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# Measuring Sustainable Development of Energy Production in the Arctic Ocean

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## Abbreviations

| | |
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| ACCESS | European Union Seventh Framework project “Arctic Climate Change, Economy and Society” |
| AMAP | Arctic Monitoring and Assessment Programme |
| AU | Assessment Unit |
| btu | British Thermal Unit |
| ECMWF | European Centre for Medium-Range Weather Forecasts |
| EER | Escape, Evacuation and Rescue |
| EIA | Energy Information Administration |
| EPA | Environmental Protection Agency |
| EU | European Union |
| EUR | Euro |
| EU SDS | Sustainable Development Strategy of the Council of the European Union |
| FDD | Freezing Degrees Days |
| GDP | Gross Domestic Product |
| GES | Good Environmental Status, as defined in the Marine Strategy Framework Directive |
| IASOA | International Arctic Systems For Observing The Atmosphere |
| ITOPF | International Tanker Owners Pollution Fund |
| MPA | Marine Protected Area |
| MS | Member States to the Marine Strategy Framework Directive |
| MSFD | Marine Strategy Framework Directive |
| NBP | National Balancing Point |
| NDACC | Network for the Detection of Atmospheric Composition Change |
| NOAA | National Oceanic and Atmospheric Administration |
| NSR | Northern Sea Route |
| OECD | Organisation for Economic Co-operation and Development |
| PAHs | Polycyclic Aromatic Hydrocarbons |
| PCB | Polychlorinated Biphenyl |
| PIOMAS | Pan-Arctic Ice Ocean Modeling and Assimilation System |
| PPP | Purchasing Power Parities |
| RMS | Root Mean Square |
| SAR | Search and Rescue |
| SL | source level |
| SLE | energy source level |
| SLiCA | The Survey of Living Conditions in the Arctic |
| UNCLOS | United Nations Convention on the Law of the Sea |
| UNEP | United Nations Environment Programme |
| UNEP-WCMC | United Nations Environment Programme's World Conservation Monitoring Center |

| | |
|---|---|
| UNESCO | United Nations Educational, Scientific and Cultural Organization |
| USD | US Dollar |
| USGS | United States Geological Survey |
| USGS-CARA | Circum-Arctic Resource Appraisal of the United States Geological Survey |
| WCED | World Commission on Environment and Development |
| WDCGG | World Data Centre for Greenhouse Gases |
| WDPA | World Database on Protected Areas |
| WEF | World Economic Forum |

# 1 Introduction

The aim of this report is the development of a set of indicators that can provide information on the sustainability of Arctic off-shore energy production, especially the production of gas and oil. As we aim to include effects from Arctic off-shore energy production also beyond the energy sector itself, the indicator set is intended to inform about the sustainability of the state and direction of development in the whole Arctic. While this report focuses on measuring the impact of hydrocarbon production, it is embedded in a series of reports on sustainable development indicators in the Arctic that cover shipping and tourism activities, sea food production, and a synthesis addressing cross-sector and governance aspects. This series of reports form part of the synthesis of the European Union Seventh Framework project "Arctic Climate Change, Economy and Society" (ACCESS) together with a marine spatial planning tool, a framework for integrated ecosystem based management and a synthesis report.

The information provided by this report is meant to inform decision makers and researchers concerned with the Arctic. Next to decision support through information, researchers may profit from this indicator set by using the indicators as input or output parameters of models and for designing scenario-based simulation exercises on future developments. The report covers early warning indicators, but lagging indicators as well. The set of indicators proposed is a working document that could be continuously refined after the ACCESS project, based on improved knowledge of the Arctic social-ecological system.

A set of indicators can typically not stand alone, and for decision support in particular it should be complemented with other methods that would help assess whether current development is sustainable, what are the underlying causes of particular changes, whether such changes are reasons for alarm and if so how they can be remedied.

# 2 Sustainable development in the Arctic Ocean – definition and relevance for decision making

The concept of "Sustainable Development" was coined by the "World Commission on Environment and Development" (WCED) in its final report "Our Common Future", or "Brundtland Report", after the name of the commission's chairwoman, Gro Harlem Brundtland. The report defines Sustainable Development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (WCED 1987). This definition has since become the seminal definition of Sustainable Development and is also taken up by the Council of the European Union in its Sustainable Development Strategy (EU SDS): "Sustainable development means that the needs of the present generation should be met without compromising the ability of future generations to meet their own needs" (European Council 2006). This notion emphasizes an inter-generational, or inter-temporal, view of Sustainable Development. Practical implementation can only partly incorporate that component, since inter-temporally comparable data with sufficient disaggregation and frequency is scarce. Complementing the inter-temporal perspective, the European Union's sustainable development strategy (EU SDS) breaks down the overall goal of sustainable development into key objectives:

- Environmental Protection,
- Social Equity and Cohesion, and

- Economic Prosperity.

The three key objectives correspond with the three dimensions, or themes, prevalent in the existing discourse on sustainable development, the environmental dimension, the social dimension, and the economic dimension. The indicator set laid out in this report is structured along these dimensions of sustainable development, breaking down the dimensions into policy categories, indicator target areas, and finally indicators. Details on the design of the indicator set can be found in Section 1.4.

Focusing on the Arctic off-shore energy production sector, this report is restricted to a relatively focused and confined scope, compared to existing studies and indicator sets on sustainable development in general. Typically, existing indicator sets take a global point of view, e.g. in terms of geographical scope, variety of economic sectors involved, variety of societal groups, variety of threats, or number of directly affected people. Indeed, a global perspective gives appropriate justice to the multiple regional, sectoral, or societal interactions that might easily be neglected by a more confined view on sustainable development. At the same time, a global approach risks to neglect important details of confined and special regions, economic activities, societal groups, or threats. We apply a more confined and yet more clearly defined approach that corresponds with the scope and focus of the ACCESS project and that favors a more in-depth consideration of Arctic peculiarities, and a more detailed description of the impact of Arctic off-shore energy production.

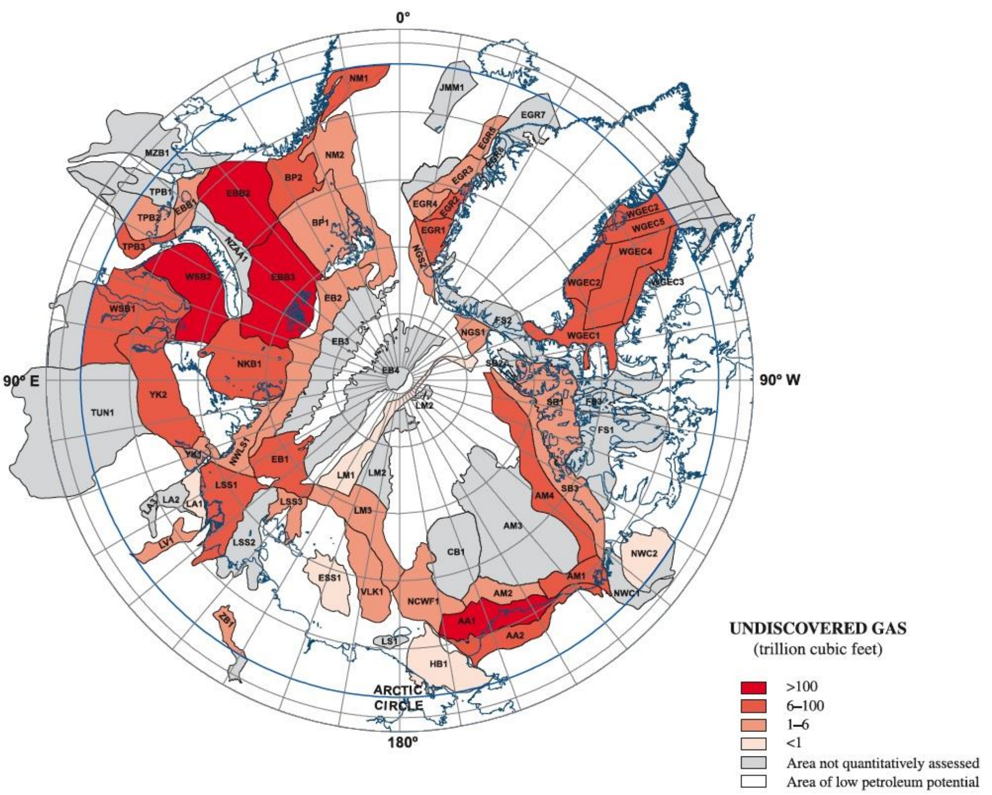
# 3 The Arctic Ocean in an era of change

There is a perception that marine resources, and in particular oil and gas, are a wealth in the Arctic region which is readily available for development. In fact, as recent assessments (World Economic Forum, WEF) have shown, this is one of several myths.. As WEF points out, “many technological, infrastructural, economic and environmental challenges impede natural resource development in the Arctic. Extracting resources is never a simple operation in polar environments, and resource development will require high levels of investment, including development of specialized technologies. The region is not homogenous with regard to development potential; strong distinctions exist between onshore and offshore environments, and between different regions and countries with regard to existing levels of infrastructure, population, environmental sensitivity and accessibility" (WEF, 2014).

Notwithstanding this reality check, reduction in sea ice coupled with improving technologies, ship design, drilling gear and logistics have made access to Arctic waters easier for the purpose of hydrocarbon exploration and extraction. As well as the newly available access to previously unexploited resources, further drivers for offshore oil and gas activities in the Arctic are the political stability of the area and transparent regulatory systems, reducing uncertainty for industry. This view is also held by WEF, who note that the region is under the jurisdiction of eight countries (the Russian Federation, Finland, Norway, Sweden, Iceland, Greenland/Denmark, Canada and the US), with few territorial border disputes among them. Even offshore in the Arctic Ocean, most coastal waters fall within existing Exclusive Economic Zones, with further seafloor sovereignty extensions pending or likely under Article 76 of UNCLOS. There will be areas beyond national jurisdiction, which will fall under the regulatory auspices of the International Seabed Authority, but these will be relatively small in size. In Canada, Greenland and the US, local control by aboriginal communities and regional business corporations can be substantial. In short, the Arctic is neither an unclaimed, contested region nor a closed military zone; it is governed under similar national structures and international frameworks to those in other areas of the world. (WEF, 2014) These factors of stability and published regulatory systems make large, long-term investments in exploration and infrastructure comparatively more attractive in the Arctic, even despite the remoteness and harsh climate. (AMAP 2007). Balanced against this positive perspective, it is not a coincidence that many non-Arctic states are showing increasing interest in the region, pressing for the opportunity to have their opinions on long-term governance and development of the region.

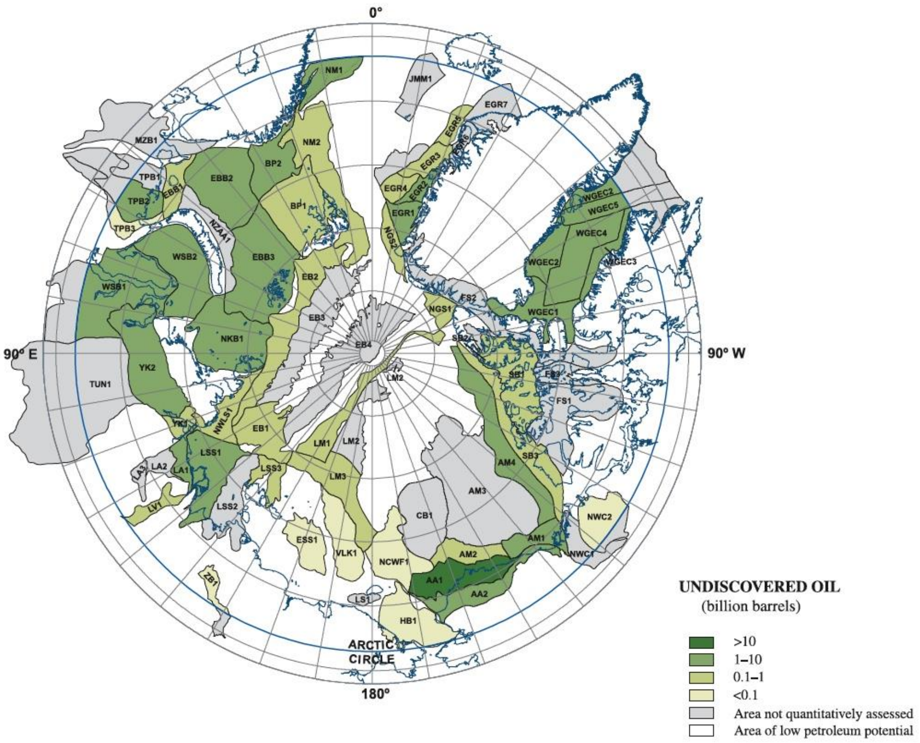
While extensive oil and gas activity has already occurred in the Arctic region this has been predominantly terrestrial. A number of onshore areas in Canada, Russia and the Unites States (Alaska) have been explored for petroleum. By 2007 more than 400 oil and gas fields containing more than 40 billion barrels of oil, 1136 trillion cubic feet of natural gas and 8 billion barrels of natural gas liquids (NGL) had been discovered – mostly in the West Siberian Basin and on the North Slope of Alaska (Gautier et al., 2009). These figures account for approximately 240 billion barrels of oil (BBOE) and oil-equivalent natural gas, which is almost 10 per cent of the world's known conventional petroleum resources (cumulative production and remaining proved reserves) (Bird et al., 2008). Nevertheless, most of the Arctic, especially offshore, is essentially unexplored with respect to petroleum (Bird et al., 2008). The United States Geological Survey (USGS) has assessed the area north of the Arctic Circle and conclude that about 30% of the world's undiscovered gas and 13% of the world's undiscovered oil maybe found there, mostly offshore under less than 500 metres of water (Gautier et al., 2009). Bird et al. (2008) estimate that 84% of the Arctic undiscovered oil and gas occur offshore (Figure 1 and Figure 2).

**Figure 1: USGS-CARA assessment of undiscovered gas reserves in the Arctic Ocean.**




Map showing the USGS-CARA Assessment Units (AUs), colour-coded for mean estimated undiscovered gas. Only areas north of the Arctic Circle are included in the estimates. Black lines indicate AU boundaries. Source: Gautier et al. (2009).

**Figure 2: USGS-CARA assessment of undiscovered crude oil reserves in the Arctic Ocean.**




Map showing the USGS-CARA Assessment Units (AUs), colour-coded for mean estimated undiscovered oil. Only areas north of the Arctic Circle are included in the estimates. Black lines indicate AU boundaries. Source: Gautier et al. (2009).

Despite the potentially huge resources and the political stability of the area and transparent regulatory systems, Budzik (2009) points out that the long lead-times required for Arctic projects can add considerable risk as the business environment may change dramatically between a project's initiation and completion dates. For example, oil and natural gas prices may be considerably lower when an Arctic project begins producing than was anticipated at the planning stage. Also, at a given level of capital investment, longer lead-times can reduce the return on that investment, if all else remains unchanged. In the Arctic, oil and natural gas projects can exacerbate this problem by requiring considerably larger investments than projects that are comparably productive elsewhere in the world. Under these circumstances and since profit margins are smaller in the Arctic compared to conventional production, the financial pressure to progress quickly is in direct conflict with the environmental and safety needs to proceed with extreme caution in the Arctic.

# 4 Measuring and assessing sustainable development

## 4.1 The use of indicator systems for measuring the immeasurable

The role of indicators is to condense, estimate, or proxy information on a potentially abstract, not directly measurable entity in one variable, and that this variable will generate understanding about changes and direction of development. In our case, we attempt to measure sustainable development, as defined in Section 2. Flues et al. (2012) define indicators as parameters that theoretically or practically can be expressed in one number and that have a direct link to the aim of the indicator, in our case sustainable development. In order to compromise between conciseness and accurate coverage of the different dimensions of sustainable development, we introduce a set of indicators. Details on how we compose this set can be found in Section 4.2.

The need to measure sustainable development in the form of indicators was already identified in the early days of the modern sustainability debate. The Agenda 21, the seminal action plan adopted by the Rio Conference in 1992 states:

> *"Indicators of sustainable development need to be developed to provide solid bases for decision-making at all levels and to contribute to a self-regulating sustainability of integrated environment and development systems."* (United Nations 1992, § 40.4)

Accordingly, the aim of our indicator systems is to provide coherent information as decision support and monitoring tool for relevant decision makers (see e.g. Meadows 1998 or Bossel 1999 for an overview on aims of indicators on sustainable development). While diagnosis of the success or failure of decisions is a central role of the indicator system, we also regard diagnosis of the developments in the Arctic as a relevant aim per se. For example, researchers may want to use the indicator system defined in this report for the definition and development of model scenarios.

The indicator system aims to facilitate orientation in a complex multitude of social and ecological systems as well as their intersection. These systems may interact in various ways; they may be sensitive to exogenous determinants as well as random shocks. Their reaction to shocks, both from neighboring systems as well as from the outside may be non-linear. Their development may be self-enforcing or self-regulating. The indicator set may ideally also provide an early warning of drastic changes that allows for prompt control or counteraction. The role of the indicator system is to simplify this substantial complexity to a manageable amount. The price of such simplification is that some information is lost during the simplification process. In that sense, the indicator system is by construction an imperfect proxy for reality.

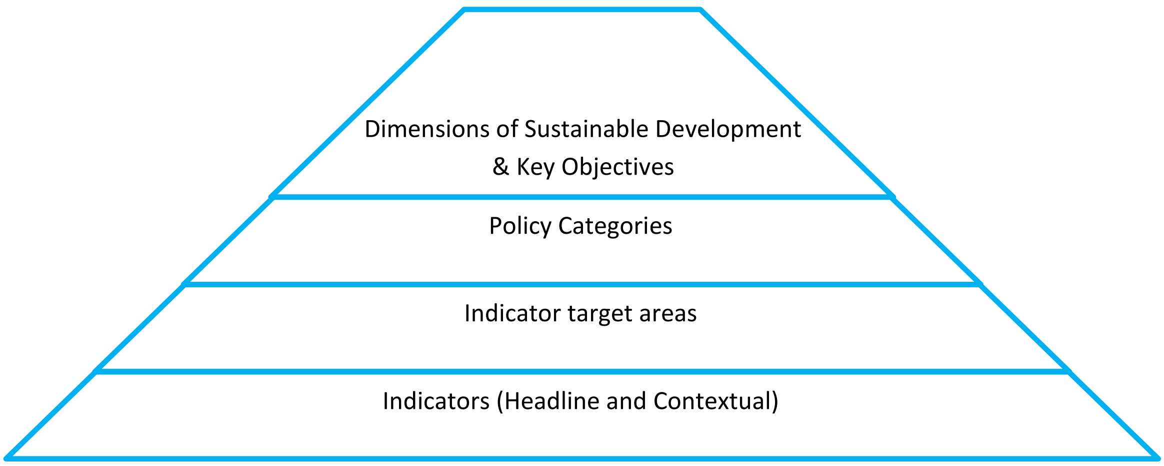
Even though there are some exceptions, many dimensions of sustainable development are meaningful only in a relative sense, also because there is rarely any general consensus about the optimal, sustainable state of the World and, in this specific case, about sustainable development in the Arctic. This means that we can only make statements that one observed state (e.g. in a specific region or point in time) is more or less sustainable than another state, provided that we have information on both states, and this statement may even vary for different stakeholders' points of view or even when we look at different dimensions of sustainable development. Thus, many indicators are meaningful only in comparison and not in absolute values, even though decision makers may want to define their own normative target corridors. For some indicators we will be able to provide guidance on what a sensible target or threshold value might be based on research or experts' heuristics.

Indicators describing sustainable development, on the one hand, and sustainable development and decisions impacting development on the other hand may refer to different stages of an underlying impact process. These different stages can be used to develop taxonomy of indicators such as the pressure-state-response taxonomy (cf. McCool and Stankey 2004 or United Nations 2007) and its various extensions. Pressure indicators reflect some kind of (positive or negative) pressure that human activity poses on ecosystems, social cohesion, or economic prosperity. They are often especially helpful as early-warning indicators. State indicators describe the state of ecosystems, social groups, or the economy. They often provide the most accurate description of, in our case, sustainable development. Response indicators reflect how decision makers, economic agents, etc. respond to changes in ecosystems, social cohesion, or economic prosperity. They are especially valuable for assessing the impact of policy measures. The pressure-state-response taxonomy has been extended to incorporate more dimensions of the underlying impact path. However, it will turn out that an adequate coverage of the pressure-state-response taxonomy is already difficult given the limited data availability for the Arctic.

