BELLONA

Environmental considerations in the Arctic: Sustainable resource exploitation

The Bellona Foundation is an international environmental NGO based in Norway. Founded in 1986 as a direct action protest group, Bellona has become a recognized technology solution-oriented organization with offices in Oslo, Brussels, Kiev, St. Petersburg and Murmansk. Altogether, some 60 engineers, ecologists, nuclear physicists, economists, lawyers, political scientists and journalists work at Bellona.

The authors would like to gratefully acknowledge their colleagues and partners for guidance and advice, and in particular Marika Andersen and Lene Elizabeth Hodge for proofreading.

Layout and graphic design: Bellona
Photo frontpage: Thinkstock

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Preface

The idea of writing this report started several years ago. Bellona, as a Norwegian environmental organization, has for long time been engaged and worried about the development in the Arctic. The fact that the alarming changes in the Arctic climate opens up new opportunities for industrial activities gives us an obligation to speak up for the Arctic nature. The reason why Bellona has written this report is also our recognition that there are people living and working in the Arctic and there will be human activity in the foreseeable future. But we cannot take for granted that the environment is protected in a proper way without a key focus on the point of sustainable management. The world is full of examples of destruction of nature caused by "business opportunities".

Our job is to convert the rising awareness of the treats against the Arctic to real world change in human behavior. We need to see changes in the Arctic nations' management and behavior to perform a smarter policy, more binding cooperation and better balance between facilitating for industry and the protection needed to preserve the physical and biological functions of the Arctic.

The authors of this report have dealt with big challenges. The lack of readily available knowledge, speed of changes and humanity's growing needs for goods and transport routes makes it hard to identify realistic solutions for a future development in the Arctic in harmony with the environment. The authors of this report has managed to give substance to Bellona's vision for a more sustainable development in the Arctic. By finding solutions and pointing out the dangers and weaknesses of current operations in the Arctic they bring us one step closer to realization of our vision."

In addition to the authors, I want to give a special thanks to Heidi Johansen which played an invaluable role in defining the scope of this report. Also the Norwegian Foreign Ministry deserves huge thanks for their support. Without their economic contribution this report would not become a reality.

The Arctic is a wonderful place - most people who have been there agree on this. It also plays vital role in the global meteorological and oceanographic system. It's the northern hemispheres rain forest. This report is intended to act as a tool for people engaged in Arctic issues.

I hope this report can inspire the reader, whether you are a politician, a business person, a scientist, an environmentalist or just love the Arctic!

Sigurd Enge
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Conclusions and Key Findings

The conclusions and key findings from this report summarize what measure needed for national authorities, the industry and science for the following headings:

- Renewable energy production in Norwegian Arctic
- Renewable energy sources in Murmansk region
- Arctic Mining
- Integrated Multi-Trophic Aquaculture

Renewable Energy Production in the Norwegian Arctic

This report has shown that Arctic renewables are attractive resources, with abundant theoretical potential. Northern Norway's energy production is already founded on renewables. The region currently boosts an aggregated power surplus of around 5TWh per year. This brings substantial opportunities for green growth. Grid enhancement and suitable industrial growth are prerequisites for further renewable power development. Settlements on the Norwegian Arctic islands are currently supplied by diesel aggregates or coal power production. Here, the scope for energy conversion and broader electrification is significant. Particularly, Bellona argues that international expectations have been established for a green, resource-friendly Spitzbergen.

Based on our findings in this report, Bellona present the following recommendations to Norwegian authorities – to promote a clean, renewable and innovative Norwegian Arctic region.

Northern Norway:

- Norwegian authorities must prioritize extended and enhanced grid capacity in the Northern part of Norway. This is a prerequisite for new renewables, new economic activity, and suitable power export. In addition to Statnett's ongoing grid upgrades, additional grid planning across the Scandinavian North, such as the Arctic Circle Grid Initiative, should be taken into account.

- The 5 TWh annual power surplus in Northern Norway brings opportunities for green growth. It can become the engine for new, long-term economic activities, powered by local resources and engaging local communities:

    - Arctic datacenters can become a green growth joker. This requires sufficient fiber infrastructure in the region and incentives to attract international customers.

    - Hydrogen production based on Finnmark's stranded wind power can provide new economic activity and jobs. This requires further project development, and is subject to a national framework for hydrogen.

    - Eco-tourism is a local sector with unrealized potential, alone or as add-on to established concepts.

    - Innovation in electrified transportation brings new opportunities that require further elaboration.

Norwegian Arctic islands:

- Norwegian authorities should investigate concepts for remote off-grid renewable energy solutions (potentially hybrid-solutions) for Jan Mayen, Bjørnøya and Hopen.

- Spitzbergen should be acknowledged as an ideal location to pilot and demonstrate new renewable technologies and climate innovations. Spitzbergen and the Longyearbyen settlement have become solemn symbol arenas in Norway's international climate work.

- The potential scenario of a Spitzbergen beyond coal mining activity calls for political attention in Norway. Bellona invites Norwegian authorities to explore the concept of Spitzbergen as an Arctic Renewable Energy Showroom, deploying different technologies for clean electricity production and storage.

- Bellona calls on Norwegian authorities to assess the possibilities for electrification of transport at Spitzbergen and shore-side electricity supply in the port of Longyearbyen.

Renewable Energy Sources in Murmansk Region

After analyzing the potential and the economic aspects of using renewable energy installations in one of the Russian Arctic regions, the Murmansk Region, where nearly the entire territory is located beyond the Polar Circle, we come to the following main conclusions:

- application of renewable energy sources for electricity production and heating purposes can and should play an important role in the sustainable development of the outlying areas of the region, by providing local residents with the necessary heat and electric power supply and thus raising their standard of living.

The Kola Nuclear Power Plant is considered to be one of the main negative factors for renewable energy sources development in the region.

- Development of renewable energy in Murmansk Region is also confined by a lack of experience, poor public information and strong diesel lobby.
- Wider use of renewables in Russia, much depends on state government and regional governments as the measures introduced in Federal law on electric power need detalization from the government by adopting governmental acts.
- Murmansk region has immense resources of renewable energy which could easily cover energy needs for off-grid settlements
- Bringing renewable energy to off-grid rural localities of Murmansk Region will not only help achieve significant savings in fuel and other costs but will also contribute to a healthier environment in these communities, thus greatly improving their standard of living overall.

Renewable energy sources should play an important role in the sustainable exploration of Arctic fragile environment staying cost effective and preserving environment in the best possible condition. This analysis of the Murmansk region energy situation is an example, which could be applied in the other Russian Arctic regions.

Arctic Mining

A rush of new mineral projects in the Arctic can be expected, but only in a long term perspective

Demographic megatrends indicate increased global demands for future minerals that may lead to dramatic expansion of the Arctic mining sector. Mining in the Arctic causes unavoidable damage to affected ecosystems that already struggle to survive extreme environmental conditions and require long recovery periods after population setbacks. Due to long transport distances, limited available infrastructure and harsh environmental conditions, production costs for Arctic mining projects are often significantly higher than for mining operations further south. Reduced economic growth in leading markets for minerals has created a temporary drop in mineral prices that make many potential new Arctic mining projects less attractive. Most experts expect several years may pass before mineral prices catches up with global megatrends. When this happen, the modern world's critical dependency on minerals make it unlikely that anything can stop a rush of new Arctic mining projects.

The negative environmental footprint of mining operations is huge and will only continue to grow unless massive efforts are made towards improving the mining methods

Although improved technology and better production methods have reduced the negative environmental footprint caused by modern mining operation, the mining industry has still a long way ahead before it will be able to apply technology and mining methods that make mineral extraction possible without unacceptable damage to the environment. Irreversible scarring of terrain, damage to biodiversity and ecosystem services, release of toxins and greenhouse gases in addition to the accumulation of mineral waste will only increase as a result of future mining operations due to lower quality ores and increased demand for mineral products. Massive efforts towards research and development of more environmentally efficient mining technology and methods have the potential to compensate and possibly reverse this megatrend. The Nordic countries are in a unique position to spearhead this initiative.

Governmental regulations that require high environmental standards are essential for a mining sector to continue improving its environmental performance

Comparing governmental regulation systems of the countries with an Arctic mining sector make two stand out. Greenland having gained political autonomy as late as 2009 has a limited legislation framework, regulatory experience and resources available for governmental regulatory procedures compared other Arctic nations and still relies heavily on Danish expertise and assistance. In Russia endemic corruption and lack of public transparency and accountability serves as a barrier to successful application of environmental regulations. Experience with Russian mining industry also indicates significantly lower ambitions when it comes to environmental performance compared to the mining industry in other Arctic regions. These facts should to a larger degree be taken into account not only by foreign policy makers dealing with Russia, but also by trading partners who buy Russian minerals.

National mineral policies should be based on a life cycle perspective

Because negative environmental impact from mining operations can't be avoided, and to prevent future scarcity of increasingly rare minerals, national mineral polices should not only aim at improving the environmental efficiency of mining operations, but also increase the efficiency in how minerals are utilized. This includes more resource efficient production and product design, more conscious consummation habits and recycling of urban ore.

Subsea mining needs better government regulation

Future Arctic mining projects include possible subsea mining. Uncontrolled large scale subsea mining has the potential to create devastating damage to marine ecosystems. For this reason, adequate environmental standards on how subsea mining should be performed is of crucial importance, and must be developed and implemented before large scale subsea mining can be allowed.

Important elements in Best Environmental Practice for the Arctic mining industry

Best environmental practice for a mining project depends to a large degree on specific conditions associated with the project. The following recommendations should be considered as best environmental practice for most Arctic mining projects:

- Backfilling in underground mines rather than open pit mining or mountain top removal
- Maintaining a belt of vegetation or other mechanical barrier around the mining site that limits soil erosion and dust formation
- Creating structures that ensures crushing, grinding, separation, storage and hauling takes place indoors or underground as far as possible
- Energy efficient processes and transport solutions that replace fossil energy with renewable energy sources as far as possible
- Restoration of topography and soil cover that support revegetation and return of wildlife
- Environmental management system that includes a detailed and extensive environmental monitoring program that answers all relevant questions regarding the environmental impacts of the mining project and makes this information available to relevant government agencies and the public

Integrated Multi-Trophic Aquaculture

Effects from climate changes which are mainly driven by anthropogenic CO_2 emissions are especially evident in the Arctic, and result in losses of biodiversity and unpredictable changes in availability of important marine food species.

This development emphasizes the need for increased food security based on local, renewable resources and local value creation, whilst simultaneously decoupling of economic growth from CO_2 emissions.

Development of Integrated Multi Trophic Aquaculture (IMTA), an ecosystem approach to aquaculture offers great potential to address these issues adequately and has potentially mitigating effects on climate change through capturing CO_2 into biomass that in turn can replace fossil hydrocarbons.

Even though IMTA will have environmental benefits over conventional monoculture, environmental challenges with development of IMTA will naturally have some similar potential negative effects as with monoculture. It is therefore crucial to build on experience from previous monoculture developments to avoid negative impact and that same mistakes are repeated. We therefore recommend

- Development of a well-defined and knowledge based legal framework
- Focus on preventive health measures (and strictly limited use of chemical agents)
- Increased share of extractive species – as opposed to monoculture of high trophic species
- Promote collaborative opportunities between marine based industries and stakeholders

Climate change affects fisheries and aquaculture somewhat differently. Effects specific for the Arctic, and with the likely most profound effects with relevance for aquaculture practices are

- Increased water temperature (positive: increased growth rates/productivity, extended growing seasons, extended geographic range, reduced winter mortality; negative: less dissolved oxygen, possible increase in toxic algal blooms, increased risk of invasive pathogens)
- Acidification; large anticipated negative effects, especially for molluscs and echinoderms
- Increased precipitation; likely increased fall-out of long-range persistant organic pollutants

Planning of species to be cultured in IMTA systems should be evaluated based on the functions they have in the ecosystem, natural occurrence, husbandry practices and technology is developed and their economic potential.

Suitable areas for IMTA should be evaluated based on ecological parameters (included possible effects from climate changes) and accessible area (not protected areas or in conflict with defined users).

Introduction

The Arctic has throughout history defined the boundary of human activity and understanding and continues to do so today. The British Franklin expedition in 1849, aimed to explore and navigate the Northwest Passage ended in catastrophe. The ships, Erebus and Terror, were crushed by ice and sank. The crew's ultimate destiny was ironically the canned food sealed with lead resulting in deadly heavy metal poisoning and coldness of the Arctic winter. As an example from our own time of the unforgiving harshness of the Arctic, the oil drill barge Kulluk drifted aground north of Alaska in December 2012 after the towing line parted in heavy weather. In 2014, Royal Dutch Shell decided to scrap the whole unit because repair was not deemed feasible. The Arctic environment and harsh climate still gives us challenges larger than what we can handle, even with today's technology and knowhow.

There is a long history of explorers, scientists, hunters and fishermen who have risked their life to expand our knowledge and scope, with limited resources and deficient tools to fulfill the goals of their visions. Today, we need their courage and determination to handle the challenges the Arctic region gives us, for the wildlife, the living environment and the Arctic impact on the global climate.

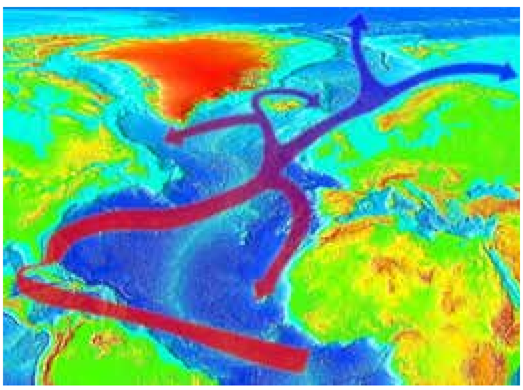
To find the most efficient strategies for the Arctic we need to look at what to do and what not to do in the Arctic. We also need to look at what impact emissions from the rest of the world have to the Arctic region. So to assess the impact of one activity, one needs to include the impact of all other stress factors in the picture.

Bellona's strategy is to always strive for a holistic and technology optimistic approach to environmental challenges. One century ago the Arctic was discovered and mapped. Today it's about to melt and disappear between our hands. Combined with the impact this development in the Arctic have on the global climate, it's a scenario unbearable for our living planet and the human race.

To find sustainable solutions for the Arctic is to work for a better climate globally. We need new technology, new guidelines and better cooperation to cope with these challenges.

What is Arctic?

The geographical definition of the Arctic is all areas north of the Arctic Circle. It's the southernmost latitude with midnight sun in summertime and polar night (sun does not rise above the horizon) in wintertime. The meteorological and oceanographically patterns and heat distribution makes the variation of climate in the Arctic multifaceted. On the west side of Spitsbergen the sea is free of ice all year around, even up to 80 degrees north. In the other end, the southern tip of Greenland, 60 degrees north, same latitude as Oslo, has definitely an Arctic climate with low winter temperatures, sea ice and glaciers. The warm water coming with the Gulf Stream and



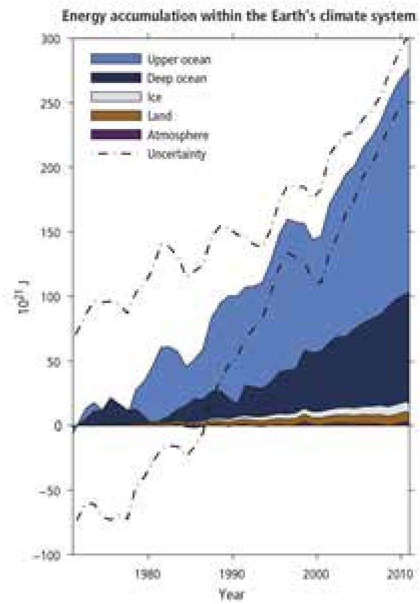
Source: NASA

further the North Atlantic Drift makes the European and the northwestern Russian Arctic warmer and with less sea ice than average at this latitude.

This report's main focus is the European sector of the Arctic, Northern Norway, Northwest Russian Arctic and the islands in north and west, Greenland, Spitsbergen, Jan Mayen and Bear Island. Despite the geographical delimitation, we will explore promising technologies from other parts of the Arctic. Our findings can also be used in other regions of the Arctic.

State of the Arctic

The Arctic is today the main battleground for global climate changes. The ecosystem's in the Arctic consists of species with extreme characteristics. The evolution and the harsh environment have developed animals and other organisms which can resist the coldness, long periods with food shortage, darkness and remoteness. The Arctic ecosystems are also characterized by shorter food chain and fewer numbers of species. This makes the ecosystems vulnerable for human impact. If one single species decreases significantly, there may not be an alternative food source available and a cascading effect up through the food chain will appear.



Source: IPCC Fifth Assessment report (2013)

The main burden human impact has on the Arctic is:

- Decreasing sea ice extent and shrinking glaciers
- Extreme temperature increase in the atmosphere
- Temperature increase in Arctic waters
- Ocean acidification
- Permafrost thawing
- Bioaccumulation of hazardous substances and micro plastics
- Air pollution from black carbon and particular matters

Today we can already see the effects of climate changes in the ecosystems of the Arctic. Fish stocks like mackerel which normally occurs in the North Sea and the Norwegian Sea, can now be caught in Spitsbergen. Only last year (2014) approximately 35 000 walrus suffered from lack of sea ice last summer, stranded on a beach.

35.000 walrus stranded on a beach. Photo World Wildlife Fund

The largest island in the world, Greenland, is approximately 80 % covered by ice. The climate changes observed in Greenland recent years is affecting meteorological patterns and the ocean currents in the northeast Atlantic. The increasing amount of melting (fresh) water, which is lighter than the surrounding, saline sea waters, changes the sea level and salinity witch can disturb the ocean circulation and thus the regional climate.

It is *very likely* that the Arctic sea ice cover will continue to shrink and thin and that Northern Hemisphere spring snow cover will decrease during the 21st century as global mean surface temperature rises. Global glacier volume will further decrease. {12.4, 13.4}

Source: IPCC, AR5

Why this report

Today's knowledge about the role of Arctic for the climate changes increases rapidly. Our knowledge of the impact of human activity is also growing. At the same time the melting and retreat of the ice from sea and land makes new areas available for industrial activities.

The speed of changes and unpredictability makes it hard to understand what reality we will face 10-15 years into the future. Where are tomorrow's vulnerable spots for the ecosystem? How seriously will the combination of climate changes, pollution, stress and human activity affect the ecosystems ability to adapt to future changes? This unpredictability makes it crucial to take the necessary precautionary steps to avoid damage caused by inadequate understanding.

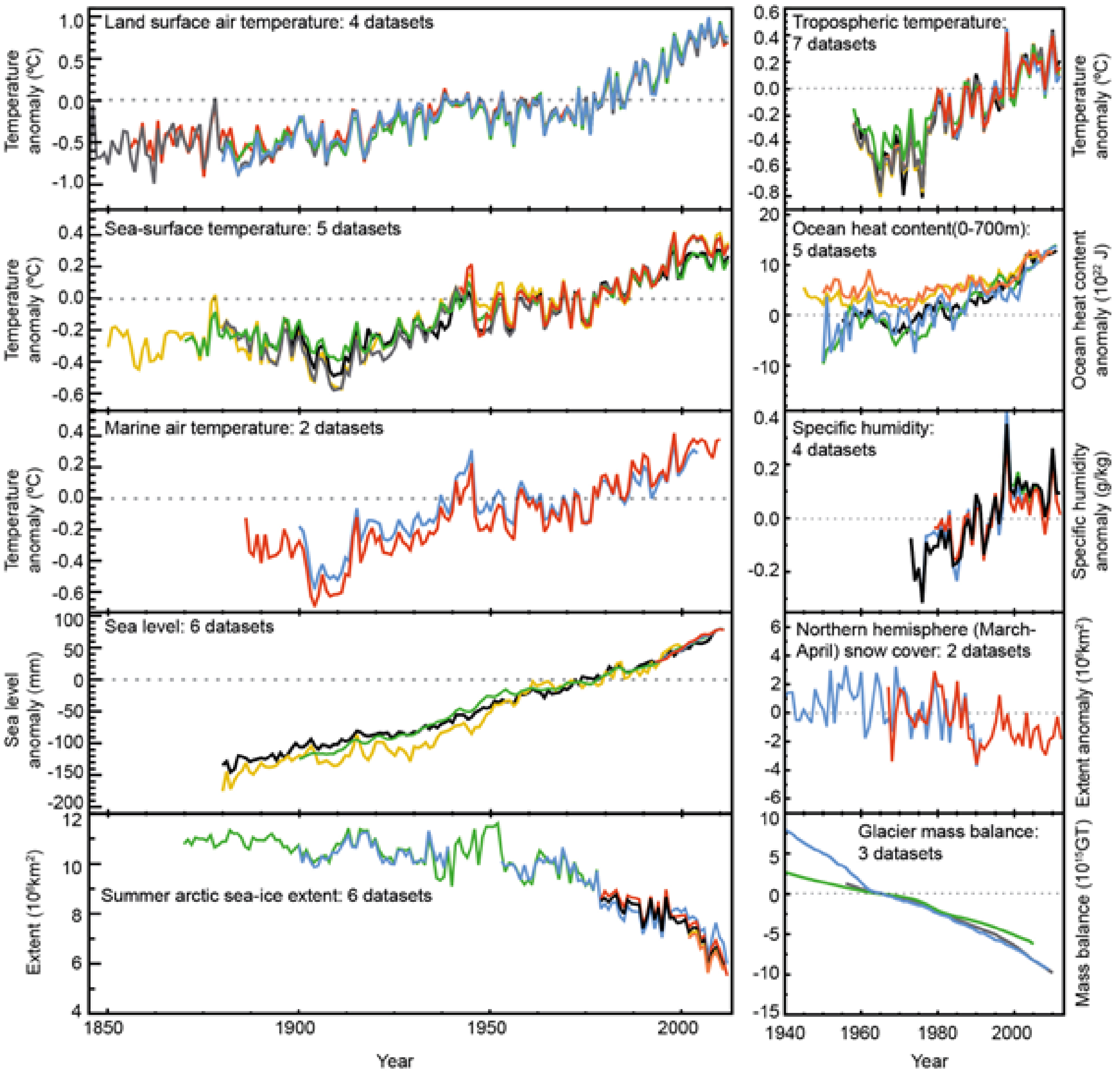
The current situation and speed of changes in the Arctic regions is alarming. It's about the climate change, the distribution of transboundary pollutants and human activity inside and outside the Arctic. There are many answers to why these changes appear. The dynamics of wind and sea current makes the region into a slop sink of human traces. A growing focus into the opportunities that the decreasing sea ice and glaciers gives makes it even more important to search for sustainable solutions. We simply need to focus more on how to reduce the human footprint that burden the Arctic. In a world of growing population, demand for more natural resources, food and transportation, the critical factor of success is to develop sustainable solutions for industry and other activity that affect the Arctic region in a negative sense.

Generally speaking, human activity in the Arctic has a bigger footprint than similar activities on lower latitudes. Our conclusions are that we need a better understanding of how different industries can perform more efficient, how governance can support and monitor the industry and finally find the knowledge gaps that can help us design solutions for tomorrow's industrial activities in the Arctic.

The goal of this report

This report's main focus is areas with "Arctic conditions" and the roughness and vulnerability which are a common characteristic in Arctic regions. The growing commercial focus on Arctic resources follows the speed of changes in climate, available technology and need for new resources.
Our motivation to focus on sustainable business methods and solutions in the Arctic is based on our perception that there will be human activity and impact in the Arctic region in the years to come. We are focusing on three different industries that are highly likely to increase; aquaculture, mining and sustainable energy production. These industries are very different, but some of the conditions and challenges are in common. The harsh environment, remoteness, vulnerable ecosystems and unpredictable future development of climate is a challenge for any industrial activity in the Arctic.

Mining activities that impact the Arctic soil will make sores for longer time and can affect e.g. sea mammals that already have increased levels of heavy metals and persistent organic pollutants. Combustion based energy production makes emissions of BC (Black Carbon) and other particles will end up on the ice and snow and accelerate the melting. Arctic aquaculture represents potentially a threat to the vulnerable Arctic marine ecosystems.



Multiple independent indicators of a changing global climate. Each line represents an independently derived estimate of change in the climate element. In each panel all data sets have been normalized to a common period of record. IPCC AR5 (2013)

At the same time this situation provides a lot of opportunities. Aquaculture as a renewable resource and the special conditions for species in Arctic waters, has a potential for high intensity production. The seasonal midnight sun gives not only salmon and fish good condition, but enables growing of seaweed and mussels with high potential of successful production. Extraction of minerals is predicted to expand caused by easier access to new mineral deposits in the European Arctic. Minerals is a crucial component in our industrialized modern world and an important building block in creating tomorrows sustainable solar panels, wind mills, etc. We also know that tomorrows Arctic will produce and consume more energy. All kinds of energy production have an impact. Solar panels are more efficient in cold climate. Solar panels in combination with batteries are replacing diesel generators with economically competitive results. What kind of energy production is suitable for the Arctic?

The Arctic seasons differ greatly. The summer season with solar radiation available 24 hours a day and relatively stable weather conditions and the winter with low temperature, darkness, wind and snow. Each chapter of this report tries to find answer to both the common challenges and specific problems and opportunities for the activity and locations.

What is the existing equipment and methods are available for a "low footprint production"? What is possible to develop and enhance of existing technology and what is missing? How should tomorrow's requirements, regulations and framework look like? Is there a "no go zone" and how to define it? These are the questions we are looking into, searching for answers, new questions, more knowledge and better understanding.

Bellona believes that focusing on better solutions is the main way to lower the environmental footprint stemming from human activity, in Arctic. Better technology, smarter logistics, limits for industrial activity and international standards for equipment, methods and practices is a need for the whole world. The Arctic region should be first in line to make use of the best of technology, knowledge and governance the world can offer.

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[Stocker, T.F., D. Qin, G.- K. Plattner, M. Tignor, S.K. Allen, J. Bosc hung, A. Nauels, Y. Xia, V. Bex and P.M. Midgley (eds.)].

Photo: Bellona

1. Renewable energy production in the Norwegian Arctic: attractive source seeks sustainable market

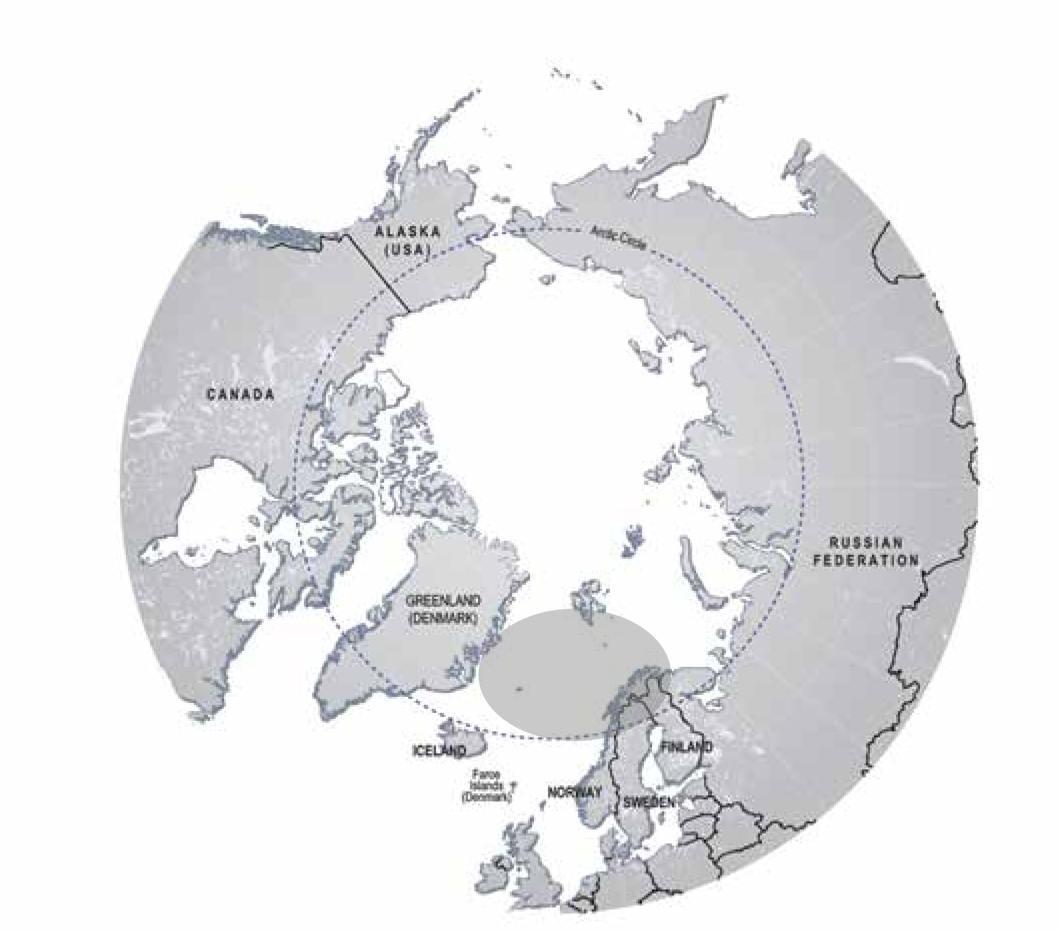
Author: Runa Haug Khoury, Senior Advisor, Energy and Industry

Climate change is largely triggered by the world's dependency on fossil fuels for energy production. Climate change affects the entire planet, but has disproportionate consequences in the Arctic. Local pollution from fossil energy use contributes to further stress on the vulnerable Arctic environment. However, the Arctic is vast in renewable energy resources – and the world is embarking on a renewable energy revolution. How will this play out in the Arctic? In this chapter, Bellona explores the scope for renewable energy production as a key to new value creation and electrification in the Norwegian Arctic.

1.1 Geographic chapter scope

The Norwegian Arctic is defined as Norwegian areas above the Arctic Circle. The figure below shows the Arctic administrative areas divided by nationalities – The Norwegian Arctic areas are shaded.

Figure 1.: Arctic administrative areas (Grid Arendal, 2015)



The Norwegian Artic areas encompass three Northern counties of mainland Norway: Finnmark, Troms and Nordland. The Arctic Circle passes through the middle of Nordland County, in the Svartisen area. As such the areas of Nordland below Svartisen are not by definition part of the Norwegian Arctic. However, this chapter applies overall figures for Nordland County. The Norwegian Arctic further encompasses the Norwegian Arctic islands: Jan Mayen, and the Spitzbergen archipelago, whereof the Spitzbergen island itself as well as Bjørnøya and Hopen islands have human settlements.

Though the Arctic is one geographic area, different regions within the Arctic vary distinctively in character. Contrary to most other parts of the Arctic, Northern Norway is rich in people. It is advanced in infrastructure and living standards, and has innovative competence clusters built around the key resources for value creation in the area – including renewable energy resources. For the Norwegian Arctic islands, the context is different, with only small and remote settlements aside from Spitzbergen's capital Longyearbyen.

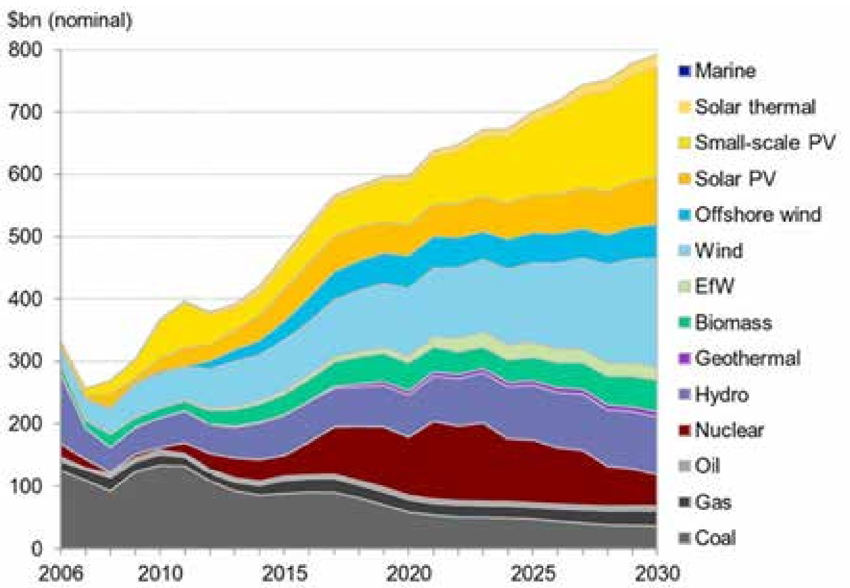
This chapter starts by examining renewable energy development in Northern Norway. It then proceeds to explore the scope for renewable energy production and electrification at the Norwegian Arctic islands.

