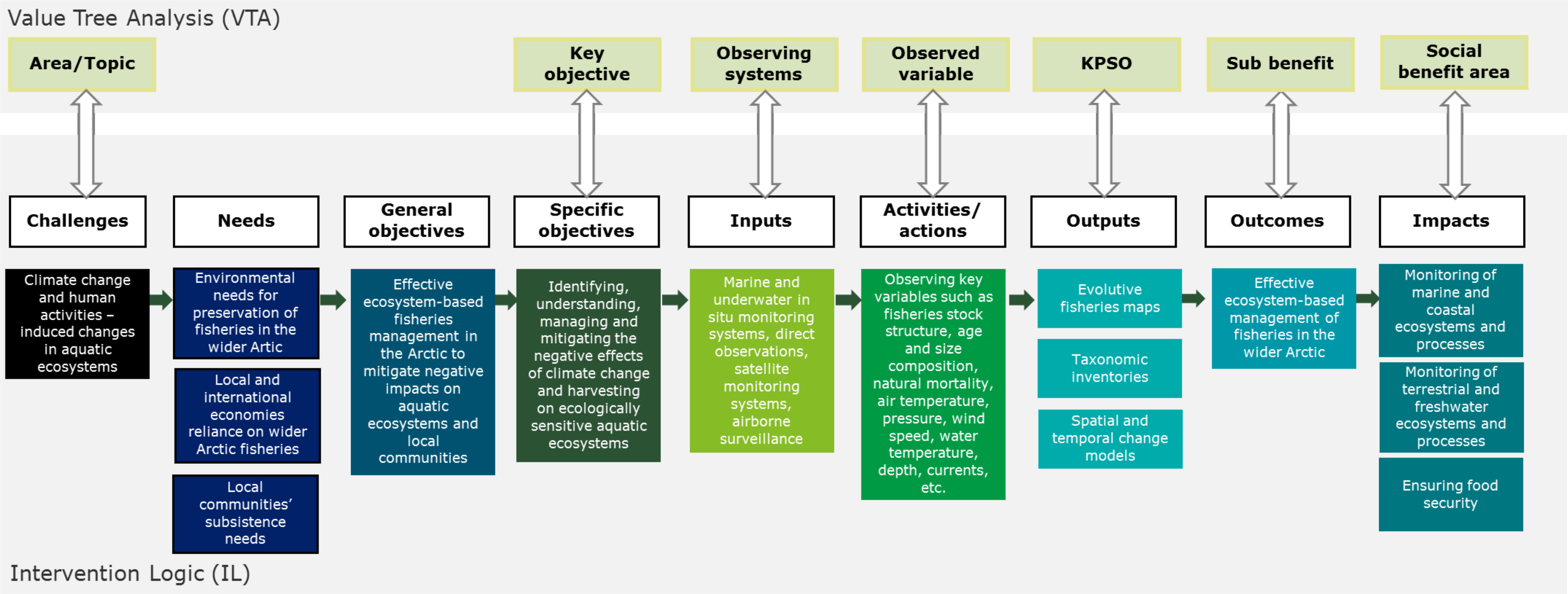


Figure 5. Value Tree Analysis and Intervention logic for fisheries

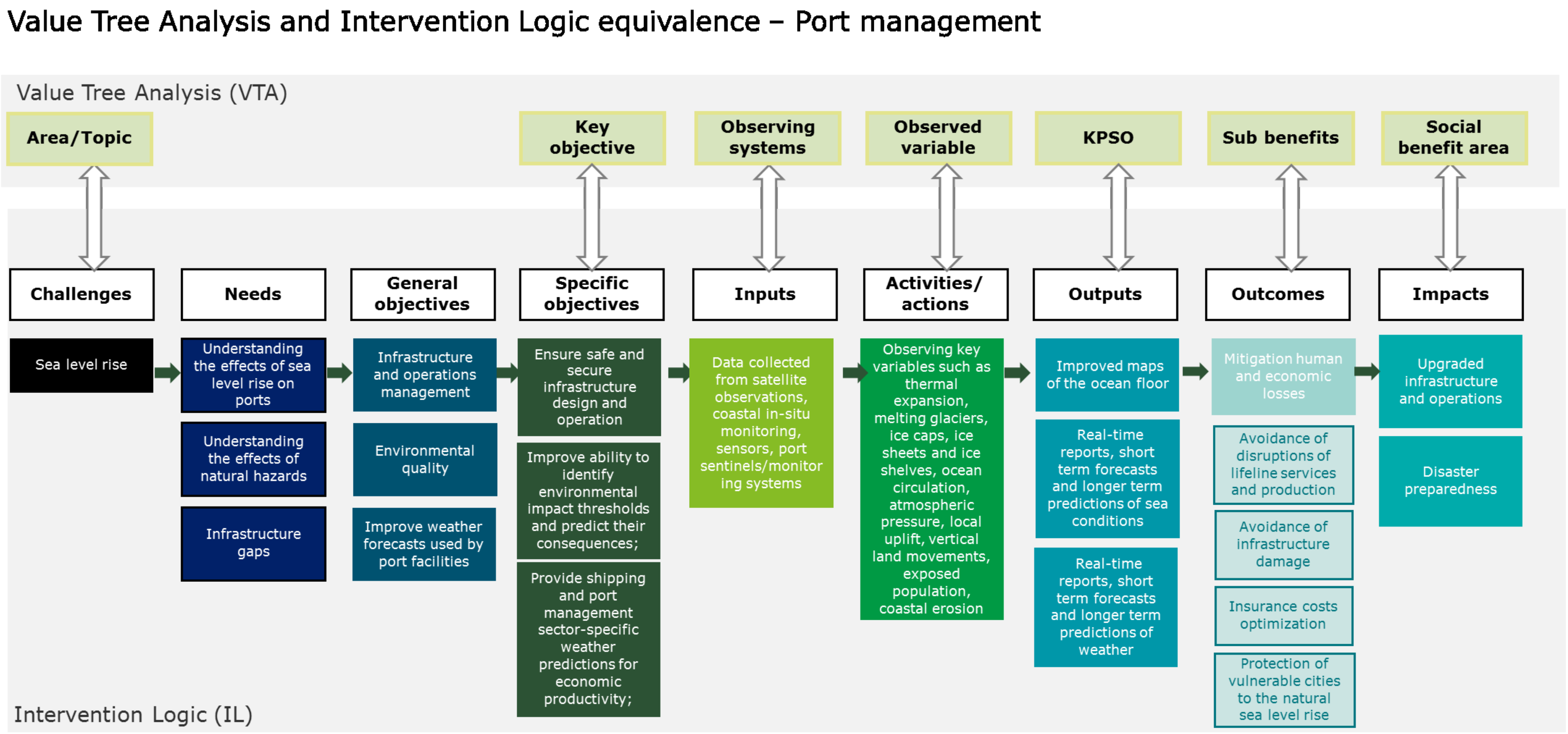


Figure 6. Value Tree Analysis and Intervention logic for Port Management.