## 4.2 Buildup strategy for the indicator system

Any indicator system must accommodate the conflicting interests of accessibility versus scope and detail. Some users would rather have a quick glance, requesting only very condensed and yet interpretable information. Other users, more deeply interested in specific dimensions of sustainable development, require multidimensional information reported by a multitude of variables. To accommodate these two needs, and following the European Union Sustainable Development Strategy, we structure our indicator set as a pyramid of indicators. The pyramid is made up of the three dimensions of sustainable development, derived from the dimensions' three key objectives, subdivided into policy categories, each specified by one or few indicator target areas, described by a number of indicators (cf. Figure 3).

**Figure 3: Indicator Pyramid.**

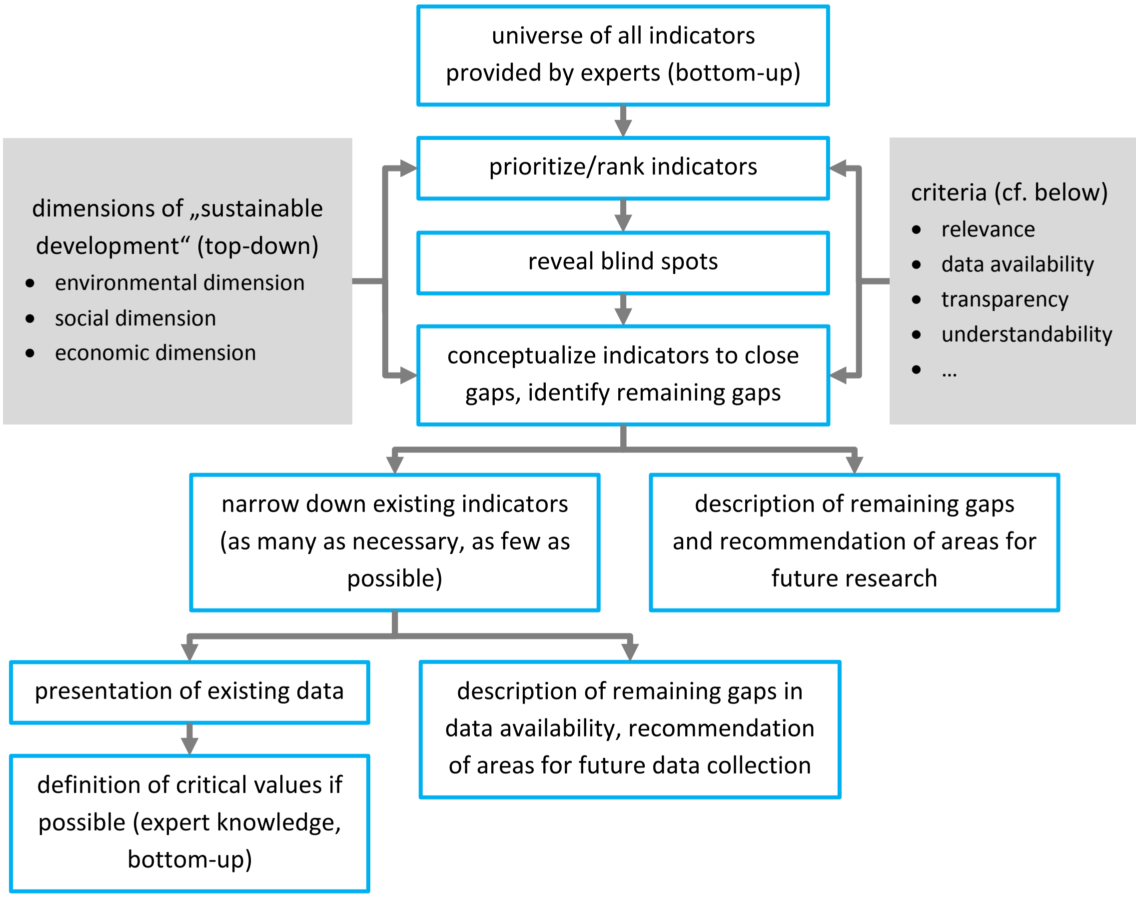



Own illustration.

By choosing this pyramid form, with the three dimensions of sustainable development as the starting point, and deducing actual indicators from there, we adopt a top-down approach that avoids defining sustainable development through the power of facts (i.e. available data) and overlooking areas where data is lacking. We complemented this top-down approach by a bottom-up approach that assessed data availability. The difference between these two reveals areas for future research.

The indicators themselves are provided by the heterogeneous experts assembled by the ACCESS project, covering a multitude of disciplines, nationalities and subjects of study. This ensures a high diversity of potential indicators and avoided narrowness. In a first step, by means of a breakout group session at the third ACCESS general assembly meeting in Villanova, Spain, ACCESS experts discussed different strategies for selecting indicators and identified a first draft of relevant indicators for Sustainable Development in the Arctic. In a second step a questionnaire was developed that relevant task leaders of ACCESS had to fill in ahead of a work package meeting dedicated to selecting relevant indicators. During this meeting, the pyramid concept in Figure 3 was introduced, each participant presented their responses to the questionnaire and raised issues related to the particular indicators proposed. Subsequently the universe of indicators provided by the experts was narrowed down and ranked within each dimension. During the whole process, selection and ranking of the indicators was guided by a set of classical quality criteria for indicator systems that are described in Section 4.3. See Figure 4 for an overview of the build-up strategy.

**Figure 4: Buildup strategy for the indicator system.**




Own illustration.

## 4.3 Criteria for good indicators

Compiling a large list of different indicators is usually easy, but most users of an indicator system ask for a concise and limited concentration on the essential. Apart from good accessibility, a concise set of indicators has the advantage that one can focus limited resources on gathering good quality information for this particular set of indicators. The selection process should be based on quality criteria or requirements that define what makes an indicator better or worse than its counterparts.

Eurostat, in its report on the European Union Sustainable Development Strategy, distinguishes three quality criteria for indicators: policy relevance, efficient communication, and statistical quality (Eurostat 2011, p. 37). This general criteria catalogue is a common basis to many indicator systems, which is in line with an extensive discussion on quality criteria of sustainability indicators summarized by the “Bellagio Principles” (Hardi and Zdan 1997). Hass et al. (2002) summarize the quality criteria derived from the Bellagio Principles as policy relevance, simplicity, validity, availability of time-series data, good quality and affordable data, ability to aggregate information, sensitivity to small changes, and reliability. Further compilations of similar-in-spirit quality criteria catalogues include Coenen (2000) or work from the Organisation for Economic Co-operation and Development (e.g. OECD 2013; see Hass et al. 2002 for details).

We based our selection of indicators on how well they perform with regard to policy relevance, efficient communication, and statistical quality. Usually, however, and similar to other indicator sets, we have to compromise between these three classes of criteria, since no indicator meet all of criteria equally well.

# 5 Indicators on sustainable development in the Arctic Ocean

The result of the buildup process presented in Section 4.2 is a compendium of indicators, organized along the environmental, social, and economic dimension (cf. Table 1) and presented in Sections 5.1 to 5.3.6. It should, however, be noted that the boundaries between the different dimensions in terms of concrete indicators are not obvious in all cases. In each of these sections, we introduce the particular indicator target area and identify and describe indicators. We highlight a limited number of indicators as headline indicators that we deem most informative about the whole dimension.

**Table 1: Proposed indicators related to energy production in the Arctic within different policy areas.**

| Dimension | Key objective | Policy category | Indicator target area | Variable/ Indicator |
|---|---|---|---|---|
| Environmental dimension | Ecosystem viability | Pollution | Water pollution | **Mussel contaminants** |
| | | | Air pollution | Aerosol and ozone concentration |
| | | | Noise pollution | Underwater noise |
| | | Habitat | Marine Protection | MPAs |
| | | Oil spill monitoring | Oil spill prevention and response | **Number of oil spills and near misses** |
| Social dimension | Social cohesion | Well being | Human Health | Crime rate |
| | | | Population dynamics | Population change |
| | | | | Migration |
| | | Social Inclusion | Access to labor market | Educational attainment |
| | | | | **Unemployment rate** |
| | | | Income equality | **Poverty** |
| Economic dimension | Sustainable economic development | Affluent and cheap energy supply | Energy production | Oil and gas produced and exported |
| | | | Energy price | Oil and gas price |
| | | | Exploration | Number of exploration drills |
| | | Regional economic and infrastructure development | Economic development | **Regional GDP p.c.** |
| | | | Infrastructure development | Number of ports |
| | | Response capability | SAR infrastructure | Helicopter concentration |
| | | | Weather forecasting | Weather forecasting precision |

Own presentation.

We choose to focus almost exclusively on few indicators rather than a multitude of indicators because of the lack of information in the region. Time series data with appropriate geographical precision does, for example, not exist for a wide range of variables. We tried to identify some headline indicators, i.e. few indicators that one could look at to get a quick glance on the state of a dimension or the whole system. These are highlighted in bold in Table 1. Since data is unavailable for many of the indicators presented here, the indicator set can also serve as a first target for improved data collection. Since climate change and the associated change in Arctic sea ice is an important driver of any development in the region, anthropogenic or not, we complement our indicator set with a describtion of "Freezing Deegree Days", an "external" indicator that describes ice conditions (see Section 5.4).

When presenting each indicator we aim to motivate our choice, describe how to calculate it, discuss available data, strengths and weaknesses and finally discuss possible threshold values of relevance. Next to highlighting the need for homogeneous data collection across Arctic governments, the indicator descriptions highlight the importance for regionally disaggregated statistics, especially in the social and economic dimension (in the environmental dimension, the data gaps are much more fundamental). Since often only small parts of the population of an Arctic country actually live north of the Arctic Circle, country-level data is only of limited explanatory power. Future data requirements are discussed in more detail in the respective chapters in Section 5, such as in the case of the measurement of health or SAR indicators.

## 5.1 Environmental dimension

The environmental dimension in this report focuses mainly on ecosystem viability and its capacity to produce ecosystem goods and services. The state of the ecosystem has a general relevance for the continued provision of ecosystems services including provisioning, supporting, regulating and cultural ecosystem services (MEA 2005).

We identified three relevant policy categories, pollution, habitat, and oil spill monitoring. We measure pollution in the Arctic by mussel contaminants (Section 5.1.1), aerosol and ozone concentration (5.1.2) as well as underwater noise (5.1.3). Data on marine protected areas is used to inform about habitat and habitat protection (5.1.4). Focusing on the energy industry, and especially offshore production, the issue of oil spills and oil spill preparedness is of particular interest. We use the number of oil spills and near misses as an indicator for the seriousness of the problem (5.1.5). Unfortunately, direct information on response capabilities is missing so far, not least because of the lack of such infrastructure. Some indicators from other dimensions are helpful here as well, including but not limited to the level of production (5.3.1) and the number of exploration drills (5.3.3) for a general assessment of the risk of a major spill as well as the number of ports (5.3.5) and weather forecasting precision (5.3.7) for an assessment of response capability.

Data availability is generally very limited in this dimension. While we were able to identify a number of informative indicators, only few of them are actually measured homogeneously and with satisfactory geographical and temporal coverage. Especially information on pollution is missing at present. We show examples for other Oceans where this data problem was successfully tackled. Data for the other indicators is much more readily available. However, accessibility could be improved by provisioning the information at a central point of access.

### 5.1.1 Mussel contaminants

*Definition*

Trends in levels of water contaminants through annual sampling of common coastal bivalves, such as mussels (*Mytilus* species), oysters (*Crassostrea*) or other easy to gather species. As filter feeders, these organisms integrate contaminant exposure, which can be analyzed in the laboratory. Samples are analyzed for contaminants and then tissues are archived for future analyses. Comparable programs exist for example for the Gulf of Mexico, the Mediterrainean, and South America. There is no such monitoring program in the Arctic, so a program initiated now would document background levels before the greatest increases in activities are expected to begin. The Arctic Council would be the ideal organization to instigate such an international program for the Arctic. There is a clear link between this indicator and the policy goal of a clean and contaminant free environment.

Existing programs are all designed to be simple to implement through simple annual collection of filter feeding organisms. Collection of organisms can be done by non-technical personnel with training in preserving and shipping organisms to qualified laboratories. Samples are analyzed for a variety of contaminants in order to document long term trends. The US mainland "Mussel Watch" program monitors 140 analytes such as metals, organics and histopathology. Metals can come from both natural and anthropogenic sources. Organics, such as Polychlorinated Biphenyl (PCB) congeners, Polycyclic Aromatic Hydrocarbons (PAHs) and pesticides are important markers. These programs have also been used to compare contaminant levels over time, or to evaluate contamination due to an expected event, such as Hurricane Katrina in the US in 2005, Macauley et al. (2010) or oil spills, such as Regoli et al. (2014) for the Costa Concordia oil spill or Marigómez et al. (2013) for the Prestige oil spill.

*Assessment*

The indicator was selected because filter feeding shellfish can be used to monitor progress toward safe and sustainable development in the Arctic. This type of information would alert the public, monitoring institutions and the Arctic Council to any concerning trends in contaminants and monitor recovery from pollution. The indicator could be measured using qualified laboratories, where these analyses are straightforward, so that the results are comparable. The program has a cost effective design because the collection can be done by local people with simple training. Long-term annual sampling would allow trends to be detected.

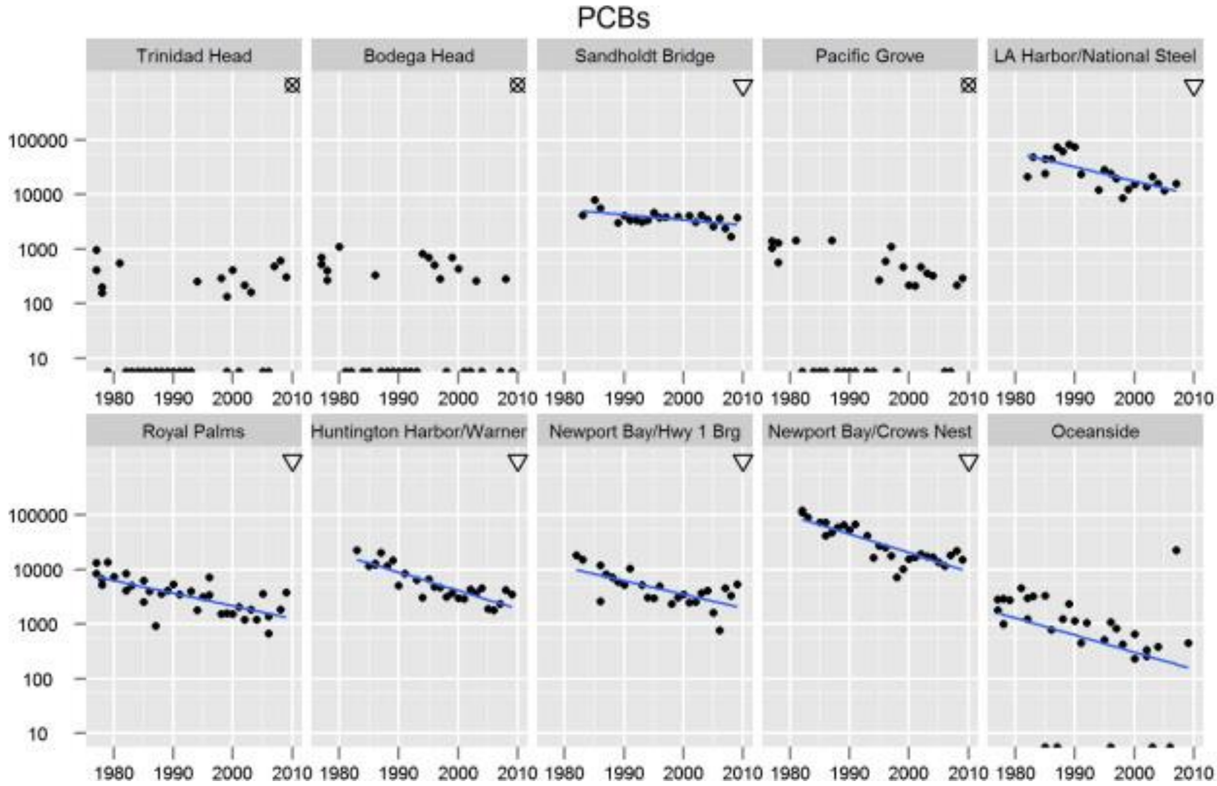
*Data and measurement*

There is no Mussel Watch program currently in the Arctic. Initiating such a program *now* would document background contaminant levels before expected expanded development in the future. Similar data from the Americas and Mediterranean allows comparisons between relative levels of contamination globally.

*Description*

The US Mussel Watch program began in 1975 in the Environmental Protection Agency (EPA) and is now run by the National Oceanic and Atmospheric Administration (NOAA). The program has expanded through UNESCO to include 17 more countries in North and South America. Several European countries (France, Italy, Spain) have implemented similar programs, also in the 1970s, with Mediterranean wide monitoring beginning in 2002. For a full summary, see Rodriguez y Baena and Thébault (2007). Literature indicates Asia is also developing a similar program (Nakata et al. 2012). Any program established in the Arctic should be organized to be inter-comparable with these programs. As an example for how the resulting data may look like, Figure 5 shows the PCB concentration for a number of Californian monitoring stations. Both the downward trend at some stations as well as the different level of contamination between stations are clearly visible.

**Figure 5: Polychlorinated Biphenyl (PCB) congeners**




Total PCBs (ppb, lipid weight) in Mytilus californicus at six California State Mussel Watch / Regional Monitoring Program stations sampled from 1977-2010. Note that there is a small symbol in the upper right corner of each graph: the crossed circle indicates that more than half of the samples had no detectable PCBs, while the inverted triangle indicates a statistically significant trend, marked as a light blue line. Source: Milwani et al (2014).

### 5.1.2 Aerosole and ozone concentration

*Definition*

We recommend using the “concentrations of air pollutants” as an indicator for the influence of anthropogenic activities on Arctic air quality and regional climate. The quantity of air pollutants is an indicator due to the policy goals of limiting anthropogenic impacts on air pollution and on Arctic climate. Monitoring of this indicator can be achieved by both long term and focused observations of key air pollutant species (e.g. ozone and aerosols including black carbon), some of which are also climate-warming substances. Here, we define air pollutants broadly as both trace gases (e.g. ozone) and aerosols (e.g. black carbon) that have negative impacts on ecosystems and health. For the purposes of this indictor, we restrict ourselves to two air pollutants, ozone (in ppbv) as well as aerosols (particle mass smaller than 2.5 micrometers, PM2.5).

The “concentrations of air pollutants” (defined above for ozone and aerosols) is a useful indicator to observe Arctic changes with respect to the impact of transported and locally emitted anthropogenic emissions. Monitoring the concentrations of air pollutants in the Arctic is one component of determining the anthropogenic influences on the Arctic atmospheric/ocean system, which is tied to atmosphere/ocean health. However, the relationship between the amount of air pollutants in the atmosphere and their impacts is non-linear and occurs at multiple levels - e.g. impacts on human health, climate, ocean health, ecosystem health, etc. There is no clear threshold that can be considered sustainable vs. unsustainable given the complexity and interconnectedness of air pollution concentrations and their multiple impacts. Nevertheless, there are air quality thresholds that are applied in North America and Europe for aerosols (particulate matter) and ozone. These thresholds are often reported as exceedences above a particular concentration averaged over a particular time period. However, it appears that chronic effects may also occur at low concentrations, they also vary significantly between countries. The recommended international standards for ozone and particulate matter are set by the World Health Organization and are currently 10 µg/m3 annual mean 25 µg/m3 24-hour mean for PM2.5 and 100 µg/m3 (close to 50 ppb, 8-hour mean) for ozone. Today, pollution in the Arctic primarily originates from emissions in Asia, Europe, and North America transported over long distances into the region. However, increasingly there are local emissions from shipping, flaring, smelting etc. in the Arctic, which may be increasingly important in the future.