1.2 Into the renewable energy revolution

In the face of global challenges such as climate change, resource depletion, and growth in the human population, the most important change for humankind to drive forward is the shift of energy sources. We need to move from fossil, polluting, non-renewable sources, to non-fossil, renewable energy sources free from CO_2 emissions. Indeed: we need to move to a fully renewably powered economy.

And the transition of the world's energy systems is well underway. We've embarked on a global renewable energy revolution. By the next 15 years, Bloomberg New Energy Finance (2013) expects that 73 % off all new energy investments will be in renewable energy capacity (Fig. 2).

Figure 2.: Forecast for new global energy investments towards 2030



Source: Bloomberg New Energy Finance (2013)

As the figure illustrates, coal, gas and oil currently represent around 40% of investments into new production capacity. By 2030 this is expected to plunge to 10-12 %. Wind and particularly solar are technologies that are expected to boost the most over the next decades. Parallel to this, solutions to store energy and balance increasingly intermittent energy systems are expected to undergo significant innovation, triggering increased uptake and hence significantly lowered deployment cost for technologies like batteries and hydrogen.

New renewables combined with energy storage innovations is already introducing disruptive change in several energy markets. 2014 marked an important milestone year for renewables: it was the first year where renewable energy additions bypassed all fossil fuels combined worldwide for new electricity capacity. In Denmark, 39% of all electricity use in 2014 was covered by wind power (TheLocalDK, 2015) and in the US solar powered alone covered 36% of all new electricity capacity, with a new solar system installed every 2.5 minutes (GreenTechMedia, 2015). Germany, with its mixed energy portfolio, had more power generated from renewables than from any other source (Bloomberg, 2014). In Norway, power production from renewable energy sources is however nothing new. Since the 1870s our hydropower resources have provided mainland Norway with clean and stable power supply. Recent years have also marked an uptake in younger technologies such as wind and solar. The next session will examine the technologies most suited for the Norwegian Arctic context.

1.3 Technology review: renewable energy solutions for the Norwegian Arctic

Producing renewable energy entails converting existing energy in various forms, to electricity or heat. Different renewable energy technologies will apply different energy forms, and with varying rates of efficiency.

The Norwegian Arctic is rich in renewable energy resources. The theoretical potential for the solutions described below is therefore enormous. But any new development will affect the local territory, its biodiversity and its natural environment, and can only be deemed necessary subject to adequate market purpose. The following sections describe the renewable energy technologies most suited to the Norwegian Arctic context. Drivers and obstacles for new development are discussed in subchapter 1.4.

1.3.1 Hydropower

Hydropower accounts for 99% of total Norwegian power production, and is a well-known and tested technology. Norway is a world leading hydropower nation with experience of developments from large-scale hydropower to run-of-river plants and small hydropower in streams.

As a consequence of climate change the average precipitation in Norway is expected to increase by 2.4-14 % during the period between 2021-2050, compared to levels between 1961-1990 (Norsk Klimasenter, 2009). As a result, the Norwegian Water Resources and Energy Directorate (NVE) expect Norwegian hydropower production to increase, even when numbers are adjusted for increased evaporation during summer months.

Hydropower production has been planned and built all over Norway, including the areas North of the Arctic Circle. In order to establish an allocated, national management of Norway's' waterways an assembled plan was established in the 1980s. The assembled plan builds on a methodology that entails systematic and verifiable sorting of hydropower projects, based on levels of conflict for the various user interests of each individual waterway, as well as power production economics. Hydropower projects are allocated in categories. Cost-effective projects of low conflict levels are allowed to apply for concession (category I). Projects that are not cost-efficient and with high conflict-levels are placed in category II and are therefore unable to apply. In 2005, the Norwegian Parliament agreed that hydropower projects up to 10MW capacity, small hydro, would be exempt from assessment under the assembled plan.

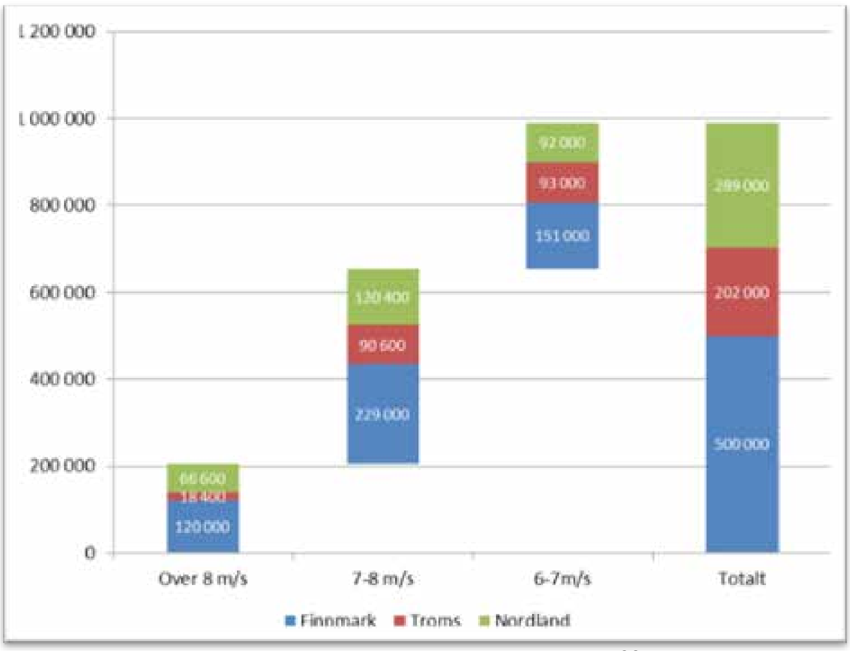
Hydro Power Station. Photo: Thinkstock

Under current climate conditions, and with protected waterways excluded, NFD et al (2013) estimates the total theoretical potential for hydropower production across Nordland, Troms and Finnmark to be approximately 28 588GWh (28.5TWh) in a mean year. Around 70 % of this potential is currently developed.

1.3.2 Onshore wind

Northern Norway and particularly the coastal areas of Finnmark are among the most suitable locations for wind power production in Europe. Almost half of Norway's available areas with favorable wind speeds for power production are located in the county of Finnmark, east of Lakselv municipality.
The total theoretical potential for onshore wind in Northern Norway is 991,000 GWh per year, with Finnmark boasting the largest share of this across all three wind speeds (Fig 3). (For overview of pre-conditions made and areas excluded before estimating theoretical wind power potential, see Kjeller Vindteknikk (2009) or NFD et al (2013))

Figure 3. Theoretical wind power production Finnmark, Troms and Nordland (GWh/year)



Source: Kjeller Vindteknikk (2009) in NFD et al (2013)

Although Bellona regards wind power as a key technology in the transition towards renewable energy systems, harnessing the total potential in counties is not realistic. To realize the full theoretical potential in Finnmark would imply wind parks covering 76 % of Finnmark's land area. This scenario is obviously neither realistic nor desirable. For Nordland and Troms counties, the corresponding levels would be 41 % and 34 % (NFD et al, 2013).

Nonetheless, wind power in North Norway remains a promising prospect. Raggovidda wind farm outside Berlevåg (picture below) is known to be Europe's most effective wind farm. Subject to sufficient grid capacity in the region, Northern Norway's wind resources could become a significant contributor to new economic activity in the region.

Varanger Kraft's Raggovidda Wind Farm in Berlevåg, Finnmark. Photo: Varanger Kraft

The level of conflict and so-called NIMBY ("Not In My Back Yard") surrounding new onshore wind developments is often considerable, also in Northern Norway. Bellona acknowledges that the concession process for new wind power development in Norway over the past decade has been poor, incentivizing excessive project applications of varying quality and realism. This has triggered more resistance to wind power than necessary.

In 2012, Bellona launched a report promoting concrete measures to reduce conflict levels related to new wind power developments. The report suggests the establishment of a national wind power strategy, where only the best projects are being pursued for development, whilst less suited projects are eliminated at an early stage. Norwegian authorities' assembled plan for national hydropower management, could serve as a framework model also for national wind power development.

For more context on Bellonas recommendations and wind power developments in Norway, please download Bellona's full report from www.bellona.no

1.3.3 Offshore wind

Norway's scope for offshore wind development is currently an area of much political focus. Norway's competences from offshore petroleum activity as well as from maritime shipping operations are both valuable assets into the development of a Norwegian offshore wind cluster. However, offshore wind parks are so far emerging on the British rather than Norwegian side of the North Sea basin.

The theoretical potential for offshore wind power in Norway is near unlimited. But the Norwegian coast and Norwegian waters cover a large area with many environmental and user interests. Practical barriers to offshore wind projects include lack of grid connection, area conflicts, and the lack of commerciality in current offshore wind technology in the Norwegian market context.

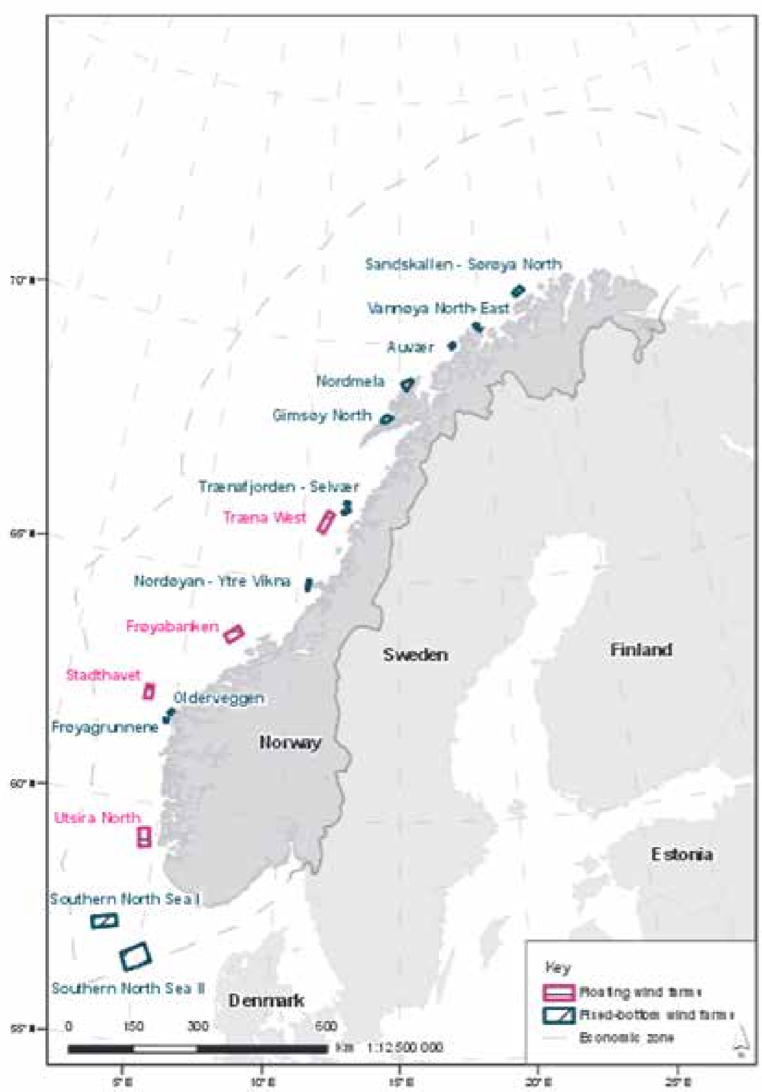
According Norwegian Ministry for Petroleum and Energy (OED), the total potential for fixed-bottom offshore wind power along the Norwegian coast is around 200.000GWh (200 TWh) per year. The total potential for deeper fixed-bottom production, at the Norwegian shelf down to 60 meters deep, is estimated at approximately 1,000,000GWh (1000TWh) per year (NFD et al, 2013).

There are no calculations that show exactly how much of this potential is located within Northern Norway. However, assuming that the overall potential is distributed as for the territorial waters from Rogaland and further North, then Norland would have 28 %, Troms 10 % and Finnmark 36 % of the total Norwegian offshore wind potential (NFD et al, 2013).

The Norwegian regulator NVE has an ongoing process of strategic environmental assessment (SEA) and considered opening for concession of 15 offshore wind park zones in Norway. Both bottom-fixed and floating technologies are considered.

Photo: Bellona

Figure 4. NVEs map of 15 relevant wind park zones in Norway subject for SIA and potential concession



Source: NVE (2010)

As shown in Fig. 4., almost half of the fifteen zones are located in Northern Norway. Industrial activity to develop offshore wind in the region has already begun, through joint ventures between renewable energy companies in Nordland and Troms county. The image below is an illustration of a possible offshore wind farm in Vannøya outside Troms, planned by Troms Kraft.

Norwegian companies are positioning themselves in the global offshore wind market, especially by engaging in commercial offshore wind projects where demand is high, such as in Britain. This is a very positive development. Through the Forewind consortium with German RWE and British SSE, Norwegian companies Statkraft and Statoil are both involved in Dogger Bank Creyke Beck, part of the larger Dogger Bank Zone offshore wind scheme currently being developed off the British West coast. During spring 2015 Dogger Bank Creyke Beck was granted planning consent for the largest renewable energy project in the UK. The total installed capacity will be 2.4GW and involves two offshore wind farms with 1.2GW-capacity and 200 wind turbines, each installed across an area of around 500 km2. The wind farms will be located 131 kilometers from the British coast and will connect with the existing Creyke Beck substation near Cottingham, in East Riding of Yorkshire. When constructed, Dogger Bank Creyke Beck will be capable of generating 8 TWh of renewable energy every year, equivalent to the energy use of 1.8 million British homes (Statkraft, 2015).

Through its Hywind prototype located outside Karmøy, Statoil has tested technology for floating offshore wind turbines since 2009. In November 2015, Statoil announced plans to build the first floating wind farm off the Scottish coast - The Hywind Sctoland Pilot Park. The park will be located near Buchan Deep, approximately 30 km off the coast of Peterhead in Aberdeenshire. The 30 MW pilot project will consist of five 6 MW floating turbines, operating in waters over 100m deep. The objective is to demonstrate floating turbine technologies for cost-efficient and low-risk commercial parks (Statoil, 2015).

Hywind demonstrates that offshore wind technologies are maturing, and that deployment costs are starting to come down. Nonetheless, offshore wind is generally expected to remain among the more expensive renewable technologies. Subject to increased demand for new power production in the Norwegian market, and thus a higher power price to secure commerciality in new projects, Bellona sees great potential for offshore wind also on the Norwegian shelf. Norway has ideal conditions for offshore wind power production, and advances in technology allows for production on greater depths and increasing distances from the shore – which in turn reduces land-use conflicts with other coastal activities such as shipping and aquaculture. Notably, countries like Germany have pioneered the deployment of offshore wind and report very positive results of combining offshore wind facilities with aquaculture, to exploit synergies in for instance maintenance. Bellona believes that combining offshore wind development with integrated aquaculture should also be explored for Northern Norwegian waters.

Illustration of Offshore Wind farm, Photo: Thinkstock

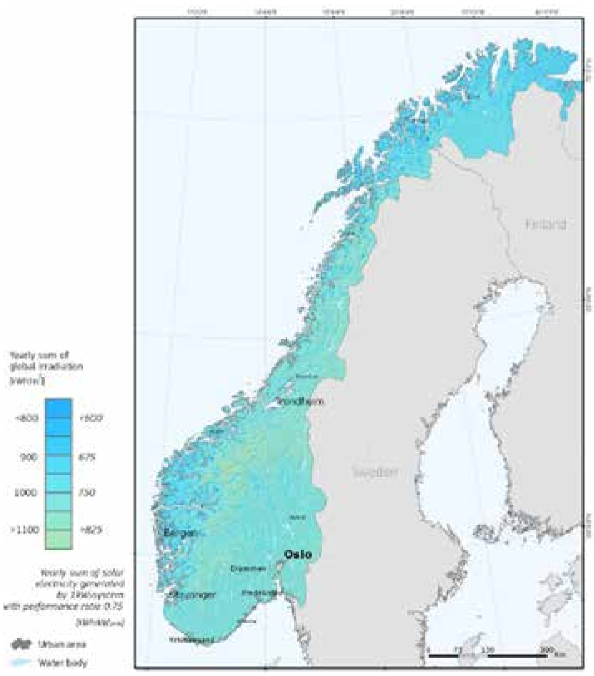
1.3.4 Solar power

Solar energy is the energy that the sun generates and produces through radiation. Solar energy can be used for heating through a solar collector, or for producing electricity, through photovoltaic cells in solar panels on buildings or even in larger solar power stations connected to traditional grid.

Using solar power as an energy source in the Arctic may sound unrealistic, but it is not. The crisp air and cold temperatures, the increased reflections triggered by snow as well as the region's topographic angling, are all favorable factors for efficient solar power production.

Irradiance describes the level of solar exposure of a given spot. In Norway, the solar irradiance has significant seasonal variations. It is also subject to local variations in topography and weather conditions. For example, the inland receives up to 50% more irradiance than coastal areas. The annual irradiance of an optimally angled surface oriented towards south is applied as an indicator to determine the suitability of a given location. This is shown in Figure 5.

Figure 5. Annual irradiance of an optimally angled surface oriented towards south (Norway)



Source: PVGIS in NFD et al (2013)

As figure 5 illustrates, the annual irradiance of an optimally angled surface oriented towards south in Norway, varies from 800 kWh/m2 to 1 200 kWh/ m2, and is not dependent on the surface latitude (Multiconsult et al, 2012). As such, areas of high irradiance (towards 1200 kWh/ m2) are found in all parts of Norway, including areas above the Arctic Circle. By comparison the average annual irradiance of an optimally angled surface oriented towards south in Germany is 1250 kWh/ m2, which is the same level as the flat areas around Kautokeino and Karasjok in Finnmark. . Germany is well known as the largest solar power market in the world, with 38 124 GWh net installed capacity in 2014 (Fraunhofer ISE, 2014). The Arctic therefore has beneficial irradiance, but moreover the cold climate increases the potential for efficient solar energy production. The lower the temperature the more efficient solar cells become; on average efficiency increases by 0.5 % per degree Celsius (°C). This means that a solar cell will have 10% higher efficiency at 0°C than at 20°C. For these reasons, open areas like Finnmarksvidda have a large potential for solar power production.

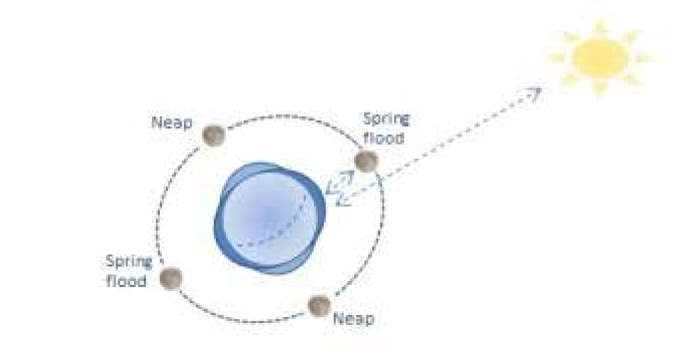
However, during the dark Arctic winter months solar power is not an alternative. This means that Artic energy systems cannot solely depend on solar power, even in combination with batteries or other storage solutions. In winter, backup power supply will always be necessary. But during the light summer months the potential is high, particularly those months of 24 hour sunlight . (Also described in this report's analysis of Arctic aquaculture potential.) However, during the summer months the sun moves 360 degrees around the horizon, which means that a great part of the sun energy cannot be stored in static solar energy systems. A sun-tracking solar energy solution is required to fully capture the potential of the Arctic period of 24hours sunlight.

Currently, electricity production from solar energy in Northern-Norway is not extensive. The technology is primarily used in small, off-grid sites such as cabins and summer houses. Norway's electricity mix is nearly 100% renewable, stable and with low electricity prices resulting in less obvious incentives to introduce solar energy technologies than for other European countries. The possibility of applying solar energy systems in local, off-grid solutions does however make the technology interesting for the remote Arctic communities, such as the Norwegian islands – especially if combined with other sources of supply during dark winter months. This is discussed separately in section 1.5.1.

Notably, Nordland has a small but strong industrial cluster within solar energy research and technology. The Norut Research Center in Narvik is strongly affiliated with the former REC solar wafer production unit in Glomfjord and remains a highly competent cluster. The massive growth in solar power installation in international markets should make this cluster even more relevant with regards to future industrial opportunities and industry growth in Nordland.

Tidal energy:

The tide differences are caused by the gravitation from the sun and the moon and the centrifugal powers on the turning Earth. These powers cause a rise of the sea level both on the part of the Earth that is facing towards and against the moon. This results in a change between a high tide and a low tide in a period of 12 hours and 25 minutes. A companionship between the sun and the moon causes a change between maximum and minimum tide difference in a period of 14 days. Bathymetric conditions also have an impact on the tide differences. The velocity of tidal currents varies by several factors.



Source: Andritz Hydro Hammerfest

1.3.5 Tidal power

Tidal and wave power are renewable energy technologies that have yet to experience deployment at significant scales. However, the world's first tidal turbine supplying electricity to a commercial grid was indeed placed in the Arctic, installed in Finnmark's Kvalsundet back in 2003.

The energy in the tidal current can be used to produce electricity in two ways. The energy from the head of water is called potential energy. By using low pressure turbines, this energy can be converted into electrical energy. The kinetic energy can be converted into electrical energy by using tidal turbines.

The kinetic energy in tidal water is what has been exploited by Andritz Hydro Hammerfest in Kvalsundet, Finnmark. The tidal turbine resembles an underwater wind turbine, but with shorter blades that rotate slower. In a tidal power park, turbines are installed in arrays at the seabed. Reports show that they will not create any visible or audible pollution above the surface, and will allow vessels to operate without restrictions. The energy is converted in both current directions by pitching the blades. Each turbine can have an installed capacity of approximately 1 MW, and arrays may consist of hundreds of turbines. The tidal power devices are installed at 40-100 meters depth in tidal streams, with velocities above 2.5m/s. The structure is designed as a tripod to reduce footprint on the seabed and is held in place by gravity and additional weight (Andritz Hydro Hammerfest, 2015).

A floating solution has been applied in Gimsøystraumen in Lofoten, Nordland. Hydra Tidal's floating tidal 1.5 MW power plant Morild II was officially opened in 2010. This marked the beginning of a two-year trial period for testing and verification of Morild II and its technology.

Tidal power technology is not broadly deployed in Norway today due to low market demand and a neutral technology support scheme not tailored to uncommercial technologies. However, the fact that the technology has been successfully tested in the Arctic already proves it interesting and worthy of further consideration.

In the next section, drivers and obstacles for new renewable energy development in the Norwegian Arctic are discussed.

1.4 Obstacles and drivers for new renewable developments in the Norwegian Arctic

Virtually all electricity supply in Northern Norway comes from renewable energy sources. The region is rich in waterfalls and wind, waves, tides and sun. But although the theoretical potential for new renewables in Northern Norway is enormous, market conditions and other practical obstacles limit the realistic scope for new development in the short to medium term. The following sections examine the current energy situation, obstacles, and potential drivers for new renewable developments as an engine for new value creation and economic growth in the region.

1.4.1 The Nordic energy market: brief political framework overview

The potential for new renewable energy production in the Arctic part of mainland Norway cannot be evaluated in isolation. Northern Norway is an integrated part of the Norwegian and broader Nordic energy system, and the assessment of new renewable power production must take this into account.

The Renewable Energy Directive (RED, 2009) was officially adopted into EU legislation in the spring of 2009. The target of the directive was to increase the share of renewable power and heat to 20 % of EUs energy mix by 2020. After negotiations between the EU Commission and the other EFTA countries, Norway was in 2012 allocated a binding target of 67.5 % renewable energy share by 2020.

To achieve this target the Norwegian and Swedish authorities introduced the Green Certificate Market. The Green Certificate Market was introduced as a joint mechanism policy instrument to fulfill the two countries' individual renewable energy targets under the Renewable Energy Directive. This market-based, technology-neutral subsidy mechanism has a goal of introducing 26.4 TWh of new renewable power production in the two countries by 2020. (Target expected to be increased to 28.4TWh, subject to ongoing bilateral political processes.) As the green certificates are traded across the two countries, there was no clear picture of how the new production would be distributed across Norway and Sweden. At the market launch in 2012, Norwegian authorities expected a significant amount of new small hydro and wind power projects to be realized in Norway. A large number of licenses were processed, to comply with the requirement of being operative by 2020. However, much more new development has come in Sweden than in Norway, particularly so for onshore wind. Even with political measures negotiated forward in 2015 by the Norwegian Government to harmonize the national framework conditions between Norway and Sweden for onshore wind development, there is a general expectation that more wind development will continue to come in Sweden rather than in Norway under the scheme. There are several reasons for this. Fundamentally, Sweden has a stronger motivation for new development, subject to growing political appetite for out-phasing Swedish nuclear of the national energy mix.

1.4.2 Embarking on a Nordic power surplus

The Green Certificate Market has functioned as intended. The scheme secures new renewable energy into the Nordic system, and both Norway and Sweden are making progress to reach their targets by 2020. However, whilst production has been stimulated to increase, electricity demand over the past 15 years has remained relatively flat (Figure 6.)

Figure 6. Nordic electricity demand 1990-2014 (Statkraft, 2015)

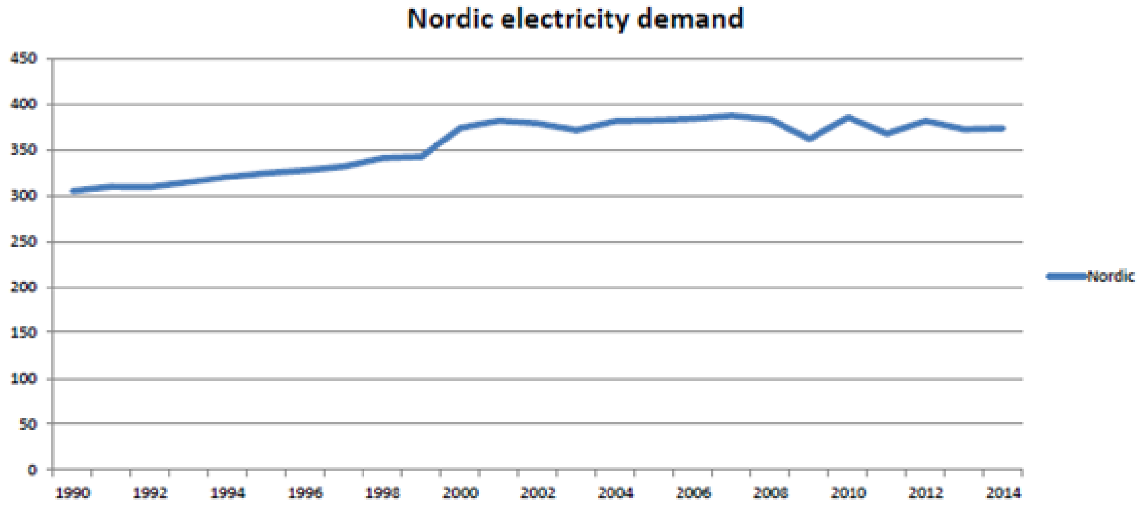


Figure 6 shows that Nordic electricity demand ranges between 350 TWh and 400 TWh per year. Even with increased population size, increased economic activity and the expected phase-out of Swedish nuclear power production, the Nordic power system is still expected to enter into a substantial and long-term power surplus. This is due to energy efficiency measures and new production entering the Nordic system, like the new Finnish nuclear plant Olkiluoto. Pöyry (2014) estimates a Nordic surplus approaching 40TWh / year by 2025.

To fully make use of new renewables and their ability to cut GHG-emissions and to ensure new value creation, Bellona strongly argues that a political "part 2" must follow up the Green Certificate scheme at the Norwegian national level. Norway's national renewable energy politics towards 2030 must focus on creating markets. The new power must systematically be steered towards replacing fossil energy use in sectors such as transport, buildings and industry: to electrify the Norwegian society, as we have seen in the adoption of emission-free electrical vehicles. Furthermore, Norwegian authorities should use the renewable power surplus to stimulate growth in traditional and new energy intensive industry.

1.4.3 The North-Norwegian power surplus

The renewable energy sector is an important contributor to society in Northern Norway. The sector contributes in the form of local government taxes and dividend payments. As the vast majority of the companies in the sector have local public ownership, they represent an important source of revenue for the municipalities in Finnmark, Troms and Nordland. As well as being a key employer in rural areas, the sector has been important in the development of industry in the region. A large proportion of the power has been used for industrial production, with both local and imported raw materials being processed. The sector is also an important contributor to a number of good social causes (NFD et al, 2014).

Finnmark, Troms and Nordland counties have an overall energy consumption of approximately 19,000GWh (19TWh) every year. The annual power production can reach 24TWh . (Commercial production during mean year, excluding pilot projects.)In the current situation, Northern Norway has a power surplus of around 5TWh every year (OED, 2012). This is an important perspective to keep in mind in the discussion on new renewable energy development of scale in Northern Norway in the short to medium term.

Energy supply in Northern Norway varies due to unregulated hydropower production in the region.

This issue is valid for the entire region north of Ofoten (Nordland), but is particularly challenging in Finnmark. Unregulated hydropower reaches its peak production during spring and fall, whilst the power consumption, particularly in domestic households, is highest during the cold winter season. In contrast to most European countries, Norway uses electricity for heating. Communities that dependent on unregulated hydro are therefore also dependent on power import during the hardest winter months, whilst they are power exporters for other parts of the year. Due to large production volumes Nordland County south of Ofoten normally has a power surplus throughout the year.

Under these conditions, Northern Norway is not an optimal place for new renewable investments. The renewable energy resource potential is vast – but there is a lack of significant markets. Both the broader Nordic and the regional Northern-Norwegian power markets are facing a growing power surplus. The further development of Norwegian Arctic renewables will be subject to two preconditions. Firstly, increased grid transmission capacity is needed. Secondly the establishment of new industrial activity must take place to spur market demand. These two factors are discussed in the sections below.

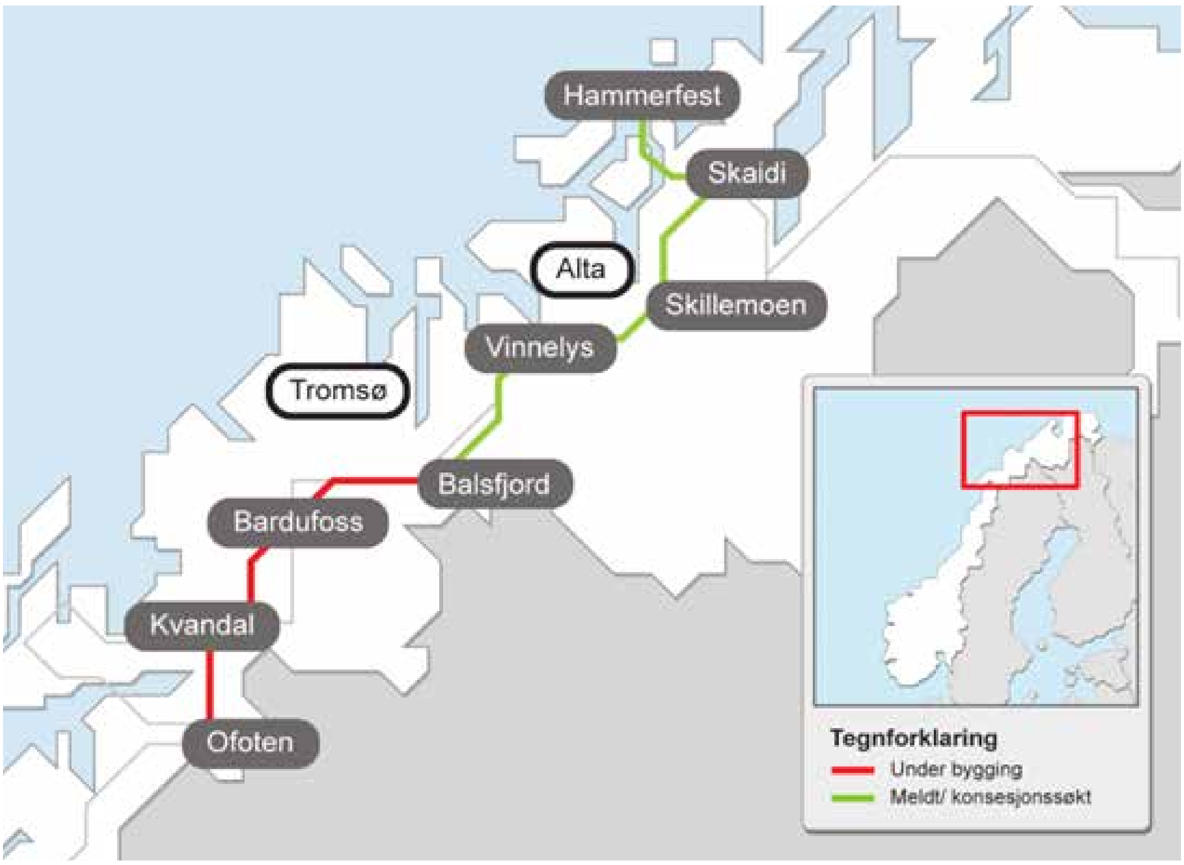
1.4.4 Grid up-scales required: the case for an integrated Arctic grid

The Norwegian grid operator Statnett is in the process of strengthening the entire Norwegian central grid in capacity and reach. This will also benefit the Northern parts of the country.