Value Tree Analysis and Intervention Logic equivalence – Property insurance

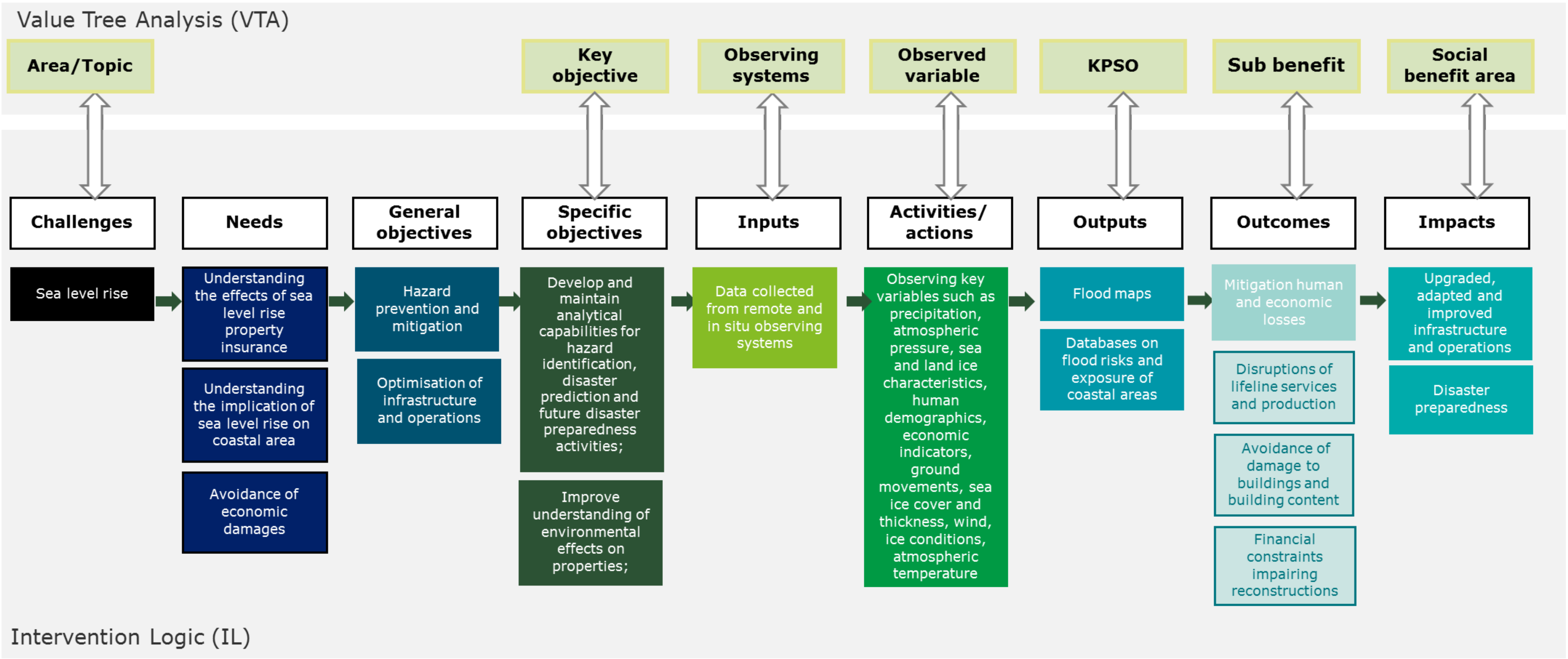


Figure 7. Value Tree Analysis and Intervention logic for Property insurance.