Aerosols and ozone are continuously measured at Arctic stations such as Zeppelin, Alert, Barrow and Summit. Pan-Arctic long-term observations are available via the World Data Centre for Greenhouse Gases (WDCGG) (http://gaw.kishou.go.jp/wdcgg/) as well as through the IASOA network (http://www.esrl.noaa.gov/psd/iasoa/home2). Ozone vertical profiles is also collected at a number of Arctic sites (e.g the Network for the Detection of Atmospheric Composition Change (NDACC), http://www.ndsc.ncep.noaa.gov/) although their temporal availability varies a lot between locations. These long-term (primarily ground based) observations do not currently focus on episodes of pollution or specific Arctic pollution sources, which require more focused measurements, such as those conducted as part of the ACCESS aircraft campaign.

*Assessment*

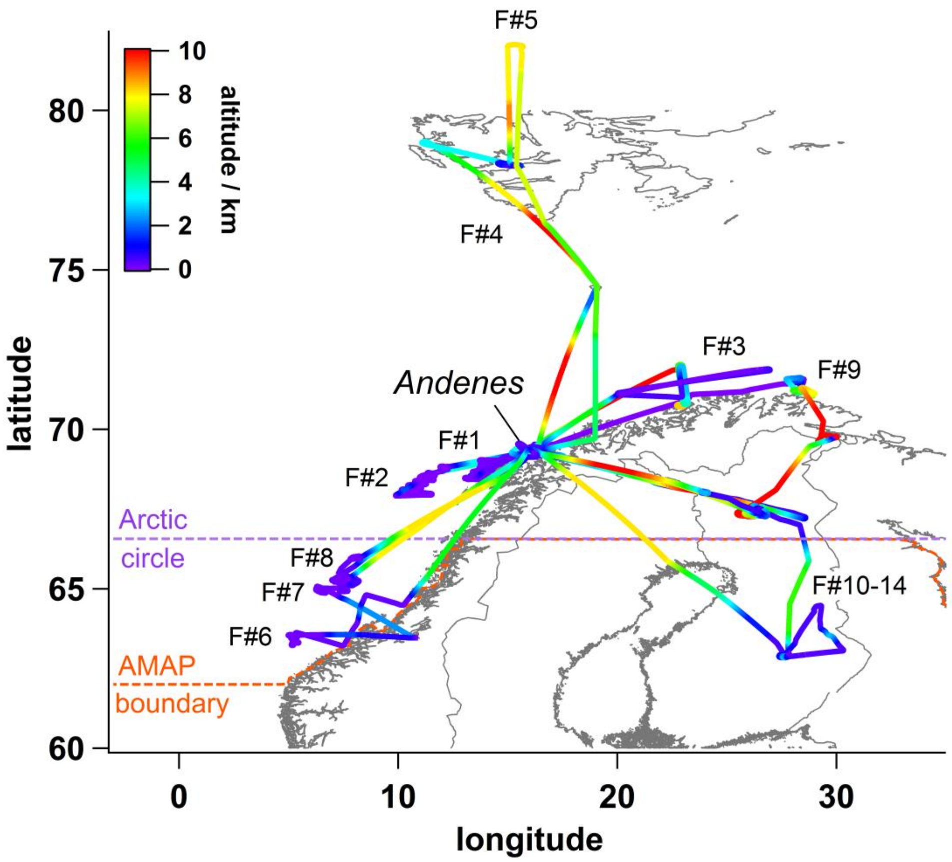
Measuring ozone and aerosols in the Arctic as part of focused campaigns is expensive, but necessary in order to provide additional datasets to compliment the long-term, fixed-location measurements. It may also be beneficial to add additional monitoring sites in regions where little or no long-term records exist, such as in the eastern Arctic or to add measurements of pollutant precursors such as hydrocarbons and nitrogen oxides, which are currently measured at very few Arctic sites.

In principle, the data is measured repeatedly, so that the construction of long-term time series is possible. However, to evaluate possible changes or trends, the measured concentrations have to be assigned to their source regions (Arctic vs. Eurasia, Europe, North America). The atmospheric transformations that occur during atmospheric transport must also be studied using models, so measurements are often combined with modeling to fully understand the origin, fate, and impacts, of Arctic atmospheric pollution. Long-term measurements are available via ground-based measurement networks, and the focused measurements on local Arctic pollution sources, made as part of ACCESS, are available from DLR.

*Description*

Long term measurements in the Arctic, coordinated internationally by IASOA, are complimented by focused measurement campaigns, which can be used to understand the processes that determine Arctic pollution concentrations. Such a focused measurement campaign was conducted with the DLR Falcon-20 aircraft during ACCESS. The aircraft included characterization of both particles and trace gases (pollution concentrations). Figure 6 shows the flight locations and aircraft altitudes for the 14 flights conducted to characterize Arctic air pollution during ACCESS. Measurements targeted local pollution sources associated with oil/gas exploration, shipping and metal smelting as well as long-range transport of pollution (from Russia) (see Roiger et al., 2014).

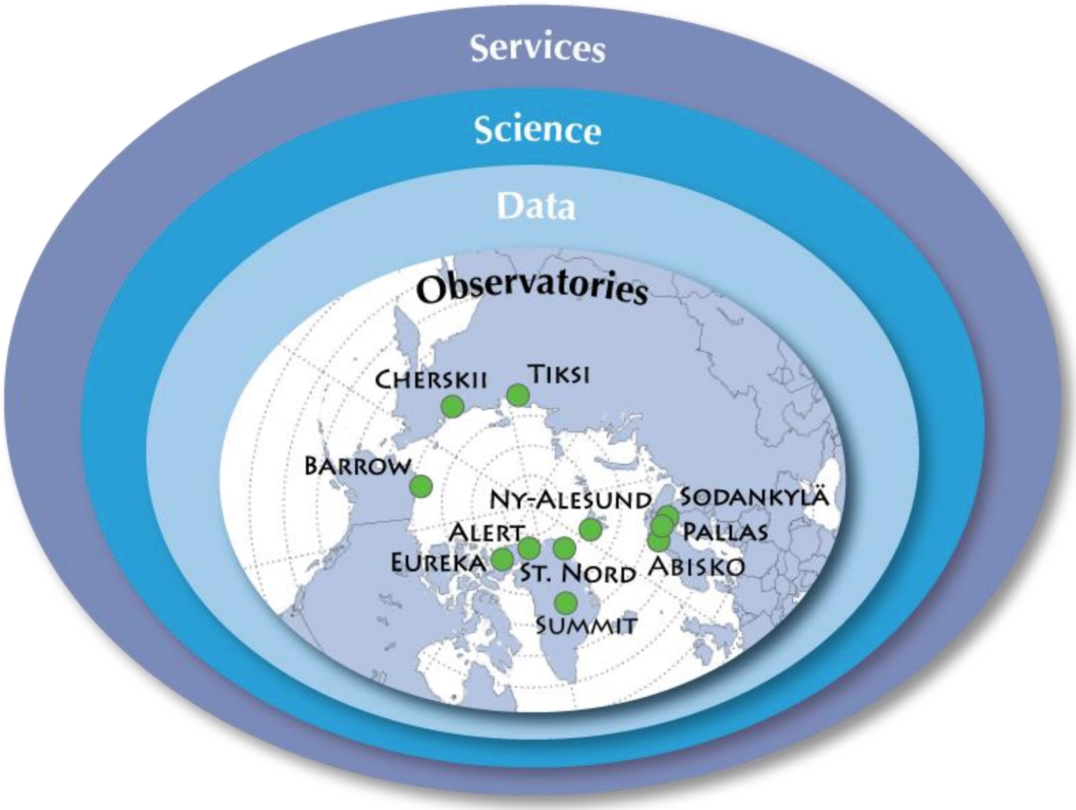
**Figure 6: DLR Falcon-20 flight tracks**




All DLR Falcon-20 flight tracks for the fourteen ACCESS flights. The Falcon aircraft was based in Andenes (69.29°N, 16.14°E). Flight altitudes are indicated by the color scale. The AMAP region (orange) and the Arctic circle (turquoise) are also superimposed. Figure from the ACCESS Campaign Overview Description publication (Roiger et al., 2014: http://dx.doi.org/10.1175/BAMS-D-13-00169.1).

Figure 7 shows locations of surface sites within the IASOA network which aims to coordinate access to pan-Arctic pollutant measurements including data collected as part of other networks such as WDCGG. These sites conduct long term monitoring of Arctic air pollution (including ozone and particles). ACCESS researchers are working with, for example, the IASOA coordinator in order to connect aircraft campaign data from ACCESS with surface data on seasonal cycles and trends.

**Figure 7: Observatories contributing to the IASOA network of measurements throughout the Arctic**




### 5.1.3 Underwater noise

The sea environment has always been filled with noise (from animals and physical processes), although the last hundred years have seen the introduction of many anthropogenic sources that are currently contributing to the general noise budget of the oceans. The extent to which noise in the sea impacts and affects marine ecosystems has become a topic of considerable concern to the scientific community. Anthropogenic noise, including acoustic signals necessary to study the marine environment, can interfere with the natural use of sound by sea organisms. For geophysicists, seismologists and oceanographers, sound is the most powerful tool available to determine the geological structure of the seabed and to look for oil and gas reserves deep below the seafloor. On the other hand, unnecessary or unintentional noise sources, i.e. sources that are associated to specific activities but contain no information (shipping for instance) are constantly introduced in the marine environment.

At the same time, human-generated noise may interfere with the normal use of sound by the marine animals (i.e. chronic effects that may affect the long-term ability of marine animals to develop their normal activities, reproduce, and maintain sustainable populations) or cause physical harm to them (i.e. acute effects that may compromise the short-term ability of these animals to survive). Therefore, measurements of underwater noise indicate the state and development of ecosystem viability in the Ocean.

In the context of this indicator system, the main focus is on indicators of underwater noise, with some relation to impacts on the marine environment. Noise has been defined in many ways. For this report “noise” is taken to mean anthropogenic sound that has the potential to cause negative impacts on the marine environment (which in this case includes component biota but not necessarily the whole environment) and includes not only sound pressure levels, but also other features of sound.

Unfortunately, there is no systematic measurement program in the Arctic Ocean in place today that would generate comparable Arctic-wide data series of consistently good quality, not least because of the substantial cost associated with such a program. However, the EU’s Marine Strategy Framework Directive (MSFD) requires the Member States (MS) to develop strategies that should lead to programmes of measures that achieve or maintain Good Environmental Status (GES) in European Seas. As an essential step reaching good environmental status, MS should establish monitoring programmes for assessment, enabling the state of the marine waters concerned to be evaluated on a regular basis. The MSFD comes with criteria and methodological standards on GES of marine waters (Commission Decision 2010/477/EU), including two indicators on noise (Descriptor 11, Noise/Energy): Low and mid frequency impulsive sounds as well as continuous low frequency sound (ambient noise). A consistent extension to Arctic non-member states to the MSFD could result in a coherent assessment of noise pollution in Arctic waters.

While the spatial coverage for impulsive sounds (indicator 11.1) is quite straight forward and described in the Monitoring Strategy document[1], the deployment of sensors to monitor low frequency continuous noise (Indicator 11.2) requires MS to choose deployment areas and use models to address the objectives of providing yearly averages of noise.

The definition for MSFD Descriptor 11 was discussed for three years by an expert group (EU TG Noise) that agrees on valid definitions of noise in their Monitoring Strategy document (Van der Graaf et al. 2012). With respect to high amplitude low and mid-frequency impulsive anthropogenic sounds, the MSFD Task Group suggests an indicator based on the incidence of sounds in a specified area. The indicator is based on reports of occurrence by those undertaking or regulating the generation of these sounds, rather than direct independent measurements. The indicator is based on the proportion of days on which impulsive sounds (defined below) exceed a specified level on at least one occasion, which produces definable harm to animals. The choice of frequency bandwidth (10Hz to 10kHz) is based on the observation that sounds at higher frequencies do not travel as far as sounds within this frequency band. Although higher frequency sounds may affect the marine environment, they do so over shorter distances than low frequency sounds. The indicator is focused on those impulsive noise sources that are most likely to have adverse effects, such as sonar, airguns, acoustic deterrents and explosives. Sources which exceed particular source levels will be used for the indicator.

Ambient noise is defined as background noise without distinguishable sound sources. It includes natural (biological and physical processes) and anthropogenic sounds. Research has shown increases in ambient noise levels in some areas in the past 50 years mostly due to shipping activity. This increase might result in the masking of biological relevant signals (e.g. communication calls in marine mammals and fish) considerably reducing the range over which individuals are able to exchange

[1] -

information. It is also known that marine mammals alter their communication signals in noisy environments which might have adverse consequences. It is further likely that prolonged exposure to increased ambient noise leads to physiological and behavioral stress. This indicator is based on direct independent measurements. The choice of representative sets of observation stations is left to Member States working together and should benefit from existing networks of underwater observatories. Recording is on the level of regional seas or national parts of regional seas. The choice of the 1/3 octave bands in Van der Graaf et al. 2012 is on the basis of scientifically justifiable signatures of anthropogenic noise that avoids most naturally generated sources. Unless relevant data already exists, the baseline year would be set at whenever the observatory system for a regional sea is established.

Even though general methodological standards are defined, the MSFD Descriptor 11 leaves some room for protocol and results interpretation, and thus requires concretion on measurement and data processing. We therefore propose the following monitoring program:

The first part of the monitoring programme described here offers an experimental approach to the criteria and indicators described for impulsive (MSFD Descriptor 11.1) and continuous sound (Descriptor 11.2). The indicator on impulsive sound (Indicator 11.1.1) is based on a literature survey and information gathering to build the required grids, and the process is clearly explained in the Monitoring Strategy document (AEE Consortium 2013). The indicator on trends in low frequency continuous noise (Indicator 11.2.1) is further developed in the sections below. This is due to the fact that monitoring of parameters required for the assessment of this indicator directly requires decisions on equipment and deployment locations to gather yearly noise averages.

Regarding impulsive sounds, the MSFD introduces the *distribution in time and place of loud, low and mid frequency impulsive sounds* (Criterion 11.1) as an indicator for noise. More concrete, it recommends to measure the *proportion of days and their distribution within a calendar year over areas of a determined surface, as well as their spatial distribution in which anthropogenic sound sources exceed levels that are likely to entail significant impact on marine animals measured as Sound Exposure Level (in dB re 1 $\mu Pa^2 s$) or as peak sound pressure level (in dB re 1 $\mu Pa_{peak}$) at one metre, measured over the frequency band 10 Hz to 10 kHz (11.1.1).* (Indicator 11.1.1).

The text does not make clear what a significant impact is but gives indications on thresholds that could be used for the sound exposure levels, sound pressure levels, or source levels: For impact pile-drivers no minimum threshold should be used and all pile-driving activities should be registered. For sonar, airguns, acoustic deterrents and explosives, minimum thresholds should be used for uptake in the registers. The generic source level (SL) threshold for inclusion in the register for non-impulsive sources is 176 dB re 1 µPa m, whereas the threshold for inclusion of impulsive sources is an energy source level (SLE) of 186 dB re 1 $\mu Pa^2$ $m^2$ s. For airguns and explosives it is more convenient to convert these to proxies of zero to peak source level (SLz-p) and equivalent TNT charge mass (mTNTeq), respectively. The recommended thresholds for these source levels and proxies of short duration sound sources are listed in Van der Graf et al. 2012.

Based on the above and until a complete protocol can be agreed upon by EU GES Subgroup on Noise and applied by the Member States, the following approach is suggested:

- Identify received Sound Exposure Levels that are considered harmful based on published literature, e.g. 183 dB re 1 $\mu Pa^2 s$ based on TTS (Temporary Threshold Shift of the hearing capabilities) for the case of some dolphin species (Southall et al. 2007);
- Identify the activities that are most likely capable of producing an environmental impact; these are mainly caused by high intensity impulsive sources like pile driving and airgun operations and other high intensity sources as some sonar and explosions;
- Retrieve information on source levels and positions for each day of their operations from the operators of activities under the above point;
- Combining the data submitted by all operators during a calendar year to create

an overview map that shows for each day of a particular operation the area (divided in suitable cells) where Sound Exposure Levels exceed levels defined in 1, as well as a map that sums the number of days over all operations during the calendar year of each cell where the received levels were exceeded as.

Regarding continuous low frequency sound (*Criterion 11.2)*, the MSFD recommends to measure *trends in the ambient noise level within the 1/3 octave bands 63 and 125 Hz (centre frequency) (re 1 µPa RMS; average noise level in these octave bands over a year) measured by observation stations and/or with the use of models if appropriate (Indicator 11.2.1).*

A difficulty with this second indicator is that establishing a (statistically significant) trend may take many years. From an environmental point of view it is important to collect information that not only allows to establish a trend in the future, but that also allows to characterise the current noise levels. It is likely that new insights in the future concerning animal welfare require different or additional indicators to be computed. The data that is collected now under this criterion should provide some flexibility to compute or estimate these new indicators. The following approach is suggested:

- Identification of areas that should be monitored or modelled. Areas of interest are those that either habitat or are regularly visited by protected species (such as marine protected areas) and those that have increasing economic activities (such as harbours or zones marked for production of oil & gas). Areas suitable for modelling are those that have a homogeneous environment with a relatively simple bathymetry;
- Ideally all modelling would be validated with on-site measurements, but this is especially important for more complex areas, which would then need measurement equipment installed. Areas that are especially suitable for measurement are those that contain resident cetaceans;

Modelling will not include unknown or unexpected sources, while measuring will include incidental high impact sources and in addition can allow real-time monitoring of an area. Measuring will also be important when a mitigation protocol needs to be implemented (e.g. with pile driving activities).

### 5.1.4 Marine Protected Areas (MPAs)

Authorities' willingness to protect areas of particular importance for sustainable development also indicate to what extent the state of the ecosystem or resource base can be sustained in the long term. Marine protected areas could be a proxy for such a measure. Marine protected areas are regions where human activity is restricted to help protect the natural environment, surrounding waters and ecosystems, or cultural or historical resources that may require preservation or management.

Marine resources are protected by local, state, territorial, native, regional, or national authorities and may differ substantially from nation to nation. This variation includes different limitations on economic development. Marine protected areas are included on the World Database on Protected Areas (WDPA), which, since 2010 is viewable via Protected Planet, an online interactive search engine hosted by the United Nations Environment Programme's World Conservation Monitoring Center (UNEP-WCMC).

While the total area of marine protected areas being established in a particular region gives some indication that this region is protected, another possible indicator could be the percentage of protected area in a particular region, which also conveys information about the size of the protected area in relation to the area that is not protected. This indicator is rather coarse however and should be complemented with information about the kind of area that is protected (breeding or feeding grounds, etc.) and what activities are allowed within the protected area. Given the slow changes in the areas protected, time series data may not convey very much information.

### 5.1.5 Number of oil spills and near misses

*Definition*

Analyses related to planning, risks, insurance and improved requirements for oil related operations require statistical information on oil spill occurrences and potential occurrences (near misses). An oil spill incident is defined as “any unplanned event that resulted in oil being released in the marine environment”. A near miss is defined as “any event, which under slightly different circumstances, may have resulted in oil being released in the marine environment”. We recommend the number of oil spill incidents per year, of any volume, be recorded as an indicator for oil spill prevention and response. These indicators should by kept by type of product spilled, e.g. crude, heavy fuel oil, marine diesel, etc. This indicator is key to evaluating key areas such as: safe transportation practices, general best practices, and understanding oil spill risk.

*Assessment*

The number of oil spill incidents and near misses represents both environmental risk and policy goals for (1) minimising risk during development and operations for oil drilling, production, transport and disposal and (2) safe shipping in the Arctic. Though some risks are not controllable, e.g. ice bergs or extreme weather, human and environmental factors for oil spills occurring need to be minimized.

Statistical oil spill information exists in a variety of forms, such as International proprietary databases, e.g. Environmental Research Consulting in the USA, and ITOPF (International Tanker Owners Pollution Fund[2]) and nationally, such as the U.S. National Pollution Funds Center, the Norwegian Coastal Administration and the U.K. Hydrocarbon Releases System[3]. These types of

[2] http://www.itopf.com/knowledge-resources/data-statistics/statistics/ accessed 28 August 2014
[3] https://www.hse.gov.uk/hcr3/ accessed 28 August 2014

information are important to coordinate for all Arctic countries in order to do analyses to identify and reduce different types of risk at a pan-Arctic level.