Historically the grid in Northern Norway has been hampered by low capacity. The security of supply in the region has been a challenge, and several incidents over the last years have resulted in major power outages due to lack of grid capacity in connection with defects. The current grid of 132 kV has limited capacity.

Statnett's grid development plan includes building a new 420 kV grid from Ofoten in Nordland, and northwards. The construction is scheduled for four stages (Figure7).

Figure 7. Statnett's grid development plans for Northern Norway (Statnett, 2015)



The first stage is to build the Ofoten-Balsfjord interconnector, which will contribute to providing the area from the north of Nordland, Troms and Finnmark with a more secure power supply. Construction on this line began in 2014, and is expected to last for 3 years. The second buildout stage is to continue from Balsfjord (Troms) to Skaidi (Finnmark) in order to strengthen the security of supply in Finnmark, and to facilitate potential increase in demand. The plan to build this section is according to Statnett fixed, but the time will be adapted to the development of the power consumption. Recently, short-term demand growth in Finnmark has become more insecure as the expansion of petroleum site Snøhvit (Train 2) was postponed indefinitely in 2012. Several mining projects are also uncertain or have been postponed. The third construction stage will be the section Skaidi to Hammerfest. According to Statnett this section will be built when the industry in Hammerfest needs more capacity and is willing to pay for the interconnector. If there is new activity in East Finnmark related to possible petroleum exploration in the Barents Sea, Statnett intends to apply for a licence for the fourth stage, Skaidi-Varangerbotn in2015. This process will primarily be governed by the need to power for new, larger industrial activities (Statnett, 2015).

There is little doubt that Statnett's grid upscale in Northern Norway will support the case for future development of new renewable production in the area. At the same time renewable energy producers in Finnmark strongly argue that more grid connection across the Scandinavian North is needed. This is logical as Northern Finland already needs to import power today, whilst Northern Norway exports power. Geographically, power export flows might be considered more convenient across the Northern parts of Norway, Finland and Sweden rather than exporting downwards in Norway. The local industry argues that developing the region's renewable energy resources can only become a true priority if there is transnational grid cooperation in the North.

Figure 8. The Arctic Circle Grid Initiative (Varanger Kraft, 2015)

Norwegian authorities must prioritize extended and enhanced grid capacity in the North area to enable new production and new industry. The power flows more naturally across these three countries than necessarily top-down within each country. The Arctic Circle Grid initiative between Northern communities and industry actors of Sweden, Finland and Norway has worked to promote this since 2008. Statnett has also had an Arctic Ring imitative in cooperation with the Finnish and Swedish TSOs to this end. Renewable power production and sustainable grid development are both keys to unleash new value creation and jobs for the Northern society. We must avoid the infamous chicken and egg complex in the North of the Nordic countries. New potential investors may not arrive until grid stability is sufficient. Investing in grid capacity is not only necessary – it is a way to invest in growth and future livelihoods in the North.

1.4.5 Sustainable markets: new industrial opportunities in the North

Bellona believes that the Arctic has vast opportunities for value creation and employment across various sectors. Environmental concerns in the Arctic region remains among Bellona's primary focus areas. At the same time, an obvious priority must be placed on ensuring local communities' rights to economic and industrial development and employment in their own region. New industrial development must be aligned with broader trends in society, securing new investments that are relevant to the future. Furthermore, new industrial development based on the vast natural resources must develop the region's own interests in terms of jobs and local value creation. For Bellona, true sustainable development in the North means using Northern Norway's clean power surplus to fuel new industrial developments in sectors that has a long-term perspective.

The next chapters of this report sets focus on two sectors with significant opportunities in the Arctic: mining and aquaculture. Both these sectors are known in the region, and both will rely on steady power supply and reliable grid capacity for large-scale developments.

This chapter briefly focuses on three areas for potential new industry development, where clean power is the key input. Arctic datacenters, hydrogen production from wind power and electrified eco-tourism could all become green growth jokers in Northern Norway over the next decades.

1.4.6 Green growth joker: Arctic datacenters?

Digitalization is happening across sectors at an enormous pace. Digitalization changes our business models, the way we organize society, and the way we live our lives. Over 90% of all our history's digital information has been produced over the past two years, according to analysis by Jefferies International. And global data amounts will continue to double every second year towards 2020.

However, despite all the benefits that digitalization brings, there is also a climate risk. The basic infrastructure of the digital economy is the datacenter. All activity on a computer or smart phone generates data that is processed and stored in a datacenter. The concept of outsourcing IT services and data storage into the "Cloud" has become a well-known phenomenon, but this "Cloud" is obviously not a cloud. In practice, the Cloud is made up of several enormous datacenters full of servers that must be operated and cooled. Datacenters are therefore highly power intensive installations, and when they run on fossil power, they generate considerable GHG-emissions. Aligned with society's fast digitalization, the datacenter industry is in massive growth. Europe alone expects a growth of 6000 MW in new datacenter power demand by 2020 (BCG, 2014). In fact, within the next five years, the datacenter industry is expected to bypass the global aviation industry in global CO_2 emissions (Schneider Electric, 2015).

To curb emissions from this rapidly growing sector the datacenter industry must be established where there is clean electricity supply. Central companies in the industry already acknowledge this important fact, and are creating an industry push for renewable energy commitments. Big companies like Facebook, Apple and Google have all invested in large datacenters in the Nordic countries during past years. The Nordic countries are favorable given the high share of renewables, stable power supply and low electricity prices compared with Europe. In addition, the Nordic countries also have cool climates, reducing efforts and costs for cooling servers, and in some cases opening for natural cooling through cold air or cold water.

Northern Norway, and indeed other regions within the Arctic with the necessary infrastructure in place or scheduled, represent favorable locations to establish new data center industry. Facebook's colossal data center establishment in Northern Swedish town Luleå, just below the Swedish Arctic Circle, is a good example of what potential lies ahead for Northern Norway. Facebook's establishment has had major positive ripple effects for the broader Luleå region, creating more jobs and industrial spin-offs than first anticipated.

Also in Northern Norway, some industrial sites are starting to mobilize the establishment of datacenter industry. In Mo i Rana, Nordland, the Arctic Cloud project has been initiated to establish a data center in the vicinity of the local industry park (Mo Industripark). In addition to creating new activity and jobs, the establishment of a datacenter would also be beneficial from several environmental perspectives. Disruptions of natural terrain associated with infrastructure would be avoided, as the industry park is already established. All of the power provided would be hydroelectric. As already stated, Nordland has a renewable power surplus, and the industry park's proximity to power plants would minimize energy loss from transmission. If industrial water is used for cooling, the same water will be used for power generation in the industrial park's own turbines both from entering and leaving the park. Existing systems for utilizing heat from the local heavy industry could also be employed to recover the energy from the datacenter's heat production, exploiting another synergy of data center development within the existing infrastructures (Arctic Cloud, 2015).

The development of an Arctic data center industry in suitable locations across Northern Norway and other Arctic regions represents both good climate policy and good business policy: clean power would curb emissions from this growing industry, and local jobs in a long-range industry would be developed. An important condition to enable such industry growth is the development of sufficient fiber infrastructure in the region. In Norway, there are currently processes initiated by the Minister of Transport and Communication to map and strengthen the national fiber capacity. It is important that Northern Norway is fully included into the scope of this work. In a future scenario, Spitzbergen could also be relevant for Arctic datacenter industry – see section 1.5.2.

1.4.7 Green growth joker: can Finnmark's stranded wind trigger Norway's hydrogen industry?

Given sufficient grid capacity in the region, Northern Norway's wind resources could become a significant contributor to new power-based industrial activity in Northern areas of Norway, Sweden and Finland. The energy company Varanger Kraft in Finnmark operates Raggovidda wind farm outside Berlevåg, a 45 MW onshore park known to be Europe's most effective wind farm.

Varanger Kraft has actively promoted the Arctic Circle Grid Initiative (see section 1.4.4), to strengthen grid capacity in the region. But the lack of stable grid capacity to export power production has made the local community search for alternative power usages. Berlevåg Municipality has for instance initiated a project to explore possibilities for hydrogen (H2) production to exploit the power surplus generated by Raggovidda wind farm. This project has now been taken over by Varanger Kraft.

Varanger Kraft is currently conducting a pre-feasibility study to clarify possibilities for production, distribution and sale of H2 based on renewable energy resources in Eastern Finnmark, with particular focus on the Raggovidda windfarm (Figure 9)

Figure 9. Wind powered H2-production in Berlevåg, Finnmark (Varanger Kraft, 2015)

The plan is first to assess the establishment of one pilot production facility in order to gain operating experience. The possibilities to further escalate the project in a step-wise approach will be considered, given that the wind power projects in the area are granted permission. One important feature to examine is the facility's ability to handle the volatility in the wind power production (Varanger Kraft, 2015).

As figure 4 shows hydrogen will be produced in direct proximity to the wind power farm, and from there transported by ship. There has already been international interest in the pilot, primarily from Japanese stakeholders. Varanger Kraft, together with other hydrogen entrepreneurs and investors in Norway, are asking for a more clear and long-term commitment from Norwegian authorities on hydrogen policy. Stable framework conditions are required to enable a market for hydrogen use, end to ensure long-term predictability for potential investments.

1.4.8 Green growth joker: eco-tourism in the Arctic

A final green growth joker in Northern Norway and the broader Norwegian Arctic could be a more extensive aiming at eco-tourism. The Arctic is a growingly interesting region for curios tourists, and the term 'climate tourism' would certainly apply here. The rate of climate warming in the Arctic is two to three times faster than the global average. This makes the Arctic the most rapidly changing region on Earth, which has already had visible impacts on regional nature and biodiversity.

Maritime electrification would also bring a new dimension and new opportunities for eco-tourism. Activities could be tailored to fit around existing concepts, such as the Hurtigruta Coastal Vessel Route. Electrified snowmobile with less pollution, emissions and noise is also an appealing concept. Eco-tourism could also include activities further north, for example to Spitzbergen, where emissions-free and silent sailing through Arctic waters amongst icebergs and wild animals provide a unique adventure.

Eco-tourism is an increasingly established business elsewhere in the Arctic. The Icelandic vessel Opal, operated by North Sailing, is the first ship in the world to be installed with a specifically designed regenerative plug-in hybrid propulsion system, and is equipped to recharge own batteries while under sails. On a day-to-day basis, the ship's batteries will be recharged when docked, utilizing the sustainable, green energy of Iceland's energy grid. During whale watching tours, the electric motor will silently propel the boat, and when the ship is under sails the propeller blades can be modified and used to recharge the ship's batteries. This technique has never been used on a sea vessel before, and has gathered considerable attention wherever it has been introduced abroad.

Opal sailing at Greenland. Photo: Bellona

In order to provide electrified eco-tourism in the Norwegian Arctic, Bellona recommends that further possibilities are continuously explored.

The remaining sections of this chapter will depart from the Norwegian mainland, and address the scope for renewable energy production and electrification at the Norwegian Arctic islands.

1.5 The scope for renewable energy production and electrification at the Norwegian Arctic islands.

Deployment of renewable energy technologies is becoming cheaper, and will continue to compete with conventional fossil fuels with increasing force. In particular, solar and onshore wind is being installed broadly worldwide. The role of energy storage technologies, and the rapid drop in cost seen particularly within the market for batteries, opens a new range of opportunities for electrification in remote areas. As the previous sections illustrate: the Arctic Norwegian mainland is neither off-grid nor particularly remote. However, the situation for the islands in Norway's high north is different. Here, energy is either produced from diesel aggregates or, in the case of Spitzbergen, from coal. This section assesses the scope for renewable energy production and electrification at the Norwegian Arctic islands.

1.5.1 Remote off-grid electrification: Jan Mayen, Bjørnøya and Hopen

Many Arctic communities are characterized by poor or no connection to the central grid. Providing electricity from local renewables in remote off-grid Arctic communities will therefore be about much more than simply clean energy without emissions. In most cases, it will also be about cost reduction, local empowerment and increased self-sufficiency. During the Arctic Futures Symposium 2015 in Brussels, EU representatives underlined how EU's regional development funds would prioritize the transformation of energy systems in the high North by moving rural energy systems away from expensive and polluting diesel aggregates to renewable local sources.

Jan Mayen is an isolated island located 500 km east of Greenland, 550 km northeast of Iceland and 1000 km west of the Norwegian mainland. Jan Mayen is the northernmost island on the Mid Atlantic Ridge and is the northernmost active volcano system above sea level in the world. Nature values on Jan Mayen are considered extensive and attached both to the island's distinctive landscape, its isolated state, intact oceanic ecosystems, large seabird populations and the cultural heritage representing different periods and nationalities (DN, 2007). The island has great importance and potential for research activities, and is an important site for meteorological observations. The great majority of Jan Mayen has since 2010 been established as an official Nature Reserve by Norwegian authorities, with 99% of the island's surface under a protection scheme. Jan Mayen has an oil storage facility near the settlement of Olonkin, where diesel for the island's energy production is stored. Bellona has not succeeded in attaining the figure for annual power consumption at Jan Mayen.

The islands of Bjørnøya and Hopen are both under the legislation of the larger Spitzbergen island group. Aside from the Spitzbergen Island itself, Bjørnøya and Hopen are the only two islands of the group with human settlements. Both Bjørnøya and Hopen have meteorological stations that conduct observations regularly. Diesel aggregates supply the energy needed to these settlements. According to the Norwegian Meteorological Institute, the total power consumption per year for the island of Hopen is approximately 300 000 kWh. On the island of Bjørnøya annual power consumption is approximately 600 000 kWh.

It is interesting to explore the possibility to convert fossil-based power production to local, off-grid and renewable energy production for all three islands. A complete transition could be made given that there is sufficient energy storage capacity in the system. An alternative is a hybrid solution with diesel aggregates as backup power supply. In either case, local pollution would be reduced or even eliminated. This is in itself beneficial to the fragile local environment. Reducing local pollution would also be positive for research activities, meteorological observations and measurements. A possible renewable technology could be solar power given its flexibility in both scale and operation, and given its good performance in cold climates. As the settlements on these islands are modest in size, wind power would be a less feasible alternative. However, tidal technology could be interesting to consider. Regardless of renewable technology choice, a solid storage and / or backup solution would need to be integrated in the energy system.

Partial electrification of remote settlements has already been piloted elsewhere, in the Canadian Arctic region the Yukon. The Yukon is the westernmost and smallest of Canada's three federal territories. Yukon Research Centre, including its Cold Climate Innovation department, has a solid record of applied research innovation projects that includes and engages the local communities to find solutions for local challenges.

The Northwestel Remote Station Solar/Diesel Hybrid Power Generation project developed in the Yukon, is an interesting example for the Norwegian Arctic islands. The Northwestel company operates 87 off-grid microwave stations, of which 37 can be resupplied only via helicopter. The costs for maintenance, repair and running are high in all remote locations. Consequently, Northwestel has investigated options to reduce operating and running costs, and the company has been particularly keen to exploit renewables. In 2013 the first 15 kW Solar PV system was introduced at one of its locations in the north of the Yukon. The PV system operates in unison with the existing diesel generating system. Given that the pilot project is successful, Northwestel will consider introducing hybrid solar/diesel systems at other remote stations. The Yukon Research Centre Cold Climate Innovation has supported the project, and organized, stored and provided access to environmental and operational data collected on site (Yukon College, 2015).

1.5.2 What power after coal, Spitzbergen?

Although remote, Spitzbergen Island has become a symbol arena for Norway's international environmental policy efforts. The settlement and research conducted at Spitzbergen has during recent years been subject to increasing and often climate-specific attention. This has generated expectations to establish a green and resource-friendly Spitzbergen. However, Spitzbergen's current energy system is coal-fired. Coal-based energy systems are in general something the world works to advance beyond, and particularly questionable in the heart of the Norwegian Arctic. Bellona suggests that renewable energy from local resources should be central component to the future energy system and economic activity in Spitzbergen. Indeed, Spitzbergen could become Norway's Arctic renewable energy showroom.

1.5.3 Global market trends with local implications

The renewable energy revolution brings with is a considerable price drop in global coal markets. This has direct and substantial consequences for the Norwegian settlement at Spitzbergen. The potential scenario of a Spitzbergen beyond coal mining activity calls for political attention and concern in Norway. At present there is no alternative sector that can replace the coal mining activity in neither volume nor employment.

Any economic activity in the Artic will rely on access to energy. Electricity shortage is already a barrier for further growth and activity in Spitzbergen's capital, Longyearbyen. Furthermore, uncertainty relates to future supply of coal as the cornerstone company Store Norske is facing the global price drop first hand, and the possibility of having to import coal for future electricity production is being discussed.

1.5.4 Spitzbergen: an Arctic renewables showroom?

Spitzbergen as an Arctic renewable energy showroom could both ensure local energy security, and in itself become a new area for research and development. Increased supply of green power would also catalyze local economic growth as well as strengthen existing operations. .For instance, Spitzbergen is internationally acclaimed for its activities within the space industry. In addition, the existing fiber infrastructure between Spitzbergen and the Norwegian mainland enables future datacenter industry. All these activities are– contrary to Spitzbergen's growing tourism sector– dependent on infrastructure to trigger expansion and growth, rather than the vulnerable nature on the island.

Which renewable energy technologies could make Spitzbergen Norway's Arctic renewable energy showroom? Solar power is a technology suited for the Arctic context, given that alternative supply or backup is available during the dark winter months. Factors such as low temperature and snow reflection enhance the effect of power production in the solar panels. Solar panels are already being installed on buildings in Longyearbyen, with very good results. The Narvik-based company Solbes is a full-range supplier of solar energy systems in Nordic markets, and has installed solar panels on the roof of a new apartment building for developer LNS Spitsbergen in Longyearbyen in 2013. The performance measurements during 2014 demonstrated a production effect 115% above expected performance (Solbes, 2015).

Solar panels installed in Longyearbyen, Spitzbergen Photo: Solbes (2015)

Solar power could be introduced gradually together with energy storage solutions to optimize the effect of the seasonal and intermittent production. Developments within both battery technology and hydrogen solutions would be relevant to this end.

Another technology that could be further assessed for the Spitzbergen context is wind power. Aslo here an example from Canadian Arctic Yukon is relevant. The Yukon Research Center's Cold Climate Innovation and local partner Kluane First Nation (KFN) are collaborating to assess the wind energy potential for the local site Burwash Landing and Destruction Bay. By installing a wind monitoring station on the site the energy potential is assessed. This station will stream wind and atmospheric data to the Yukon Research Centre data server. The information will then be stored and analyzed to determine potential wind energy production for the Burwash location. The project also aims to initiate a Yukon-wide wind atlas (Yukon College, 2015). Such assessments could also be considered for Spitzbergen.

Another renewable energy technology to consider could be tidal power. In general, an Arctic renewable energy showroom concept would require a mix of technologies feeding into the existing grid system. As previously mentioned, energy storage technologies would need to be a vital part to enable a renewable energy system. Even so, a hybrid system with fossil fuel as backup power supply could still be necessary.

An alternative to a hybrid solution would be connection to the North Norwegian mainland through a power exchange interconnector cable. A power cable would enable a substantial increase in power supply to Spitzbergen. And as described in previous sections, Northern-Norway is already experiencing a regional renewable power surplus. Still the cost and technical feasibilities of a power cable would need thorough investigation and coordination with other projects. However, for comparison, the Icelandic Landsvirkjun Power Company is examining options for the interconnector IceLink, connecting Iceland to the British Islands. The potential interconnector will be over 1000 km long and have a capacity of 800 – 1200 MW (Landsvirkjun, 2015). The cable would have to pass ocean depths of over 1600 meters, significantly deeper than the ocean areas between Norwegian mainland and Spitzbergen. The motivation behind the Icelandic interconnector to the UK is obviously commercial as the UK is has high power demand and relies on imports. In contrast, motivations for a power cable between the Norwegian mainland and Spitzbergen would be clean power for sustaining the settlement and growth at Spitzbergen, and geopolitical considerations.

Regardless of concept choices, broad assessment of how to establish Spitzbergen as an Artic renewable energy showroom would be required, and Bellona invites Norwegian authorities to explore this idea further.

1.5.5 A symbol arena for electrification and clean-tech innovation

Local pollution and GHG-emissions would be reduced dramatically subject to electrification of transport at Spitzbergen. Electrifying cars, local vessels and snow mobiles could also increase possibilities for eco-tourism as electric engines are comparatively silent, allowing tourists to approach local wildlife in a smoother way.

Local initiatives are already exploring the scope for electrified transport at Spitzbergen. The company Pole Position Logistics operates vans and trucks around Longyearbyen. The company has invested in one fully electrical car into its fleet. Pole Position now aims for all new investments to the company's fleet to be electrical, as the operational experiences of using the electrical car have been positive. Furthermore, Pole Position Logistics explores the possibility of testing solar panels as a means to supply a battery charging unit during non-dark seasonal months. During months of 24 hours sunlight, the vehicles can be charged during nighttime, whilst solar panels recharge the battery pack during the day. The goal is to operate electrical vehicles within the company's fleet fully by solar power during the summer months (Pole Position Logistics, 2015).

Another obvious point for electrification would be establishing power from land for the increasing cruise traffic visiting the port of Longyearbyen. The shipping industry emits CO2, Sulphur dioxide (SOx) and nitrogen oxide (NOx). Furthermore, black carbon from shipping in the Arctic gathers on top of the ice, and is known to further accelerate the Arctic ice melting. Therefore, harbor facilities enabling shore-side electricity supply would constitute an important contribution for improved local air quality. Bellona has actively contributed to the development of the ISO standard for shore-side electricity supply for ships in harbor, and through our cooperation with Color Line and the port of Oslo we have contributed to the establishment of the first high-voltage facility for shore power in Norway. Overall, there is growing attention to the environmental benefits of shore power in the Norwegian society and amongst policy makers. For the ship-owners, conversion to shore power will also have positive economic effects.

Traffic in Longyearbyen harbor is increasing, but is at the same time located in a very vulnerable environment. Reducing local emissions from ships in the harbor is therefore all the more important, and the effects are substantial. Bellona estimates that for engines operating on heavy oil, every kg of fuel emits 3.1 kg of CO_2 - every 24 hours. The equivalent for diesel based engines is 3.2 kg CO_2. Table 1 below gives and overview of estimated CO_2 per 24 hours for small, medium and large cruise ships.

Table 1 CO_2 emissions per day, cruise ships in harbour

Size of cruise ship	Average effect (kW)	Emissions of CO_2		
		g/kWh	Tonnes/hour	Tonnes/day
"Small"	3 000	210	0.63	15.12
"Medium"	5 000	210	1.05	25.2
"Large"	8 000	210	1.68	40.32

Source: Bellona, 2015

As Table 1 shows, 20 – 30 tons of CO_2 are emitted every day from the larger cruise ships in the harbor. Cruise traffic is set to increase in Svalbard, meaning that emissions must be curbed rather than increase. Bellona therefore encourages the Norwegian authorities to promptly assess possibilities for shore side electricity supply in Longyearbyen port.

Electrification of existing fossil energy use in Spitzbergen will undoubtedly trigger positive reductions in local pollution. However, the climate effect of electrification in Spitzbergen will be limited as long as the energy system continues to be based primarily on coal. Early ideas to convert Spitzbergen's energy supply into renewable production have been launched in the previous section. Furthermore, it is important to underscore the following: Spitzbergen, and the Longyearbyen settlement, represent solemn symbol arenas in Norway's efforts to battle global climate change. This alone makes Spitzbergen an ideal arena for piloting and demonstrating new climate technologies and innovations. As the debate about what Spitzbergen would become post coal mining industry is pressing itself upon us, Bellona urges Norwegian authorities to bear these perspectives in mind.

1.6 Key findings and recommendations

This report has shown that Arctic renewables are attractive resources, with abundant theoretical potential. Northern Norway's energy production is already founded on renewables. The region currently boosts an aggregated power surplus of around 5TWh per year. This brings substantial opportunities for green growth. Grid enhancement and suitable industrial growth are prerequisites for further renewable power development. Settlements on the Norwegian Arctic islands are currently supplied by diesel aggregates or coal power production. Here, the scope for energy conversion and broader electrification is significant. Particularly, Bellona argues that international expectations have been established for a green, resource-friendly Spitzbergen.

Based on our findings in this report, Bellona present the following recommendations to Norwegian authorities – to promote a clean, renewable and innovative Norwegian Arctic region:

Northern Norway:

- Norwegian authorities must prioritize extended and enhanced grid capacity in the Northern part of Norway. This is a prerequisite for new renewables, new economic activity, and suitable power export. In addition to Statnett's ongoing grid upgrades, additional grid planning across the Scandinavian North, such as the Arctic Circle Grid Initiative, should be taken into account.
- The 5TWh annual power surplus in Northern Norway brings opportunities for green growth. It can become the engine for new, long-term economic activities, powered by local resources and engaging local communities:
  - Arctic datacenters can become a green growth joker. This requires sufficient fiber infrastructure in the region and incentives to attract international customers.
  - Hydrogen production based on Finnmark's stranded wind power can provide new econom-

ic activity and jobs. This requires further project development, and is subject to a national framework for hydrogen.
- Eco-tourism is a local sector with unrealized potential, alone or as add-on to established concepts. Innovation in electrified transportation brings new opportunities that require further elaboration.

Norwegian Arctic islands:

- Norwegian authorities should investigate concepts for remote off-grid renewable energy solutions (potentially hybrid-solutions) for Jan Mayen, Bjørnøya and Hopen.
- Spitzbergen should be acknowledged as an ideal location to pilot and demonstrate new renewable technologies and climate innovations. Spitzbergen and the Longyearbyen settlement have become solemn symbol arenas in Norway's international climate work.
- The potential scenario of a Spitzbergen beyond coal mining activity calls for political attention in Norway. Bellona invites Norwegian authorities to explore the concept of Spitzbergen as an Arctic Renewable Energy Showroom, deploying different technologies for clean electricity production and storage.
- Bellona calls on Norwegian authorities to assess the possibilities for electrification of transport at Spitzbergen and shore-side electricity supply in the port of Longyearbyen.

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2. Renewable energy sources in the Murmansk Region: A brief introduction.

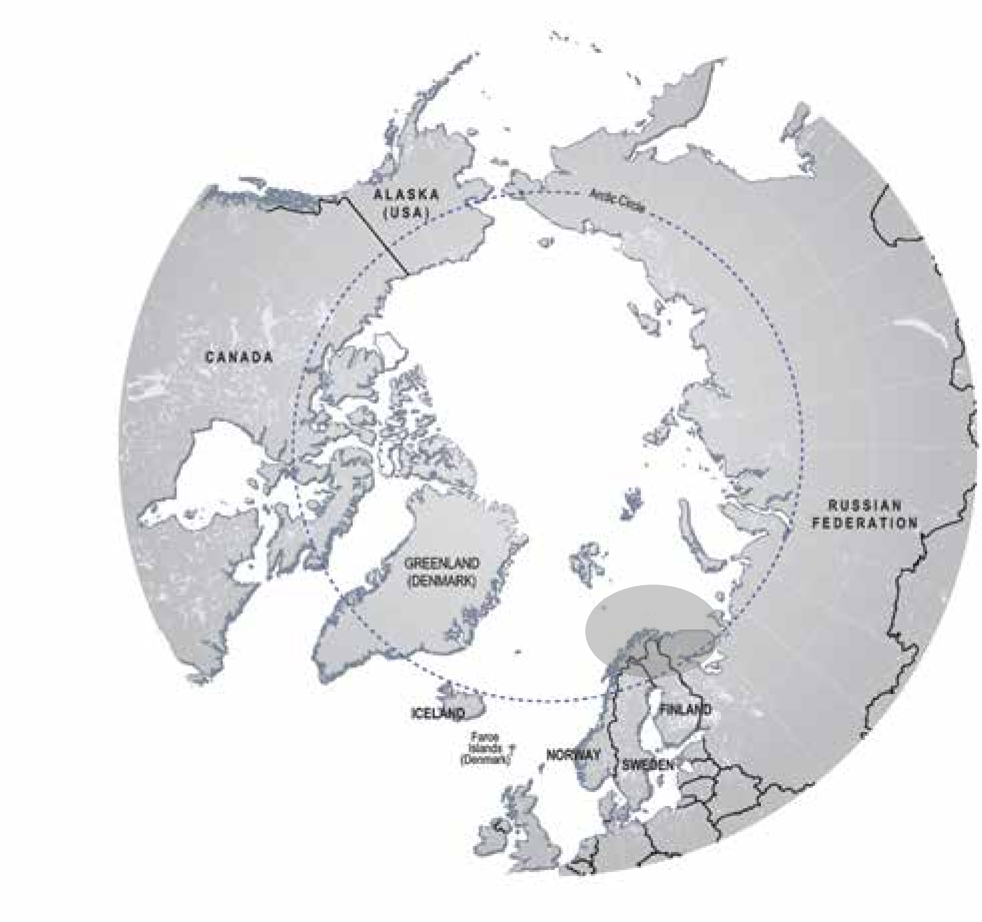
Author: Gradislava Potapova, Russia Group Advisor

In this chapter Bellona identifies various types and possibilities of using renewable energy sources on the Kola Peninsula of the Murmansk Region, in the northwest of the Russian Federation. To the west it borders on Norway and Finland, and to the south on the Republic of Karelia. At its greatest,the length from north to south is 400 km, and from west to east - 580 km. The area is about 144.9 thousand km2. Nearly the entire region is located above the Arctic Circle.

The Murmansk Region is an administrative province within the Northwestern Federal District, and coincides almost exactly with the territory of the Kola Peninsula. Among Arctic regions, the Kola Peninsula is the most populated region with over 766, 000 inhabitants, the majority of which, almost 93 %, are urban.

The Kola Area as it appears today is a result of heavy and continuous industrialization and militarization started back in Soviet times. It is unique on a world basis in regards to represented industries and natural resources, as the industrial complex of the Murmansk Region occupies about 0,5% of the entire Kola Peninsula. One feature of the Murmansk Region is the elevated anthropogenic loads on limited areas of dense population.