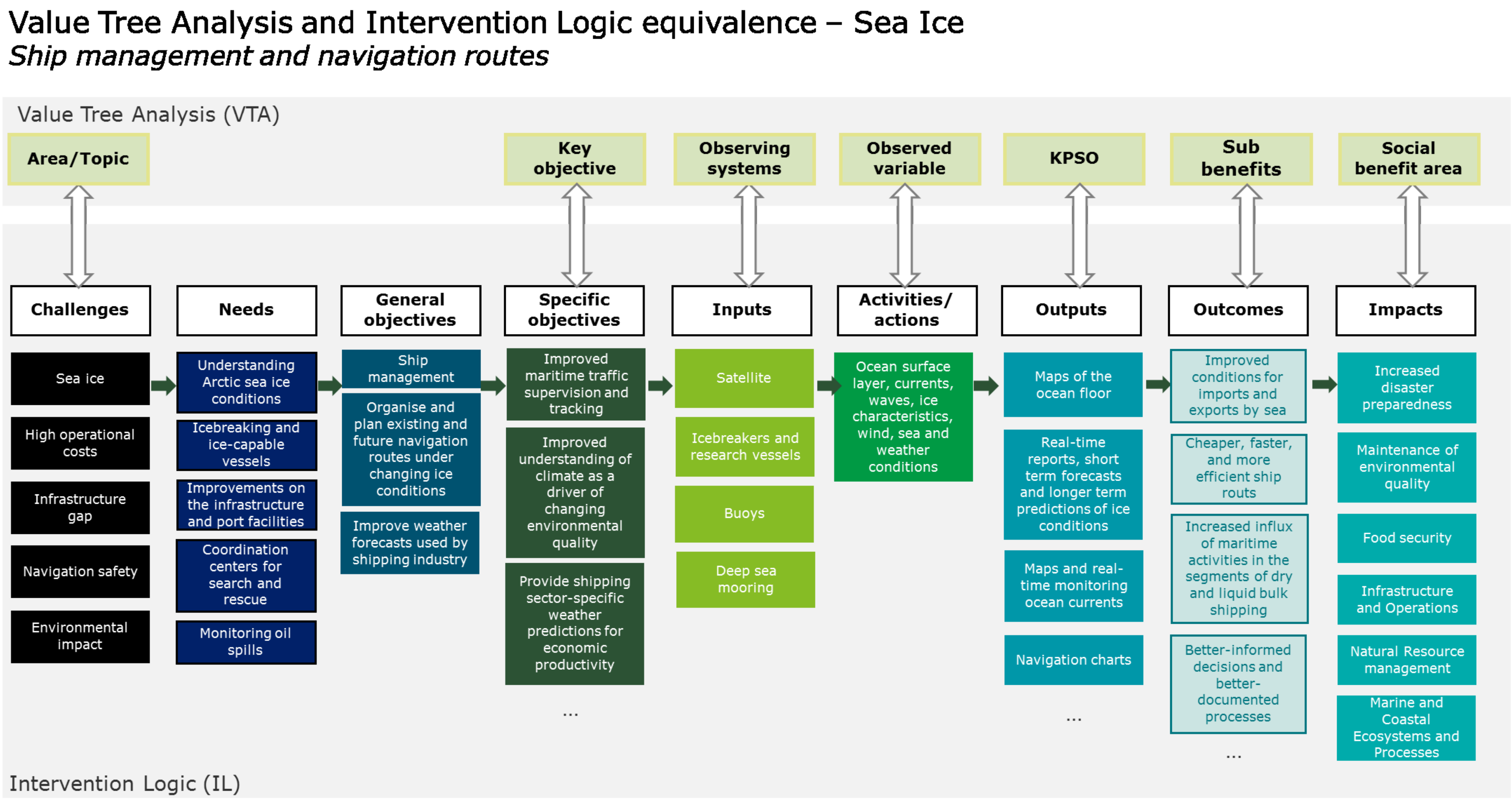


Figure 8. Value Tree Analysis and Intervention logic for shipping.