Data quality varies both by the country and by the reporting requirements. For example, the total volume is not generally known until the response is over. Initial estimates can be extremely low, as operators will tend to under-report and the correct information will not be known until later. Reviewing information within key databases after an incident is important to ensure data quality.

*Data Sources*

This type of information in generally collected by local authorities as part of any damage claims. In many developed countries, the spiller or responsible party must pay damages, so good information is kept and reviewed. In general, countries make these types of information publically available. Support organizations, such as the US Coast Guard, the Norwegian Coastal Administration and ITOPF, keep statistics for analysis. Permitting and monitoring groups also utilize or keep oil spill databases for their own estimates of risk or other purposes.

The indicator is easy to understand and not sensitive to small changes. Counting the number spills of any size, rather than only major events, is critically important, as chronic small spills can lead to significant environmental impact. As a result, the indicator is more sensitive to a large number of low volume spills, than rare very large events. This is a list of additional statistics related to oil spills that should be kept:

1. Date/time (use 24-hour time);
2. Location (including latitude and longitude in decimal degrees);
3. Location type (marine, coastal, estuarine, river, inland, arctic, etc.);
4. Source information (vessel name, type, size, hull configuration, IMO number; loaded/ballast, cargo and fuel contents/capacity; well name, flow rate);
5. Volume of spillage by oil type;
6. Potential volume of spillage by oil type;
7. (Potential spills – i.e., incidents in which a spill might have occurred but didn't)
8. Oil type(s) spilled;
9. Cause of incident;
10. Impacts caused by incident;
11. Response costs;
12. Third-party claims;
13. Environmental damage claims;
14. Natural resource damages (birds, fish, etc.);
15. Response type.

The success of this indicator is the routine and accurate gathering of data on a pan-arctic scale. We do not have information on whether this has been done in the past.

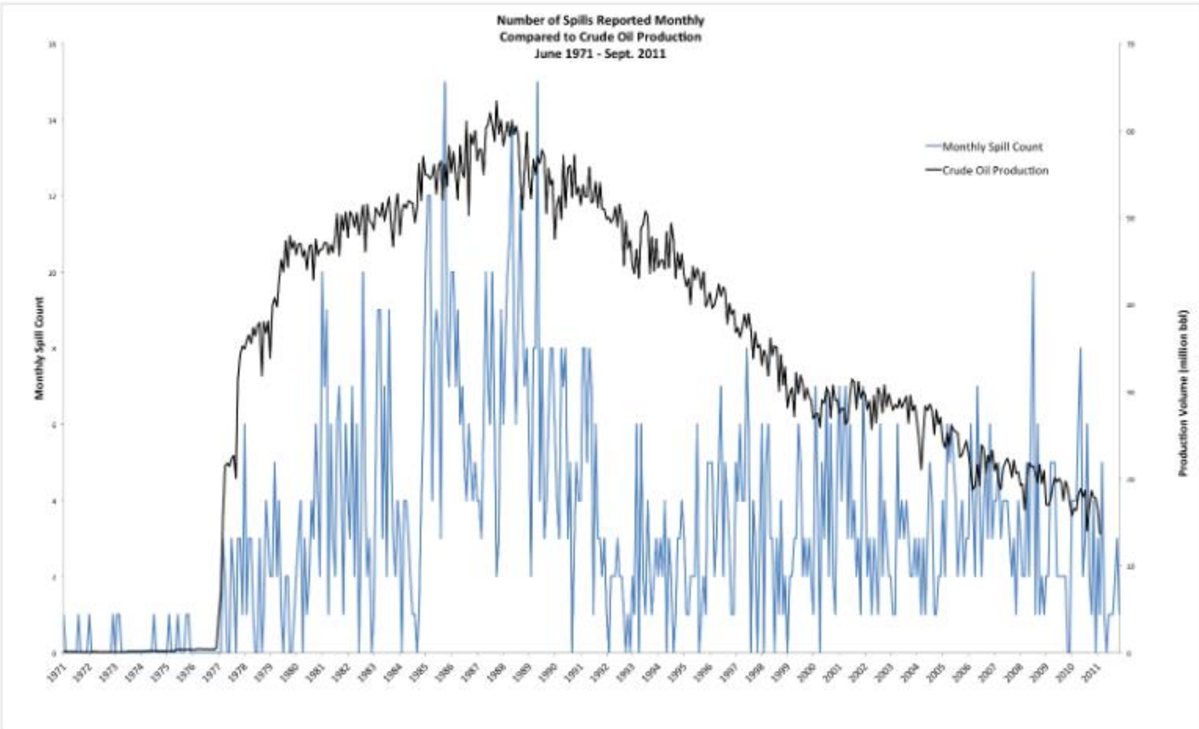
Statistics of oil spills are fairly straightforward to understanding safe operations in oil development, transport and disposal. Statistical information is important for analysing potential policy changes and safety of operations in specific environments. There has been some evaluations relative to risk acceptance, e.g. Psarros et al. (2011) and cost-effectiveness of marine oil spill measures, e.g. Vanem et al. (2008).

This indicator demonstrates sustainable development in the Arctic. Large spills create news headlines, but more frequent small spills can be more environmentally damaging. Safe operations are important for minimising environmental risk and evaluating companies involved in shipping and transport of oil, as well as oil users, e.g. cruise ships and fishing vessels. Insurance rates go up in industries that have high spill rates, and regulations can limit operations for unsafe groups.

*Description*

Figure 8 shows a statistical analysis of spills, both crude and refined products, for the Alaskan North Slope. Note that the number of spills roughly is related to the volume of crude oil production over time, with some significant events also occurring. Note there is a sharp change in the oil spill statistics after 1989, when the T/V Exxon Valdez oil spill occurred, leading to widespread changes in oil transport safety practices.

**Figure 8: Monthly total number of spills recorded compared to crude oil production (June 1971-September 2011).**




Source: Robertson et al. (2013).

## 5.2 Social dimension

Today, social sustainability is less well understood than environmental and economic sustainability. Varying definitions of social sustainability can encompass social equity, liveability, health equity, community development, social capital, social support, human rights, democracy, labor rights, place-making, social responsibility, social justice, cultural competence, community resilience, and human adaptation. Thus it is a very wide concept and given different values placed on some aspects of social sustainability, measures can be interpreted very differently. For example democracy or certain human rights are not valued highly in some countries but in others. Furthermore, many of the concepts are difficult to measure. For example, people may have very different views on the 'liveability' of an area depending on personal preferences. As such it is difficult to put forward a definitive set of general social sustainability indicators. However, a range of indicators that are less subjective and cover key aspects of social sustainability have been put forward in the academic literature. Our suggestions build on such previous approaches.

Unfortunately, data availability for social dimensions indicators is a serious problem particularly if the focus is on regions rather than countries, which typically is the case. Thus, some indicators are not available for all regions. This is an issue for the Russian Federation for which very little data was found on the regional level and available data may not be broadly accessible due to language barriers. The data presented in Figure 9 to Figure 13 shows national figures and represent a placeholder rather than an accurate indicator. There are also differences in the size of region for which data is available. For example for Alaska the data is at county level while for Canada only province and territory level was found. Such data is likely to exist for Russia as well, but again language barriers make access difficult.

In addition, there are some differences in definitions, particularly with respect to the definition of poverty. Finally, except for population change most data on social indicators is static i.e. refers to a point in time. Hence it would be useful to also monitor changes in the indicators.

For the social dimension of sustainable development we focus on the two policy categories of well-being and social inclusion. We follow a pragmatic approach considering data for key indicators related to the indicator target areas of population characteristics (Section 5.2.1), human health (5.2.2), labor market access (5.2.3 and 5.2.4) and income inequality (5.2.5). Naturally, especially economic indicators have a bearing for social cohesion, including but not limited to economic activity (5.3.4) or infrastructure development (5.3.5).

### 5.2.1 Population change and migration

Population change is important because social sustainability is irrelevant without people. Population demography is an important domain on the list of statistical monitoring of broad areas of social concern (United Nations 1975, 1989, 1996). In the sparsely populated Arctic areas and especially in the rural communities even relatively small changes in population dynamics can drive many challenges for sustainable development. Areas that experience population decline may become socially unsustainable as the population shrinks below a minimum size to maintain services. In contrast, areas with particularly strong population growth may experience significant social pressures, perhaps due to change in the way of life, increased ethnic heterogeneity or competition for resources and services. Figure 9 illustrates population change for the most recent two years for which data is available. This change is measured as a percentage of increase in the population due to migration and natural reproduction between two years. Parts of Alaska (North Slope Borough, Denali Borough, South Fairbanks, Lake and Peninsula Borough, Matanuska-Susitna) experienced significant population growth. Likewise in Canada, Alberta and Seskatchewan grew significantly. However some parts of Alaska (Yukon-Koyukuk and Nome) and Canada (Northwestern Territories) also recorded a population decline. Greenland, Iceland and parts of Northern Sweden and Northern Finland also declined.

While basic population statistics are among the most important indicators and are routinely collected by governmental agencies, migration could be considered as relevant sustainability indicator of the energy sector. Migration in general is one of the significant demographic forces in the North. In Northern Norwegian communities there is a mismatch between employment opportunities and the labor forces for example in the energy, but also e.g. the fish processing sector, which triggers changes in population structure. While employers do not find adequate labor force, there is still a large rate of unemployment and sickness in the region (Stammler-Gossmann, forthcoming). This problem is often solved by attracting foreign labor force. Net migration has particular importance for Arctic places, where the arrival of newcomers or departures of local young adults can quickly reshape community life (ASI 2010: 41).

Out-migration by young people and aging population in small settlements can bring following economic and infrastructural decline, including e.g. interruption in fishermen's knowledge transmission as experienced by some communities in Finnmark/Northern Norway (Stammler-Gossmann, forthcoming).

The in-migration may indicate an economic revival or growth, but may also be perceived at the local level as certain disturbance on the community's way of life. At the same time the newcomers may experience some stress because of the lack of language skills, different cultural background, and lower wages. In the Arctic to a greater degree than elsewhere, net migration often dominates population structure and change. Population and migration growth may also indicate an increased pressure on resources.

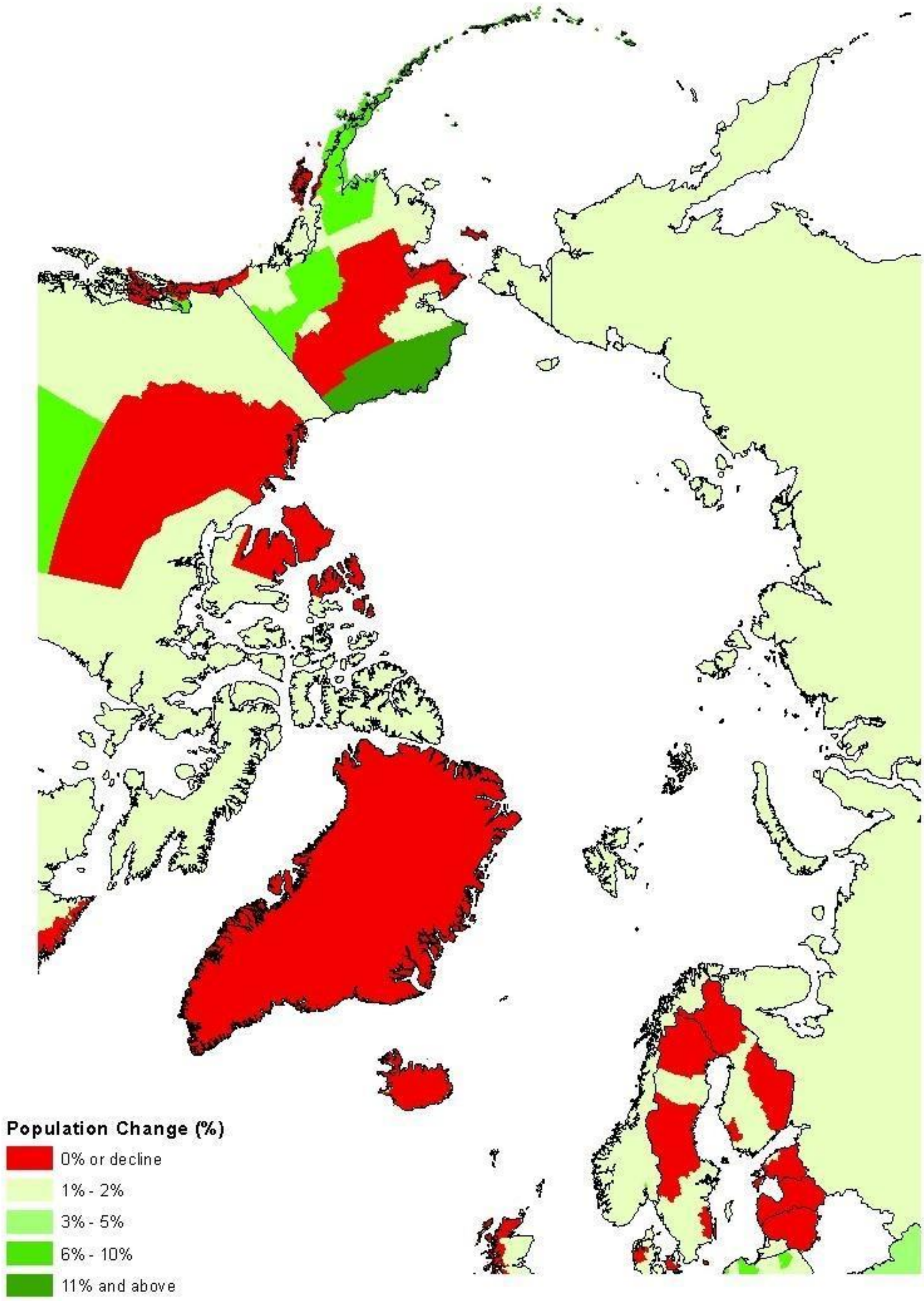
Although demography/migration is an appropriated indicator related to sustainability, its application is no straightforward task. Not all statistics in Norway and Russia, for example, are sensitive to the ethnic components of migration and substantial interpretational effort may be required. However, progress in this issue is essential to understand how to keep Arctic communities viable.

National census data, in-between census estimates of population, register statistics on different scales provide time series of total population down to the community or enterprise level. Socio-economic circumpolar database ArcticStat provides data on the movements of the population according to variables Internal Movements, Immigration/ Emigration, Residents One Year Ago, Moved, Entered, Year of Entry etc. This web portal provides access to web pages with links to data produced by the national statistical agencies of Arctic countries.

The long-term SLiCA (The Survey of Living Conditions in the Arctic)[4] survey may provide a supportive part in understanding the role of demography/migration for the present living conditions relevant to Arctic communities. Data is available from Eurostat New Cronos database, Statistics Canada, Statistics Norway and data for Russia can be found through the World Bank World Development Indicators.

[4] Available online: http://www.arcticlivingconditions.org/, retrieved March 28, 2014

**Figure 9: Population Change (%), between the two most recent years.**




Sources: For EU countries, Iceland and Norway the data is from EUROSTAT New Cronos database, Data for Canada is from Statistics Canada, data for the USA is from the US Census Bureau, data for Greenland is from Statistics Greenland, data for Svalbard is from Statistics Norway and data for Russia is from the World Bank World Development Indicators. For Canada, EU and Norway the data are for 2010/11, for Alaska 2009/10, Russia for 2011/12 and for Iceland 2012/13.

### 5.2.2 Crime rates and indicators of human health

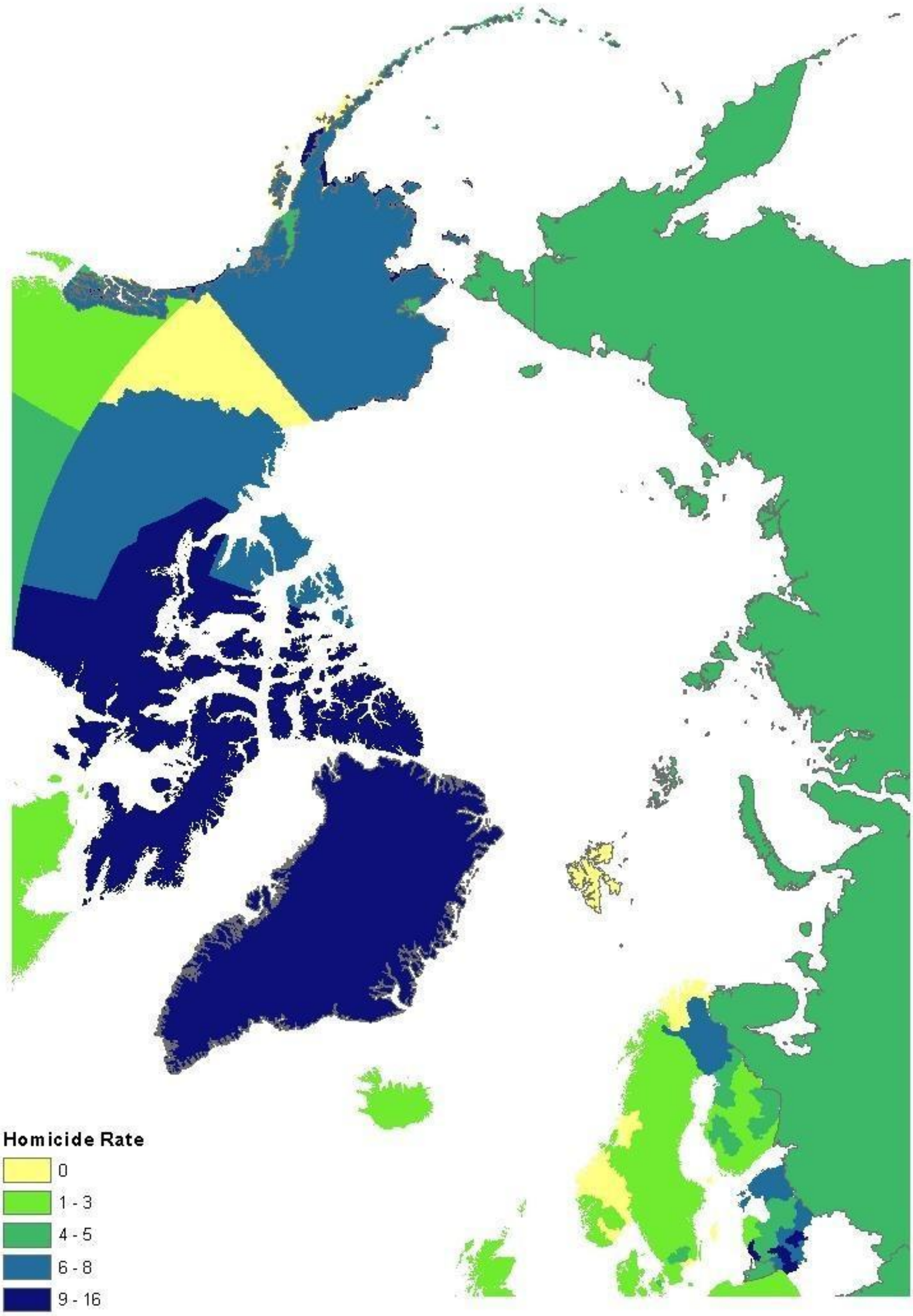
Human health is a tricky target area to monitor. We suggest focusing on crime rates as a relevant indicator. High crime rates lead to a lower sense of security among residents and visitors and they are also an indicator of the effectiveness of the rule of law. High crime rates against property tend to be associated with a lack of economic opportunities while crimes against persons (assault, rape, murder) tend to have socio-demographic drives. Given the focus on social sustainability, crime is measured as the homicide rate. This indicator has the advantage of being similarly defined across jurisdictions, and unlike crime against property is typically well reported. Obviously, it is also suited to measure other target areas and policy categories in the social dimension, namely social inclusion.

Figure 10 shows homicide rates across Arctic regions. These appear to be higher in Nunavut, Greenland and most of Alaska. In Europe, Northern Finland was found to have higher rates.

Other health indicators are related to population characteristics discussed in Section 4.1. For example, the numbers of births and deaths are essential health indicators. Population characteristics such as size, sex ratios, age structure, in- or out-migration, and rates of growth or decline are widely recognized as a reflection of the health of a community. Population growth, presence of young people, return or circular migration in the small coastal communities of the Barents region is considered by the local residents as powerful factor for the community viability. (Stammler-Gossmann, forthcoming)

Data is available from EUROSTAT, New Cronos database, from Alaska County Health Rankings, Statistics Greenland, Canadian Centre for Justice Statistics. For the Russian Federation no regional data was found but national homicide rate can be obtained from the UNODC Global Study on Homicide.