Figure 1.: Administrative areas (Grid Arendal, 2015)



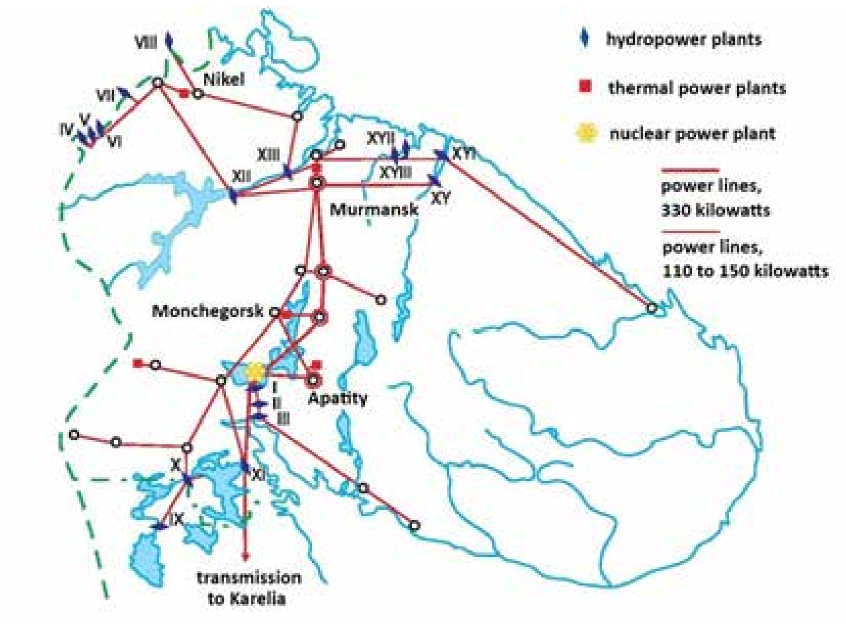
Icebreaker, Photo: Thinkstock

Nikel, a typical industrial town at the Kola Peninsula. Photo: Thinkstock

The main industries are ferrous and non-ferrous metallurgy, chemical industry, fisheries, mining of minerals and metals (with giant nickel deposits among others), navy and shipyard operations, including nuclearpowered icebreakers, submarines, and the Kola Nuclear Power Plant (Kola NPP). The latter is one of the main negative factors for development of renewable energy sources in the region.

Kola NPP is the only nuclear power plant in the county of Murmansk, and was the first nuclear power plant in the Soviet Union to be built north of the Arctic Circle. The nuclear power plant is centrally situated in relation to the heavy industry on the Kola Peninsula, 15 km west of the town of Polyarnye Zori on the shores of Lake Imandra. The monotown of Polyarnye Zori grew in parallel with the construction of the nuclear power plant. The nuclear power plant is the most important employer in the town, employing approximately 6,000 of the town's 21,300 inhabitants.71 The industrial towns of Monchegorsk, Kirovsk, Apatity and Kandalaksha are located within a radius of 120 km of the Kola Nuclear Power Plant. The distance from the Kola NPP to the Norwegian border is only 240 km.

Quite often the energy regulator in Murmansk Region would ask the area's hydro energy producers to limit generation and delivery to the local grid because they had to load the capacity of the Kola NPP and keep its reactors in operation. Kola NPP annually produces between 11 and 12 TWh, which is 50 to 60% of the total energy capacity on the Kola Peninsula. The main consumers of the energy are the mining industry and the surrounding cities of Polyarnye Zori, Monchegorsk, Kirovsk, Apatity and Kandalaksha, which consume more than 70% of the energy. Kola NPP itself consumes about 8% of the energy production. The rest of the production, about 20%, is exported to Karelia, Leningrad and Finland.



Map 2. Electric power networks of the Kola Power Grid. [9]

Hydropower plant cascades: I-III: Nivsky (Niva) Cascade; IV-VIII: Pazsky (Paz) Cascade; IX-XI: Kovdinsky (Kovda) Cascade; XII-XIII: Tulomsky (Tuloma) Cascade; XV-XVI: Serebryansky (Serebryanka) Cascade; XVII-XVIII: Teribersky (Teriberka) Cascade.

In regards to centralized power networks, the majority of the Murmansk Region's urban and rural energy consumers receive their power from the regional Kola Power Grid. The grid's total installed capacity exceeds 3,700 MW and is unique in composition: It derives electricity from 17 hydropower stations; five thermal power plants; the Kola NPP; and a tidal power plant Kislogubskaya, the only one in operation in Russia. All these sources supply power to a unified high-voltage transmission network (Map 2) for distribution managed via central dispatch. The Kola grid is connected by 330 kilovolt overhead transmission lines with the Republic of Karelia, to the southwest of the Kola Peninsula, and, via Karelia, with the unified power grid of Northwest Russia. High-voltage power lines also link the Kola power system with those of Norway and Finland.

Centralized power supply is available on roughly one half of the territory of the Murmansk Region, or to over 99 % of total population. At the same time, several dozen settlements, due to their locations at considerable distances from the grid and low levels of power consumption, do not have access to centralized electricity supply and instead receive their power from small diesel-fired stations running at capacities of between 8 and 500 kW. This often means that power supply is only available for 8-10 hours per day. Application of renewable energy sources for electricity production and heating purposes, can and should therefore play an important role in the sustainable development of the outlying areas of the region, by providing local residents with the necessary heat and electric power supply and thus raising their standard of living.

According to Bellona`s present study, the Murmansk Region could cover its entire energy need without nuclear power if all the hydro energy capacity were more efficiently used. Furthermore, wind energy, which is not yet present in the region in full scale, could contribute to the region's energy production and thereby eliminate the need for nuclear energy in the region. For deeper discussion on the nuclear issue in the Murmansk Region, see the Bellona Nuclear Report. [1]

2.1 Renewable Energy Sources in the Murmansk Region: Current status

As discussed,, renewable energy is presently not widely used on the Kola Peninsula. The capacity of power installations running on renewable energy in the Murmansk region is about 19000 kW. In 2014, in collaboration with The Ministry of Energy, Industry and Housing Utilities of the Murmansk Region, Bellona published a complete Register of installations powered by renewable energy sources in the Murmansk Region. [2]

The number of power installations running on renewable energy per late 2015 include:

a) A hydroelectric plant, Kaitakoski, installed in 1959 – 11200 kW. According to Russian classification, only hydroelectric plants of 25 MW or less are characterized as renewable sources. This is therefore the only one of 17 hydroelectric plants on Kola Peninsula which is classified as renewable .

Hydroelectic plant Kaitakoski. Foto: Kolskiy JSC «TGK-1»

b) Kislogubskaya tidal power plant – 1500 kW, the first and currently only tidal power plant in Russia. The plant is officially registered as a Russian monument of science and technology. It consists of two parts, an old building from 1968 and a new construction built in 2006. [3]


Kislogubskaya tidal power plant (Foto: OAO «RusHydro»)

c) Bioenergy plants in Kuropta and Lyvenga – totally 5520 kW (4.75 GCAL/h)


Bioenergy plant in Kuropta- 1,75 GCAL/h (Foto: Kovdor Municipality)

Wood pellets instead of coal (Foto: Bellona)

d) Low-grade heat from installations in Murmansk and Monchegorsk, which include a geothermal energy mini station - 13 kW, and purified sewage energy installation – totally 213 kW.


Left: Geothermal energy installation in Murmansk (Foto: Bellona)
Right: Sewage treatment installation in Monchegorsk, 200 kW (Foto: The Murmansk Region`s Agency for Energy Efficiency)

e) Wind energy from installations in Murmansk, Molochnyi and Novaya Titovka – 214 kW (Not taking into account the windmill that was set off in a test mode in July 2015 by the LLC «Green House». Its capacity is 500 kW.)


Left: Wind power installation in Novaya Titovka, 9 kW (Foto: OOO «Murmansk»)
Right: Choose Clean Energy! Wind power installation in Murmansk (Foto: Bellona)

f) Combined renewable energy – 47 kW (includes combined wind-solar-diesel electric station set up in the village of Pyalitsa (Pic. 2.1 No. 8 below) with total capacity of 95 kW.

Pyalitsa Project (Foto: The Ministry of Energy Industry and Housing Utilities of the Murmansk Region)

The installation in the village of Pyalitsa is a pilot project of the regional government. The complex includes four wind turbines of 5 kW each, two diesel generators of 30 kW each and 60 solar panels with total capacity of 15 kW. The project realization in Pyalitsa will reduce the village`s fuel and diesel oil consumption with more than 50 % (fuel with minimum 60 tons per year and oil with minimum 0.3 tons per year). This will also reduce the self-cost of generated electric energy with at least 60 % and extend the exploitation time of diesel units with 25 %. The station will furthermore provide electricity 24 hours a day, an improvement on the previous eight hours. It is stated that use of this new equipment, based on renewable energy sources, saves the settlement 3.75 million rubles a year on diesel fuel deliveries into complex geography. [4]

The Murmansk Regional Government declared that such projects will be implemented in the settlements of Chavanga, Tetrino and Chapoma. In total, the three villages require 515 kW of energy. Some 175 kW (34%) of this will come from wind and solar sources, and the remainder from the four diesel generators. Plans show that they are going to implement 10 wind turbines of 10 kW, and four of 5 kW, as well as four 88 kW diesel generators, two 17.6 kW, and 300 solar panels with an installed capacity of 75 kW. The savings will equal 8 million rubles a year. By August 2015 the energy stations have already been installed in the villages of Chavanga and Tetrino.

g) Solar panels – 23 kW (installed in the framework of the Russian-Norwegian project 1996-2010 on utilization/decommissioning of Radioisotope Thermoelectric Generators (RTGs) and installation of alternative power sources in the Russian lighthouses and seamarks.)

Lighthouse Svyatonosskiy (Foto: http://www.lightphotos.net/)

2.2 Legal framework for using renewable energy sources in Russia

The main legislative act which describes the legal framework for use of renewable energy sources in Russia, is the Federal law on electric power [A], adopted in 2003 and since then amended several times. It sets a framework for the electricity market in Russia, identifying market participants, main regulations and responsibilities of governmental and non-governmental bodies to run and control the market. Provisions regarding renewables appeared in the law in 2007. For the first time, renewable energy sources were defined in state legislation for further legal purposes. The list includes:

- solar energy;
- wind energy;
- water energy, including energy of waste waters, with exception of using this energy on pump storage power plants;
- tidal energy;
- wave energy of water basins, rivers, seas, oceans;
- geothermal energy of natural underground heat powers;
- low-grade energy of the Earth, air and water with usage of special heat transfer medium;
- biomass, including plants and trees, grown specifically for energy purposes, and industrial and household waste with exception of waste from using hydrocarbonic raw materials and fuels;
- biogas;
- gas from industrial and household waste;
- gas from coal mining.

According to the law, the Russian electricity market should work on a basis of free trade and competition, although managing the national grid and transmission services are state monopolies and remain highly regulated by the government when it comes to electricity tariffs for people (households).

The electricity market in Russia is divided into wholesale and retail markets.

On the *wholesale electricity market* the main product is electric capacity, not electricity itself. By signing the contract, generators guarantee that they will be able to produce certain amounts of electricity as needed in each and every moment. Contracts are long-term (10 or more years). For more detail see chapter 3.3. On the *retail electricity market*, where the product is electricity itself, see chapter 3.4.

Both markets are competitive, with generators competing with each other to get the contract for delivering certain capacity or providing certain amounts of electricity. Electricity prices for people (households) are fixed by regional governments, prices for other consumers depend on the region. Most of Russian regions belong to the so-called pricing zone, where electricity prices are defined by free market rules, but not exceeding a certain level, which is stated by regional governments. Other regions belong to so-called non-pricing zone, where electricity prices are fixed by regional governments. For now, non-pricing zones include the Kaliningrad and Arkhangelsk regions, the republic of Komi and territory of the Far East (the Primorsky, Khabarovsky, Amursk regions, Jewish autonomous region and South-Yakutsky district of the republic of Sakha). [5]

Based on the above principles, theoretically, generators working on renewable energy sources have the same rights and access to the Russian electricity market as other generators.

The *Federal law on electric power* states the necessity to develop renewable energy in Russia, but at the same time delegates all responsibilities for adopting concrete support measures to the executive authorities. It does, however, list a few possible stimulating mechanisms, which the government can use to support power generation from renewable energy sources. Among them:

- subsidies from the federal budget to compensate for the cost of technological connection to the electricity grid for power plants, which work on renewable energy sources, with installed capacity not exceeding 25 MW;
- amount of power generated by renewable energy sources, which electricity consumers are obliged to purchase;
- obligation of the electricity transmitter to compensate losses in the grid primarily by purchasing electricity from generators working on renewable energy sources;
- special premium, which should be added to the equilibrium price of the wholesale electricity market, when purchasing electricity from renewable energy generators;
- long-term contracts for the delivery of capacity on the wholesale electricity market with renewable energy generators.

In practice these measures cannot be used without prior detailing from the government by adopting governmental acts. State government and regional governments can also introduce other support mechanisms by adopting special goal-oriented programs, either state, or regional.

For the moment the Russian government has adopted acts on subsidies for getting compensation for the connection fees [B, D, G], acts introducing competitive tenders for renewable energy projects on wholesale electricity market [F], and is working on acts on support mechanisms on retail electricity market [I].

2.3 National targets

National targets for generating power from renewable energy sources in Russia are set in several strategic documents. The main one is the Energy strategy of the Russian Federation till 2030 [C] (the Strategy). It outlines the intention of the Russian government to increase the share of electricity produced by renewable energy sources to 4.5 % in 2020 and around 7 % in 2030 (80-100 bn kWh per year). Till now the share of renewable energy sources in electricity production remains less than 1 %. The Strategy acknowledges further that per now 45 % of fuel in the Russian regions is being shipped/transported to them, instead of generated locally.

The strategy also defined strategic objectives for the use of renewable and local energy sources, as follows:

- reducing the anthropogenic impact on climate change while meeting growing energy demand;
- the rational use of available fossil fuels;
- maintaining the health and quality of life of the population; reducing government health expenditure;
- reducing the rate of increase in the costs of electricity transmission and distribution and related electricity losses; diversifying the country's fuel and energy mix;
- enhancing security of energy supply through decentralization.

Concrete support measures are to be described in the state program *Energy efficiency and development of the energy sector* [H], which was adopted in 2014 instead of its older version of 2010.

The program sets its own targets, which do not correspond with the strategy of 2009 (the Strategy). The target index is 2.5 % of electricity produced by solar, wind or small hydro-power in total electricity production by 2020. The target amount of electric capacity for newly established power plants working on solar, wind and hydro-power is 5,871 MW for the period from 2013 to 2020. The program allocates

190 million rubles from the Federal budget, which should support the implementation of the program with 95 million in 2014 and 95 million in 2015. Further financing of the program by the Federal budget is not planned. These funds should be used for compensation of technological connection costs, competitive tenders on wholesale electricity market, development of special tariffs for the retail electricity market and evaluation of renewable energy potential in Russia.

Bioenergy is not included in this program, although in the program on development of bio-technologies in the Russian Federation for the period till 2020 [6], adopted in 2012, an allocation of around 367 billion rubles in 10 years for developing bioenergy technologies in the program on energy efficiency was 'promised'.

Since 2014 the Ministry of Energy has been preparing a new energy strategy until 2035. Its draft is available on the website of the Ministry [7] and should be adopted in autumn 2015. The draft strategy sets new targets: (1) by 2035 2,2 % of electricity should be produced by renewable energy sources, which is approximately 34-35 billion kWh per year; (2) by 2035 3.7 % of newly installed capacity should be of generating facilities working on renewable energy sources, which means more than 18 GW.

The draft strategy suggests certain ways of possible state support for the renewable energy sector:

- compensation of technological connection costs (all necessary acts are adopted by now);
- removal of grid connection barriers for renewable energy facilities (the government started work on this and set a number of targets, including reduction of days needed for the connection procedure from 281 to 40 [8]);
- subsidies to cover interest on credits taken for production development by generators using renewable energy sources (has to be developed in governmental acts);
- development of measures of state support of industry and research institutes to provide the renewable energy sector with Russian machinery, components, and advanced technologies (has to be developed in governmental acts);
- transfer of technologies and their localization on Russian production facilities, which produce components for power plants working in renewable energy sources (has to be developed in governmental acts).

2.4 Compensation of technological connection costs

In order to be eligible for the compensation of the technological connection costs the generator should be qualified as a renewable energy generating facility and meet the special criteria. Qualification criteria were specified in 2008 by governmental Act no. 426 [B], and criteria for getting the compensation were stipulated in 2010 by governmental Act no. 850 [D].

A power plant can be qualified as a renewable energy generating facility if it generates electricity from renewable energy sources or combines it with other sources, is connected to the national grid and included in the scheme and perspective electricity development plan of the region where it is situated.

The electricity market council, which is a non-commercial partnership of all the main players on the Russian electricity market, is responsible for the qualification procedure. Since adoption of the act on qualification, 18 generating facilities managed to get a status of qualified renewable energy facility, including four solar power stations, the wind power stations, six hydro-power stations, two geothermal stations, one biomass thermoelectric power station, one power plant powered by gas from industrial and household waste and one biogas power plant.

Two years later the Ministry of Energy issued eligibility criteria for getting the compensation of connection fees, as follows [D]:

- the generator must be qualified as a renewable energy generating facility in accordance with the procedure specified in the Act no. 426;
- installed capacity of the generating facility must not exceed 25 MW;
- the generating facility must be put into operation after the entry into force of the amendments to the Federal Law on electric power concerning renewables dated 04.11.2007;
- the generator must not be subject to insolvency proceedings;
- the generator must not be in a process of liquidation.

Three years after the criteria were set, the Ministry of Energy issued an order to define the rules for the procedure of getting the subsidy [G]. According to these rules a qualified generating facility can get a subsidy covering no more than half of its connection costs, but not exceeding 30 million rubles and only in case certain funds are allocated in the Federal budget for the current year.

2.5 State support scheme on the wholesale electricity market

In 2013 the Russian government adopted an Act on state support of renewable energy projects on the wholesale market [F]. It established an annual competitive tender among renewable energy projects. Winners get a 15-year contract on delivering power capacity on the wholesale electricity market with the price which can cover their operational and capital costs.

In order to participate in the competitive tender the projects should meet certain requirements:

- projected generating facility should work on solar energy, wind energy or hydro-power with installed capacity not exceeding 25 MW;
- part of machinery and equipment on the projected facilities should be produced on the territory of the Russian Federation (55-65% for wind-power stations, 50-70% for solar stations, 20-65% for hydro-power, depending on the year of their application), so called localization criteria;
- duration of the construction should not exceed 4 years;
- capital costs per 1 kW of the installed capacity should not exceed certain amount which is defined in the governmental act for different generating facilities;
- each project should have a guarantee from the larger energy supplier with installed capacity exceeding 2500 MW or a bank guarantee.

Since the adoption of this Act there were two competitive tenders held. Both of them showed that conditions of these tenders are more attractive for solar project and less attractive for wind and hydro-power projects. As a result 65 solar projects, eight wind projects and three hydro-power projects got state support. Their total installed capacity is 1,081 MW, which is only 21 % from the planned numbers. The first generating facilities with total installed capacity of 35 MW should have been put into service in 2014, but did not manage to do so and started to pay fines. The problem was mostly in meeting localization criteria. The first solar station, which won the tender, was put into service in 2015 in the Orenburg region.

A competitive tender in 2015 was planned for June but was postponed till late November 2015 because the Government needed to review amounts of capital costs due to recent currency fluctuations.

2.6 State support scheme on the retail electricity market

In the beginning of 2015 the support scheme on the retail electricity market was adopted by the Government [I]. It encourages electricity transmitters to compensate grid losses by purchasing electricity from renewable energy generators, including those working on solar, wind, hydro-power, biomass and biogas.

The price for electricity should ensure return on investments for renewable energy generators for 15 years. Though the amount of electricity bought from renewable energy generators as a compensation of losses is restricted to 5% from the forecasting losses. From the other side generators should be qualified as renewable energy facilities, be connected to the grid, be included in the regional electricity development scheme and meet localization requirements similar to the ones on the wholesale market.

Inclusion in the regional electricity development scheme should be based on the results of the regional competitive tenders, organized by regional governments. Specific electricity prices (tariffs) will also be calculated on the regional level, taking into account marginal capital and operational costs, market profit level, payback period and localization level (to be taken into account from 2017). In the isolated areas, which are not connected to the national grid, the following principle should be held: construction of a renewable energy facility should decrease the electricity price.

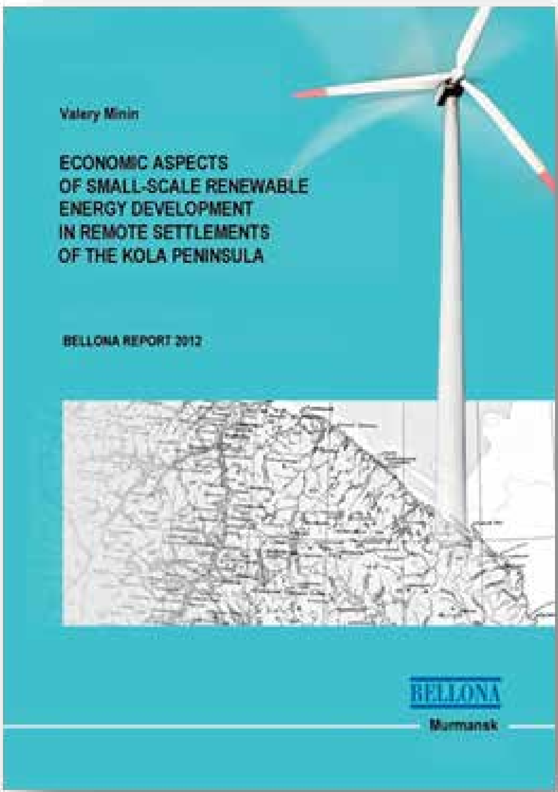
Nevertheless, before this scheme starts working, regional governments should adopt all necessary procedural documents.

Analysing the current legal framework for renewable energy, several conclusions could be made for upcoming years:

- adoption of necessary acts for stimulating renewable energy sector goes slowly and it will be likely developed further;
- lowering national targets means limited federal support for renewable energy projects for the upcoming years;
- regions have enough freedom to set regional programmes and invent own mechanisms to stimulate development of renewable energy sector if there is a political will for that.

2.7 Renewable energy potential for off-grid consumers in Murmansk Region

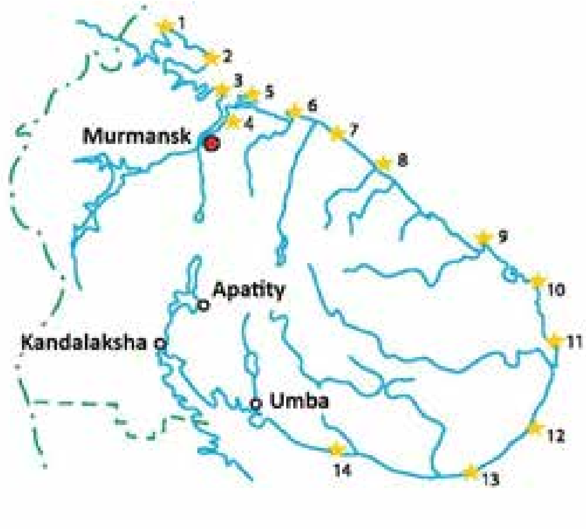
In 2012 Bellona published its scientific study on renewable energy potential in the Murmansk Region [9], which provides a starting point for the presentation, main conclusions and recommendations below.



Bellona`s Report 2012 [9] (Foto: Bellona)

A special category among the region's energy consumers is formed by many remote off-grid consumers, such as weather survey stations (Pic. 2.1), lighthouses (Pic. 2.2), coastal border outposts, fisheries, and deer farms.

Pic. 2.1. Remote weather stations operating in Murmansk Region
1 – Vayda-Guba; 2 – Tsyp-Navolok; 3 – Kharlov Island; 4 – Kolmyavr; 5 – Svyatoy Nos; 6 – Tersko- Orlovsky; 7 - Sosnovets Island; 8 – Pyalitsa; 9 – Chavanga; 10 – Kashkarantsy; 11 – Kanozero; 12 – Nivankyul.



Pic. 2.2. Lighthouses run by the Hydrographic Service on the coast of the Kola Peninsula.
1 – Vaydagubsky; 2 – Tsyp-Navolok; 3 – Set-Navolok; 4 – Tyuvagubsky; 5 – Kildinsky Severny (North Kildinsky); 6 – Teribersky; 7 – Russkiy; 8 – Kharlovsky; 9 – Svyatonossky; 10 – Gorodetsky; 11 – Tersko-Orlovsky; 12 – Sosnovetsky; 13 – Nikodimsky; 14 – Kashkarantsy.

Due to their location at considerable distance from the grid and low levels of power consumption, the villages do not have access to centralized electricity supply and instead receive their power from small diesel-fired stations running at capacities of between eight and 500 kW.

Fuel deliveries to such consumers are generally fraught with significant logistical difficulties. They depend on seasonal factors and the current condition of the traffic network, with the result that the prime cost of electric power and heat produced at local diesel-fired power stations and boiler plants ends up being several times higher than that of electricity and heat provided to consumers served by the grid.

The search for alternatives in the Murmansk Region is confined by, among other factors, a lack of experience, poor information and a strong diesel lobby.

Bellona`s study shows that immense resources of renewable energy are technically available to the Murmansk Region. While evaluating the prospects of practical application of these renewable energy sources, the analysis below demonstrates that wind energy converters and small hydroelectric power stations could be the optimal solutions for off-grid power supply in remote settlements of the Kola Peninsula.

Wind energy could be used both for electric power production, in combined operation with diesel-based power plants, and for heating purposes, to assume part of the load currently covered by boiler plants running on fossil fuel. The second option – using wind energy for heating purposes – offers the advantage of turning wind from a climate factor responsible for high heat losses in the severe weather conditions of the Arctic North into a reliable energy source that will supply the much-needed heat during the windiest periods of the year. The Murmansk Region also has a great number of small rivers with potential for the development of small-scale hydropower projects.

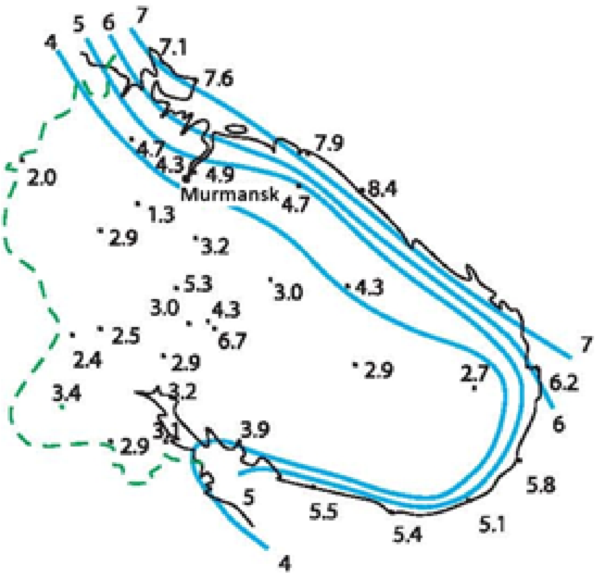
2.8 Potential by RES type

2.8.1 Wind power

Summarizing the analysis of the wind energy potential of the Murmansk Region, one can draw the following conclusion: wind energy resources are not evenly spread throughout the region. Wind intensity is noticeably above average level in the coastal and mountainous parts of the peninsula. On the coasts of the Barents and White seas, in fact, wind conditions are nothing short of unique, with annual average wind speeds reaching six to eights meters per second at an elevation mark of 10 meters. This, simply put, is one of the windiest areas in all of Russia's European North. Such favorable factors as wind speed recurrence rate, the presence of stable prevalent winds, and the winter wind intensity maximum, combine to create unquestionably favorable conditions for successful use of wind energy converters in the area.

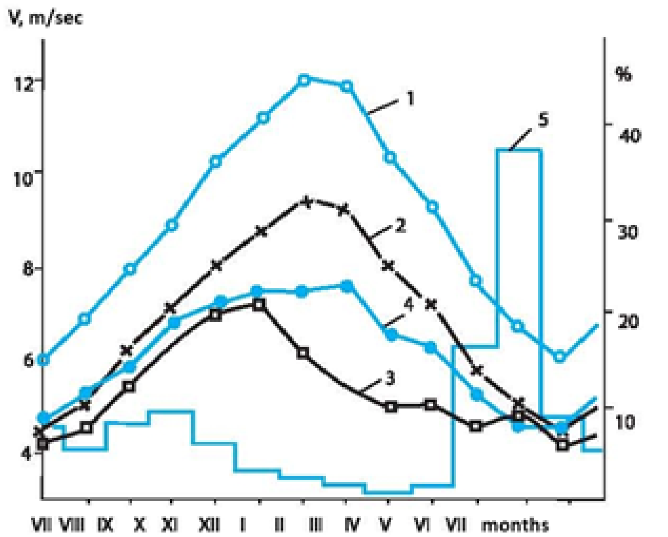
Wind as a source of energy is described as a total of its aerologic and energy properties unified into a concept of wind power cadaster. These cadastral characteristics include such parameters as average annual and monthly wind speeds, annual wind cycle, and recurrence rate of wind speeds. Data on average annual wind speeds serve as the basic parameter used to estimate the overall wind intensity level, allowing, as a first approximation, for an assessment of the prospects available for the application of wind energy converters in a particular area.

Results of analyzing data compiled from a series of wind speed observations carried out at the Kola Peninsula's weather survey stations over a period of 20 years are summarized in Pic. 3.1.



Average multi-year wind speeds (in meters per second) at a 10-meter mark above the ground in a flat open-surface area.

Pic. 3.1: Because wind speeds depend on the area's land relief, the wind's elevation above the ground, and other factors – conditions that vary considerably from one survey station to another – survey data have been analyzed with these parameters processed accordingly for a comparison under commensurable conditions, namely, flat open surface and a set wind elevation. The map shown in Pic. 3.1 demonstrates that the highest wind speeds can be observed in the coastal areas of the Barents Sea. Here, on the northern coast of the Kola Peninsula, and at an elevation equaling 10 meters above the ground, wind speeds reach seven to nine meters per second. It is worth noting that the farther inland from the shoreline, the more noticeable the decrease in wind speeds. But the higher the elevation, the greater are the values of average multi-year wind speeds. Incremental changes in elevation from 10 meters to 20, 50, and 70 meters result in average multi-year wind speed increases of 0.6, 1.7, and 2.1 meters per second, respectively.



Annual cycle of average monthly wind speeds (V, in meters per second) on the islands (1) and coast (2) of the Barents Sea, on the coast of the White Sea (3), in the Khybiny mountains (4), and a river hydrograph (5)

Pic. 3.2: The annual wind cycle, represented in Pic. 3.2, reflects seasonal changes in average wind speeds. On the Kola Peninsula, these changes are manifest most prominently on the northern coast, where the difference between the winter wind speed maximum and the summer wind speed minimum reaches 5 to 6 meters per second. The curves in Pic 2.2 show that in all areas surveyed, rather favorable conditions exist for efficient application of wind energy in the region. Maximum wind speeds are observed during colder seasons of the year and coincide with the seasonal period of peak electric power and heat consumption.

Wind energy could be used both for electric power production, in combined operation with diesel-based power plants, and for heating purposes, to assume part of the load currently covered by boiler plants running on fossil fuel. The first alternative is probably the best for the coastal communities of Tsyp-Navolok, Kharlov Island and Tersko-Orlovsky (Pic. 2.1, 2.2), where the average annual wind speeds at an elevation of 10 meters above the ground reach 7.1, 9.2, and 7.3 meters per second, respectively. Applying wind energy for heating needs in parallel operation with boiler plants in Tsyp-Navolok and Kildin (average annual wind speeds at a 10-meter elevation mark reach 7.5 meters per second in Kildin, Pic. 2.2, 3.1) will likewise result in considerable savings of the expensive fuel delivered to these localities from other regions.

2.8.2 Small hydropower

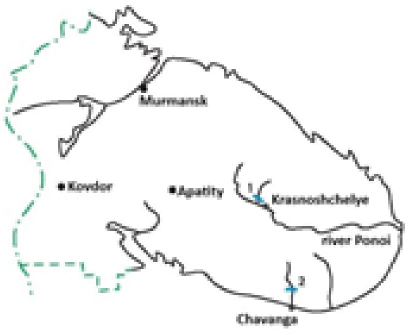
For a long time, the development of the energy production industry of Murmansk Region pivoted on a steadily expanding use of high-efficiency hydropower resources. By now, a considerable portion of the potential offered by the region's major rivers has been put to use; seventeen hydropower stations have been built in the Murmansk Region. The large and medium-sized hydropower plants are plugged into the grid and supply grid electricity via the system's high-voltage transmission lines.
As already mentioned, the term «small hydropower» is usually applied to generation facilities with capacity not exceeding 25 MW, built primarily to supply energy to isolated consumers or groups of small consumers. Because of this, only one of 17 hydroelectric plants – Kaitakoski plant – is qualified as a renewable energy facility on the Kola Peninsula.