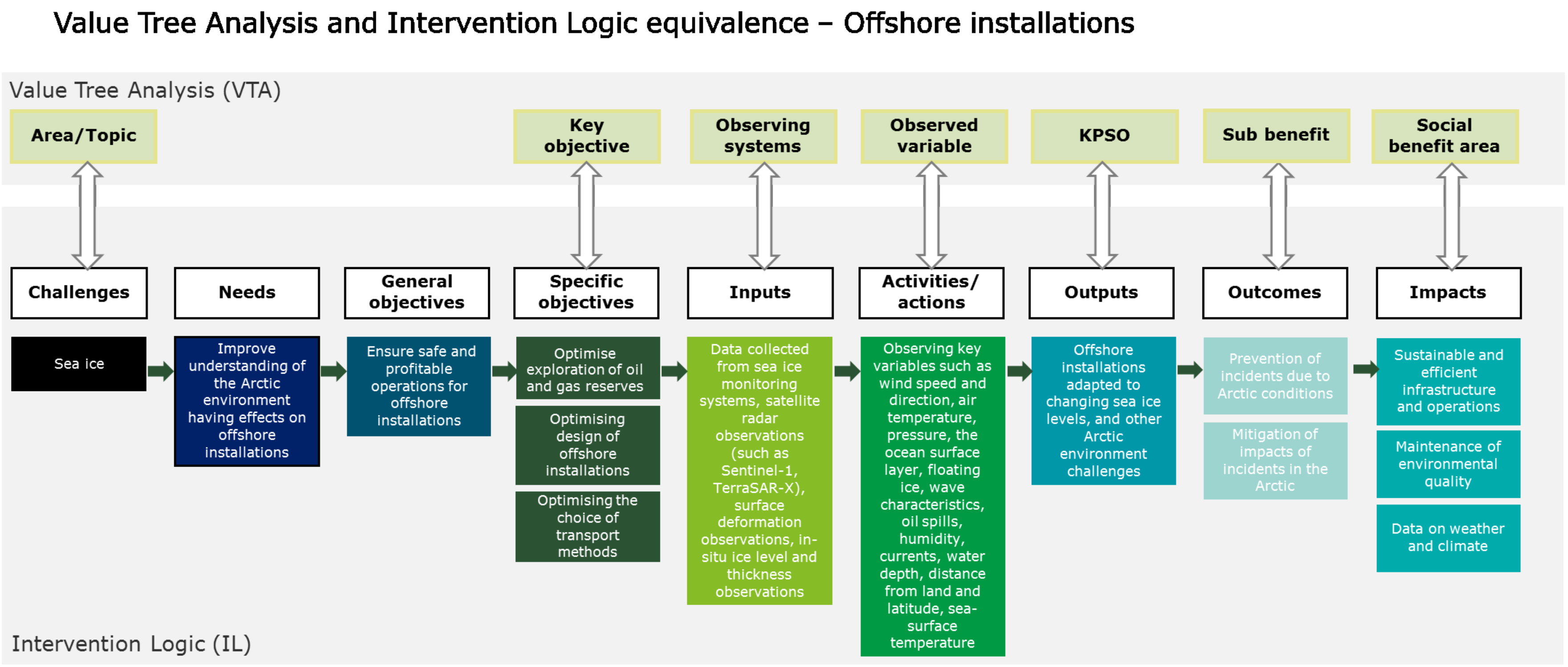


Figure 9. Value Tree Analysis and Intervention logic for Offshore installations.