**Figure 10: Homicide Rate (Homicides per 100,000 persons), for the most recent years.**




Sources: For EU countries, Iceland and Norway the data is from EUROSTAT, New Cronos database, for Alaska the data was obtained from County Health Rankings 2011, for Greenland the data is sourced from Statistics Greenland, for Canada the data was taken from the Canadian Centre for Justice Statistics. For the Russian Federation only the national homicide rate is available from the UNODC Global Study on Homicide. All data are for 2009, 2010 or 2011.

### 5.2.3 Unemployment rate

The unemployment rate is a useful indicator of the degree to which individuals can partake in paid economic activity, which impacts on their living standards, the status that people have within society and the degree to which they can participate in wider social activities. This is an indicator related to the policy category of social inclusion, which focuses particularly on access to labor market. Furthermore, the unemployment rate is correlated with measures of economic prosperity, such as GDP per capita, as well as poverty indicators, such as the Gini coefficient. It is also believed to be driving the general health situation to some extent. It is measured by relating the number of unemployed people to the total size of the labor force.

Unemployment rate has been widely used in assessments of social inclusion. It measures the economic foundations for social participation of a large part of the population, namely the labor force. Furthermore, unemployment is supposed to correlate with psychological stress and isolation. Since the unemployment rate is usually calculated relative to the labor force, it is not informative for those parts of society that are not part of the labor force. This typically includes children, senior citizens, people suffering from chronic illness, people in education, participants of public job training schemes, or in many cases also people that are voluntarily unemployed (such as homemakers).

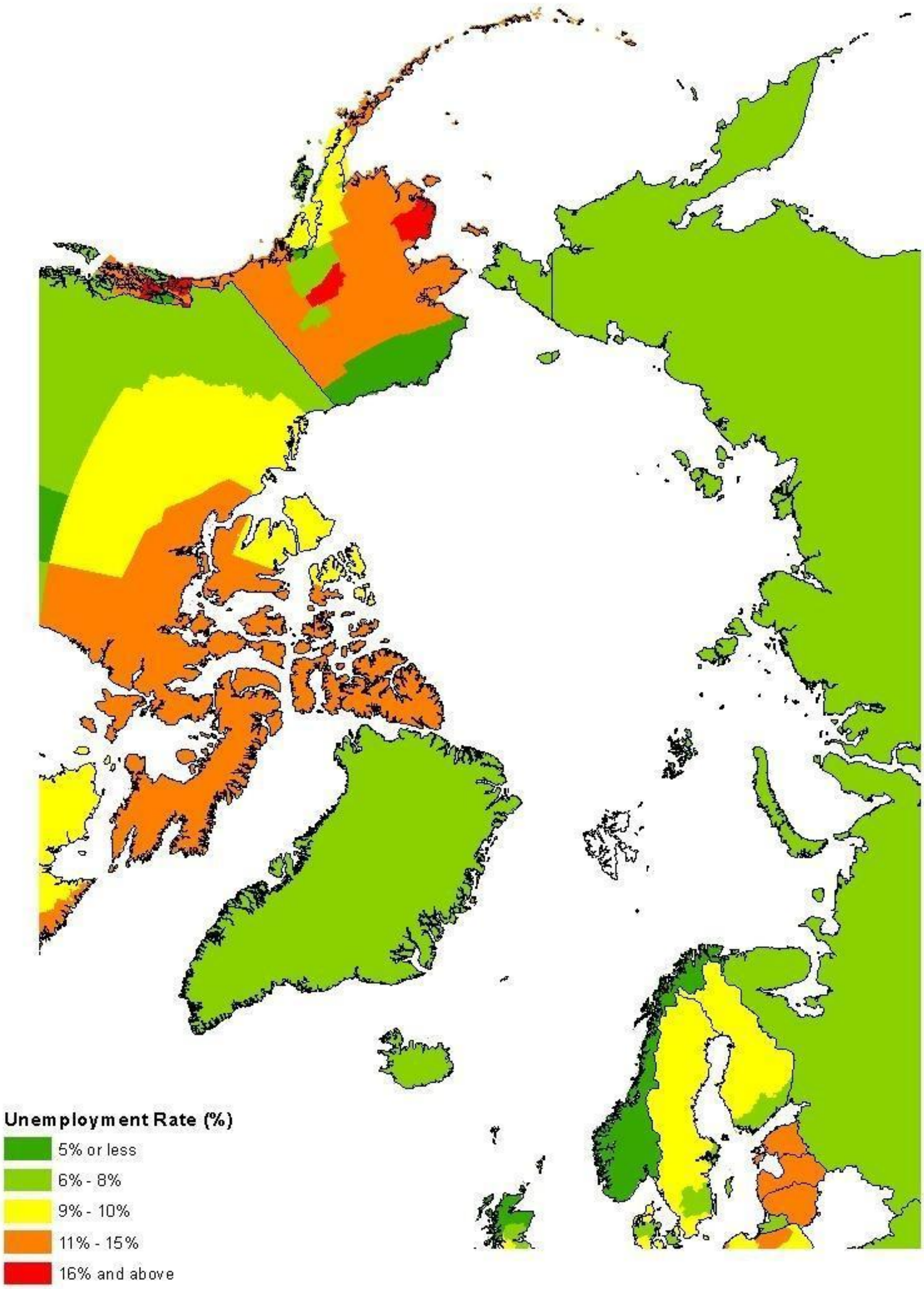
Unfortunately, unemployment rate is measured differently in different countries official statistics making straightforward comparisons between countries challenging. Apart from this issue, unemployment rate is usually readily available from official statistics and measured according to international standards, ensuring transparency, data quality, and intertemporal comparability. For most countries, multi-decadal time series are available.

The unemployment rate is responsive to a number of policy measures, especially from legislation from the social security field. It does, however, also respond to changes in the general economic situation which could be exogenously driven, e.g. by world market developments.

For EU countries, Iceland and Norway the data is from EUROSTAT New Cronos database, Data for Canada is from Statistics Canada, data for the USA is from the US Census Bureau, data for Greenland is from Statistics Greenland. While unemployment data is available for the sub-national level for some countries, namely Alaska, Sweden, and Finland, it is often only published for the national level. Especially for countries with a large share of non-Arctic residents, such as Russia, this limits validity with respect to Arctic issues.

Figure 11 suggest that there are large variations between the different Arctic regions. The unemployment rate is low in all of Norway, Iceland, Greenland and North Slope Borough in Alaska, while particularly high levels of unemployment were recorded in Wade Hampton, Denali Aleutian-East and Skagway boroughs of Alaska. Unemployment is also relatively high in most other parts of Alaska and Nunavut and Newfoundland and Labrador.

**Figure 11: Unemployment Rate (%) 2013.**




Sources: For EU countries, Iceland and Norway the data is from EUROSTAT New Cronos database, Data for Canada is from Statistics Canada, data for the USA is from the US Census Bureau, data for Greenland is from Statistics Greenland

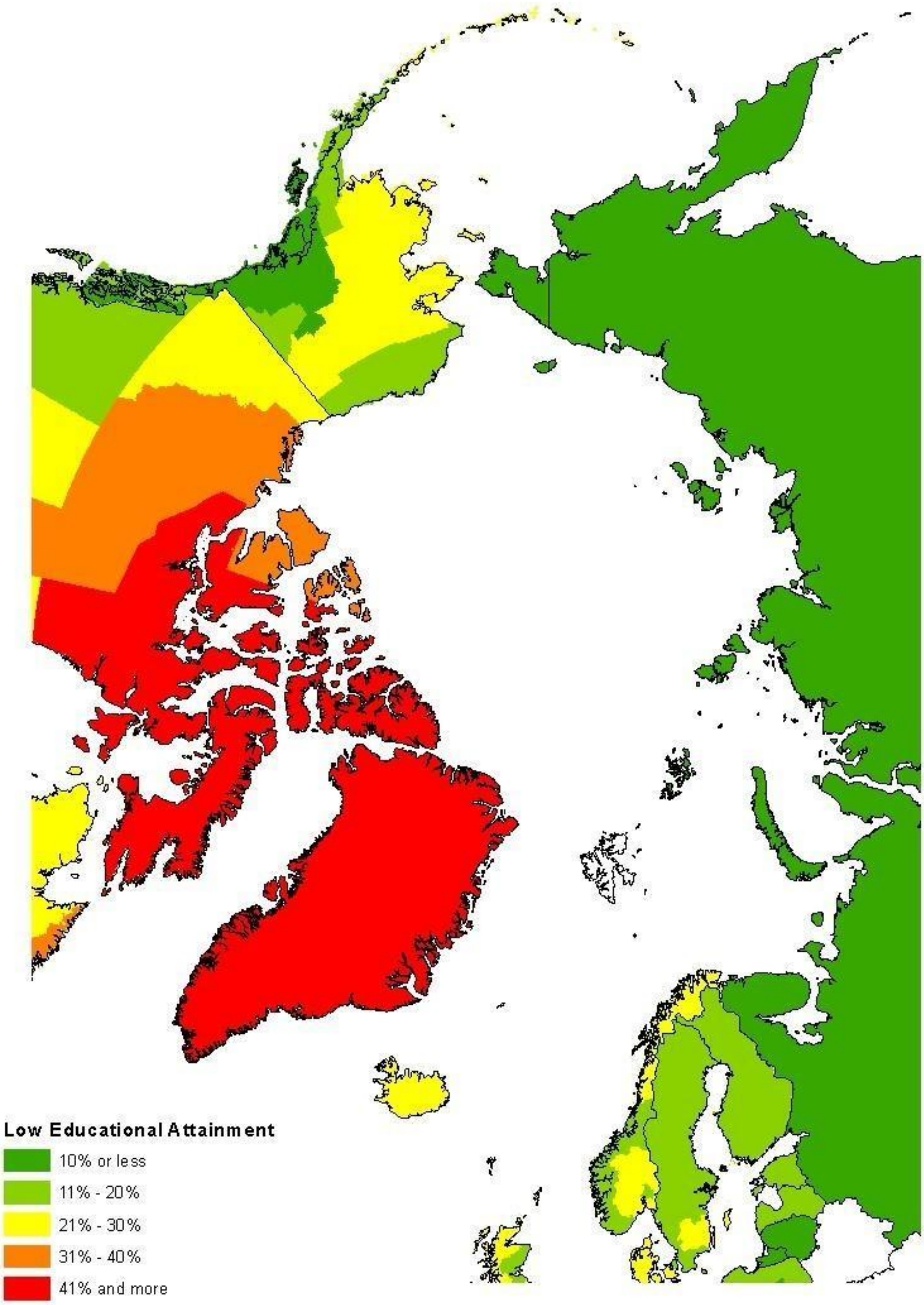
### 5.2.4 Educational attainment

Educational attainment is a useful indicator both of the educational opportunities an area provides as well as the economic return on educational qualifications. Areas that offer few employment opportunities tend to have a lower average educational attainment rate, which in turn limits the type of economic activities that can be carried out in these areas. This in turn tends to result in out-migration of better educated individuals to areas with better job opportunities and thus further reduces the average educational attainment rate. Such, areas, unless they are rich in natural resources, tend to be economically underdeveloped.

Here we suggest using a measure of educational attainment as the percentage of the population without a High School Certificate. With respect to educational attainment (Figure 12) there is a relationship between the latitude and the percentage of the population that does not hold at least a high school diploma, with the highest rates recorded in Greenland and Nunavut. With the exception of North Slope, the northern parts of Alaska also have a lower educational attainment rate. For Europe, Iceland and Northern Parts of Norway also have lower attainment rates.

Data is available from EUROSTAT New Cronos database, Statistics Canada and US Census Bureau.

**Figure 12: Percentage of the Population without a High School Certificate.**



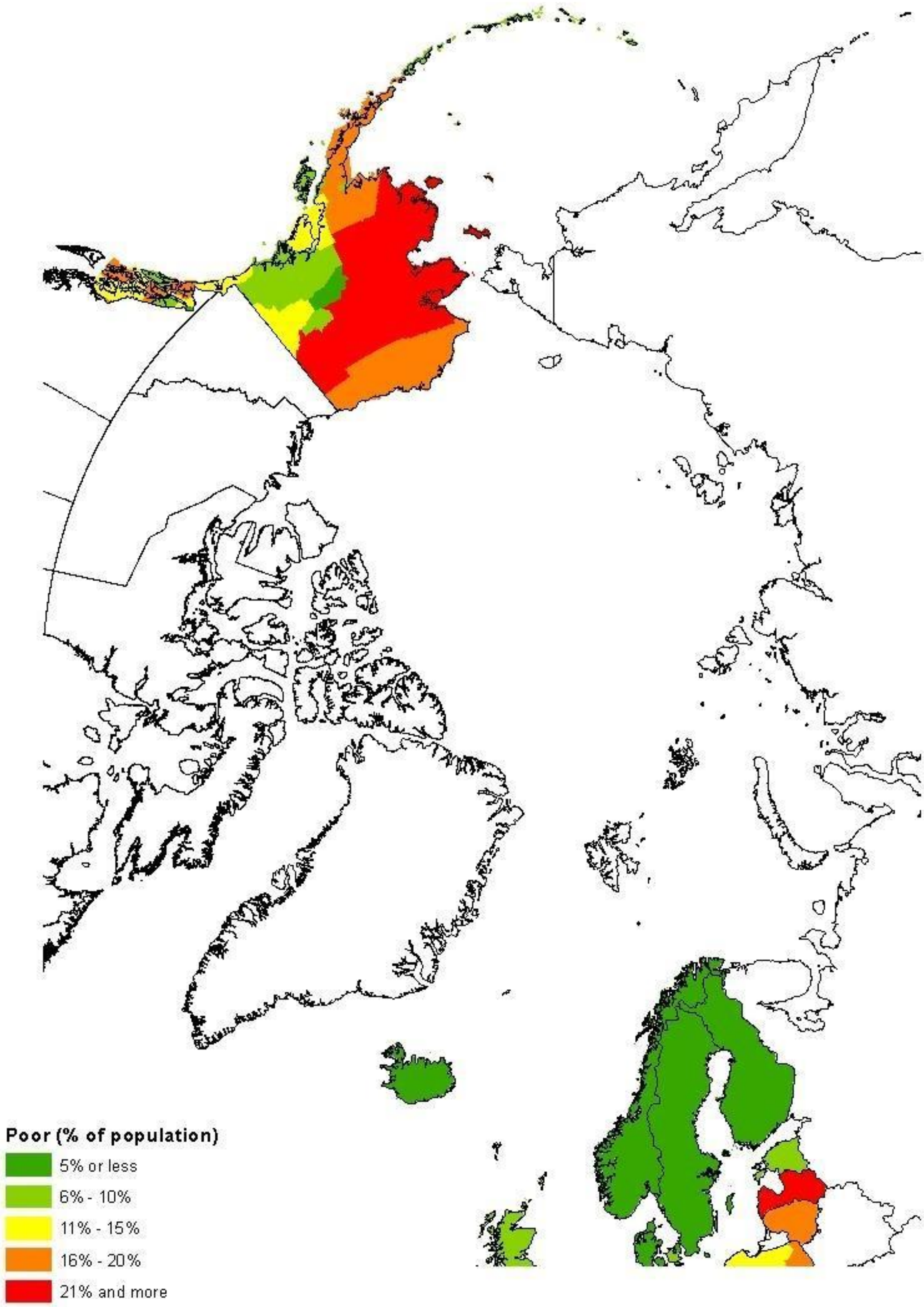

Sources: For EU countries, Iceland and Norway the data is from EUROSTAT New Cronos database, Data for Canada is from Statistics Canada, data for the USA is from the US Census Bureau. Data for the EU, Norway, Iceland and Greenland is for 2012, data for Alaska is for 2011, for Canada 2006 and Russia for 2011.

### 5.2.5 Poverty

Poverty is a function of earned and unearned income and the distribution of income across the population. High levels of poverty in particular areas tend to reduce social cohesion within countries, but also within affected areas. Poverty is measured as the percentage of poor people in the population. Data with a common definition across all countries is not available. For Alaska the poverty rate is measured relative to an income cut-off defined by the US Census Bureau, whereas for the EU, Norway and Iceland, the indicator is the percentage of the population living in severe material deprivation, which is a wider concept.

Only limited consistent data is available across Arctic regions. However, Figure 13 shows the poverty indicators for Alaska and Europe calculated as the percentage of poor persons in the total population. In Alaska Northern and Western parts tend to have a higher level of poverty than Southern parts. In Europe only the Baltic countries have high levels of poverty, but this is related to the differing levels of wealth across the countries shown in the map, primarily Norway, Sweden, Finland and Iceland and differing social welfare systems.

**Figure 13: Poverty Rate (poor persons as % of total population, 2012).**




Sources: For EU countries, Iceland and Norway the data is from EUROSTAT New Cronos database and data for the USA is from the US Census Bureau.

## 5.3 Economic dimension

The economic dimension focuses on a number of corresponding policy categories that nevertheless must not necessarily be directly related. We focus on cheap and affluent energy provision, regional economic and infrastructure development, as well as response capability, especially related to SAR. We measure energy supply directly by the amount of energy produced and exported (Section 5.3.1), energy prices (5.3.2), and exploration activities (5.3.3). Regional economic and infrastructure development is measured by (regional) GDP (5.3.4) and by the availability of ports (5.3.5). We found the measurement of response capability especially difficult to measure. We resort to the concentration of helicopters (5.3.6) and weather forecasting capabilities (5.3.7), but coherent data supply is lacking here, too. Some indicators from other dimensions have a bearing for the economic sustainability, e.g. if marine protected areas restrict economic activity (5.1.4) or if qualified labor is scarce (5.2.1, 5.2.3, 5.2.4). Thanks to the availability of official statistics, the data situation is often good. Nevertheless, lack of regional disaggregation often prevents meaningful analysis of the Arctic in particular, so that specific Arctic developments remain hidden behind the development of the larger entity.

### 5.3.1 Oil and gas production and export

*Definition*

The most immediate indicator for activity in the energy sector as well as affluent energy supply is produced oil and gas in a region. With respect to secure energy supply both in the region itself and at its trading partners, oil and gas exports are the indicator of choice.

*Assessment*

Data on oil and gas production and exports is provided by official statistical offices and edited in a comprehensive and transparent way by a number of governmental and private actors. This ensures international and inter-temporal comparability, high data quality standards, transparent data collection, regular updates and easy and costless accessibility. Nevertheless, the indicator is mainly descriptive and only to a limited extent predictive of activity in the energy sector. Data is usually available on the country level, but for some countries sub-national data is available, including the US and Russia for exports and more countries for production.

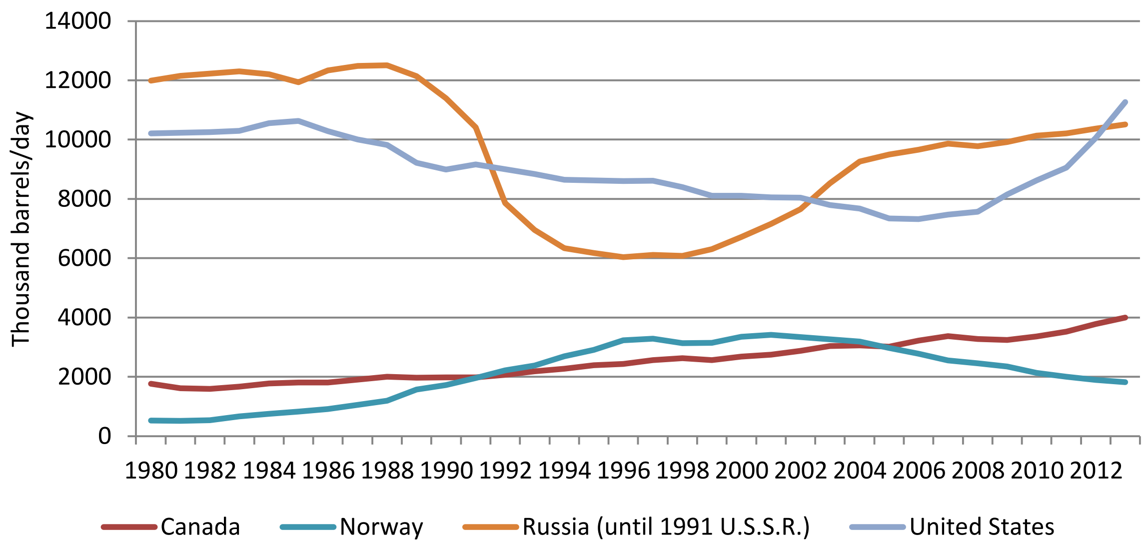
*Description*

Figure 14 and Figure 15 display production data for oil and gas from the US Energy Information Administration (EIA), which collects data mostly from national statistical institutions[5]. Monthly and quarterly data are available as well and data are updated with only few months lag. While more regional production data is available from different sources, consistent data over time is easily accessible only on the country level. As the Figures show, the production paths of the various countries differ substantially. In Norway, oil production is declining after peak production around the new millennium, while Norwegian gas production is still ascending. Both, oil and gas production have been declining in the US for several decades before the onset of unconventional production around 2008 (although not in the Arctic). Oil production in Russia and the Former Soviet Union has seen a

[5] Cf. *http://www.eia.gov/cfapps/ipdbproject/docs/sources.cfm* (downloaded 22 October 2014).