The rivers that have remained untapped for power generation, though they have suitable sites for prospective hydropower development, are far removed from areas characterized by high energy demand, which implies sizable increases in the capital and operating costs associated with building new power stations here. Some of these sites are situated on rivers considered to be of great importance for fisheries management and the region's fishing industry, and construction of hydropower installations is not permitted. At the same time, grid electricity still remains inaccessible for many outlying villages, fishing settlements, lighthouses, weather stations, and other energy consumers. Construction of overhead power lines to bring grid electricity to these consumers is a costly enterprise, and these populations are forced to rely on fuel deliveries for local diesel-based power stations and heat-generating plants. The need to find a cost-effective off-grid energy source is the driving force behind the ongoing research into the potential and application prospects of local renewable energy sources, including the energy of small rivers.

In Russia's Arctic regions, because of the low population density – around 3 inhabitants per square kilometer – small hydropower stations can be expected to come with capacities below three to five MW. In a number of cases, a hydropower plant of a capacity ranging between less than a hundred to a few hundred kilowatts would in fact be viewed as the most appropriate option. Hydropower stations with an installed capacity of less than 100 kW fall under the category of micro hydropower. The flooded area per unit of installed capacity and the overall cost incurred by building a small hydroelectric power station are, as a rule, greater than those involved in the construction of large and medium-sized installations. But the expediency of using a small river for electric power generation is nonetheless determined by local factors.

As far as prospects for the development of small hydropower on the Kola Peninsula are concerned, the following can be noted: the hydropower potential of small rivers implies an unavoidable dependence on the stream flow. What possibilities are offered by this renewable energy source is limited to the extent to which suitable sites are available for the construction of small hydropower stations in close vicinity to the prospective consumer. In the Murmansk Region, such locations would be coastal communities residing near a river mouth, as well as a number of localities in the region's central and western parts that are also situated near stable river flows.

For instance, a small hydropower plant on the river Chavanga, at a distance of 7.5 kilometers from the settlement of Chavanga is such prospective hydropower plant site option (Pic. below alternative 2). This is also a recommended alternative for the settlement of Krasnoshchelye, at the Yelreka river (Pic. below alternative 1).



Transmission of power from small hydropower stations to the grid involves significant additional costs and is considered to be economically ineffective. But the appeal of using small hydropower stations for off-grid electricity supply has grown considerably in the past years both in Russia and elsewhere in the world.

2.8.3 Solar power

To evaluate the potential of solar energy and the prospects of its application in the Murmansk Region, one could look at the results of surveys taken at the region's actinometric facilities, i.e. measurement of the heating power of electromagnetic radiation facilities. There are several such stations in the region, of which three – Dalniye Zelentsy, Khibiny, and Umba – compile data that provide information on the solar radiation conditions in the north, south, and central area of the Kola Peninsula, respectively. An analysis of this information shows that the potential annual values for cumulative solar radiation exposure of the Murmansk Region on clear days correspond to between 1,280 and 1,360 kikWlowatt-hours per square meter. High cloudiness, which is characteristic for the Murmansk Region as a whole, decreases direct solar radiation exposure here by 60 to 75 %. However, the same conditions are responsible for increasing diffuse radiation exposure by more than 50 %. When actual weather conditions and cloud cover are taken into consideration, the resulting total annual solar radiation exposure fluctuates between 650 and 850 kWh per square meter (see Pic. 3.3).

The higher the sun is over the horizon, the less the depth of the atmosphere that sunbeams have to penetrate, and, accordingly, the greater the amount of solar radiation that can reach the Earth's surface. Pic. 3.4 summarizes data on cumulative solar radiation exposure for polar latitudes (as measured at Khibiny actinometric station, 68° north latitude), moderate climate areas (Minsk, Belarus, 54° north latitude), and Russia's south (Sochi, 44° north latitude). As demonstrated in the graph, global solar radiation exposure in the north and south differ most during the winter months. In the summer, exposure values become commensurate on account of the increased length of day in the northern latitudes. In overall annual values, the subpolar areas of the Kola Peninsula will receive 1.3 times less solar radiation than the middle latitudes, and 1.7 times less than the south.

Pic. 3.4 illustrates seasonal changes in both solar energy supply and the potential yield of wind power installations in the examined areas. As solar and wind energy are in an antiphase, they can compliment each other, which serves as a premise for the joint application of their resources.

The diurnal solar radiation cycle is first and foremost determined by the changing values of the sun's elevation during the day. The highest irradiance values are observed during daylight hours in June through July and reach, on average, between 0.4 and 0.5 kW per square meter. On some days, favorable weather conditions with minimal cloud cover obscuring the sun will allow for an increase in irradiance values to between 0.9 and 1.0 kW per square meter.

When assessing solar energy potential and prospects for its application, sunshine duration becomes an important value as it determines the scope of incoming solar energy and the conditions for the efficient use of solar energy systems. In the Murmansk Region, which lies almost entirely above the Arctic Circle, the average monthly number of hours of sunshine fluctuates widely throughout the year – between zero hours in December and 200 to 300 hours in June and July (see Table 1). Cumulative annual sunshine duration is about 1,200 hours in the north of the region, but increases to some 1,600 hours in its southern parts.

Table 1 Monthly breakdown of sunshine duration (hours) in various localities of Murmans Region.

Locality, name	Month												Total per year
	I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII	
Tsyp- Navolok	0	27	103	173	169	234	209	145	86	44	6	0	1,195
Dalniye Zelentsy	1	37	114	176	177	25	204	141	84	48	6	0	1,213
Murmansk	1	32	121	203	197	246	236	146	73	43	3	0	1,297
Yaniskoski	3	41	126	200	195	242	258	162	74	48	4	0	1,353
Khibiny	3	37	128	166	200	258	243	176	97	54	10	0	1,372
Krasnoshchelye	4	38	135	186	180	256	256	157	75	45	9	0	1,335
Umba	8	43	151	198	229	309	309	204	115	67	15	0	1,632
Chavanga	10	42	136	200	221	302	302	196	96	63	17	2	1,575

On the whole, the technical resources of solar energy in the Murmansk Region are considerable – around 1013 kWh. But these resources are scattered across a vast area and have low density. Significant investment will be required to develop practical application of solar energy in the region.

The examination of prospects for solar power development in the Murmansk Region shows that solar energy resources available to the region are not insignificant. But because this is a territory located almost completely beyond the Arctic Circle, the region's potential solar energy supply is still 1.5 to 1.7 times less than that available to the country's southern regions. Maximum solar radiation exposure values in the

Murmansk Region are observed in the summer, while consumer demand for energy reaches its peak in the winter.

Considering all of the above, use of solar power installations in Russia's Arctic regions could be a viable alternative – but only in such isolated cases when other energy supply options are associated with even higher costs. One such case, for instance, is the need to provide uninterruptible telephone communication, via a satellite link, between the Murmansk Region's remote localities – weather stations, lighthouses, and similar – and the rest of the Kola Peninsula or Russia's other regions. The good example that is already implemented on Kola Peninsula is the use of combined wind-solar integrated power systems for payphones in remote villages by the Murmansk branch of JSC «Rostelecom». Additionally, Norway and a number of other countries have since 1998 provided financial support to the program of installing solar panels in place of radioisotope thermoelectric generators used as power sources at lighthouses and navigation beacons in Russia's Northwest. Altogether on the coastline of the Barents, the Kara, the White and the Baltic seas 251 radioisotope thermoelectric generators have been replaced in the course of this program.

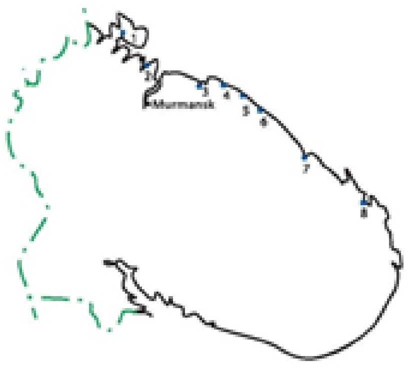
2.8.4 Tidal power

An important characteristic of tidal energy is the reliability of its average monthly supply both across the yearly and multi-year spans. It is owing to this feature that tidal energy, despite its intermittent availability throughout the diurnal cycle, is a powerful source of energy and can be recommended for use in combined operation with reservoir hydropower plants. In such a combination, the pulsating, intermittent, but nonetheless invariably guaranteed flow of tidal energy, regulated by the energy of hydropower plants, can contribute to power supply to provide for the necessary electric power load.

In contrast to the energy derived from river flow, assessing the potential of tidal energy is tied to certain peculiarities. Where the capacity of a hydroelectric power plant is determined by the product of water head and flow rate, the average capacity of a tidal power plant will be calculated by multiplying the area of the basin to be dammed for the future plant by the value of tidal range to the power of two.

A reconnaissance survey of the shorelines of the Barents and White seas to research optimal sites for the potential construction of tidal power plants was carried out in Russia by Lev Bernstein as far back as 1938 to 1941. Already then, a number of suitable sites for construction of tidal power plants were identified along the coast of the Kola Peninsula (see Pic. 3.5).

Because of the relatively low height of tides washing against the peninsula's coastline – the average tidal range is two to three meters – and the limited basin areas that could be cut off by a dam, construction of tidal power plants in many locations are from the start an economically inefficient option. The concept of an efficient tidal power plant suggests that such a plant will have a capacity of hundreds of MW, but such capacity range greatly exceeds the levels required to meet the demand of small remote communities whose energy needs are examined in this report.



Pic. 3.5. Possible distribution of tidal power plants on the Kola Peninsula's coastline. 1 – Ozerko; 2 – Kislaya Bay; 3 – Severnaya; 4 – Dalniye Zelentsy; 5 – Porchnikha; 6 – Rynda; 7 – Drozdovka; 8 – Lumbovsky.

The following conclusion presents itself: Tidal energy resources available to the Murmansk Region are found along the entire 1,000-kilometer coastline of the Kola Peninsula, but successful application of this type of energy is only possible in certain locations where a suitable basin exists, such as a bay, that can offer a higher range of tidal wave (four to five meters or higher).

In that regard, a noteworthy site is Lumbovsky Bay (Pic. 3.5 No. 8) of the White Sea, in the east of the Kola Peninsula, where the average tidal height is 4.2 meters, and the size of the water basin suitable for use by a tidal power plant is between 70 and 90 kilometers. A tidal power plant with a capacity of several hundred megawatts could be built in this location. An installation of such capacity, however, would imply a large, grid-connected energy-generating site.

At present, there is only one tidal power station, Kislogubskaya, in the Murmansk Region. The plant is located in Kislaya bay (Pic. 3.5 No. 2) of the Barents Sea, near the Ura-Guba settlement. The height of the tide in the narrow part of the Kislaya bay reaches 5 meters.

Kislogubskaya tidal power plant (Foto: OAO «Malaya (Minor) Mezenskaya Tidal Power Plant»)

2.8.5 Wave power

Wave energy possesses a higher energy density than wind and solar energy. Ocean waves accumulate wind energy as they move over significant distances, and it is this advantage that make them a "natural energy concentrate." Another advantage of this renewable energy source is the availability of ocean waves to a large group of consumers residing along a coastline. The disadvantages of wave energy, on the other hand, is its periodic instability, dependence on ice conditions, as well as difficulties associated with converting and transmitting the power derived from ocean waves to the consumer onshore.

Table 2 shows different values of wave energy flux in Russia's seas. The values pertaining to the Barents Sea, which borders on the far northeastern part of the Atlantic, are commensurate with those describing the potential of ocean wave energy available at the shoreline of Norway, where these values reach 25 to 30 kilowatts per meter.

Taking this into account, one can conclude that in the Barents Sea, average annual wave energy can be within the range of 20 to 25 kilowatts per meter. For the White Sea, the wave energy potential is much lower – no more than 9 to 10 kilowatts per meter.

Table 2 Wave energy flux in Russian seas.

Name of Sea	Wave energy flux, kW per meter
Sea of Azov	3
Black Sea	6-8
Baltic Sea	7-8
Caspian Sea	7-11
White Sea	9-11
Sea of Okhotsk	12-20
Bering Sea	15-44
Sea of	21-31
Barens Sea	20-25

When considering the practical and, especially, economic aspects of using tidal energy for power generation, the prime cost of electric power produced by ocean wave energy converters is at present still quite high – much higher than the prime cost of power produced by conventional power facilities. In the future, as fossil fuel prices rise and wave energy converters improve in design and efficiency, this gap in costs will gradually decrease. The prospects of using ocean waves for power production will thus improve accordingly. But this report details options that could be available to the small remote communities of the Murmansk Region in the short term; because of this, ocean wave energy as a renewable energy source has been left outside the margins of this study.

The following, however, can be concluded when assessing the possibilities of using ocean wave energy for power generation: The potential of wave energy in the Barents Sea is, on average, 25 kilowatts per one meter of wave front edge. This is comparable to the wave energy flux observed in the Sea of Okhotsk (29 kilowatts per meter) and is two or three times less than that in the Bering Sea (45 kilowatts per meter) or the North Atlantic (70 to 75 kilowatts per meter). In the White Sea, this value is even lower – at around 10 kilowatts per meter.

Furthermore, application of ocean wave energy in the conditions of the Arctic climate presents certain challenges – first and foremost, because ocean waves reach their peak during the colder seasons of the year, when air temperature falls below zero and metal components or structures (such as those that may be used in an ocean wave energy converter) become exposed to icing. For this reason – and also because of the short length of day in the Arctic (the Polar Night) – the operation of wave energy installations will be difficult in the Murmansk Region. Another technological problem will be the transmission of power produced by these installations to the consumer onshore. As a whole, this makes application of ocean wave energy a challenging option in the Murmansk Region.

2.9 Bioenergy resources

2.9.1 Biodegradable wastes from livestock and poultry breeding farms

The development of agricultural industries worldwide has resulted in a significant concentration of livestock and poultry populations on farms and farming complexes and, by extension, in the accrual of large quantities of organic waste, namely, liquid dung and poultry droppings near the farms. In broad use at present is the method of so-called anaerobic recycling of biodegradable livestock waste, a multi-stage process of decomposition of organic matter in special containers, or digesters, where organic waste is processed in an oxygen-free environment by anaerobic microorganisms and produces methane and carbon dioxide as a result.

The biogas generated as a result of waste fermentation comprises 60 to 80 percent methane, 20 to 25 percent carbon dioxide, and lesser quantities of hydrogen sulfide, hydrogen nitride, and nitrogen oxides.

Through a series of relatively simple operations, biogas can be freed from the carbon dioxide and the traces of hydrogen sulfide and thus distilled to the grade of natural gas. As natural gas, purified biogas can be compressed into gas cylinders and used as fuel for automotive vehicles or burned to generate heat energy. The heat-generating capacity of biogas is 5,000 to 6,000 kilocalories per cubic meter.

In the Murmansk Region, the severe climate and weather conditions do not allow for a vigorous development of the agricultural and farming industries. Still, there are several large and medium-sized pig, poultry, and cattle (dairy) farming complexes in the region. The majority of these are located near the regional center; other farms operate in the vicinity of large industrial centers such as Apatity, Kirovsk, Kovdor, or Monchegorsk. All these agricultural and farming complexes are, as a rule, connected to the grid and receive their electric power and heat energy from major external power sources, which solves the problem of independent power and energy supply for these consumers.

2.9.2 Wastes from the wood-logging and wood-working industries

A considerable portion of the Murmansk Region's wood resources was exhausted in the 1930s to1980s. Timber felled in the region nowadays is no longer used for the production of paper or pulp. In the past five years, wood harvesting output has fallen by 3.2 times – from 125,000 to 39,000 solid cubic meters. Part of the lumber resources is sold for export, but the majority is used locally to produce sawn timber. For the time being, lumber and woodwork wastes are only used in very insignificant quantities as fuel for electric power supply and heating. A number of various obstacles still hinder the development of full-scale application of wood-logging and woodwork wastes. Lumber camps are often located at great distances from industrial centers or other populated areas, and no developed infrastructure is available to effectively collect, transport, or recycle wood-logging waste.


Bioenergy plant in Lyvenga, 3 GCAL/h (Foto: The Murmansk Region`s Agency for Energy Efficiency)

2.9.3 Fishery and fish processing waste

Waste produced by the fish processing industry was used to a great extent in the 1980s as animal feed at fur farms. For a variety of reasons, the fish processing industry in the Murmansk Region has seen a pronounced decline in the last fifteen years, with both the output of seafood and fish products, and by extension wastes, falling significantly. At the moment, fish processing waste is not considered for application as a power-generating option.

To summarize, the Murmansk Region's bioenergy resources – livestock and poultry breeding waste, primarily – are concentrated around large enough populated localities that receive their power supply from the grid. These are the areas where issues of biodegradable waste reprocessing have relevance, and these issues are being dealt with both by the management of the farming enterprises in question and by representatives of the regional administration.

But taking all of the above into account, the prospects of using agricultural and farming wastes, wastes from the wood-logging and woodworking industries, as well as fish processing waste as bioenergy resources for potential power and heat generation in the Murmansk Region are not under consideration at the moment.

2.10 Key findings and recommendations

This chapter analyzes the potential and the economic aspects of using renewable energy installations in the Murmansk Region, where nearly the entire region is located beyond the Arctic Circle. The study focuses especially on its remote communities that have no access to central power supply because of the great distances that separate these form the rest of the region and, comparatively to gigantic industrial players, the low rate of energy consumption. Fuel deliveries to these communities are contingent on the condition of the roads and other transport networks and show a clear seasonal dependence on the availability of transport links. Both the lack of a developed transport infrastructure and the complicated multi-stage shipping logistics result in fuel losses during transportation and increased fuel costs for the end consumer.

Therefore, application of renewable energy sources for electricity production and heating purposes can and should play an important role in the sustainable development of the outlying areas of the region, by providing local residents with the necessary heat and electric power supply and thus raising their standard of living.

The Kola Nuclear Power Plant, which represents 50 to 60% of the total energy capacity on the Kola Peninsula, is considered to be one of the main negative factors for renewable energy source development in the region. Quite frequently the energy regulator in the Murmansk Region has asked hydro energy producers to limit generation and delivery to the local grid because they had to load the capacity of the Kola NPP and keep its reactors in operation. According to Bellona`s present study, the Murmansk Region could cover its energy needs without nuclear power if all the hydro energy capacity is used more efficiently. Also the wind energy, which is not present in the region in full scale, could contribute to the energy production, thus eliminating the necessity of nuclear energy in the region. The search for alternatives in the Murmansk Region is also confined by a lack of experience, poor public information and a strong diesel lobby.

Another important aspect with this chapter is a detailed study of the Russian electricity market and legal framework for using renewable energy sources in Russia, including the main legal acts and national targets for generating power from renewable energy sources. This aspect is particularly important for defining economic potential of the renewable energy sources in any region. The technical – or hypothetical – capacity for energy production on renewable energy sources will always be higher than its economic potential. In regards to wider use of renewables in Russia, much depends on state government and regional governments, as the measures introduced in Federal law on electric power need detalization from the government by adopting governmental acts. We describe all state support mechanisms that exist for the moment, which also apply in the Murmansk Region.

There are immense resources of renewable energy available to the Murmansk Region – the sun and wind, small rivers, tides and ocean waves, energy of organic waste/biomass, etc. – but they are scattered across a vast territory and have, for the most part, low concentration. The analysis demonstrates that wind energy converters and small hydroelectric power stations would be the optimal solutions for off-grid power supply in remote settlements of the Kola Peninsula.

Wind energy could be used both for electric power production, in combined operation with diesel-based power plants, and for heating purposes, to assume part of the load currently covered by boiler plants running on fossil fuel. The first alternative is probably the best for the coastal communities of

Tsyp-Navolok, Kharlov Island and Tersko-Orlovsky. Applying wind energy for heating needs in parallel operation with boiler plants in Tsyp-Navolok and Kildin will likewise result in considerable savings on the expensive fuel delivered to these localities from other regions.

The Murmansk Region has a great number of small rivers with potential for development of small-scale hydropower projects. In Bellona's view, among the off-grid communities of the Murmansk Region that could benefit from using small hydropower for reliable and cost-efficient electricity supply, the settlements of Krasnoshchelye and Chavanga are such localities where mini hydroelectric power plants could be best recommended for these purposes.

Finally, bringing renewable energy to off-grid rural localities of the Murmansk Region will not only help achieve significant savings in fuel and other costs, but will also contribute to a healthier environment in these communities, thus greatly improving their overall standard of living.

2.11 List of references

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List of main legal acts on renewable energy

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C. Order of the Ministry for energy of the Russian Federation no. 1715-r dated 13.11.2009 'On adopting the energy strategy of the Russian Federation for the period until 2030' - http://minenergo.gov.ru/aboutminen/energostrategy/

D. Governmental Act no. 850 dated 20.10.2010 'On the approval of criteria for the provision of subsidies from the Federal budget to compensate the costs of the technical connection of generating facilities with an installed capacity not exceeding 25 MW and that have been qualified as renewable energy facilities to entities, which own such facilities or have other proved possession rights' - http://www.consultant.ru/document/cons_doc_LAW_106071/

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3. Arctic mining: feasible without unacceptable environmental damage?

Author: Karl Kristensen, Advisor, Industrial waste

The Arctic is receiving growing interest as a supplier of minerals. A world with increasing human population and consumption rates puts increased pressure on remaining mineral resources. Extraction of minerals comes at a huge cost however in terms of environmental damage. Receding Artic glaciers makes new areas available for mineral extraction in an area with especially vulnerable ecosystems and human communities. Is mineral extraction in the Arctic with an acceptable environmental footprint possible, and what criteria will have to be met for this to occur? This chapter presents an analysis of the best available and methods of mineral production when it comes to environmental performance, and compares legislation, licensing practice and inspection routines for verification of compliance with license conditions between different Arctic nations. The analysis is followed by a set of recommendations on how to limit environmental damage caused mineral projects in the Arctic. Mining projects in both Arctic and sub-Arctic areas are considered.

Mining in the Arctic: coal mine on Svalbard (Photo: Thinkstock)

3.1 Key factors concerning mining projects in the Arctic

In the following section, four key factors for Arctic mining are considered. What drives new and continued Arctic mining operations? What are the geological conditions necessary for a mining project? Which technology is available for mineral extraction and processing, and finally: what are the environmental consequences of Artic mineral operations?

3.1.1 Drivers for mining projects

Minerals are critical inputs in maintaining a modern way of living. All materials that can't be grown or harvested from biomass must be mined in some way. This includes all metals, building materials like limestone and gypsum, industrial minerals like olivine and rutile and agricultural nutrients like phosphate and potassium. Mineral products aren't just necessary in covering basic human needs, but also crucial inputs in efforts to replace a petroleum based economy with renewable energy alternatives.

Figure 1 Minerals are crucial inputs in renewable energy solutions and battery technology Illustration: Bellona

Global human population growth and expanding economies creates larger demands for minerals in a world with limited reserves. This creates pressure to explore new areas for available ores. USA, Japan and European Union have all implemented policies to secure their supply of critical raw materials [1].

All artic nations including Norway, Sweden, Finland, Denmark (Greenland), Russia, Canada and USA (Alaska) have ongoing mining operations in their Arctic and subarctic territories, with a potential to increase this activity significantly. Although increased mineral prices caused by higher demands has been predicted, current prices for many minerals, including iron, copper and zinc, are low and have not caught up with the corresponding megatrend, causing some analysts to question whether the need for finding new mineral reserves have been overstated in a short term perspective. Mineral prices are historically known to be volatile. This is illustrated by a steady rise in mineral prices that boomed from 2002 to 2008, followed by a significant drop in the price of many minerals from 2012 – 2015 [2]. Although the long term expectation is for mineral prices to recover, few investors seem willing to enter into new Arctic mining projects given the current situation. The cooling of the Chinese economy has reduced the global demand for many minerals. In addition expectations regarding the economic performance of many of the worlds advanced economies are not very high. Uncertainty regarding the continued length of the European stagnation, the effectiveness of Japanese economic reforms and the real strength of the US economy makes it hard to predict when this situation will change.

Table 1: overview of some key data for central mineral products

Mineral/element	Annual global production 2013 (metric tons)	Proportion of earths crusts (%)	Approximate energy consumption per ton metallic product
Sand and gravel	15 billion	not relevant	3
Cement	3,5 billion	not relevant	6-8
Iron	1,24 billion	5	7-8
Photosphate rock	235 million	0,13	7-11
Aluminium	47,1 million	8,2	9-11
Magnesium (compounds)	46,9 million	0,095	12-20
Copper	18,1 million	0,006	
Zinc	13,5 million	0,0075	
Titanium (compounds)	6,1 million	0,6	
Nickel	2,55 million	0,009	15-44
Silver	26.100	0,0000075	21-31
Lithium (compounds)	25.500	0,002	20-25
Gold	2.790	0,00000031	

Source production data: World Mineral Production 2009 - 2013, British Geological Survey

3.1.2 Geological conditions for mining

The Earth's crust is composed of approximately ninety unique elements that with current mining technology, are mainly found in concentrations far too low for industrial extraction. Ores are mineral deposits where geological processes have concentrated elements or chemical compounds to levels where profitable extraction is possible. Volcanic activity and chemical deposition are examples of processes that can lead to the formation of ore. Ore forming processes are very slow and means that currently available ore deposits must be regarded as stored resources that can't be replenished in a human time perspective. Most minerals that are part of a product are lost when these products are discarded as waste. By incineration or landfilling useful elements and chemical compounds that the waste contains is blended together with other materials in a way that dilutes the concentrations in a way that complicates future recycling. In addition, airborne dust and sediment runoffs following waterways allow significant amounts of valuable minerals to spread over long distances, and will for a large part eventually end up as diluted sediments on the seabed.

Because extraction of minerals is done most profitable by utilizing highly concentrated ores, remaining reserves is becoming increasingly less enriched. Extraction of minerals from ores with lower content of relevant elements involves not only higher production costs but also higher consumption of energy and chemicals, larger waste volumes and landscape interventions per unit produced. Future mineral extraction based on today's technology will therefore have an increasingly negative environmental footprint.

In addition to damage to human health, mineral extraction causes irreversible scarring of terrain, damage to biodiversity and ecosystem services, release of toxins and greenhouse gases in addition to the accumulation of vast amounts of waste. Although stricter environmental standards and the development of better technology has led to reduced environmental footprint per unit produced in developed countries over the last decades, increasing production volumes and mining practices without any regard for environmental impacts in many developing countries results in increased negative global environmental footprint from mining operations. Since extraction normally occurs from the most concentrated ores, this leads to depletion that forces future extraction to rely on ore deposits of a lower quality. The size of the environmental footprint of a mineral product is largely a function of how concentrated the ore is. Halved mineral concentration in the ore often means that twice as large areas will be affected by the mining operation, and that energy use, chemical consumption and waste generation will double when producing equivalent amounts of mineral product compared to the relative footprint of high quality ore mining. At the current rate of extraction, it is likely that a significant portion of the environmental benefits associated with future technology improvements will be eaten up by steadily declining ore quality in the remaining minerals. The need for more intensive R & D efforts both in terms of efficient recovery and utilization of mineral resources is therefore crucial

Subsea mining

Many valuable mineral ores are located on the seabed. Metal ores are of special interest, and many are located around subsea volcanic formations along the Atlantic ridge, which passes through Iceland and extends all the way to Svalbard. Surveys of the subsea ores in the Arctic have so far identified few deposits of commercial interest, but this may change due to higher mineral prices, new technology or the discovery of more accessible ores [5, 6].

Subsea mining in international waters is regulated and controlled by The International Seabed Authority (ISA), based on the Law of the Sea Convention. This agency issues the rules operators of subsea mining projects are required to follow during prospecting, exploring and/or extraction of subsea minerals in sea areas outside national jurisdiction.

Plans for subsea mining do exists, but have yet to be implemented large scale in international waters. Because no industrial tradition for subsea mining exists, and many ores are located at areas outside any national jurisdiction, many questions remains to be answered regarding how and by who should revenues be taxed, and what environmental standards should be included in the license terms that subsea mining operators are required to apply by. A draft for regulations of exploitation of subsea minerals has been proposed by ISA, but has yet to be accepted [7].

There are large knowledge gaps when it comes to the environmental impact subsea mining may cause. When minerals are collected from the seafloor, all bottom dwelling organisms whitin the area where the minerals are collected will be removed as well, and when waste materials is pumped back to the seafloor the plume and sediments forming on the seafloor will smother most or all marine life in a large area. Only a fraction of the species comprising marine ecosystems has so far been described, and the extent of disturbance caused by the operation can therefore only be estimated with a large degree of uncertainty.

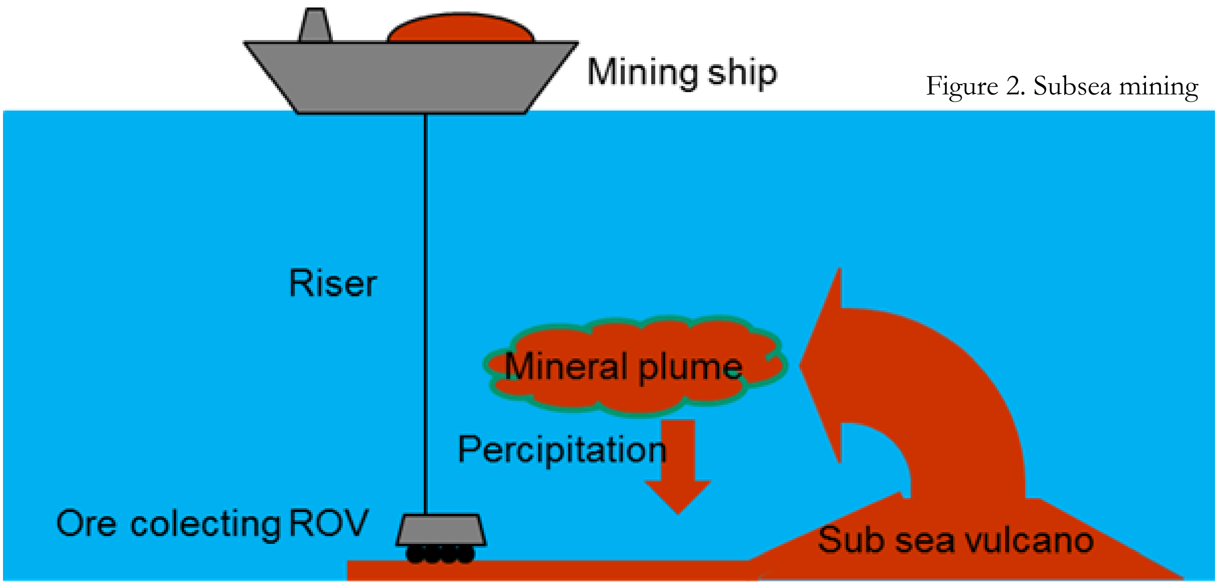

Figure 2. Subsea mining

Due to increased political tension in the Arctic, future subsea mining projects in the region may face increasingly complicated and uncertain framework conditions. The Arctic Council has played a leading role in coordinating efforts from the member states in finding common rules on how the region should be administered, but is experiencing increased pressure in different directions both from within, and from observer states that are taking an increased interest in available resources and transport routes that are becoming available due to climate changes. An increasing number of border disputes between Arctic nations are also arising.

3.1.3 Available technology and methodology for mining

How minerals are extracted and processed is determined by serval factors, most importantly the geological composition and localization of the ore. Minerals can be extracted through underground operations or open pit mining through a combined use of explosives and mechanical cutting and digging. The extracted ore is transported to a process plant by trucks, rail systems or conveyor belts. Permafrost, icing and low temperatures present additional challenges when it comes to moving minerals in the Arctic. In addition long transport distances often add additional costs to mining operations in the Arctic. In a Canadian study added costs for mining production located far north were 2 – 2,5 times higher than for mining projects further south [4].

An ore is processed by crushing and grinding it into particles of a suitable size. The desired minerals are then separated from remaining materials based on differences in density, magnetic or other physical or chemical properties. Chemicals are often used to increase the efficiency of the separation process. Since the usable fraction of most ores is low, large waste masses are generated. Most waste masses are deposited at landfills or even sea fills, but this practice remains controversial.

Technological development during the last decades has replaced some of the most hazardous chemicals with less damaging alternatives, minimized the generation of tailings through more efficient processing and alternative use of tailing masses, and found ways to minimize uncontrolled sediment escape and toxic leakage to the surroundings, although the remaining environmental footprint remains high. The potential for further improvements seems obvious, but depends on systematic R&D efforts.