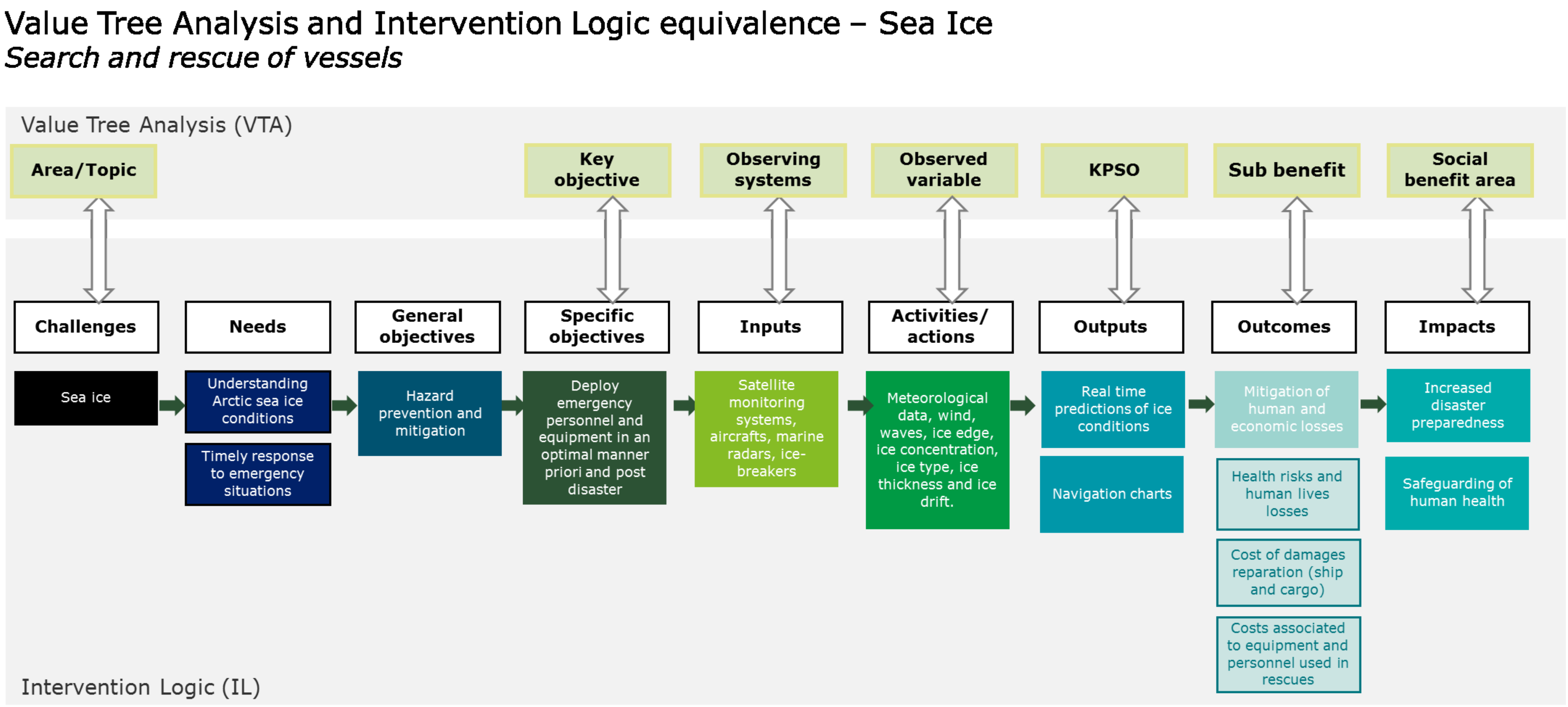


Figure 10. Value Tree Analysis and Intervention logic for Search and Rescue.