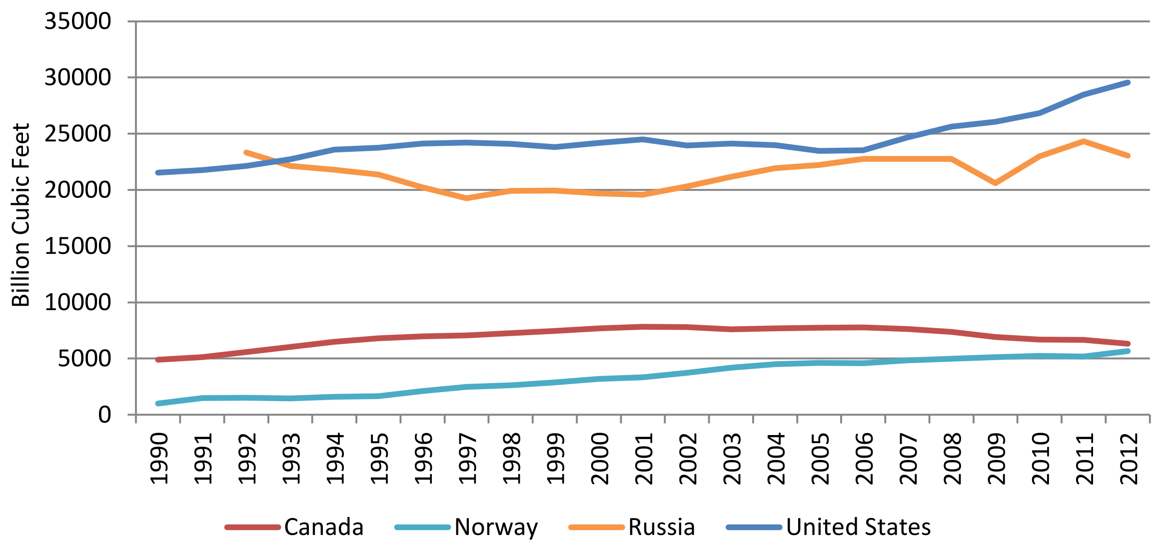
rapid decline after the collapse of the Soviet Union, also but not only because of the secession of central-Asian Soviet Republics. With the rise of the oil price and following infrastructure investments, oil production has been increasing again after the mid-1990s. Due to the export orientation, especially natural gas production in Russia remains relatively volatile and susceptible to world market developments, such as the Financial Crisis after 2008.

**Figure 14: Production of Crude Oil, NGPL, and Other Liquids.**




Source: US Energy Information Agency 2014. http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=55&aid=1&cid=CA,GL,IC,NO,RS,US,&syid=1980&eyid=2014&unit=TBPD (downloaded 22 Oct 2014).

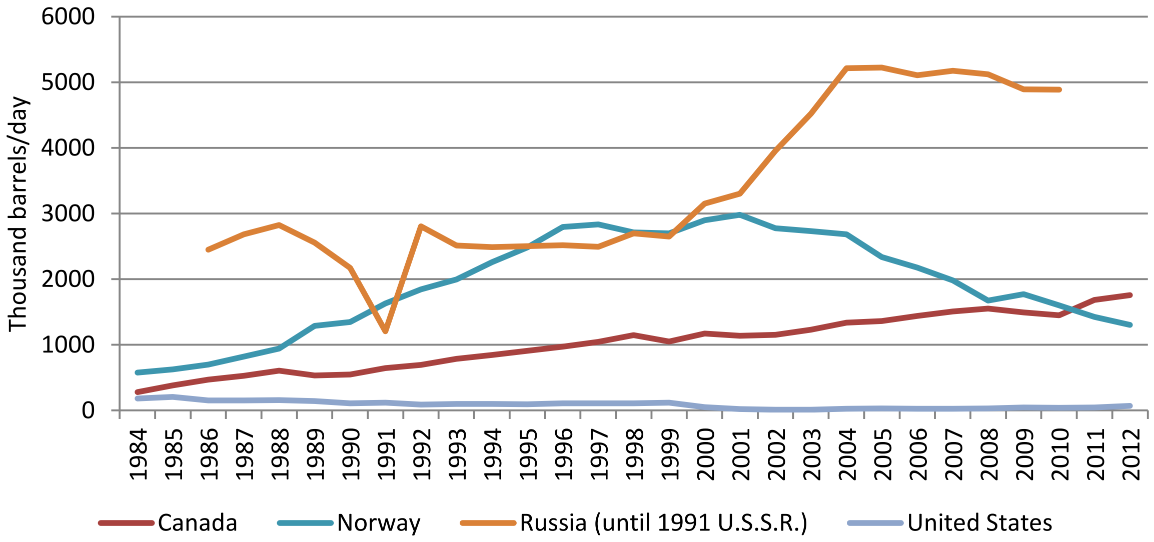
**Figure 15: Production of Natural Gas (Gross Production).**




Source: US Energy Information Agency 2014. http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=3&pid=3&aid=1&cid=CA,DA,GL,IC,NO,RS,US,&syid=1980&eyid=2012&unit=BCF (downloaded 15 November 2014).

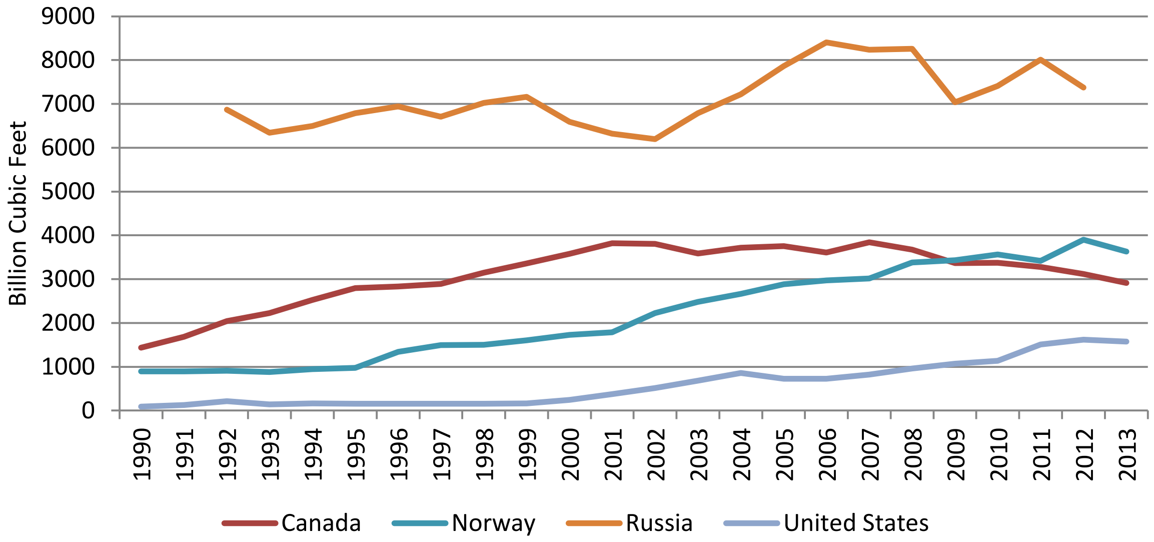
Exporting activity often follows a similar pattern (see Figure 16 and Figure 17). While in some countries, like Norway or Canada, the discovery and depletion of productive wells steer exporting activity, exporting activity of other countries, and especially large domestic consumers, is driven by national demand (e.g. in the US), global prices, or economic disruptions (e.g. in the Former Soviet Union in the early 1990s).

**Figure 16: Exports of Crude Oil, NGPL, and Other Liquids.**




Source: US Energy Information Agency 2014. http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=5&pid=57&aid=4&cid=CA,UR,GL,NO,RS,US,&syid=1984&eyid=2012&unit=TBPD (downloaded 22 Oct 2014).

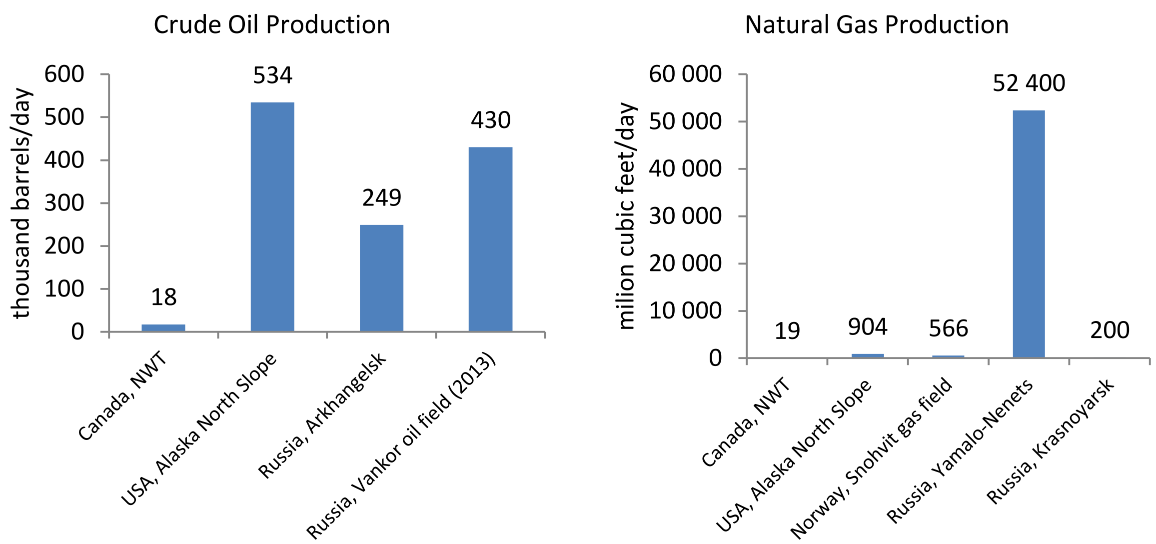
**Figure 17: Exports of Dry Natural Gas.**




Source: US Energy Information Agency 2014. http://www.eia.gov/cfapps/ipdbproject/iedindex3.cfm?tid=3&pid=26&aid=4&cid=CA,GL,IC,NO,RS,US,&syid=1980&eyid=2013&unit=BCF (downloaded 15 November 2014).

More regional data is less available. We show data on a non-exhaustive number of Arctic regions or production sites in Figure 18. Data sources, however, are scattered and non-harmonized, limiting comparability. Also, since regions are usually defined along administrative borders, it is not always clear whether non-Arctic production is included in regions that stretch beyond the Arctic Circle, as in the case of the Yamalo-Nenets Autonomous Okrug in Russia. Since the level of production in the Arctic will usually be small on a regional level, relatively small changes such as the opening of a new production site will have large effects on the indicator.

**Figure 18: Oil and gas production in selected Arctic regions (2012 data).**




Sources: Canadian Association of Petroleum Producers (CAPP) (http://www.capp.ca/library/statistics/handbook/pages/statisticalTables.aspx?sectionNo=3, download 24 Oct 2014), Energy Information Administration (EIA) (http://www.eia.gov/dnav/pet/pet_crd_crpdn_adc_mbbl_a.htm, download 24 Oct 2014), EIA (2013): Russia country profile, Norwegian Petroleum Directorate (http://factpages.npd.no/factpages/Default.aspx?culture=en&nav1=field&nav2=TableView%7cProduction%7cTotalNcsYear, download 12 Nov 2014), own calculations.

### 5.3.2 Oil and gas prices

The extent of Arctic energy supply, and in its wake the economic and infrastructural development of the Arctic, depends on the profitability of Arctic oil and gas relative to competing sources worldwide. While the cost of Arctic production is usually at least publically unknown, the break-even average cost of production projects is given by the oil and gas price. As Arctic offshore oil and gas projects are among the most expensive oil and gas sources globally (energyglobal 2014), they will only be implemented if the oil or gas price is sufficiently high. Thus, the oil or gas price represents both global competition and the cost effectiveness of Arctic production – the price will usually be the cost of the most expensive barrel of oil or cubic meter of gas in the market that Arctic oil or gas has to compete with. Even though the long-term economic viability of Arctic oil and gas projects, and hence the implementation of new projects, is determined by the (unknown) planning horizon of the producer, the short-term oil and gas price is a viable indicator of expected Arctic energy supply and the indirect effects of Arctic energy production, including regional development or environmental stress. While for oil, where there is one global market, one price is sufficient to inform about the general development, the situation is different in the case of regionalized gas markets. We chose an average

OECD import price for oil and a number of (recently deviating) import prices for gas. Naturally, the choice of prices, especially for crude oil, is relatively arbitrary.

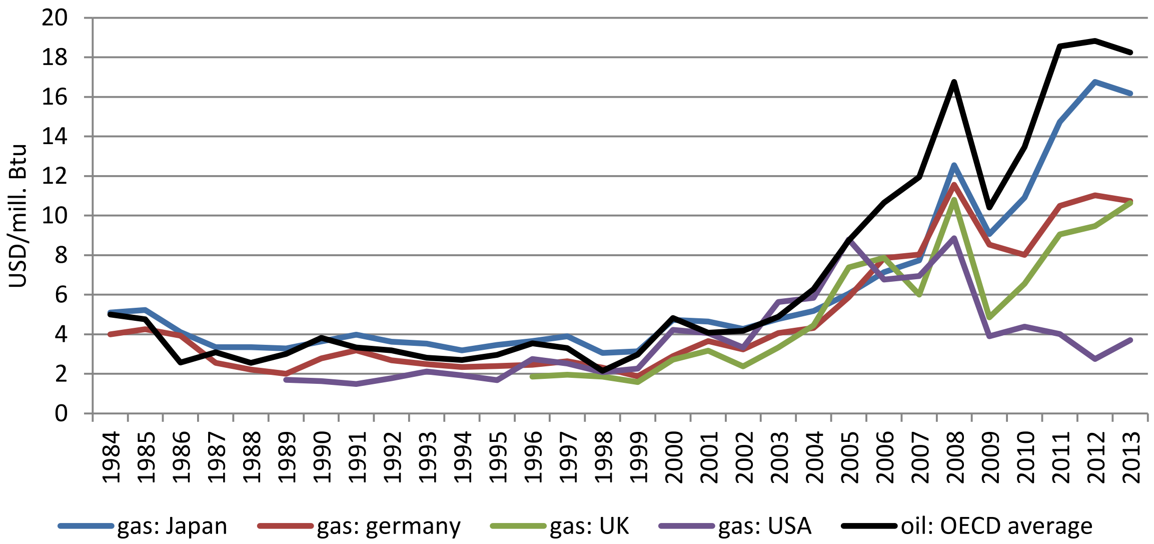
*Assessment*

As price data is more or less public knowledge and published by a multitude of sources, the indicator is very accessible. While energy prices are easy to understand, its determinants are much more complex, so careful interpretation of changes is advisable. Price developments are sensitive to a number of demand and supply side determinants, including geopolitical risks, market power and developments of substitute fuels. At the same time determination of the indicator by developments in the Arctic is marginal.

*Description*

As Figure 19 shows, energy prices follow a similar pattern until the beginning of the 2000s, also because many gas supply contracts were (and still are) linked to a crude oil price. Since the end of the 1990s, most oil and gas prices have been continuously increasing, with a temporary (with exceptions) pause during the financial crisis of 2008. With the onset of the fracking boom in the Unites States prices started to diverge. In 2005, a decoupling between the oil price on the one hand and gas prices on the other hand emerged, and even though the indices share some common determinants, such as the global financial crisis after 2008, the level of coupling between the oil and gas prices is now much lower than towards the end of the last century. Apart from the decoupling of the oil price from gas prices, the differences among the various gas prices after the financial crisis are notable. While in LNG-dependent Japan as well as in the UK gas import prices have continued to increase after the drop in 2009, prices in Germany have developed more moderately, and prices in the US have actually fallen. For Arctic natural gas this means that the destination of exports plays a much larger role nowadays than it has years ago.

**Figure 19: Import Prices for crude oil and natural gas.**




All prices are average prices including cost, insurance, and freight (cif). “Gas: Germany” is taken from the German Federal Statistical Office (1984-1990) and the German Federal Office of Economics and Export Control

(BAFA) (1991-2013), gas: UK is the Heren NBP Index, gas: USA is the US Henry Hub price taken from ICIS Heren Energy Ltd. Source: BP (2014).

### 5.3.3 Number of exploration drills

*Definition*

The number of exploration drills is a useful lead indicator for future oil and gas activity in an area. While a large number of exploration drills does not necessarily lead to (increased) production of hydrocarbons in the future, exploration drilling is a necessary precondition for production. As a lead indicator for oil and gas production activity, the number of exploration drills on a sufficiently high aggregation level informs also about future energy supply, and indirectly also about future regional economic and infrastructural development as well as future risk to the environment. We advocate a broad definition of exploration wells that summarizes the various classes (such as wildcat, shallow or deep pool tests etc.) in order to promote understandability and ease-of-use, even though this means compromising on detail and depth of information. In the future, a summary of increasingly used 3D-seismic surveys and complex geologically based computer models might complement this indicator, but as of today data is unavailable on this issue. In the meantime, the increasing efficiency and effectiveness of exploration drilling should be taken into account when interpreting time series, as on average less exploration drills are necessary for successful production today compared to before.

*Assessment*

Registers of exploration drilling are kept by national authorities. While a supranational, pan-Arctic register that is updated in predefined time steps does so far not exist, exploration drilling is, nevertheless, transparent enough to be regarded as practically public knowledge, not least due to the limited number of players and the bureaucratic preconditions for exploration drilling. The Arctic Monitoring and Assessment Programme (AMAP) compiled in its 2007 report an overview of all Arctic drilling operations, including exploration drilling in multi-year time bins and until 2004, both using detailed maps and relatively small Arctic sub-regions. Even though more up-to-date data is desirable (and available for some countries), this already constitutes a workable time series for the past. Additional data from individual countries include for example

- aggregated yearly data over all states via the EIA[6],
- Province/Territory-level data on drilling activity in Canada on a yearly basis with varying degree of detail via the Canadian Association of Petroleum Producers[7],
- yearly data by area from the Norwegian Petroleum Directorate[8] as well as
- a summary of Greenland's (relatively young) exploration history from the Government of Greenland[9].