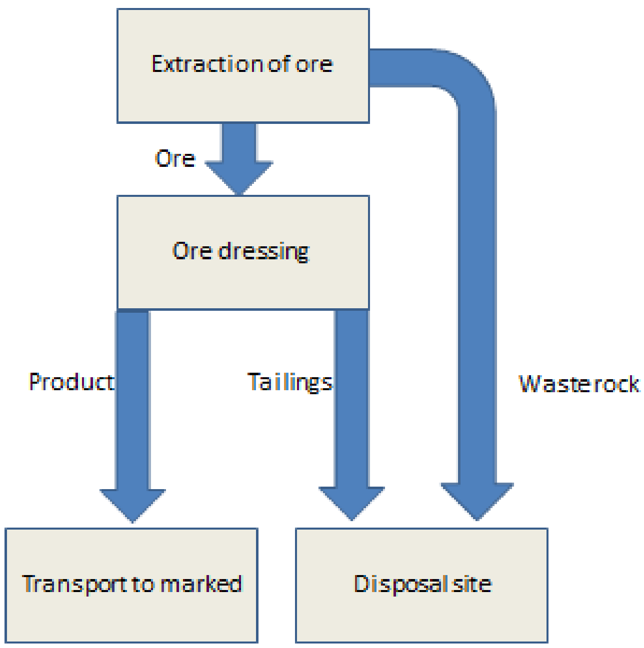

Figure 3. Overview of the main steps in mining

3.1.4 Environmental impacts of mining

Mining operations has always been associated with injuries and the risk of damage to workers and to the environment. Mines in historical times was often one of the worst places a person could end up, and although much has been done to ensure workers in a modern mine a safe working environment, the risk of a mine collapse, blasting accidents and contact with hazardous chemicals and mineral particles remains a clear health risk. Also toxic leakage from mines creating local pollution problems has been known since ancient times. Among negative environmental effects caused by mining are landscape scarring, disposal of large amount of waste rock and tailings and emissions of chemicals and greenhouse gases. Together these effects damage local ecosystems, and may lead to significant disturbance and inconvenience for local communities. Without necessary environmental standards or precautions applied to mining operations, these effects have the potential to become catastrophic.

Ecological damage and landscape scarring

Mining projects occupies not only areas where the ore is located and waste materials are disposed. Additionally areas are required for infrastructure such as processing plants, administrative buildings and transport routes. Ecosystems within several square kilometers may be affected by a major mining project. When mining is done through open pit extraction, all vegetation and soils over a large area is removed, and then the topography of the area is drastically changed when large masses is excavated and moved around. Both rivers and aquifers can be greatly affected. When mining is done through underground extraction, landscape disturbance is significantly reduced. Due to the slow growth rate of Arctic vegetation, limitation of the areas affected by a mining project should be an especially high concern.

Example of landscape scarring due to mining (Photo: Thinkstock)

Disposal of waste rock and tailings

Mining operations will normally generate two types of waste. Waste rock is surrounding masses that must be removed to reach the ore. Tailings is the residual matter after the crushing and separation processes in the ore dressing where the valuable minerals are separated from other components. Waste rock and tailings will normally differ from each other both in terms of mechanical properties and chemical composition. While waste rock will be in the form of gravel with small residues of explosives components, tailings normally takes the form of finely ground sand with low particle size and small residues of process chemicals and explosives residues. The more low-grade ore mined, the greater amounts of waste will be left with per unit produced. In practice, a large mining project gives rise to several million tons of waste masses per year, and for countries with a large mining industry, the mining waste will sometimes exceed the total amount of waste arising from all other activities. For example, a single iron mine in Norway, (Sydvaranger mine, gruve AS) in 2012 generated more mineral waste than the total amount of municipal waste generated in the whole country in the same period. If residual masses can't be used for other purposes, some sort of disposal is needed. Three different ways to dispose of waste masses exist: These are landfills, seafillins and backfills.

Example of disposal site for tailings (Photo: Bellona)

Chemical emissions

Chemicals used in mining include explosives and products used to support the separation processes in the ore dressing. Some mining operations use extremely hazardous compounds such as mercury and cyanide in the extraction process. Large volumes of highly corrosive compounds such as sulfuric acid and sodium hydroxide are also used in some mining operations. .

Traditionally the mining industry has used chemicals that are toxic, resistant to degradation and

bio-accumulating. Today chemical products with lower eco-toxicological damage potential are normally available. Modified processes have also been developed to utilize chemicals more efficiently. Although the environmental footprint per produced unit caused by chemicals has been reduced in many mining operations thanks to better products and more efficient use, pollution caused by mining chemicals is still a significant concern. Emissions of organic chemicals from mines in the Arctic is an especially high concern due to longer degradation rates caused slow metabolisms in the colder temperatures.
Energy consumption and climate gas emissions

Approximately 10% of global energy production is used for extracting and processing mineral products [8]. Because energy consumption is largely proportional to the recoverable proportion of mineral ore, and because extraction of minerals in the future will happen in lower grade ores, energy consumption in mining is expected to rise. However, more energy efficient processes are to some extent expected to compensate increased energy use. A future mineral industry based on renewable energy has the potential to eliminate greenhouse gas emissions from the sector.

Emissions to air from mining operations (Photo: Thinkstock)

3.1.5 Conflicts with local communities and other industries

Mining projects have a long history of conflicts with local communities Many Arctic mining projects have been criticized for destroying important pastureland and fisheries used by indigenous people for several generations. Regulations such as the ILO convention and national legislation in most Arctic countries grant indigenous people special rights within their traditional living areas. Many artic countries have recently seen more protests from ingenious groups against new mining projects inside their territories. This continued high conflict level may indicate that their rights are being tested more than before.

3.2 Special ecological challenges in the Arctic

Arctic terrestrial ecosystems exist under extreme environmental conditions with low temperatures, short growth seasons and within areas with low biodiversity and densities of available biomass compared to ecosystem conditions further south. Slow growth rates for vegetation that often operates on the border of their metabolic limit is especially vulnerable to environmental disruptions. These factors make it especially difficult to restore damaged vegetation in the Arctic.

Arctic vegetation Photo: Thinkstock

Arctic marine ecosystems are more diverse and contain a higher abundance of biomass compared to Arctic terrestrial ecosystems, partly due to large scale migration of fish, seabirds and marine mammals during the spring season attracted by large amounts of plankton around the receding ice edge.

Persistent organic pollutants accumulate in Arctic ecosystem to a larger degree than further south. For volatile pollutants this is caused by a process called global distillation where these compounds are transported by northern wind currents until they reach climate conditions where they precipitate permanently. This is an important reason for the unexpectedly high levels of POPs (persistent organic pollutants) found in many Arctic species especially high in the food chain. Humans living in the Arctic unfortunately often suffer from the same condition.

Climate changes affect the Arctic more than any other part of the planet, and the mean temperature is expected to increase more in this region than anywhere else [9]. This will lead to massive ice melting. Arctic summer ice will continue to shrink and the ice cap on Greenland is expected to recede significantly, releasing enormous amounts of fresh water into the North Atlantic. In addition the permafrost will continue to withdraw further north. As ice melts, trapped pollution will be released into the environment increasing the risk of fatal exposure to affected organisms.

Ongoing and expected changes in environmental conditions present a serious threat to many Artic species. Although few Arctic species has so far been listed as endangered, local populations of Arctic species with unique genetic material face increased risk of becoming extinct due to the stress caused by a rapidly changing environment.

3.3 Mining industry in the Arctic

The Arctic has a long mining history dating back over 200 years – from the early gold explores in Alaska to the famous Klondike gold rush. In Sweden Arctic mining has been going on since the 18th century. Open pit mining started in Kiruna as early as 1890, and underground mining continues to this day. The most northern Arctic mines are located on Svalbard where Norwegian and Russian companies have been extracting coal since 1890 [3].

Arctic mining is limited with only around 50 active mines north of the Arctic Circle. The output from the average Arctic mine is large however, and minerals from Arctic mining accounts for a larger part of world production than the small number of mines would suggest. Several large mines are located south of but still close to the Arctic Circle [3].

High production costs drives Arctic mining projects to large scale production, and explains why small scale Arctic mining in the future also seems less likely due to lower profitability. Arctic climate changes lead several effects for mining operations. Receding glaciers lead to increased accessibility for harbours and ore deposits. At the same time loss of permafrost increases challenges for transport over land.

3.3.1 Mining industry in Nordic countries

Mining in Norway

The Norwegian mineral industry employs around 6000 workers, exports 60 % of extracted minerals and has an annual turnover of around 12 billion kroner (kr) .The annual turnover consists of construction material (gravel) for 4,7 billion kr, industrial minerals for 2,9 billion kr , metals for 2,5 billion kr and natural stone for 0,9 billion kr. A significant part of this production takes place in the Arctic and Sub-Arctic regions and major companies include Sydvaranger Gruve AS in Finnmark which produces iron and Store Norske Spitsbergen Gruvekompani AS in Svalbard which produces coal. In 2011 around 1300 workers were employed in mineral production in Arctic and subarctic regions in Norway [10]. Due to fluctuating prices on minerals in the past years companies have been struggling financially, and in November 2015 Sydvaranger gruve AS was declared bankrupt

Mining in Sweden

At the end of 2012, Sweden had 16 active ore mines. Important northern mines include the iron ore mines in Kiirunavaara, Gruvberget and Malmberget. The Kiruna mine is the largest Arctic mine, and also the largest underground iron ore mine in the world. Aitik is Europe's largest copper mine and is also Sweden's largest gold producer. The Swedish mining and mineral industry employs around 8400 workers and exports products with a value of EUR 17.5 billion [11]. Compared to Norway, Sweden has a larger mining industry and also a significant technology and consultancy sector that provides products and expert services to mining community worldwide.

Mining in Finland

Finland's mineral industry, including the technology sector employs around 7000 workers and has a total turnover of 808 million EUR. Around 40 larger mines are currently in operation. Only a small fraction of the minerals extracted in Finland is exported, as most is refined by Finnish industry. In addition Finland's technology sector supplies the international mining industry with equipment and expertise. Here, 4900 people are employed and the annual turnover is 2 billion EUR [12]. A large part of Finland's mining industry is located in the northern part of the country in Arctic and subarctic climatic conditions.

Mining on Greenland (Denmark)

Greenland has long been expected to rise as one of the world's new leading supplier of minerals due to increased areas becoming available for mining as a result of receding ice caps. High production costs due to lack of existing infrastructure and harsh weather conditions have so far together with an unexpected drop in mineral prices prevented Greenland's limited mining industry to boom. Since gaining political autonomy from Denmark in 2009 the government of Greenland has worked to attract new mining projects, but so far to little effect. Although large mining projects are likely to come to Greenland eventually, the time frame for this is considered by most experts to still lie many years into the future [13].

3.3.2 Mining industry in Russia

The mining sector is central to Russia's raw material based economy. Drawing on the vast mineral resources Russia supplies around 14 % of all minerals consumed worldwide [14]. Despite its dominant role in the Russian economy, the mining sector faces many challenges including dilapidated infrastructure and government corruption and lack of transparency [15]. Russian mining industry has received considerable negative international public attention due to its low environmental standards and many examples of disruptive pollution. One of the largest Russian mining companies is MMC Norilsk Nikcel which operates several sites, including facilities in Monchegorsk, Zapolyarny and Nikel, all close to the Norwegian and Finnish border. Emissions of sulphuric oxides and heavy metals have devastated local vegetation and create cross border environmental concern [16].

The mineral town of Nikel. Photo: Bellona

3.3.3 Mining industry in Canada

Canada has a large mining sector that employs 63 775 workers, and had in 2013 a total turnover in of 46,9 billion Canadian dollars. A significant number of mines are located in the northern Arctic part of the country and includes Nuavut (gold), Raglan (nickel and copper), Yellowknife (diamonds) and Grand Falls (copper and zink) [4].

3.3.4 Mining industry in USA

Non-metalic mineral mining operations in Alaska employed 4940 workers and contributed 1 155 million USD to GDP in 2012 [17]. Important mines include Fort Knox Mine Gold (Alaska's largest surface gold mine), Greens Creek Mine (Silver, zinc, gold, and lead), and Usibelli Coal Mine.

3.4 National government practices regulating mineral operations in the Arctic

3.4.1 Government regulation in Nordic countries

Many parallels exist between the governmental systems regulating the mining sector in Norway, Sweden and Finland. Denmark is the exception with the autonomous territory of Greenland, and has for this reason implemented mining policies that will be assessed separately.

National mining strategies for Nordic countries and Greenland

The governments of Norway, Sweden, Finland and Greenland have all published a national mineral strategy in accordance with recommendations from the EU-commission. Compared to the strategy of the other two countries the Norwegian strategy is most explicit regarding targets to reduce environmental impacts from mining, but paradoxically also most hesitant to describe measures on how to fulfill these targets. The Swedish strategy contains the most ambitious and detailed description on how to close the mineral-loop through recycling and urban mining, and also defines the development of technology for urban mining a target for future export.

Mining operations in all Nordic countries are regulated by a Mineral Act and an Environmental Protection Act. Several licenses and consents must be obtained during the lifetime of a mining project. Ore extraction requires a mining permit as described in the Mineral act. The operation also requires an environmental permit based on conditions laid out in the environmental protection act and must include both extraction and processing of ore in addition to waste treatment. Normally the permit also presents requirements for how the mining area shall be rehabilitated after the mining operation is at an end. In some cases clear demands are made when it comes to the application of best available environmentally technology and methods, but this is complicated by the fact that these considerations may vary depending on the specific conditions for different projects. A permit is also required to planning and construction additional infra-structure for a mining facility under the Land Use and Building Act. Damage and degradation to local ecosystems are limited by the Nature conservation act, although this law contains few concrete regulation measures. For all countries the EU directives on water framework and mineral waste apply. The directives demand systematic monitoring and measures to protect the chemical and biological qualities of water.

Regulations given in the Mining Act and Land Use and Building Act are followed up by the Directorate of Minerals and Mining, while regulations under the Environmental Protection Act and Nature Conservation Act are followed up by the Environmental Protection Agency.

Exploration activities also require several permits and licenses as described in the Mineral Act, but these depend on where exploration takes place and which methods are used. Exploration of mineral resources is coordinated through the National Geological Survey.

Table 2: overview of central permits and concents necessary in phases of mining project

Phase	Mining Act	Environmental Protection Act	Land Use and Building
Exploration	Notification of exploration plan or perspective permit	Notification of pilot activities	
Construction		Environmental impact assessment Environmental permit Waste treatment plan	Acceptec plan for mining project
Mining and processing	Mining permit	Environmental impact assesment Environmental permit Waste treatment plan	
Closure	Closure and rehabilitation plan		

Government regulation practice on Greenland

Greenland gained political autonomy from Denmark in 2009, and has since taken charge of the governmental administration of mining projects. This is regulated through the Mineral Resources Act. This act regulates all mineral extraction on Greenland, including oil and natural gas, and also contains the environmental legislation for mining operations, as Greenland does not have a separate Environmental Act. Although the Mineral Act requires environmental impact assessments for any large mining project, small scale mining projects do not face the same requirements [18]. The Mineral Resource Act requires that best available technology and practice is used to protect the environment, but does not clearly make use of the precautionary principle or polluter-pays-principle. Operators of a given license are required to limit pollution and other unwanted environmental effects as much as possible, but the law specifies no general prohibition of pollution that is not licensed. In addition, although the law requires compensation for environmental damage caused by unintentional pollution, it lacks clear and detailed rules for fines and sanctions when environmental license conditions are disregarded. Greenland has a population of only 56.000 and limited resources when it comes to funding its own bureaucracy. With a very short history and experience with self-government and a significantly weaker environmental legislation compared to the Nordic countries, it raises a general concern of whether environmental issues within a growing mining sector on Greenland can be addressed and dealt with in an adequate manner.

3.4.2 Government regulation practice in Russia

The Federal Law On Subsoil is central to the governmental administration of the Russian mining sector. The law is connected to several ministerial orders and regulations that regulate the licensing regime for the mineral sector. License requirements normally include commitments to reach annual production targets and limits pollution. The environmental legislation includes restrictions on emissions to the air, water and soil, disposal of hazardous waste, decommissioning and cleanup operations post-production and protection of flora and fauna. Pollution control legislation includes a pay-to-pollute-principle and obligations to pay compensations for environmental damage caused by pollution. Corruption and lack of transparency severely restricts consistent compliance from the Russian mining industry's with Russian environmental law. Russia is ranked no. 127 on the Corruption Perceptions Index 2013 of Transparency International, and Russian government procedures are known for their lack of transparency and accountability. In particular, Corruption affects both the judicial system and public procurement [15]. Environmental legislation is also affected by this situation [19].

3.4.3 Government regulation practice in Canada

The Canadian regulatory system for mining operations is complicated by government regulations on both federal and local level. A mining project in Canada requires several permits and consents from both specific mineral and environmental legislation. The Canadian Environmental Assessment Act (CEAA) regulates most Canadian mining projects regarding required environmental impact studies.

3.4.4 Government regulation practice in USA

The National Strategic and Critical Minerals Production Act is a key component of the American regulatory system for the mining sector. When the Act was adopted in September 2013 it replaced a large part of earlier mining regulations. Additional mining laws are the Federal Mining Law and the Federal Mine Safety and Health Act. Several additional laws regulate the environmental performance of the mining sectors and include the Clean Air Act, Clean Water Act, National Environmental Policy Act, Safe Drinking Water Act and Solid Waste Disposal Act.

3.5 Best available technology and practice in mining

Mining can be done in many different ways. Choosing the right solutions when planning a mining project is crucial for both cost efficiency and optimal exploitation of the mineral resource, and key to minimize the environmental impact. To some degree, best environmental practice depends on the specific operating conditions for a mining project. However, some general guidelines are summarized in the following sections. Best available technology and technique (BAT) means to apply mining equipment and methods that lead to cost-efficient exploitation of the mineral resources with minimal environmental impact. Best environmental practice (BET) means to apply equipment and methods that reduce the negative environmental impacts of mining far as possible.

3.5.1 Design of the mining operation

Ore can either be mined through open pits or underground mining. Often these two methods are combined, where initial mining is done through open pit, and in a later phase switches to underground mining.

In most cases open pit mining (or mountain top removal) has a significantly larger negative environmental footprint. The pit itself creates a large scar in the landscape where all vegetation is removed and all ecosystems are destroyed or displaced. In addition open pit mining creates much more waste rock than underground mining which has to be disposed, leading to additional areas being affected by the fillings. The ore to waste rock ratio for metal ores has been reported to vary between 1:1 to 1:14,5 depending on whether the open pit or underground mining method is being used [20]. This ratio can be reduced even further by backfilling waste rock back into the empty spaces created during underground mining leading to ore - waste rock ratios as low as 1:0,4 [20]. Due to larger areas being affected by open pit mining this method also requires larger efforts to rehabilitate and restore landscape and vegetation after closure. Large pits are more or less impossible to restore to an environment comparable to pre-mining conditions, and must for this reason be considered as irreversible impacts. Dust pollution, leakage of contaminated water and noise are more of a problem in open pit mining than in underground mining. In underground mining vent fan noise may be an issue, and the air intake should be designed and placed with this in mind.

Mine designs should include detailed plans for the entire life span; from construction to closure. It is important to design sufficient space for treating contaminated water. Incorporating urban ores into the processing of a virgin ore is another possibility to consider. During closure and abandonment of mining areas and waste disposal sites, it is crucial to leave these areas in a safe and stable condition to avoid accidents and limit local pollution. This work demands considerable skills and resources. During the demolition phase maximum recycling of demolished materials should be upheld. Restauration of topography and soil cover and revegetation should also be planned to allow for optimal and speedy restauration of local ecosystems.

Open pit mining (Photo: Thinkstock)

3.5.2 BET for resource efficient ore exploitation

Optimal exploitation of mineral resources from an ore depends on a mine design that creates and maintains access to the space where the ore is located and on efficient separation processes where a minimal fraction of the ore product is left in the tailings.

Compared to open pit mining, underground mining may limit ore access due to the need for stabilization of the underground mine through walls and rock formations that must be left for support of the stability of the mine. Sub-optimal backfilling may block or limit access to remaining ore if done too early or into areas where residual ore unsuitable for extraction may later become economically favorable to extract.

An optimal separation process involves grinding the ore to its optimal particle size, and a separating scheme that recovers as much mineral product as possible.

All mining projects should consider the possibility to include urban ore as an additional source of raw material into the ore dressing process. Incorporation of urban ore will both utilize a waste resource that will otherwise most likely be lost, and at the same time reduce the footprint from virgin ore extraction. However, if done without proper control h, urban mining may lead to unwanted contamination and other challenges in the production process.

The water treatment process and dust collection can also be used to recover minerals if they are present in sufficient quantities, although it is unlikely that this represents a significant additional source of mineral resources.

3.5.3 BET for minimization and disposal of tailings

The management of tailings and waste rock should be planned to minimize the amount of waste material that requires long term disposal. Both waste rock and tailings may be utilized as a resource in other industries, or as construction material. Great care should be taken to find alternative purposes for these materials. High costs and energy consumption during transport limits how far mineral waste of this type can be transported, before costs and environmental impact due to climate gas emissions becomes prohibitive. This barrier is especially significant for many Artic mining projects where low population density and long distances combined with less developed transport infrastructure makes cost effective distribution of mining waste to other projects more difficult. It is very important that regional planning processes take available mineral waste from local mining projects into account and consider this as a potential input in all relevant projects. Regional planners should also help to coordinate this action where possible.

Examples of industrial application of tailings include raw material to produce concrete, ceramics and other building materials and also as a filler for landscape and building projects. Waste rock can be used as a filling material (gravel) and capping material. Potential use of tailings and waste rock depends to a large degree on their specific chemical and physical properties that have to be evaluated before any recommendation can be made for further use.

One way to minimize the amount of onsite mining waste is to export mineral concentrates that have only been obtained through mechanical separation during crushing and grinding, leaving further ore dressing steps to be performed later. This will not eliminate the negative footprint from tailings, but may allow for this to be created at a location where the material can be disposed of with less environmental impact. This practice may limit the local environmental damage in an exceptionally vulnerable environment, but will increase costs and climate gas emissions during transport.

Even if all possible efforts are made to find alternative use for mineral waste from mining projects, a residual amount of waste material will normally have to be disposed. Before tailings or waste rock is permanently disposed, the material should be treated to make sure it is as chemically stable as possible and hazardous components should be removed as far as possible.

If a dam is constructed as part of a landfill for waste materials, waste rock and tailings can be minimized by using this as construction material for the dam structure. Tailings are often not an ideal construction material for dam structures, and if done improperly it may lead to increased risk of dam erosion and possible dam breach.

Disposal of mineral waste into a landfill (Photo: Bellona)

Landfills

When tailings are landfilled, the masses are deposited in a depression in the landscape, often modified and expanded with a dam structures that hold the tailings and possibly water back from escaping. A landfill will occupy a large area where all vegetation will disappear as long as the filling operation happens, and all wildlife will normally also be dispelled. The migration patterns of species that pass through the area may also be disturbed.

Because landfills are often associated with extensive dam constructions, a dam breach constitutes a potential risk. If a dam is breached, huge amounts of tailings and contaminated water may flow out and flood large areas below the dam. Dam breaches represent some of the worst environmental accidents in modern history, and great care should be taken to construct dams with a minimal risk of breaching.

Risk of dam breaching or uncontrolled leakage can be minimized through robust dam design that minimizes erosion, has sufficient freeboard to avoid overfilling or flooding and avoids excessively steep slopes that weakens the dam structure. The dam wall should also be made as impenetrable as possible to reduce runoffs, minimize oxidation of sediments and erosion of wall structure. The design of tailing dams in the Arctic should take into account that frost and icing causes additional erosion.

In addition, landfills often lead to large amounts of mineral fallouts in the surroundings due to airborne particles escaping with the wind or through water runoffs. This may damage vegetation and disrupt the biodiversity in affected areas, in addition to being a nuisance for affected human communities. Dust escape can be minimized through sprinkling water to keep the surface moist, or through sprinkling lime milk that creates a hard surface that prevents particles from escaping. Covering the surface with rocks or revegetation will also prevent dust from escaping. In the Arctic treatments with lime milk will have to be repeated more often to maintain the effect, because the cover is destroyed during the winter.

Leachate is precipitation or surface water that flows through the tailings and to varying degrees washes out mineral compounds that may cause significant water contamination. The water contamination may be especially severe if the tailings contain sulfides which in contact with oxygen form sulfuric acid. Acid conditions also increase the wash out of heavy metals. Seepage water from landfilled tailings can be heavily polluted and kill fish and generate further loss of biodiversity in the affected water bodies.

Pollution from tailings from a copper mine (Photo: Thinkstock)

Pollution caused by runoffs from mining sites can be minimized through collection and treatment of the runoff water. Controlling the leachate pollution requires well-functioning water treatment plants which have to be operated for a long time after the landfilling has ended. Water treatment is normally performed through a combination of active and passive treatment steps. Active treatment involves adding chemicals to change or remove unwanted components in the water. Examples of such measures include pH adjustments and precipitation of heavy metals with lye, lime or other carbonates containing minerals, in addition to further precipitation of heavy metals or arsenic with ferric sulphate. Examples of passive treatment steps include removing suspended particles from the waste water by settling in sedimentation ponds or microbiological treatment where microorganisms capture or break down unwanted components in the wastewater. Both active and passive measures are normally necessary to achieve acceptable water quality for the discharged waste water. Active treatment methods are normally critical to control emissions during pilot and the operational stage, while passive treatment may be sufficient after the mine is closed [20].

Table 3 Examples of active methods to treat mining waste water

Active treatment	Chemical used	Effect
Alkali treatment	Lime, lye or other carbonate containing mineral	Normalize pH and prevent acidification and increased pollution og heavy metals
Addition of flocculation/ coagul ating chemicals	Organic surfactants or mineral salts	Increases settling, precipitation and separation of suspended particles
Airing	Air bubbled through waste water	Increases precipitation of heavy metals in combination with iron salts and oxidizes H2S
Oxidation chemicals	Ferric sulphate	Oxidation of soluble arsenic increase precipitation
Sulphate removal	Lime, Al (OH)3 or Basalts	Remove sulphate
Pollution retaining diches around landfill	Organic matter absorbs pollution	Removal of heavy metals and other toxins

Table 4 Examples of passive methods to treat mining waste water.

Passive treatment	Priciple	Effect
Sedimentation in ponds	Suspended particles are given time to settle	Removes suspended particles
Nitrogen removal	Bacteria metabolizes soluble nitrates/amines to N2	Removal of nitrogene compounds
Constructed wetlands around landfill	Break down or retain pollution	Removal of heavy metals and nutrients
Filter and membranes	Retains suspended particles and large molecules	Removal of particles and toxins
Ion-exchange resin filtering	Zeolite or other material used to exchange cations	Removal of heavy metals
Recycling of waste water	Collect waste water for use in ore procrssing	Minimizes total waste water discharged to surroundings

Removal of small particles and dissolved pollutants is possible through use of ultra-small pore membranes and reverse osmosis. This is a promising technology that has yet to be developed into its full potential, and should be the focus of increased F&D efforts. In addition, recycling waste water back into the process has the potential to significantly reduce discharges of waste water to the surroundings.

Sludge collected from different steps in the treatment process that contain different levels of contaminants should be stored and treated separately. Of especially high importance is the treatment of sludge that meets criteria for hazardous waste and must be treated accordingly.

It is possible to limit dust escape through continuous irrigation of the landfill surface, which in turn may increase the volumes of leachate. Both challenges with leachate and dust escape can be reduced through revegetation of landfill surface as soon as possible. Distribution of airborne dust can also be limited by topographic barriers like rock walls or tree lines. Regularly cleaning dust forming surfaces and collection of drill dust is also important. In the Arctic airborne dust may be an especially high concern due to the high vulnerability of affected ecosystems and the increased albedo effect caused by particle fallouts that may lead to additional unwanted ice melting.

If the tailings are filled into a natural or artificially made lake, problems with dust escape and leakage of contaminated water is often reduced compared to a dry landfill [1]. Aquatic ecosystems within the filled will be destroyed in the same way as ecosystems covered by tailings in a landfill or a sea filling.

A water cover will also limit the acidification caused by oxidation of sulphite into sulfuric acid thus reducing the release of heavy metals due to slower diffusion of atmospheric oxygen into water compared to air [21]. Water covers are less effective in limiting oxygen transport during spring and autumn when reversal of the temperature gradient leads to free circulation in the water column. Impermeable dam structures are more costly to construct but limit the flow of water through mineral sediments and will for this reason limit oxygen exposure and the washout of heavy metals. To avoid leakage into groundwater basins and waterways cracks and channels that makes it possible for water to escape must be either plugged or redirected to collection basins for water treatment when preparing a location for water covered landfilling of tailings.

To avoid the formation of toxic leakage, controlling the pH and acid forming material is very important. Acid forming waste material, often in the form of iron sulphides, can be handled by removing sulphide before deposing, or by mixing the waste with lime or other alkaline forming materials. If parts of the waste rock are alkaline, it should be separated from other materials and mixed with sulphide containing waste to avoid acid formation. Reactive alkaline zones around the acid forming waste are another way to minimize the toxic leakage from acid forming materials.

Sea filling

Sea filling means that tailings are mixed with water into slurry that is led to a location on the seafloor through a pipeline. Seafills will normally change the topography of the seafloor and local water currents, and damage marine ecosystems in a large area. A seafill will smother all bottom dwelling organisms within the affected area. Water currents, salinity and particle size determines sinking speed, and how far the mineral particles will be distributed. Above the seafill a large plume of sinking particles will form during the operation that may damage or disturb pelagic organisms including migrating fish. Deposition of sediments reaching a thickness of one centimeter per year or more will in many cases eradicate all life on the seabed. In addition, particles and dissolved chemical compounds in the water can interfere with or damage populations of pelagic species in the area. Sinking speed of tailings can be increased partly by venting of air bubbles and use of seawater instead of freshwater as transport medium for tailings.

Chemicals that follow the tailings may cause significant environmental damage. In Bøkfjorden in Norway, where Sydvaranger gruve has been seafilling tailings from iron ore production, a certain chemical (Lilaflot D817) can be detected in sediments more than 12 years after the chemical was banned. Many other mining chemicals are also known to be persistent to degradation, and for this reason will accumulate in the environment.

Spawning grounds and seabed fauna are probably the most vulnerable parts of marine ecosystems affected by seafills. But also organisms moving through the water column may be negatively affected. Recolonization of sea fills will normally take place five to ten years after sea filling has ended. If the tailings have an unfavorable composition, this process may be significantly delayed or limited. Whether sea filling can be regarded as best environmental practice remains a highly controversial question. The National Institute for Marine Research in Norway has repeatedly stated that seafilling has unacceptable consequences for marine ecosystems and shouldn't be considered or allowed.

Backfilling

Backfilling means that tailings and waste rock are returned to the cavities formed from extracting minerals. The advantage of backfilling is that the deposit of tailings does not occupy new areas or affect ecosystems beyond the extraction area. A significant disadvantage of backfilling is that it can block future access to the residual ore, if this becomes an economical option in the future. Because waste rock and tailings have lower density than the extracted masses, and not all mined out space can be backfilled, backfilling is not possible for all the mineral waste. In addition, the cavities must normally be completely mined out before backfilling can start. Before this time some other type of disposal must be applied. Temporary storage of mineral waste before startup of backfilling is possible, but may imply significantly increased costs and climate gas emissions due to extra movement of masses. Like landfills, backfilling may also be associated with leachate challenges, if the mining space that is being backfilled is in contact with groundwater bodies through cracks or channels. For this reason designated areas for backfilling must be assessed and adequately prepared before backfilling can start.

In Norway, the Directorate of Mining has for many years been hesitant regarding backfilling as disposal method for mineral waste, because it can block later extraction of remaining residual minerals. In the EU Reference Document on Best Available Techniques for Management of Tailings and waste-Rock in mining, backfilling is nevertheless listed as best available technology for minimizing the negative environmental footprint of the mine. Bellona considers backfilling to be the environmentally best disposal method for mineral waste, and believes that this should be used whenever practically possible.

In underground mining some backfilling is normally necessary to support the stability of mined out spaces and tunnels to prevent collapse. Often the backfilling material is stabilized through added cement limestone or fly ash [20].