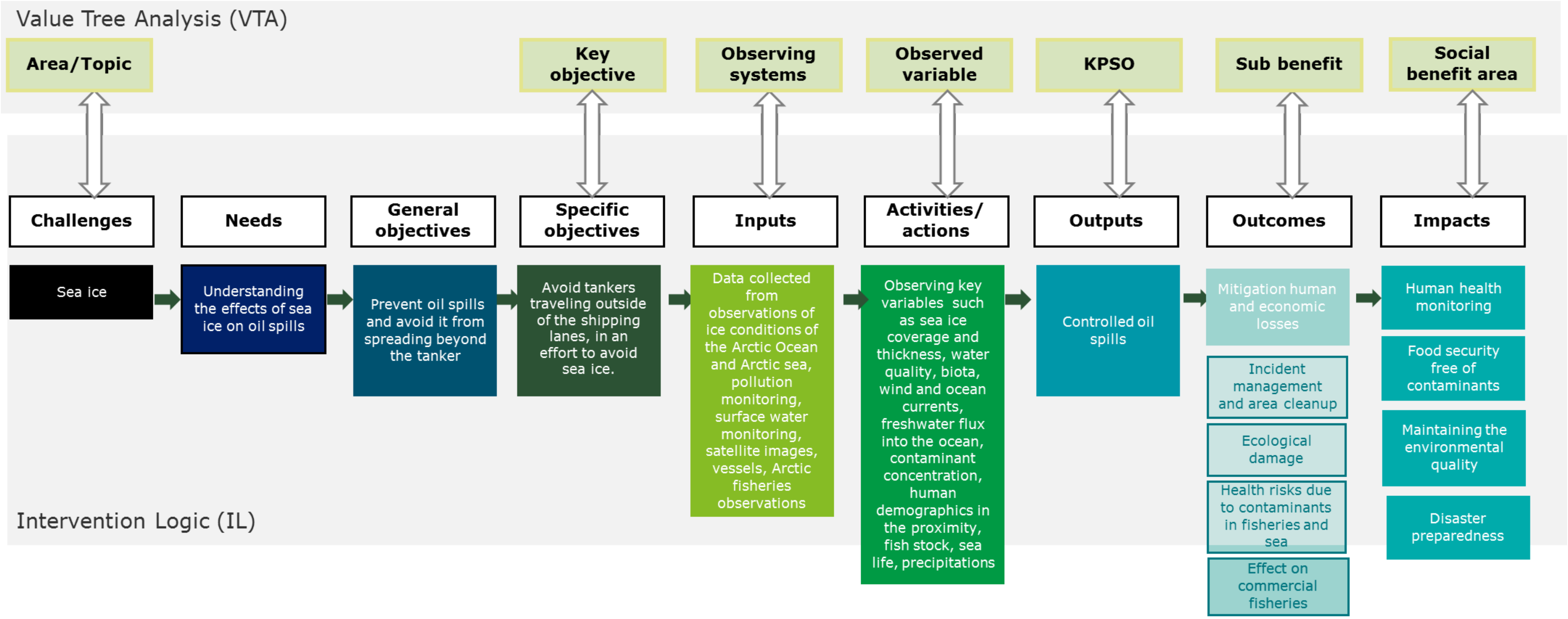


Figure 11. Value Tree Analysis and Intervention logic for Oil spills.