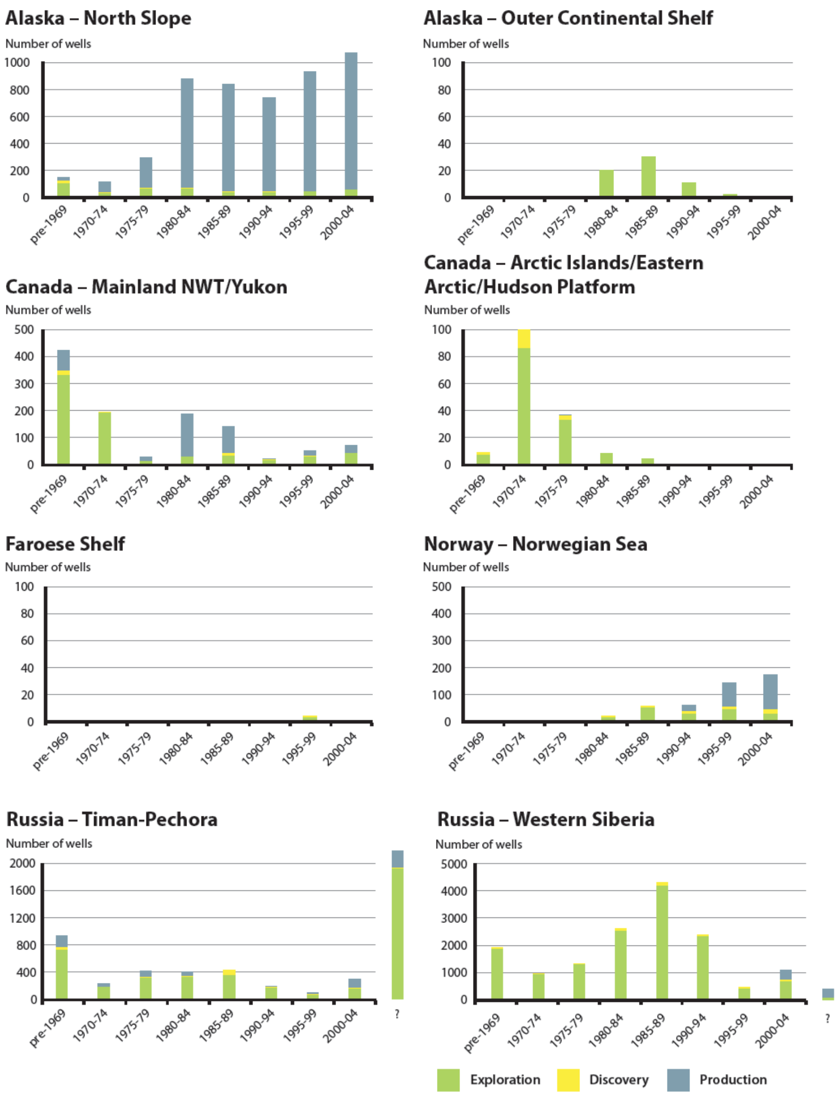
While the overall data landscape presents itself relatively scattered, the AMAP summary delivers a consistent, easy-to-understand presentation.

*Description*

[6] http://www.eia.gov/dnav/ng/ng_enr_wellend_s1_a.htm
[7] http://www.capp.ca/library/statistics/handbook/pages/statisticalTables.aspx?sectionNo=1
[8] http://factpages.npd.no/factpages/Default.aspx?culture=en&nav1=wellbore&nav2=Statistics%7cEntryYear
[9] http://www.govmin.gl/petroleum/exploration-wells

The AMAP assessment report gives a clear picture of the development of exploration drilling in the Arctic (Figure 20). The various sub-regions give several good examples on the predictive power of exploration drilling for actual production and the role of orders of magnitude. While on the Alaska North Slope or in the Norwegian Sea exploration drilling served as a good predictor of future production (although with different multipliers), the same is not true for the Mackenzie/Beaufort as well as Arctic Islands/Eastern Arctic/Hudson Platform regions in Canada or West Greenland, at least until today. Even if exploration drilling was successful, as in the aforementioned Canadian Provinces, economic viability of production is another issue. At the same time, the number of exploration drills may be small relative to future production, as in the case of Alaska's North Slope. Given the data until 2004, the number of exploration drills suggests increased future activity in some parts of Canada, Barents Sea and the Russian Provinces. Whether small amplitudes such as the one for West Greenland or the Faroese Shelf have any predictive capacity remains to be seen in the future.

**Figure 20: Number of exploration, discovery and production wells drilled in different Arctic sub-regions over time.**




Note the difference in scales. ?: Drilling with dates unknown. Source: AMAP (2007): *Assessment 2007. Oil and Gas Activities in the Arctic – Effects and Potential Effects.* P. 2_17, Figure 2.15.

### 5.3.4 Gross Domestic Product (GDP)

*Definition*

GDP, measured by the official National Account Systems of practically every country in the world, is one of the, if not the most frequently used indicator of general economic activity. GDP is most frequently defined as the sum of all marketed goods and services produced in a given area and time span. We will use real GDP, i.e. GDP corrected by the inflation rate, to exclude changes in the overall price level.

*Assessment*

GDP is often, and rightfully, criticized when it is used as a measure of welfare, as it does not include any goods and services that are not traded on (official) markets, including grey and black markets, but also unaccounted environmental impacts or changes in cultural norms. Also the valuation of produced goods and services at market prices is subject to criticism, e.g. when it comes to the evaluation of educational services or culture. It is, therefore, important to interpret GDP not as a measure of comprehensive welfare or well-being, but merely of market activities. Any assessment beyond a relatively narrow assessment of economic activity should take into account other indicators, for example those described under the economic or social dimension of this indicator set.

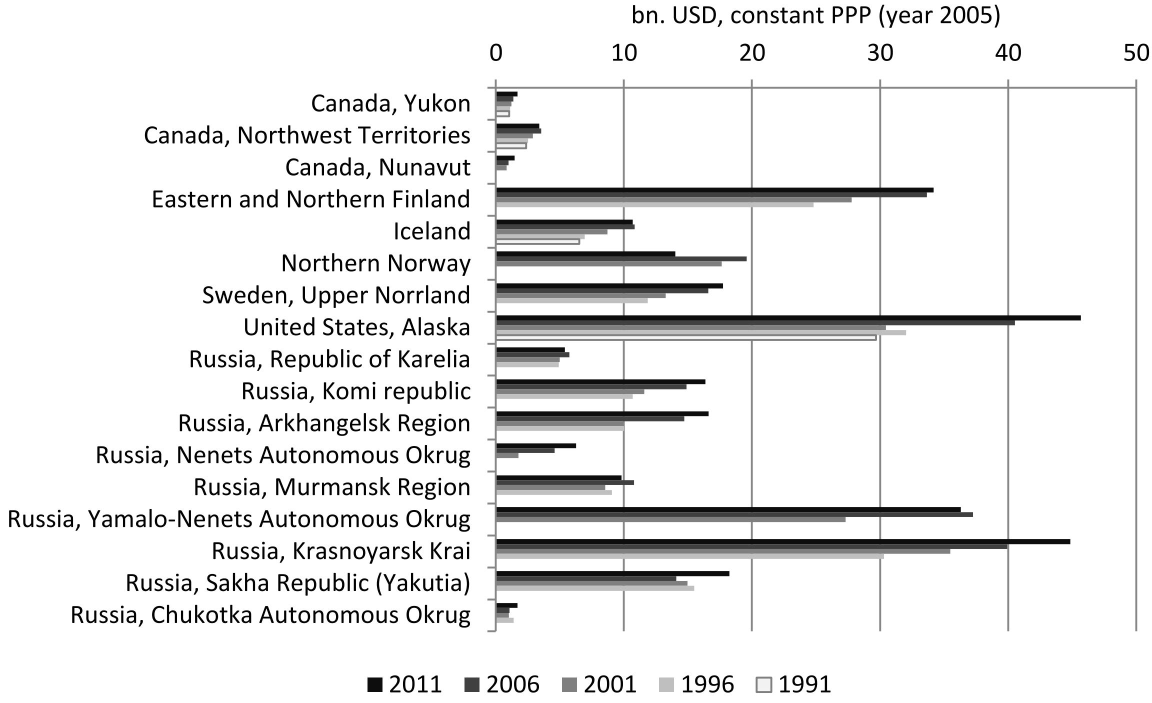
It is also important to note that GDP per se, although being an important input for economic forecasting exercises, is only a descriptive indicator without any predictive capacity per se. Nevertheless, as preliminary data on GDP is available practically immediately after the end of the period of observation, GDP is one of the timeliest available economic indicators. Data quality as well as inter-temporal and inter-country comparability is good. Data is available from the official statistical offices and a number of institutions provide cross-country compilations, such as the OECD. Data is often available for sub-national levels, even though data access is more difficult in that case, which is important for our analyses, where whole countries usually spread across both Arctic and non-Arctic areas.

Part of the appeal of GDP as an economic indicator is the high correlation with a number of other indicators, both economic and beyond. Notable examples are the connection to public and private investment, also in infrastructure, the unemployment rate, price changes, natural resource exploitation, but also environmental stress and pollution.

*Description*

Figure 21 shows GDP in the Arctic on a sub-national aggregation level, following the OECD’s “large regions” classification (except for Iceland, where data is only available on the National level). GDP is inflation corrected and also expressed in Purchasing Power Parities (PPP), in order to correct for differences in purchasing power between regions. Data on Greenland is unfortunately not available from the OECD. Immediately visible are the different sizes of the regional economies, as well as their economic development since the beginning or middle of the 1990s. Almost all regions have been continuously growing in GDP between 1991 or 1996 and 2011. Some notable exceptions are the Sakha Republic in Eastern Russia, where the economy has recently been growing again after years of shrinking, and Northern Norway, where the economy has been shrinking between 2006 and 2011 (in Purchasing Power Parities), as opposed to a growing economy in previous years.

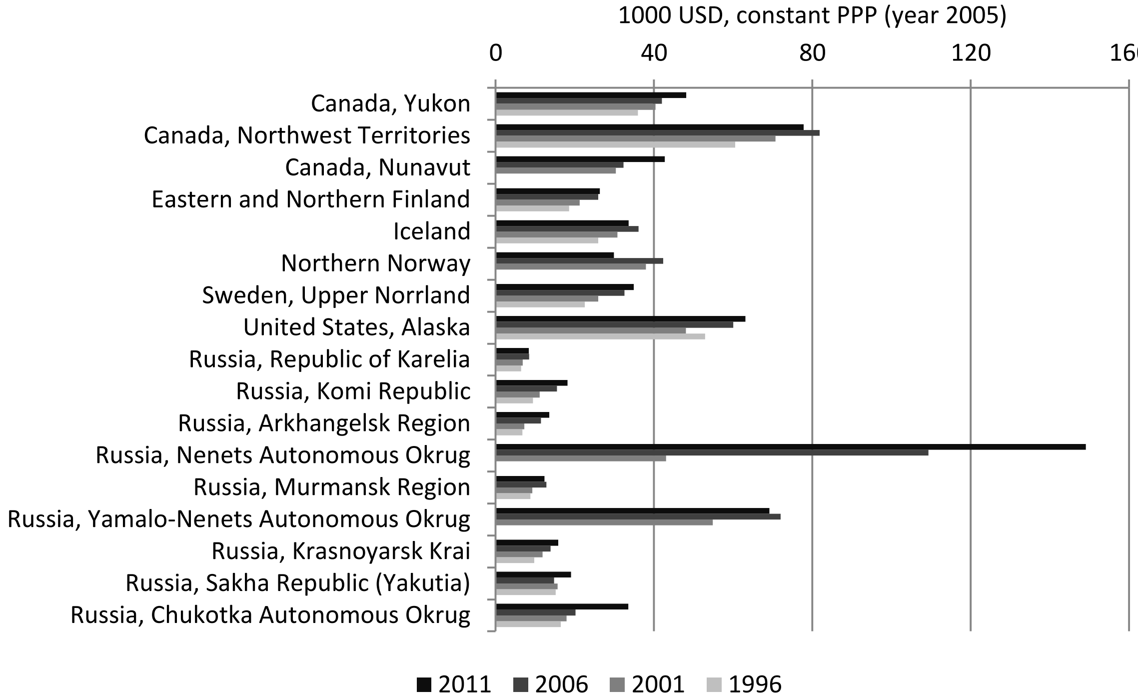
**Figure 21: Regional GDP.**




PPP: Purchasing Power Parities. Source: OECD 2014. http://stats.oecd.org/Index.aspx# (downloaded 15 November 2014).

Even though differences in absolute GDP are informative regarding the absolute size of a local or regional economy, which is important e.g. to assess its role in regional and international trade or the significance of a region relative to larger entities, they do not necessarily inform about the wealth or material welfare of its inhabitants, as the regions do not only differ in GDP, but also in size and population. For this reason, we present information on per-capita GDP is Figure 22. Some of the cross-regional differences from the information in total GDP prevail. As an example, most Russian regions are not only smaller than European or US regions overall, but also per capita. Nevertheless, some important differences emerge, too. It becomes clear that Canadian regions may be small in overall size, but relative to the small population per-capita GDP is large. But also some Russian regions have just recently become comparable to Arctic regions in the highly-developed countries of Arctic Europe or North America. The resource-rich regions of Nenets or Yamalo-Nenets, for example, have just recently experienced rapid growth in per-capita GDP, that put them on par with regions as rich as Alaska or Yukon.

**Figure 22: Regional GDP per capita.**




PPP: Purchasing Power Parities. Source: OECD 2014. http://stats.oecd.org/Index.aspx# (downloaded 15 November 2014).

### 5.3.5 Ports

*Definition and Assessment*

Virtually all activity in the Arctic Ocean relies on onshore infrastructure as a basis for operation. In most cases, this infrastructure will include harbors or airfields, often in combination. The transportation of natural resources and their products out of Arctic regions as well as the delivery of goods into the Arctic will mainly be done by merchant vessels. Offshore resource exploitation depends on ports for supply. The exchange of workers and travel of engineers and business men and women will be organized by air craft. Icebreakers, supply vessels, anchor handlers as well as rescue and salvage vessels need a base for operation. For medical transport, the use of air plane and airfields is a must. For these reasons the number of ports with airfield operational and accessible year around is a good indicator for development of arctic regions. We demand a port that can hold a ship of size 180m x 28m x 8m, i.e. the maximum draught should be 8m, and 250m of wharfage should be supplied.

Given the importance of ports for overall infrastructure development, e.g. because of lacking accessibility from land, the number of ports is a valid indicator for infrastructure development and regional prosperity. On the other hand, ports also increase the risk of pollution and to habitat.

*Data sources and Description*

Up until now, the number and size of ports with berthing and cargo handling facilities for larger ships is restricted to a limited number of spots along the Northern Sea Route and certain bays in the Canadian archipelo, where either exploitation of natural resources (mainly hydrocarbons and ores) takes place, as well as to areas with a special strategic relevance or military operations. As especially latter ones have lost their importance after the breakdown of the Soviet Union, it can be expected that an increase of the number of ports or an enhancement of their technical structure will be related to an increase of industrial or economic activities in that region. On the Northern Sea Route many places are restricted in their capacity of berthing larger ships due to natural conditions (e.g. low water depth, ice barriers). Nevertheless, a lot of ports with a significant structure fulfilling the criteria mentioned in the first paragraph exists already now (see Table 2 for information on the Northern Sea Route).

**Table 2: Selected ports along the Northern Sear Route.**

| Port on NSR | Max Draught | Length of Wharfage |
|---|---|---|
| Murmansk | Deep | 10km |
| Kandalaksha | 9.8m | 600m |
| Vitino | 11.1m | 512m |
| Onega | 13.6m | 900m |
| Arkhangelsk | 9.2m | 15km |
| Mezen | 4.5m / 3.9m | flexible (floating cranes) |
| Naryan-Mar | 4.9m | 400m |
| Varandey | 14m | 200m + Sea Offloading Terminal |
| Amderma | 2m | 500m |
| Sabetta | 12m | 975m |
| Dikson | 15m | ? (8 Mooring Berths) |
| Dudinka | 11.8m | 1.7km |
| Igarka | 8m | 400m |
| Khatanga | 4.6m | 350m |
| Tiksi | 5.6m | 1.5km |
| Pevek | 13m | 500m |
| Provideniya | 10m | 500m |

Source: Northern Sea Route Information Office.

### 5.3.6 Helicopter concentration

The key goal of Escape, Evacuation and Rescue (EER) is that no personnel is harmed during the event of an emerging hazard scenario that requires an emergency escape, evacuation and rescue response in any environmental condition. Evacuation options involving helicopters are generally the preferred method and fulfil a primary role in most evacuation plans.

The particular strengths of helicopters are speed and manoeuvrability, i.e. helicopters can reach very remote areas onshore and offshore within minutes to evacuate and rescue small groups and/or to fight fires. Helicopter operations are usually referred to as "Long Line" and "Short Haul". They are in use throughout the world and in particular along coast lines and mountains.

Any evaluation of helicopter options must include an assessment of:

- The defined evacuation plan i.e. distance of helicopter base to incident on shore, ships or other installations, loads, etc.
- Availability of helicopters and crew (i.e. day or night).
- Typical and current whether condition.
- Possible problems in the access and loading process.

The presence of sea ice around an offshore structure or ship has little impact on the performance of the helicopter. But operations are restricted by adverse weather conditions such as strong winds, low air temperatures or atmospheric icing. The wind speed limit for a helicopter to operate on a helicopter deck is about 55 to 60 knots, but normal flying operations may be performed at wind speeds with gusts up to 60 knots. The main issue though is visibility. Normal operations require a minimum cloud base of 200 to 300m and a horizontal visibility of 900m. Also, the hazardous situation on board can prevent the helicopter to safely access the platform. Examples are major on board fires or gas plumes around the facilities.

Noteworthy, the Arctic wind-chill factor near a hovering helicopter can freeze exposed flesh in a matter of seconds. Thus, protective measures must be considered.

Typical ranges of helicopters, e.g. Eurocopter EC225 Super Puma, as used by Norway and Iceland SAR, may go up to 400 Nm – carrying only 3 passengers – including additional tanks. Depending on number of passengers and additional load the range can shrink significantly, i.e. 150 Nm – carrying 25 passengers – without any additional tanks.

Due to these restrictions of helicopter operations, they have to become part of a comprehensive system for EER, including other infrastructure components as well. Typical “Air-Land-Sea” EER systems include helicopters, fixed-wing planes, vessels, heliports, airports and very importantly hospitals at the end of the rescue chain.

The overall infrastructure for any national EER systems is usually provided and operated by multiple organisations, e.g. Navy, Coast Guard, Military, Red Cross, etc. with their individual infrastructure of helicopters, planes, vessels, etc. All incoming emergency requests are received and coordinated by a central “Control Centre”, e.g. the Joint Rescue Coordination Centre in Canada, which are often non-profitable organization. This makes it, however, difficult to assess the overall number of available helicopters per country. To give a rough presentation of the dimensions, we present information for Canada, where 18 helicopters are available for primary SAR and another 33 for secondary SAR for the whole of Canada (2012 data, Spears 2012). At the same time, the outer edge of Canadian internal waters spans almost 5000 km north of the Arctic Circle, meaning a theoretic 100 km per SAR helicopter, a comfortingly small number on first sight. This disregards, however, that the large majority of helicopters are stationed south of the Arctic Circle, and that the coast line of the Canadian Archipelago stretches far inwards of the Canadian internal waters. This illustration shows again the importance of regionally disaggregated data also for this indicator.

Hence the amount of helicopters along a coast line gives a good indication for the SAR operations assuming that related SAR infrastructure is fully developed in line with amount of helicopters.

### 5.3.7 Weather forecasting precision

*Definition*

Managing weather related risk in the Arctic in day-to-day operations depends on forecasting capability. While good weather forecasts are a crucial necessity for many human activities in the Arctic Ocean, they are pivotal for responding to unexpected emergencies, such as oil spills or search-and-rescue operations. We therefore include weather forecasting precision as an indicator of response capabilities in our indicator set. The quality of forecasts has increased with time, but still the weather forecasting capability is lower in the Arctic than at lower latitudes due to gaps in the observing system etc.

We define weather forecasting precision as the deviation of forecasted pressure vs. observed pressure at the observing station Bjørnøya (Bear Island, position 74.5°N, 19.0°E). We use the root mean square value of the deviation of ECMWF[10] forecasts (18-42 hrs range) from observations, averaged over one year. The suggested indicator is well defined and easily computed.

*Assessment*

The indicator is a valid measure of forecasting capabilities. The main goal of the parameter is to have a view of our short-range weather forecasting capabilities in support of operations in the Arctic. This capability could change in the future, hopefully improve, if more observations become available in the Arctic, if our modelling capability of processes in the Arctic improve etc. There is some "natural variability" in the predictability of Arctic weather on top of that, but averaging over a year will reduce that, and indeed monitoring the trend over a longer time period will give us a view how the capabilities evolve.