3.5.4 BET for minimization of area use and ecosystems disturbance during mining operations

If crushing, screening and drying circuits are set up outdoors, this may lead to significant noise and dust pollution. In addition outdoor operations are more vulnerable to extreme weather conditions which are common in the Arctic. For this reason all ore processing steps should be built indoors or underground if possible. Storage space for concentrates and mineral products should also be built indoors. All mineral products should be transported or shipped in closed containers for the same reason. This will have the additional benefit of protecting the mineral products from quality deterioration caused by weathering and product loss due to run offs. Ventilation outlets should be filtered to remove mineral particles, and flue gasses should be cleaned for toxic compounds before emitted.

As for landfills, other parts of the mining site may also be a source for contaminated runoffs and airborne particles. Sprinkling the dust covered surfaces with water will normally reduce dust problems, but may increase leakage of contaminated water. Dust escape can also be reduced by application of calcium chloride to bind the dust particles, although this may lead to an unwanted increase in chloride concentration in nearby water bodies. In addition, dust emitting surfaces should be sprinkled with water, and transport vehicles and equipment smeared with dust should be frequently washed or flushed.

3.5.5 BET for revegetation and restoration of mining areas after end of operation

After a mining operation has ended, all areas that have been affected by the operation should be restored to ecosystem conditions as close to outset as possible. This means recreating topography and soil cover that supports revegetation and returning wildlife. Having restored soil conditions, revegetation can be accelerated by sawing or planting of local plants that are expected to form the new flora in the area. Revegetation has the additional benefit of drastically reducing dust formation and leakage from the mining area, and should be a continuous process during the life time of the mining operation.

Rehabilitation of ecosystems has been shown to be more successful and cost effective when attention to these aspects is paid already during the planning and design of the mine. These operations are also complex and should be performed by professional experts that specialize in landscape restoration. In many cases restoring landscape and revegetating can and should start up in the mine's operational phase. A running restoration process of mined out areas or filled up waste disposal sites may reduce the efforts and costs necessary for an optimal restoration, and limit the negative environmental impact during the life span of the mining project (20).

Removed soil should be collected and stored in a way that makes it available for later restoration of the mining area. All areas including dam slopes and cover structures should be revegetated as far as possible. When restoring the soil cover attention should be paid to how penetrable this cover will be to surface water. For areas where oxygen transport needs to be limited due to chemical conditions in the layers below, dry covers can be provided by either covering the surface with a watertight synthetic membrane, or layers of sediments that are impenetrable to water. If a synthetic membrane is used, care should be taken to avoid ruptures in the membrane due to contact with large or sharp rocks, heavy point loading on the ground above, weak linings or exposure to sunlight.

Before soil covers can be restored the topography of the landscape must be remodeled according to a plan that allows for the return of vegetation and wild life. This will often include the physical change of vertical walls or steep slopes into more gentle ones or filling pits and underground caves with water. In some cases the topography of a mining area may already be favorable for important species, for instance birds nesting in cliff walls or endangered plant species thriving in newly created soil covers. All remaining infrastructure like buildings and roads should be removed as far as possible.

3.5.6 BET for energy consumption and climate gas emissions

Mining requires large amounts of energy from both electricity and fuels. The total amount of energy per ton processed ore may be as high as 80 kWh, with mining consuming 12 – 25 kWh per ton, ore processing consuming 30 -50 kWh per ton, and other activities consuming 2-4 kWh per ton [20]. This means that a mine may consume as much as 80 GWh for every million ton of ore it processes. Examples of energy consuming processes in mining are:

- Electrohydraulic tools
- Pumping water
- Compresing air, ventilation and heating
- Transport (dump trucks, conveyor belts or railway)
- Crushing, grinding and screening

- Pumps and stirring in separation processes
- Heating and drying of products

Grinding is a very energy intensive process that sometimes demands as much as 60 % of the total energy consumption of a mining operation [20]. For this reason optimizing the grinding process has the potential to significantly reduce both environmental footprint and economical costs of the operation. The energy needed for crushing depends on how hard the ore is. As the hardness of the ore increases, so does the energy demand for crushing and grinding. Although energy efficient crushing and grinding techniques may reduce the amount of energy needed, a theoretical minimum of energy input necessary for breaking the ore into mineral particles exists, and is defined by the Bond Work Index [20].

Frequency converters can be used to adjust the speed and output of pumps and motors. In addition high efficiency engines are available that will reduce the need of energy further. High efficiency electric motors are classified as IE2 or EFF1 engines while premium efficiency electric engines are classified as IE3 or NEMA Premium motors. Electric engines with even higher efficiency are available but are not yet produced commercially [20].

The following steps should be taken to ensure energy efficient extraction and dressing of ore:

- Design operations with energy efficient equipment (engines, pumps, frequency converters etc.)
- Scaling of equipment that limits the number of steps in the process will increase energy efficiency
- Optimization of the crushing and grinding processes
- Increased energy efficiency for the drying process by selecting pressure filtration. Ceramic filters in genral consume even less energy, and should be chosen were possible.
- Installation of heat recovery systems where possible

Arctic mining operations are often located at isolated production sites away from stable electricity supply from the grid. These mines are therefore more dependent on fossil energy sources. One example of projects to improve this situation is undertaken in by Shell Canada and Caterpillar to develop haul truck engines where diesel is replaced as fuel by liquefied natural gas. Pilots testing LNG-fueled power plants have also proven successful and cost effective to replace diesel. There are also examples of wind power partly replacing diesel generators as a power source [4].

3.5.7 BET for water management

Mining operations need water for drilling, grinding- and separation processes, pumping and rinsing and cleaning processes. The huge amounts of water needed in many mining operations may overburden available water sources and increase existing regional shortage of fresh water. At the same time a lot of waste water is normally generated through the collection of precipitation and drained water that accumulates in open pits and or underground tunnels, and this water may cover part of the water needed in the mining process. I addition much process water may be recycled further minimizing the need for external water input. Efficient recycling of process water sometimes relies on chemicals that may have damaging effects on surrounding ecosystems. A tradeoff between water efficiency and minimized use of chemicals is therefore necessary and must be based on an environmental impact assessment for the specific location.

3.5.8 BET for management of chemicals

Chemicals are most commonly applied in mining as explosives and additives that support separation of ore components and in water treatment. Use of chemicals increases the efficiency of the mining operation by increasing the product yield, and indirectly limits the relative amount of waste and emissions of pollution generated. Residual chemicals that follow emissions to water and air will often have unwanted environmental effects. Chemicals should therefore be chosen with regard to environmental damage potential and process effectiveness. This tradeoff may involve complicated evaluations where less toxic chemicals may turn out to cause larger negative environmental impacts overall, if they at the same time the chemicals are also less process effective leading to larger overall consumption and emission rates.

Mining industry consumes large amounts of chemicals Photo: Thinkstock

Three properties are of special importance when it comes to evaluating the environmental damage potential of a chemical. A chemical should have as low acute and chronic toxicity as possible for all relevant organisms that are affected by the emissions. Of special importance are low mutagenicity and low potential for damage or disturbance of reproductive and endocrine functions. In addition all chemicals should be biodegradable and break down into harmless components in nature, and not accumulate in organisms and the food chain. Due to slow metabolic rates in Arctic ecosystems, and low temperatures the time needed for degradation of discharged chemicals may be significantly longer than for conditions further south. This must be taken into consideration during chemical evaluation in Arctic mining projects.

Chemicals applied should be part of a continuous evaluation where risks and benefits are benchmarked. The marked for chemicals should be continuously screened for new product alternatives with a more beneficial set of properties. When better products are identified a substitution process should be initiated.

Chemicals should be treated according to high quality and safety standards from procurement to disposal as waste, including high safety levels during transport and storage. All chemicals must be handled by competent personnel with adequate training and follow a recognized standard for chemical management.

3.5.9 BET for noise and vibrations management

Noise emissions and vibrations can disturb both wildlife and humans living close to a mining operation. These effects can be minimized to some degree through a well-planned design of the mine, and mitigation techniques during the operation of the mine. Choosing low noise equipment and creating or utilizing existing noise barriers is important in limiting noise emissions. Underground mining normally reduces noise problems compared to open pit mining. Noise from crushing, grinding or other ore dressing processes can be reduced by placing them indoors or underground. Trees and vegetation may together with stockpiles serve as effective noise barriers. Public information about blasting procedures and when blasts are scheduled may reduce stress responses created in the human population living within the noise range of the blasts. Keeping the public well informed regarding timeframes for haulage routes may also prove important. If possible, blasts and noise generating transportation should be performed at times during the day when the disturbance is minimal. It is also important with frequent noise measurements to verify that the mining operation complies with noise regulations.

Vibrations from blasts during extraction of ore can travel several kilometers, and will often be stronger from open pits than from underground mining. Vibrations that travel offshore may disturb both fish and sea mammals in harmful ways. Disruptions from blasts may be minimized through planning of the number, type and size of blasts that limits the affected area, and selects an optimal timing. Disturbance of populations of Arctic birds during the nesting period should be treated as a topic of especially high concern.

3.6 Best practice in government mining regulation

Adequate legislation that demands high environmental performance standards for all operators that want permission to mine is crucial for any country that wants to minimize environmental damage caused by mining operations. Also of vital importance are government agencies that diligently monitors and make sure license conditions are met, and a high degree of public transparency through all steps of the application process with accountability from both operator and regulator, and the public right to appeal any misconduct.

Legislation should be based on the precautionary principle and enforce a practice where a lack of knowledge about environmental effects is dealt with in a decision process as if the effects are unacceptable. Legislation should also build on the polluter pays-principle where the mining company is held economically responsible for all costs due to environmental damage caused by the mining operation. Legislation should also provide solid protection of vulnerable biodiversity and ecosystem services.

3.6.1 Legislation and licensing practice

Mining operations need to be regulated in a way that limits the environmental damage caused by the operation. All phases in the life span of a mining project from exploration to closure and abandonment of the mine must be part of this legislation to make sure that minimum standards for environmental performance are met. The planning and design of mining projects together with systems for monitoring performance to verify compliance with governmental demands are of special importance. Legislation must also allow for adequate sanctioning of serious failure from mining operators to comply with environmental performance standards required by the license agreement.

A sufficiently detailed and well documented Environmental Impact Assessment (EIA) must be required as a condition for any mining project to be considered. The EIA should include a thoroughly description of expected effects of the mining project in relation to the assessed vulnerability of the affected ecosystems and human communities. Expected effects from all relevant production methods that may be considered should be evaluated to allow for the identification of optimal environmental performance design of the project. Legislation should also require the EIA to be performed by competent and independent experts. The EIA should include a detailed and thorough description of all endangered species or valuable ecological resources within the area affected by the mining project. The EU directive 2001 42 provides a detailed description of topics and concerns that should be taken into account during an EIA [22].

A license to operate should only be given for a mining project that presents a plan that documents an ability to extract and process mineral products without unacceptable damage to the environment. Acceptance criteria should be defined based on evaluations from scientific and independent experts. When evaluating the total environmental impact of a mining project, roads, power lines, loading ports and all other secondary infrastructure should be included in the evaluation. If the acceptance criteria are not met, the project should be rejected.

Requirements for use of BET-standards and political measures for continued development of improved technologies and practices

BET requirements imbedded in license terms for a mining project should as a minimum include orders to include a system for optimal management of tailings and waste rock, and press for backfilling of these waste materials as far as possible. The operating license should also include orders to remove infrastructure and process facilities and restore topography and soil cover for optimal restauration of vegetation and wildlife after end of the mining operation as far as possible, and collect necessary financial guaranties for this to happen regardless the financial situation of the operating company at the end of the mining project.

Improvements in technology and production methods have reduced the relative environmental impact of modern mining projects, and have the potential to continue to do so. As an example Canadian mining industry is reported over the past two decades to have reduced emissions of many heavy metals including mercury, nickel and copper by more than 99% due to cleaner processes (4). For this reason political measures should be implemented to stimulate R&D efforts based on cooperation between the mining industry, scientific communities and relevant government agencies. Required technology and methods issued in mining licenses should be based on industrial standard documents describing best available environmental practice (BET). Global trends in the mining sector should be closely monitored with the goal of early detection of new and relevant advances in technology and methods.

Planning process, public consultation and objection rights

Legislation should guarantee a high level of transparency during all steps of the application process for new mining projects, and also allow for public inquiries and objections to license terms that will lead to environmental impacts that are considered unacceptable to the public. All documents should be made available to the public both in paper and electronic form. Government and industry should also invite and stimulate a continuous dialogue about plans, EIA, license conditions, monitoring programs and best environmental practice.

3.6.2 Organization of governmental management of mining industry

For any governments efforts in regulating the mining industry to be successful, adequate legislation must be enforced through a body of competent agencies with sufficient resources. A license to operate should be based on the principle of self regulation, where the mining company is made responsible for not only following regulatory requirements, but also for establishing a robust system for verifying its own compliance with the given license terms. Government supervision and monitoring of license terms should include frequent inspections to verify compliance with license terms including a well functioning self regulatory system.

At the heart of the required self regulatory system should be a detailed and comprehensive environmental management system that includes procedures for continuous monitoring of all parameters relevant to reducing the environmental footprint of the mining project. The data collected should enable the operator to answers all relevant questions regarding the environmental impacts of the mining project.

Supervisory practices and ensuring compliance with environmental requirements

All environmental aspects of the license terms should be monitored by the mining operator and frequently inspected by government regulatory agencies to verify compliance. This should at least include regulatory limits of tailings and waste rock disposal, emissions of particles, heavy metals, chemicals and other pollutants to air and in waste water and noise emissions. Repeated failures to comply with these restrictions should result in fines that are large enough to ensure incentives for further compliance. Another important topic for government inspection is dam safety, if there is a landfill or other functions that require a dam structure.

3.6.3 Overall assessment of the potential for reduced environmental footprint through the use of best available practice in governmental regulation practice in mining industry

Although the mining industry is dominated by multinational companies that operate in many different countries, one company's operational standard in a specific country relies heavily on regulations required by the government. A lack of governmental regulations will often increase the negative environmental impact of mining operations and increase the risk of accidents with catastrophic damage potential. Strong environmental standards set by the government are especially important for mining projects in the Arctic where the ecosystems has a higher vulnerability compared to ecosystems further south.

3.7 Key findings and recommendations

3.7.1 A rush of new mineral projects in the Arctic can be expected, but only in a long term perspective

Demographic megatrends indicate increased global demands for future minerals that may lead to dramatic expansion of the Arctic mining sector. Mining in the Arctic causes unavoidable damage to affected ecosystems that already struggle to survive extreme environmental conditions and require long recovery periods after population setbacks. Due to long transport distances, limited available infrastructure and harsh environmental conditions, production costs for Arctic mining projects are often significantly higher than for mining operations further south. Reduced economic growth in leading markets for minerals has created a temporary drop in mineral prices that make many potential new Arctic mining projects less attractive. Several years may pass before this situation changes significantly, but when this happen, the modern world's critical dependency on minerals make it unlikely that anything can stop a rush of new Arctic mining projects. Although improved technology and better production methods have reduced the negative environmental footprint caused by modern mining operation, the mining industry has still a long way ahead before it will be able to apply technology and mining methods that make mineral extraction possible without unacceptable damage to the environment. For this reason increased R&D efforts to further improve the environmental efficiency of mining processes are of crucial importance.

3.7.2 Governmental regulations that require high environmental standards are essential for a mining sector to continue improving its environmental performance.

Government regulations that require high environmental standards from all mining operators are essential for lowering the negative environmental footprint form the mining sector. Comparing governmental regulation systems of the countries with an Arctic mining sector make two stand out. Greenland having gained political autonomy as late as 2009 has a limited legislation framework, regulatory experience and resources available for governmental regulatory procedures compared other Arctic nations and still relies heavily on Danish expertise and assistance. In Russia endemic corruption and lack of public transparency and accountability serves as a barrier to successful application of environmental regulations. Experience with Russian mining industry also indicates significantly lower ambitions when it comes to environmental performance compared to the mining industry in other Arctic regions. The mining legislation of the Nordic countries has a very similar structure, although Sweden and Finland seems to be ahead of Norway when it comes to require best available environmental standards from mining operators. When it comes to urban mining, Sweden seems to be leading the way.

3.7.3 Subsea mining needs better government regulation

Future Arctic mining projects include possible subsea mining. Uncontrolled large scale subsea mining has the potential to create devastating damage to marine ecosystems. For this reason adequate environmental standards and regulations on how subsea mining should be performed is of crucial importance, and must be developed and implemented before large scale subsea mining can be allowed. Also a system for environmental impact assessments and limits to how large effects that can be accepted together with a system for monitoring these effects is of great importance. There is also an urgent need for establishing more and larger marine reserves that protects hotspots for marine biodiversity and ecosystem services from damaging human activities including subsea mining. One example of important biodiversity that should be included in these considerations are the unique ecosystems and organisms located around hydro-thermic vents that also serves as important sources to formation of seafloor ore. Coral reefs and sponge communities are other examples of vulnerable ecological resources of high concern. For this reason a global system that identifies and creates multisector protected subsea areas and provides the necessary measures for monitoring and controlling them are of great importance, and would be especially beneficial in the Arctic.

3.7.4 National mineral policies should be based on a life cycle perspective

Because negative environmental impact from mining operations can't be avoided, and to prevent future scarcity of increasingly rare minerals, national mineral polices should not only aim at improving the environmental efficiency of mining operations, but also increase the efficiency in how minerals are utilized. This includes more resource efficient production and product design, more conscious consummation habits and recycling of urban ore.

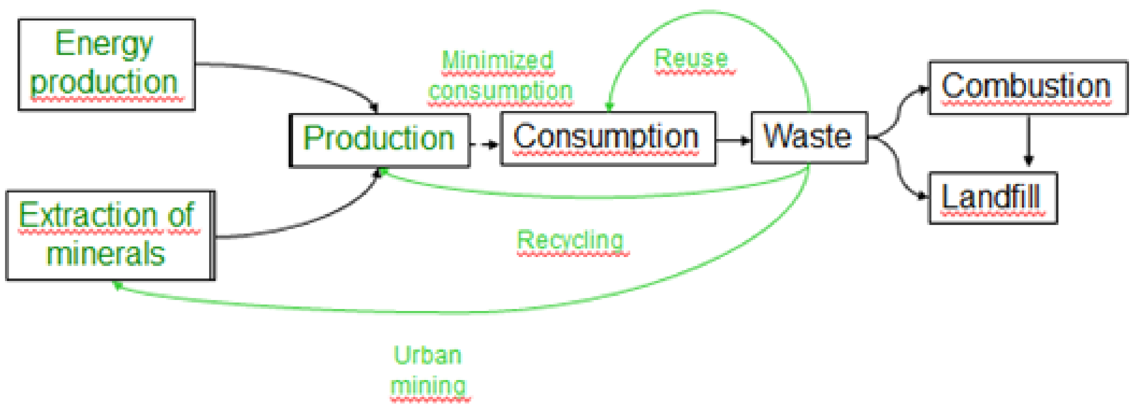

Figure 4. Essential steps in more resource effective use of minerals

3.7.5 Important elements in Best Environmental Practice for the Arctic mining industry

Best environmental practice for a mining project depends to a large degree on specific conditions associated with the project. The following recommendations should be considered as best environmental practice for most Arctic mining projects:

- Backfilling in underground mines rather than open pit mining or mountain top removal
- Utilization of waste rock and tailings as input in other industry or as building material as far as possible
- Incorporation of urban ore in the ore dressing process when possible
- Maintaining a belt of vegetation or other mechanical barrier around the mining site that limits soil erosion and dust formation
- Creating structures that ensures crushing, grinding, separation, storage and hauling takes place indoors or underground as far as possible

- Energy efficient processes and transport solutions that replace fossil energy with renewable energy sources as far as possible
- Restoration of topography and soil cover that support revegetation and return of wildlife
- Environmental management system that includes a detailed and extensive environmental monitoring program that answers all relevant questions regarding the environmental impacts of the mining project and makes this information available to relevant government agencies and the public

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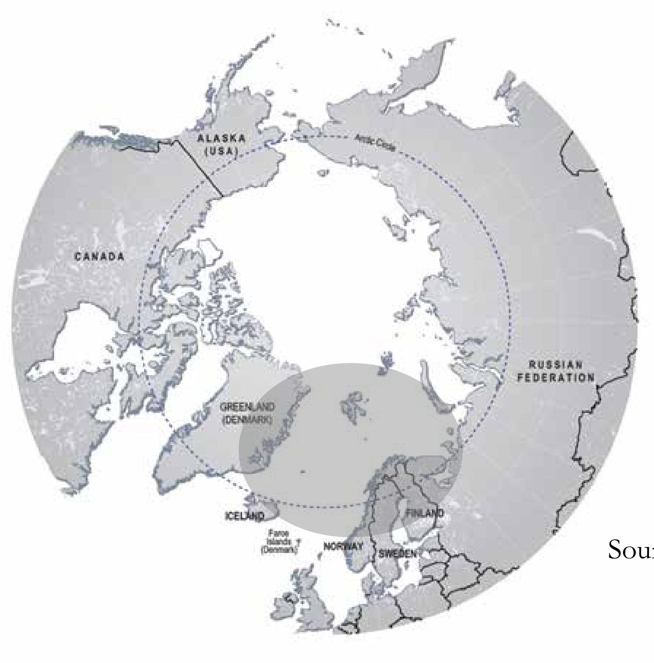
4. Integrated Multi-Trophic Aquaculture - a measure for increased food security

Author: Solveig van Nes, Manager Aquaculture

Many Arctic communities are living from the sea and with a geography and climate largely unsuited for land based food production. Effects from climate changes mainly driven by anthropogenic CO_2 emissions are especially evident in the Arctic, and result in losses of biodiversity and unpredictable changes in availability of important marine food species. This development emphasizes the need for increased food security and local value creation, whilst simultaneously decoupling economic growth from CO_2 emissions. For this purpose, we evaluate development of so called Integrated Multi-Trophic Aquaculture (IMTA), ecosystem based aquaculture that combines the culture of fed species (e.g. salmon) with that of extractive species (e.g. mussels and seaweeds), and with the potential benefit to mitigate ecological effects from fish monoculture. In addition to recycling nutrients, marine biomass like mussels and seaweeds naturally bind CO_2. Provided performed within ecologically sustainable limits, IMTA offers potential solutions to increased production of local, resource efficient and climate friendly food and biomass for energy purposes - whilst capturing CO_2.

Based on important ecological differences between IMTA and conventional aquaculture, as well as lessons learned from negative impacts of previous monoculture development, we evaluate relevant and important environmental aspects and give recommendations to secure a development in line with ecological carrying capacity and physical conditions in the Arctic.

The main focus of this chapter will be on the European Arctic; Northern Norway, Northwest Russia, Greenland, Spitsbergen and Jan Mayen, and modified to include areas south of the Arctic circle thereby *including* the Faroe Islands and Iceland. For overview and comparison purposes, data will often be shown for the whole Arctic region.



Source: Grid Arendal

4.1 The marine environment plays a vital role for future food security

Due to a geography and climate largely unsuited for land based food production and with no or limited access to arable land due to glacial ice and barren rocks, many coastal communities and countries in the Arctic traditionally live from the sea as hunters and fishers. A study comparing Arctic economies based on value added to GDP by different industries showed that the Faroe Islands, Greenland, Iceland and Arctic Norway all have economies and livelihoods strongly connected to fishing, fish processing and export of sea food [1] (Figure 1).

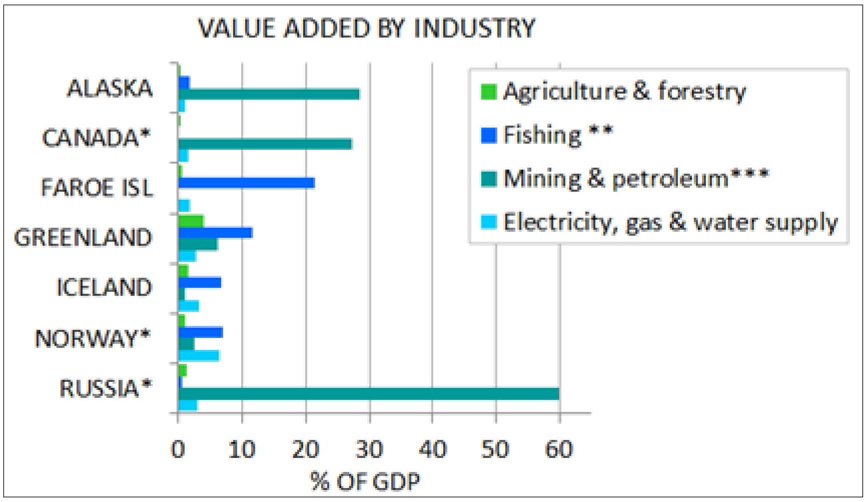


Figure 1. Value creation from selected industries presented as percentage of GDP. *Data solely from the arctic regions **Data include fishing and processing. ***Data include extraction of coal, lignite, oil and gas, other mining & quarrying, and processing of these. Based on data from Glomsrød et al., 2009 [1].

The same study reveals that in the Faroe Islands, more than 80 % of export is due to fish exports and the economy is critically dependent on fishing. Fisheries, fish farming and fish processing together account for more than 20 % of GDP. Moreover, other sectors also rely heavily on deliveries to the fishing industry. In Greenland, fishing is also the largest resource based sector, and all in all, fish and other marine products make up about 85 per cent of total export. Iceland and Arctic Norway depend to a lesser extent on the fishing industry, but it is still a major source of income. This is in contrast to Arctic Russia, Alaska and Northern Canada, where the economy largely depends on mining and petroleum (Fig1), [1].

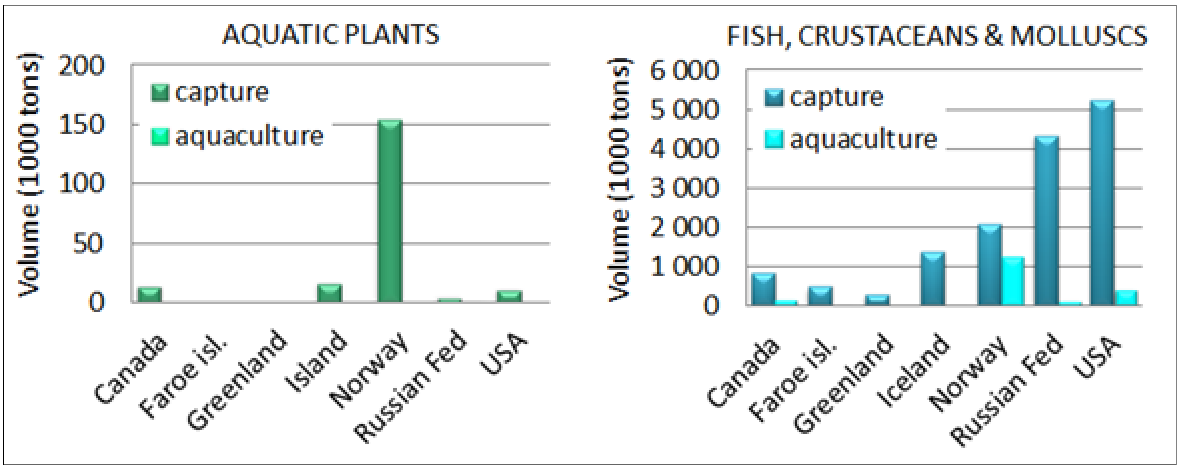


Figure 2: Seafood production (aquatic plants left, fish, crustaceans and molluscs right) in countries with an Arctic coastal line, by wild capture and aquaculture. Data used represent the total of each nations´ production, and thus not only Arctic production. Further; the statistics include both freshwater and marine production. Based on FAO statistics for production in 2013 [2].

As is illustrated in figure 2, the largest volumes of marine biomass in the Arctic come from wild fisheries and harvest rather than from aquaculture. More specifically, seaweeds are only harvested to a very limited extent Arctic in regions (208 000t in 2013) and only from wild crops [2], whereas globally (mainly Asia) cultivated seaweeds constitute 96% of the total production of 24.9 million tons. Carrageenan seaweeds (including Kappaphycus alvarezii and Eucheuma spp.) are the main cultivated seaweeds (8.3 million tons), followed by Japanese kelp (5.7 million tons) [3].

A total of 558 100 tons of fish, molluscs and crustaceans was produced by mariculture in European Arctic in 2013 (Figure 3). Atlantic salmon *(Salmo salar)* is by far the main cultured single species in this region. In Arctic Norway alone (the three northernmost counties) the production volume of Atlantic salmon in 2013 was 460 000 [4], which equals 82.4 % of the total mariculture in the European Arctic.

Also in Russia and Iceland, the main species farmed at sea is Atlantic salmon [5, 6], though on Iceland closely followed by Arctic charr *(Salvelinus alpinus)* mainly produced in *landbased* systems (hence, data not included in figure 4). In 2013, the production volumes of Arctic charr and Atlantic salmon were 3400 and 4000 tons, respectively [6].

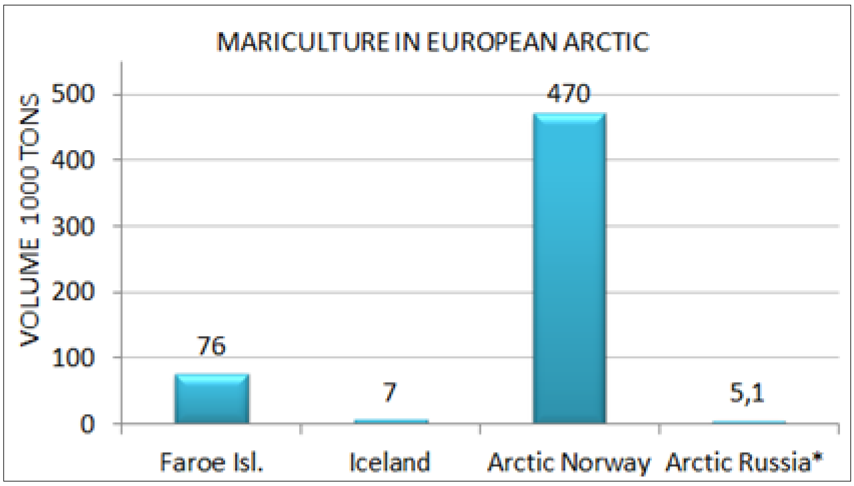


Figure 3: Marine aquaculture of fish, crustaceans and molluscs in European Arctic in 2013 (* 2014). Values shown for Norway and Russia are data only for the three Northern most counties and the Kola peninsula.

Sources: Norwegian fisheries directorate, FAO, and barentsobserver.com.

Other commercially farmed species in the arctic marine environment are Atlantic cod *(Gadus morhua)*, Atlantic halibut *(Hippoglossus hippoglossus)*, and blue mussel *(Mytilus edulis)*, but to a much lesser extent compared to Atlantic salmon.

In total, aquaculture in the Arctic region contributes 2% of global production [2, 4]. This may seem small, but is of the same magnitude as the EUs total aquaculture production.

At present aquaculture in the Arctic thus mainly comprises salmon farming in so called monoculture systems, thus a system for culture of one single species. This is in contrast to integrated multi-trophic aquaculture (IMTA) that combines the culture of fed species (e.g. salmon) with that of extractive species (e.g. mussels and seaweeds), and with the potential benefit to mitigate ecological effects from fish monoculture, amongst others [7, 8] (see also chapters 4.3 and 4.5)

The concept of integrated aquaculture has been widely practiced by small households in freshwater environments, and in large scale variations of IMTA in shallow sea waters, so called suspended multi-species, in Asia. But in the marine Arctic region or temperate region in the Northern Hemisphere (between latitudes 23.5° and 66.5°N), it has been much less reported. An extensive review of IMTA summarizes that even though the potential is enormous in temperate waters, most countries in this region mainly produce in monoculture systems and less than 10 % of the IMTA systems are near or at commercial scale. Most IMTA sites have remained at a small scale level and/or in pilot and R&D state. Canada has since 2001 been in the forefront with development of IMTA projects with integrated systems focusing mainly on Atlantic salmon, blue mussel *(Mytilus edulis)* and kelps *(Saccharina latissima and Alaria esculenta)* [8, 9].

IMTA in the Bay of Fundy, New Brunswick, Canada. Salmon is farmed in cages (front left), blue mussels are grown in bags and on ropes (front right) and kelp is grown on ropes (back right) (Photo Thierry Chopin).

Since climate change affects availability of important marine food species, jeopardizing food security and predictability for those living from the sea, IMTA (provided performed within ecologically sustainable limits) could be an important future means to increase food security as well as value creation and livelihoods in the Arcticl. And since fisheries are a traditional form of livelihood in many Arctic regions, logistics for slaughter and transport of marine food species are already present, and can be used for products from IMTA.