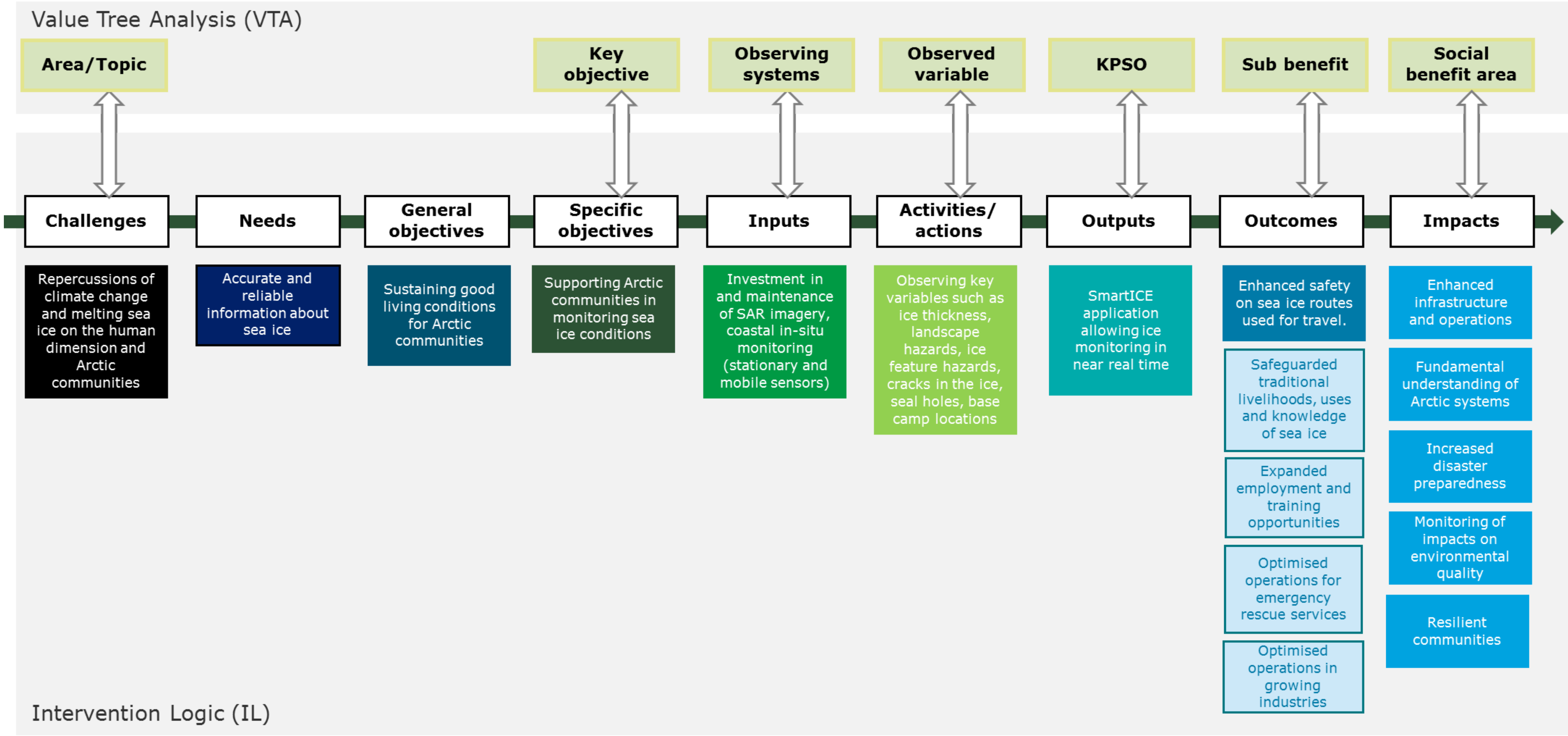


Figure 12. Value Tree Analysis and Intervention logic for SmartICE.

KJ-NA-29400-EN-N

The European Commission's science and knowledge service

Joint Research Centre

JRC Mission

As the science and knowledge service of the European Commission, the Joint Research Centre's mission is to support EU policies with independent evidence throughout the whole policy cycle.

EU Science Hub
ec.europa.eu/jrc

@EU_ScienceHub
EU Science Hub - Joint Research Centre
Joint Research Centre
EU Science Hub

Publications Office

doi:10.2760/713084
ISBN 978-92-79-96697-2