Ideally, a measure should cover a larger part of the Arctic with more observing stations (which are scarce in the Arctic) and more than one parameter, but that would increase the complexity involved, and make it more difficult to establish a parameter which is defined in a consistent way over time, making it suitable for following forecasting capabilities over time. Sea level pressure is a good indicator for assessing overall forecast capabilities because it is not influenced by local topography and surface characteristics. The European Centre for Medium-Range Weather Forecasts (ECMWF) has a leading model for global forecasts, and is used as boundary data for many regional and local models. The location is chosen for being a relatively remote, isolated location in the Arctic, but still with availability of measurements. The location is believed to have properties representative of high-latitude ocean areas, where there could be increased activities and operations in the future.

The indicator is well defined and transparently computed. It is easily and affordably accessible, since observations from the station are freely available and ECMWF forecast data is available to all European national meteorological services. Thus, computing the indicator is a matter of simple computations on already existing datasets.

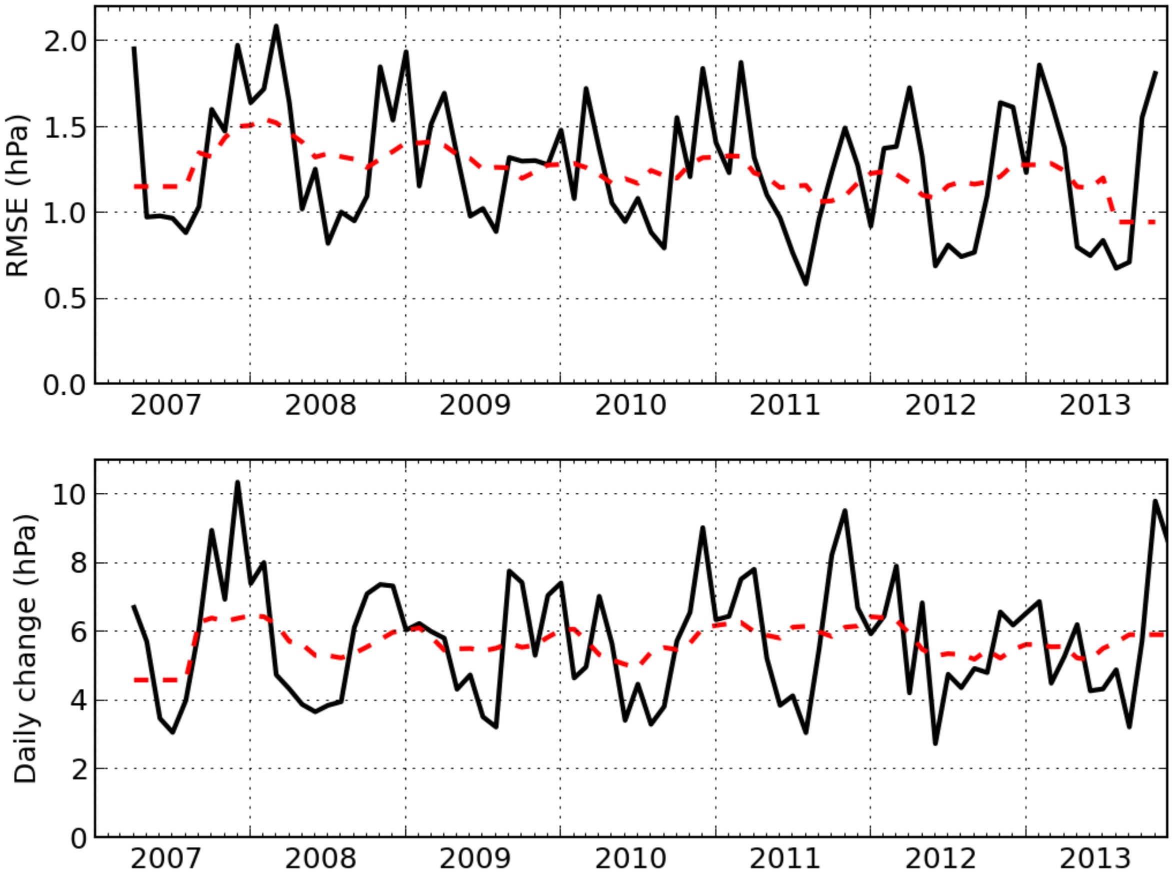
The data is measured repeatedly, allowing for the construction of a meaningful time series. Both data sources are available for a long time in the past and are expected to be available long into the future.

*Description*

Observations are available from the Norwegian Meteorological Institute (http://met.no/) and forecasts available for member state national meteorological services from European Centre for Medium-Range Weather Forecasts (http://www.ecmwf.int/). Figure 23 shows the weather forecasting precision for Bjørnøya for the years 2007 to 2013. Forecasting precision is measured as RMSE, i.e. the smaller the better. Comparing the upper panel, showing model-based forecasts, and the lower panel, showing a trivial day-ahead forecast, both the superior forecasting quality of the weather models as well as the improving trend over time of model-based forecasts are visible.

[10] European Centre for Medium-Range Weather Forecasts.

**Figure 23: Weather forecasting precision based on modelling and day-ahead forecasts**




Upper panel: Time series of monthly root mean square errors (RMSE) in pressure (hPa) for forecasts in the range from 18 to 42 hours for the ECMWF global model.

Lower panel: For reference a corresponding time series of mean absolute day-to-day observed pressure differences in hPa. This is the error one would get if one made a forecast saying that the state one day ahead is identical to the present state (persistence).

Both figures show monthly average data (black curve) as well as time smoothed data (red dashed curve, ±5 months smoothing period).

## 5.4 Freezing Degree Days

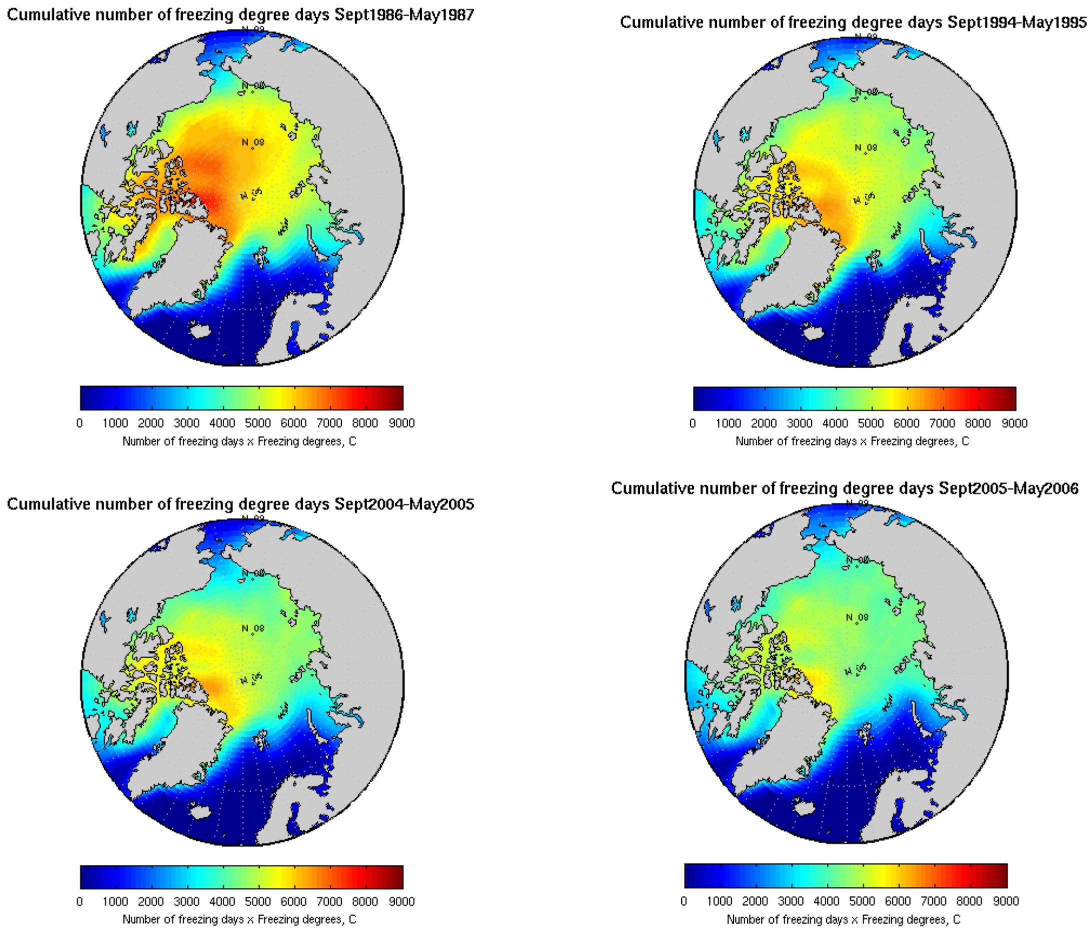
*Definition*

Freezing Degrees Days FDD are based on air temperatures measured and/or estimated at 2m altitude above sea level (and sea-ice). FDD are calculated from in situ air temperatures over the entire Arctic Ocean by summing up the number of degrees below sea water freezing point (-1.7°C) over a daily period and during an entire freezing season extending from Fall to Spring the following year, each year. The in situ air temperatures used for this FDD calculation are provided by the ERA-interim data reanalysis from 1980 until 2014. ERA-interim is a newly generated reanalysis database produced by the European Center for Medium-Range Weather Forecast (ECMWF). ERA-interim air temperatures resolution is 6 hours in time and 0.75° latitude in space. ERA-interim air temperatures were averaged over one day period and FDD are calculated each year from 1980 until 2014 over the entire Arctic. On Figure 24 below, FDD appear as a function of the area expressed in million km$^2$. FDD can be integrated over a certain area to produce a winter index. FDD can also be converted in meters of sea-ice (Figure 25) in order to calculate the volume of sea-ice produced each year by the atmospheric cooling over the entire Arctic Ocean by multiplying sea-ice thickness and sea-ice extent (Figure 26).

*Assessment*

The FDD indicator is relevant for estimating sea-ice conditions and in particular sea-ice volume (or mass) formed each year over the entire Arctic Ocean due to cooling from the atmosphere. The quality of the data is entirely depending on the quality of air temperatures measurements (or estimations). The absolute accuracy of air temperatures estimated from the ERA-interim data reanalysis is estimated to be of the order of half a degree Celsius. It is easy and affordable to calculate the indicator based on air temperatures measurements that are done anyway. The ERA-interim data are well accessible. The data are obtained routinely and it is quite easy to construct time series.

**Figure 24: Freezing Degree Days in spatial resolution**

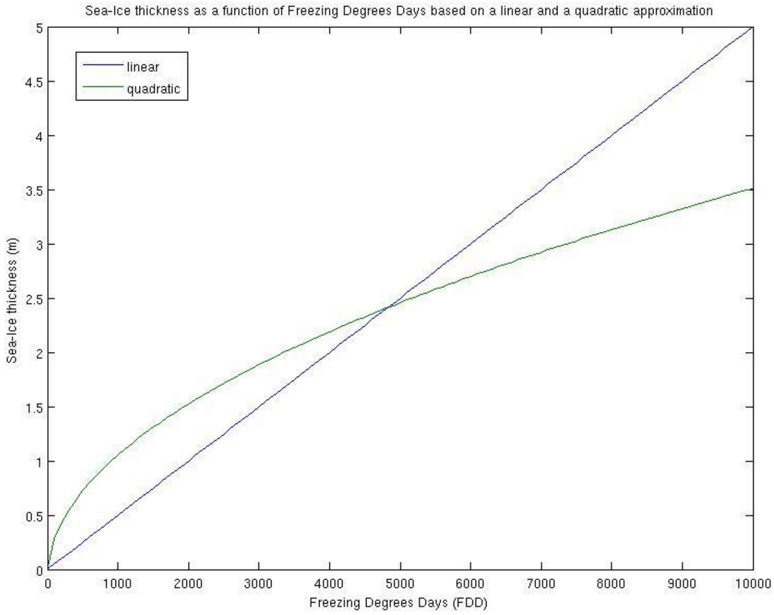



Freezing Degrees Days (0 in blue to 9000 in red) obtained during freezing seasons (September to May) during 4 different periods starting in 1986 and ending in 2006. The red color (intense cold) is decreasing over the 20 year period and characterizes the warming of the Arctic Ocean. Freezing Threshold is -1.7°C.

*Description.*

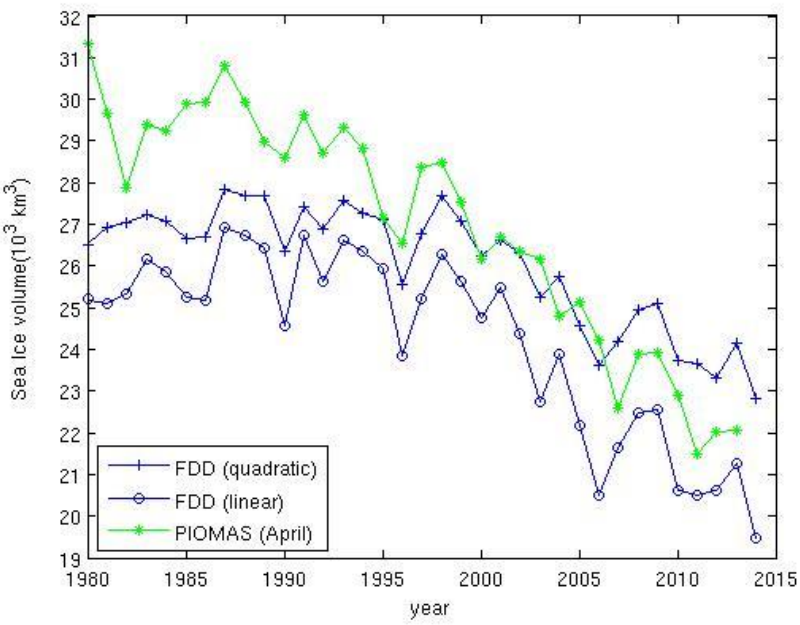
Figure 24 shows the distribution of Freezing Degree Days in the Arctic over time, showing a marked warming of the Arctic Ocean between the 1986 and 2006. This decrease in FDD goes in line with a reduction in Sea Ice thickness (Figure 25) as well as Sea Ice volume (Figure 26). Both links are non-linear. Implications of the reduction in Sea Ice for other dimensions of sustainable development, including not only environmental, but also social and economic implications, are evident, but not always rigorously researched.

**Figure 25: Freezing Degree Days and Sea Ice thickness**




FDD can be converted in sea-ice growth rate by using a linear or a quadratic thermodynamic function depending on sea-ice thickness. The linear function is more appropriate for thin ice and the quadratic function is more adapted to thick ice.

**Figure 26: Freezing Degree Days and Sea Ice volume**




PIOMAS: Pan-Arctic Ice Ocean Modeling and Assimilation System.

# 6 A general caveat – uncertainties in the description of sustainable development

Apart from complex dynamics including nonlinearities, uncertainty is a major challenge for indicator systems. Given the vast changes the Arctic Ocean (as well as the oil and gas industry in general) is facing, it is impossible to cover changes in sustainable development in a comprehensive way. Uncertainty comes in various forms. To begin with, we simply do not know about all indications of changes in sustainable development, no matter how important some of them might be. In some cases, we might miss a whole dimension of sustainable development or its indication. In other cases, we might know about some cause-and-effect chains that affect sustainable development in the Arctic Ocean, but we may not know how, or in which direction, sustainable development is affected. In these cases, we do capture the relevant dimension of sustainable development, but we may fail in correctly interpreting changes in the indicators. These various types of uncertainty will affect the explanatory power of any indicator system. Furthermore, unexpected exogenous events, such as natural disasters, world market movements, or global economic crises will, although influencing sustainable development, impede the ability of the indicator set to reflect the success or failure of policy measures. For that reason, indicators will usually be merely descriptive of potential outcomes of decisions, without necessarily implying an underlying causality. Assessing causality between changes in different indicators requires the use of additional explanatory tools like models. In spite of this, the choice of a relevant set of indicators should still be driven by an underlying understanding of dimensions that would potentially affect the direction of sustainable development.

# 7 Conclusions for decision making

This report is an attempt to provide advice for selecting a relevant set of indicators of sustainable development in the Arctic, with a special focus on sustainable offshore energy production in the Arctic. It is one of a series of reports resulting from the ACCESS EU FP7 project. One existing report focuses on the fisheries and aquaculture industry (Crépin et al. 2014) and others are planned with a focus on marine transportation as well as governance. The indicator set is meant to be used for monitoring purposes by a diverse audience in a diverse number of settings. A proper set of indicators has the potential of being a powerful monitoring device that conveys useful diagnosis of the system based on relatively limited available information. Sets of indicators have shown to be efficient inputs in a number of different control systems. The holistic approach, the heterogeneous multitude of potential use cases, together with the uncertainty of the systems necessarily means that the indicator system will usually be a second-best option for specific problems and target functions, but we hope that it provides a meaningful summary of the broad picture. A summary of this indicator system is given by Table 1 (page 13).

Any decision maker will necessarily have to find their own appropriate weighting system between the different dimensions, policy categories, and target areas. The indicator system presented here is also supposed to give impulses on what potential unintended consequences decisions might have that could be taken into account. In the prototypical case of a new production site in a sensitive area, we encourage the reader to take social issues next to the prevalent economic and environmental arguments into account – and a broad understanding of each of the three dimensions. In order to make consequences quantifiable and countable, we encourage the use of the indicators suggested here, or in any other existing indicator system.

Nevertheless, there are substantial limitations associated with both the identification and the measurement of useful indicators and sets of indicators. Some of these limitations appear obvious in the descriptions parts of each indicator. For example the amount of data available is often limited and there are usually only few and limited time series for some of these indicators. In addition, the necessary information has generally not been collected in the same way in the different Arctic countries or is not collected at regional level making data for Alaska or Russia for example quite irrelevant as most of the data applies to regions in these countries that are outside of the Arctic. Efforts towards more homogeneous, disaggregate and in-depth data collection, but also easier accessibility, would improve the situation in that regard. In some cases, such as water or air pollution, meaningful data could be collected with only limited effort.

Even if data is limited, there is a plethora of possible indicators of dimensions of sustainable development and monitoring all of them is costly and not very informative, as one cannot see the forest for all the trees. Ideally, one would like to have a very limited set of so called headline indicators that would really be able to represent the main trends for the whole system. Some of the indicators suggested in this report have the potential to serve as such headline indicators. For example, regional GDP as well as energy production are good candidates as they correlate with infrastructure development, risk for the environment, and labor market improvements. Unemployment rate is another candidate to monitor the social dimension of sustainable development as it is often correlated to several of the other social indicators presented here. Nevertheless, no single indicator will ever be sufficient to cover the whole spectrum of all dimensions and sub-dimensions of sustainable development.

Some dimensions are particularly challenging to represent with a small set of indicators. In particular the state of the marine ecosystem that is the base for the whole seafood industry is difficult to summarize into a handful of time series given the current knowledge about the system. The interactions between species, their habitat, the geophysical environment and the economic activities taking place in the seascape (and beyond, for that matter) form a complex adaptive system. Our lack of data and monitoring information about the Arctic implies that we probably only have information about the variables that have been changing relatively quickly with observable impacts. However, coming changes may be triggered by accumulating stocks that are unnoticed at the moment but can cause substantial system transformation when released, so called regime shifts (Crépin et al, 2012 and Regime Shifts Database: www.regimeshifts.org ).

The indicator system proposed cannot be used solely to guide policy either. While an indicator system may help identify unsustainable trajectories, it is unlikely that the best response to change this trajectory can be identified by just looking at the indicators. More information is necessary and available about how different variables impact and feedback on each other. The interactions between different variables in a complex adaptive system are by definition complex and can take unexpected routes before some “final” equilibrium impact occurs. For example, the current climate change debate and derived policy changes will have direct impact on energy markets.

Hence this indicator system must be complemented with other management tools. Examples are marine spatial planning tools (developed under ACCESS D5.82, forthcoming) or integrated modeling frameworks of the social ecological interactions (developed under ACCESS D 5.71, forthcoming). These tools produced within the ACCESS project should be used to assess and identify variables in the system that are of particular relevance for the Arctic system’s evolution toward sustainable development. Such information would help further refine the set of indicators proposed here and also help identify additional headline indicators, i.e. the key variables in the Arctic social-ecological system related to energy production. Such set of indicators would provide a system for early warnings to help identify unsustainable trajectories early on so that a proper set of policy tools can be put in place. If these tools are complemented with proper models of interactions between the most important variables or indicators it would also be possible to simulate different policy responses and compare them to each other with regard to how they perform in the different dimensions of sustainability.

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