As will be further elaborated in the following chapters, there are many potential benefits in a transition from monoculture practices to IMTA from a general environmental, climate and socio-economic perspective. However, commercialization has so far been limited by low cost effectiveness and absence of commercial scale technology for production, harvest and bioprocessing of marine biomass (when it comes to products others than finfish).

4.2 Potential for value creation from future aquaculture development

In addition to the core activities aquaculture has spin-off effects in other sectors which represent a vital value creating and employment potential. For example, core activities in a typical aquaculture-based value chain include breeding (broodstock), hatchery (smolt/juveniles), edible fish and shellfish, harvest, slaughter, processing and export/trade. In addition there are suppliers of goods and services (diverted or spin-off activity) which are essential to all parts of the value chain, such as feed, fish health products and services, transport, technical equipment and buildings, and legal, business and R&D-related services.

SINTEF performs annual spin-off studies which describe the influence of the seafood sector on employment and value generation in terms of its contribution to Norwegian GDP and the economic value of production [10] (Figure 4).

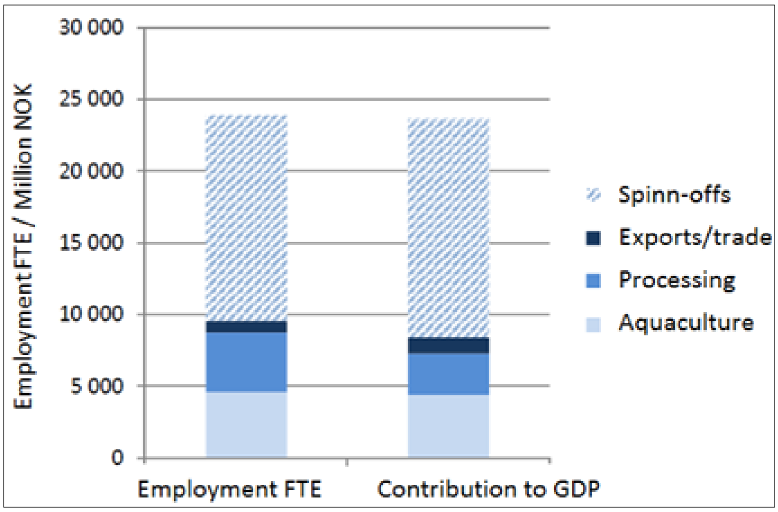


Figure 4: Distribution of employment (FTE) and value creation (contribution to GDP) in core activities and through spin-offs in diverted activities and other industries.
Based on data for 2012.

Illustration and data: Sandberg et al., 2014. SINTEF [10].

This study shows that in 2012 spin-offs from Norwegian aquaculture constituted a contribution to GDP of approximately 15 billion NOK through value creation in other industries, compared with close to 8 billion NOK in the core enterprises themselves. This means that each NOK value creation in the core activities results in an additional doubling of value creation in other industries through economic ripple-effects. Similar numbers are found for employment, where one FTE in core activities equals approximately 1.6 FTEs in other industries. The three sectors with the largest spin-off effect are feed producers, specialist advisory- and technical services, and building and construction industries.

The value creation potential from aquaculture is further emphasized when comparing value creation per employee across industries. Aquaculture has by far the highest value creation per employee, compared to industries like fisheries and fish processing, tourism, cultural industries, agriculture and reindeer husbandry [11].

All in all, this indicates the large potential for green jobs (employment within renewable industries) and the local and regional value creation from development of aquaculture activities in the Arctic could represent. Based on the assumption that future aquaculture activities will include integration of lower trophic species such as mussels and algae, it is likely that the spin-off effects on services and technologies needed for these "new" species will be mirrored in further value creation and employment.

4.3 Development of IMTA; a climate friendly increase in food security

As previously mentioned, conventional monoculture is the most common form of mariculture in Northern Europe. Whilst IMTA is a multiculture system which farms several species from different trophic levels (different levels in the food chain) in proximity (Figure 6). Similar to a natural ecosystem, the waste or excess nutrients produced from the fed fish (e.g., uneaten feed, faeces and metabolites), are recycled and become nourishment and thus a resource for lower trophic species within the same system, such as mussels and seaweeds, thus an ecosystem based production, so to say [7].

In a "small" perspective IMTA can minimize the ecological footprint from aquaculture. In a larger perspective; integrated aquaculture is a resource efficient solution for production of healthy seafood, feed and renewable energy whilst removing CO_2 from the atmosphere and the ocean.

IMTA is adaptable for both land-based and offshore aquaculture systems in both saltwater and freshwater environments, though in this report we will only discuss/evaluate development of IMTA in open sea based systems.

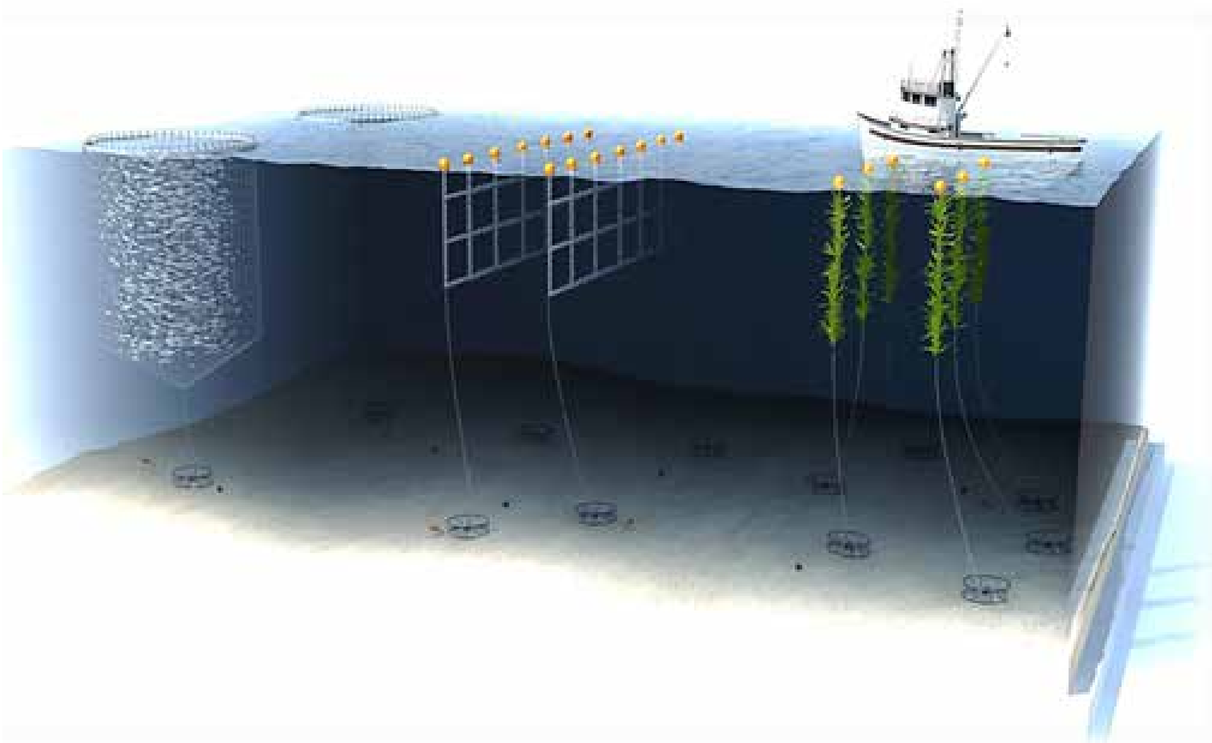


Figure 5. Integrated Multi-Trophic Aquaculture: Low trophic species like kelp and mussels are produced in proximity with higher trophic species; fed fish. Waste from one species becomes a resource for the other species. Illustration: The Dude / The Bellona Foundation

4.3.1 Important drivers for development of IMTA in the Arctic

Increased demand for food security: Arable land and fresh water are restricted resources, especially in many Arctic regions. As described in chapter 4.1 food security and economy therefore largely depend on food production from the ocean, and mostly from wild capture rather than from culture. Future potential for fishing and hunting from the marine environment is uncertain due to climate changes resulting in likely loss of biodiversity and unpredictable changes in size and distribution of wild marine fish stocks and other important food species such as seals [12, 13, 14]. Therefore there is a need for new means to increase food security, and preferably to do so from local and renewable sources that secure local value creation (rather than reliance upon import) and to avoid additional energy use and CO_2 emissions from long transport routes.

Maintain existing culture related to ocean harvest: The traditional lifestyle for the Arctic islands and coastal communities are largely adapted to limited access to arable land and inhabit culture, tradition and skills for hunting, trapping and fishing from the marine environment [1]. Therefore, in development of new aquaculture practices one could build on existing experience with harvesting food from the ocean, as well as utilize existing logistics for processing and transport of seafood products.

Need for decoupling of economic growth and energy-related CO_2 emissions: At present CO_2 emissions are on track for a 3.2 – 5.4°C likely increase in temperature above pre-industrial levels. Large and sustained carbon negative solutions and reduced emissions are an absolute necessity in achieving climate goals and to keep global temperature rise below 2°C [15]. And thus, there is a need for transition from fossil-based energy towards carbon capture and non-polluting bioenergy as well value creation from green jobs rather than from fossil-based industry.

Development of IMTA can address several of these issues adequately and at the same time possess environmental benefits over conventional monoculture

4.3.2 Potential benefits from development of IMTA

IMTA is a different way of thinking about aquatic food production as it is based on the concept of recycling. Instead of growing only one species (monoculture) and focusing primarily on the needs of that species, IMTA mimics a natural ecosystem by combining the farming of multiple, complementary species from different levels of the food chain

The natural ability of these species to recycle the nutrients (or wastes) that are present in and around fish farms can help growers improve the environmental performance of their aquaculture sites. In addition to their recycling abilities, the extractive species chosen for an IMTA site can also be selected for their value as marketable products, potentially providing extra economic benefits to farmers [7]. And, as will be further elaborated, there are large potential benefits from IMTA in a climate perspective.

Carbon capture into marine biomass that can replace fossil hydrocarbons: Algae naturally capture CO_2 through photosynthesis. Due to the high carbohydrate content of the kelp species, sometimes up to 60% of the dry weight, they are an attractive biomass resource for production of ethanol, butanol and more advanced fuels. As opposed to fossil energy sources, marine biomass is renewable and the released carbon from combustion equals the absorbed carbon during growth/photosynthesis, and therefore *not adding* any *new* carbon to the atmosphere.

Of further great importance is the fact that "first generation" biofuels are produced from biomass like rapeseed, soy and corn. In contrast to seaweeds, the production of these require arable land, freshwater and pesticides, and should preferably be used for food purposes rather that for production of energy. Hence, seaweeds offer an excellent alternative for production of clean and renewable energy [16, 17].

An additional major aspect from the climate mitigation aspect of carbon capture is the potential mitigation effect from seaweed capture of CO_2 on the ongoing acidification (se also chapter 4.7).

Increased food production at a reduced "carbon-cost": In general, production of seafood requires less energy input and has a lower carbon footprint than food produced on land. Meaning, replacing a share of for example beef with seafood in the human diet would contribute positively in a climate perspective. Yet another reduction of the carbon footprint can be reached through eating non-fed species, since the largest contributor to carbon emissions from the value chain of for example farmed salmon comes from production and transport of feed [18]. Hence, a transition to increased use of non-fed seafood species such as mussels and algae in the human diet would have large positive implications for the anthropogenic carbon emissions.

Seaweeds have been extensively used as sea vegetables in Asia since prehistoric times, but in the Western and Northern cuisine their use for consumption is still very limited.

Seaweeds used as sea vegetables can be a real treat for the eye as well as the palate. Source/Photo: Fremtidens mat (Food of the future)

Increased resource efficiency I: Removal of waste and recovery of valuable minerals: In an IMTA system, extractive species like algae, mussels and other low trophic species extract organic and inorganic nutrients from the water masses (hence, the name extractive species) that are in excess from the fed cultured species. One important benefit from this is the mitigation of possible negative effects from potential local nutrient overload. But an additional, and extremely important aspect, is the fact that these nutrients otherwise had been lost. Thus IMTA systems increase resource efficiency, since it transforms "waste" into valuable biomass. In doing so, IMTA systems also recycle/recover valuable and limited (!) minerals such as phosphate (P). Both algae and the shell of molluscs (such as blue mussel) – can be used as fertilizer, thereby bringing nitrogen and phosphorus back into the food chain. It is also possible to extract nitrogen and phosphorus from waste streams after production of biogas. In many countries around the world, macroalgae are used as fertilizer. Macroalgae contain all the trace elements and plant nutrients needed for healthy crops, in addition to alginates, which are known to be excellent soil improvers [16].

In addition, since the shells of molluscs largely consist of calcium carbonate, they can be crushed and used as liming agents (neutralize acids) or as a filtration media.

Increased resource efficiency II: More food without additional need for feed: Production of low trophic, extractive species such as algae and mussels enables large additional production of biomass without any addition of manufactured feed: Mussels, algae and other low-trophic species naturally live from (extract/filter) organic and inorganic nutrients in the water column and on the sea bed. Close to areas with run-offs from land or in IMTA systems, nutrient levels will be elevated and can boost growth of these species. Therefore, both harvesting further down the food chain and development of IMTA promotes increased harvesting of seafood without depending on manufactured feed.

Area efficient production with little or no use of limited resources: Compared to land-based biomass production marine biomass is more resource efficient and more area efficient [16, 19] (Figure 6). Also, as compared to land-based biomass production for biofuel purposes; marine biomass such as seaweeds do not compete with use of arable land for food purposes, grow faster and produce no hemicellulose (group of polysaccharides) and lignin, which makes it much easier to ferment algal cellulose. Even more so; Seaweeds do not require any use of freshwater or pesticides [17].

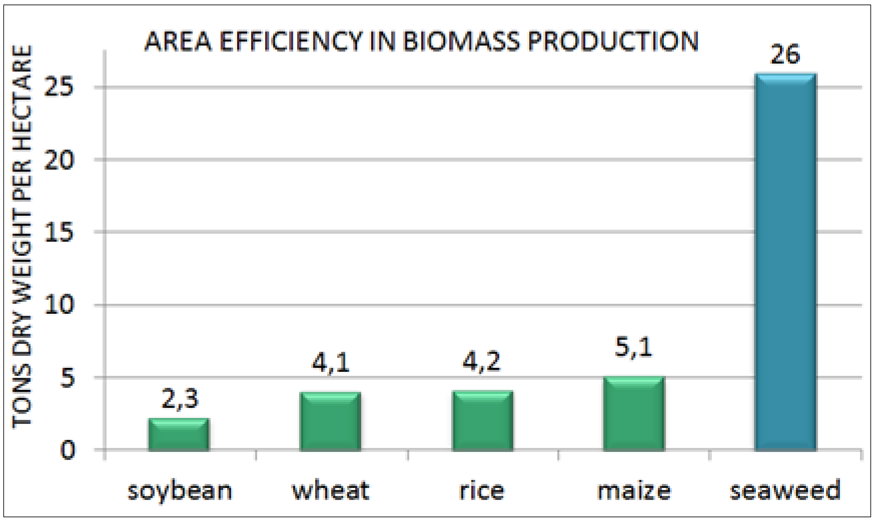


Figure 6: Area efficiency of marine and land plants measured in dry weight per hectare.

Seaweeds produce a 5 to 10 fold higher yield as compared to land plants.

Data from: SINTEF

The natural distribution of seaweeds is basically restricted by the combination of the presence of nutrients, sufficient light to drive photosynthesis and a firm substrate to attach to. Nutrients such as nitrogen and phosphorus can be limited nutrients, and ice cover can limit incoming light thereby limiting the growth season and suitable area for wild populations of seaweeds. In an IMTA system; the waste from fed fish (e.g., uneaten feed, feces and metabolites) will add nitrogen and phosphorus to the water and a substrate will be provided in the photic zone. Hence, IMTA systems possess an immense potential for increased production of carbon capturing marine biomass as compared to wild populations alone.

More self-contained with (marine-) feed ingredients: Feed for carnivorous fish such as salmon and trout contains marine fish meal and fish oil. The fish meal and oil contain marine proteins (amino acids) and lipids (omega-3) that are important for human nutrition, but also in the fish diet since they are essential for many important biological functions in fish as well. The share of marine ingredients in for example salmon feed has been reduced from 90 to 30 % the last decades, and an increasing part of the marine ingredients come from fish trimmings/by products from wild fisheries, largely reducing the dependency on fish caught for feed purposes. But the increasing share of replacing vegetable ingredients come from sources that have long transport routes, thereby increasing the CO_2 footprint, and the use of restricted resources such as farmland, phosphate fertilizer and freshwater [16, 18, 19]. In this aspect, IMTA in fact offers a great potential for production of local, suitable and sustainable feed resources. Several of the organisms that can be produced in IMTA systems contain both the essential omega-3 fatty acids as well as the correct amino acid profile (building blocks of the protein) to fulfill the fish´es dietary needs/requirements. Hence, these organisms are highly suitable as feed ingredients and can be cultured with a low carbon footprint and without the use of freshwater, arable land and fertilizer.

4.4 Development and implementation of IMTA – based on important lessons learned

Even though IMTA will have environmental benefits over conventional monoculture, environmental challenges with development of IMTA will naturally have some overlapping/similar potential negative effects as with monoculture, such as possible effects from disease transfer, escapes and discharge of chemical agents and medicines used for disease control. And as goes for conventional monoculture practices, development of IMTA systems also depend upon suitable area for production.

It is crucial in future development of IMTA in the Arctic to build on experience and to secure transfer of knowledge from previous development of conventional aquaculture practices to avoid negative impact and repetition of mistakes.

Therefore in this chapter we outline suggestions for important measures for environmentally responsible development of IMTA in the Arctic. Also, there are environmental considerations that can be unique or different when it comes to IMTA, which are also considered in this chapter.

There is large heterogeneity in the Arctic region when it comes to aquaculture practices as well as dependency of seafood as a main source of income and food security (se also chapter 4.1). Some countries and/or regions have developed commercial scale (monoculture-) aquaculture production, whereas other regions have no or very little aquaculture activity. Therefore, in some areas development of IMTA would in practice mean to *broaden or expand* activities from conventional monoculture to IMTA (main goals; reduce environmental impact, increase resource efficiency, increase biomass production without use of additional feed) whereas in other regions development of IMTA would mean to start from scratch. Considering the amount of experience and knowledge gained from previous mistakes, establishing IMTA from the start is likely to have the advantage of less environmental impact overall.

4.4.1 A well-defined and knowledge-based legal framework is crucial

To secure that commercialization of IMTA practices in the Arctic regions is performed within ecologically sustainable limits appropriate regulatory and policy frameworks need to be developed.

At present, there is to our knowledge no legal framework considering IMTA systems specifically.

In Norway, the production volumes of marine organisms that the aquaculture industry is allowed to produce is controlled by the authorities through means of licenses, localities and biomass regulation which in turn are based on/limited by environmental considerations.

The new governmental strategy (recent White Paper to the Norwegian Parliament) consists of guidelines based on predetermined (measurable) environmental impact factors. These must be within acceptable limits for growth to be awarded within a defined production area. If environmental impacts are unacceptable the production volume is either frozen or reduced depending on the severity of the environmental influence.

But when it comes to IMTA systems, the licenses for the different species/components are treated separately, rather than as a unit and on a basis of scarce available knowledge.

If development of IMTA would be executed in new areas in the Arctic, it is crucial that there is a well-defined and knowledge based legal framework regulating the development in a similar matter, ensuring that regulation is limited by environmental considerations.

Therefore, Bellona has initiated an interdisciplinary project to contribute to securing knowledge based decision making and IMTA commercialization

Responsible development of IMTA will depend on knowledge based decision making and continued research to find innovative ways to improve the environmental performance. Bellona has recently initiated an interdisciplinary project with leading research institutes and managing authorities in Norway with the aim to contribute compile a knowledge base for decision- and policy makers as well as development of a theoretical platform for improved environmental performance of IMTA systems. This knowledge platform may also have decisive influence in promoting more sustainable aquaculture practices internationally. Briefly outlined:

A theoretical environmental impact assessment (EIA) is developed to better understand and regulate the impacts that are unique to IMTA and to establish sustainable, ecosystem-based practices: The EIA will aid management authorities in knowledge based decision making as well as to proactively address environmental concerns with the potential scaling up of the IMTA practices. In addition, the EIA could form a basis for future development of a legal framework for IMTA.

In addition, a theoretical life cycle assessment (LCA) will be developed. Through looking at the separate parts of the IMTA value chain, this analysis will highlight areas for potential improvement to increase environmental benefits (or where the largest effects from system improvements could be expected). Also, LCA could examine the development potential for IMTA operations, and how this type of aquaculture could help fish farmers improve fish health and the environmental performance of their operations while maintaining economic viability.

4.4.2 Focus on preventive fish health measures (limit use of chemical agents)

An important lesson learned from development of monoculture practices is the importance of adopting management practices and to use production technology to avoid or reduce the likelihood of disease transmission (within and between aquaculture facilities as well as between facility and natural aquatic fauna). Both from an environmental and a welfare point of view, such preventive measures are highly preferable over disease control using medicinal or chemical treatment. Recommended preventive fish health measures are for instance:

- Local production of seedlings, fingerlings, smolt etc. and avoidance of import of such to eliminate the risk of importing infected organisms into the production system
- Only use of native/naturally occurring species for production purposes to avoid introduction of new (non-native) pathogens.
- Sufficient distance between production sites to maintain an infection barrier
- Coordinated and efficient fallowing within defined areas/zones (areal planning)
- Constant use of cleaner fish (to keep parasite/salmon lice levels constantly low)
- Adapt stocking density to prevailing physical and environmental conditions (avoid stress)

4.4.3 Collaboration in development – avoid conflicts – increase positive synergies

Securing close cooperation between different relevant stakeholders will likely be beneficial in development and/or commercialization of new aquaculture practices to avoid conflicts, and rather promote positive synergies. Industry, academia, general public and non-governmental organizations should preferably work together on integrated coastal zone management development. Further, local value creation should be secured, visualized and implemented (local communities should benefit from the development). Close cooperation between fisheries and aquaculture will promote positive synergies, such as sharing existing logistics and/or infrastructure related to processing, transport to market etc. Also, close cooperation between fisheries and aquaculture can promote use of by-products from fisheries as a resource for aquaculture: Trimmings and other by-products from wild capture fisheries are valuable resources which naturally contain both omega-3 and marine proteins. To some extent, fish meal and fish oil is already produced from trimmings and by-products from fisheries. This practice should be imported when developing IMTA in the Arctic. Close collaboration between wild fisheries and local feed producers will be a win-win situation for both parties both from a socio-economic as well as from an environmentally sustainable point of view.

4.4.4 Increased share of extractive, non-fed species

As was described in chapter 4.1 marine food production from Arctic culture mainly comes from farmed salmon in monoculture. This is in large contrast to the world wide marine food production [3, 20] (Figure 7). Globally (and largely influenced by Asia) an extensive share of the cultured marine species are low trophic, non-fed species with extractive properties, thus species living from and naturally removing excess nutrients in the surrounding aquatic environment. Since this allows for harvesting of nutrients/resources otherwise lost, both from run-offs from land and from fed aquaculture species, and these species do not require addition of manufactured feed, increased cultivation of extractive species should be promoted. This also illustrates that aquaculture is not synonymous to finfish culture which seems to be the general mindset in the (North-) Western parts of the world.

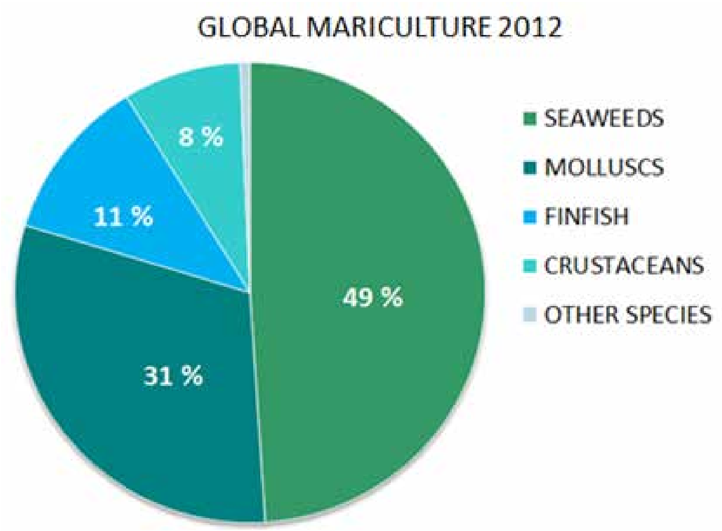


Figure 7. World production of farmed species groups from mariculture in 2012.

23.7, 14.9, 3.9 and 5.6 million tons of seaweeds, molluscs, finfish and crustaceans were produced, respectively.

Values shown as share (%) of total marine production.

Data source: FAO 2014

4.5 Arctic IMTA systems

4.5.1 General components

Components in an IMTA system are typically fed aquaculture species (e.g. finfish) combined in appropriate portions with organic extractive species (e.g herbivorous fish, suspension feeders, deposit feeders) and inorganic extractive aquaculture species (e.g. seaweeds). The by-products (wastes) from one species are recycled to become inputs (fertilizers, food and energy) for another [7, 8] (Figure 8).

The fed component: Some farmed species, such as salmon and trout, require manufactured feeds, small portions of which go uneaten by the fish. The wastes produced by fish, which include uneaten feed, feces and metabolites, provide high-quality nourishment for other species within the IMTA system as well as wild species.

The organic extractive component: Filter-feeding molluscs, such as mussels, clams, oysters and scallops filter the water column, feeding on micro-algae and small zooplankton and fine particulate matter. They can be used to reduce the level of finer organic particles that result from other fed or non-fed components of the IMTA system.

Sea cucumbers, sea urchins and certain worm species are deposit- and bottom feeders that sift through sediment to feed on organic particulate matter. They can be used to recycle the larger organic particles, that result from the other (fed or non-fed) components of the IMTA system, and that settle beneath the farm site.

The inorganic nutrient extractive component: Kelps and other seaweeds naturally extract dissolved inorganic nutrients (e.g., nitrogen and phosphorus) and can help reduce the levels of dissolved inorganic nutrients generated by the other fed and non-fed components of the IMTA system (as well as from land run-offs). The seaweed component of the IMTA system should be placed a little further away from the fed component as compared to the organic extractive component so as to better capture the inorganic dissolved nutrients that are lighter and travel longer distances than the organic nutrients.

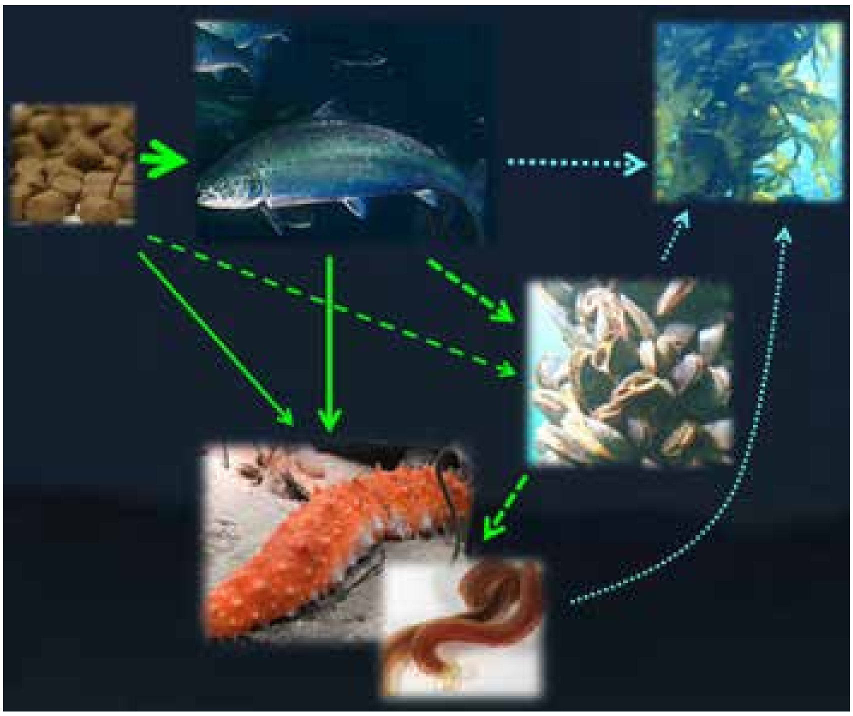


Figure 8: Schematic illustration of nutrient cycling in an IMTA system.

Organic large particulate matter from uneaten feed and byproducts flow towards deposit feeders and filter feeders

Organic fine particulate matter also flow from filter feeders to deposit feeders for nutrient extraction.

Inorganic dissolved nutrients coming primarily from finfish flow towards kelp.

Based on illustration from Fisheries and Aquaculture Canada 2013 [21].

4.5.2 Main relevant species

Species suitable for production in Arctic regions are species that are naturally distributed wholly or primarily in northern areas and adapted to relatively cold waters (<10°C) and related aspects of the habitat such as short growing seasons, extensive ice presence and long periods of darkness.

Wild species can migrate and actively seek preferred temperature areas, at which physiological processes are optimal, whereas cultured organism are limited in their mobility, and need to be chosen based on important parameters as temperature, salinity etc.

Also, it is important that the appropriate organisms are chosen based on the functions they have in the ecosystem, their economic value or potential, and their acceptance by consumers. More specifically, criteria for selection of species for IMTA systems are [7, 8]:

- Naturally occurring species
- Avoid import of new diseases
- Perform well/ high productivity and within given Arctic environmental conditions
- Suitable for culture systems
- Established husbandry practices are developed (can be reproduced in captive)
- Technology available
- Function in IMTA
- Complementary roles with co-cultured species
- Biomitigation ability (contribution to improved environmental performance)
- Economic value/market demand and commercialization potential

Within an effective IMTA system, peak production may not be achieved for any one species. Rather, the focus would be on optimizing sustainable production and the overall performance of all the combined species.

Generally, sea surface temperatures in the Arctic are low, but the naturally occurring marine organisms are well adapted to the physical conditions. In principle, organisms grow faster the higher the temperature up to an optimum range, which can be from 5 to 17° C for species living in the Arctic (see table 1).

Blue mussels, for instance, tolerate low temperatures for extended periods. The northward distributional limit is not determined by its tolerance of low sea surface temperatures, because sea water never gets colder than 1.5 - -2°C. Instead, it becomes limited by the requirements for sufficiently long periods of water temperatures above 5°C to allow somatic and germinal growth [22].

It was long thought that the low sea temperatures in Northern Norway would not offer optimum conditions for fish farming. However, this assumption proved false, and production of cultured fish in Northern Norway for instance, now accounts for 34% of national salmon and trout production [11]

Arctic seaweeds are also well adapted to low sea temperatures. Optimum temperature for photosynthesis in the spores of different species of kelp from Arctic Spitsbergen is 7 – 13 °C, thus relatively cold. Sporophytes of the endemic Arctic kelp *Laminaria solidungula* grow up to temperatures of 15°C with optimum growth rates of 5-10 °C and an upper survival temperature of 16°C [23].

Table 1: Temperature limits for tolerance of selected cold water species. Lower incipient lethal temperature is the temperature below which an organism cannot survive for an indefinite time. Higher incipient lethal temperature is the temperature above which a fish cannot survive indefinitely. Optimal range is the temperature at which the organisms exposes optimal growth.

Sources: Fishes [24], blue mussel [22] and kelp [23]. d.a; data not available.

Table 1 Temperature limits for tolerance of selected cold water species.

	Incipient lethal temp ^{O}C		Optimal range^{0}C
	Lower	Higher	
Arctic char *Salvelinus alpinus*	0	19,7	6 to 15
Atlantic salmon *Salmo salar*	- 0,5	25	13 to 17
Blue Mussel Mytilus Edulis	- 10 to - 15	27 to 29	d.a
Arctic kelp Laminaria solidungula	d.a	16	5 to 10

Some relevant species for IMTA in cold waters

Fin fish (fed component)

- Arctic charr *(Salvelinus alpinus)*
- Atlantic salmon *(Salmo salar)*

Organic extractive species (filter feeders and deposit (bottom) feeders)

- Blue mussel *(Mytilus edulis)*
- Green sea urchin *(Strongylocentrotus droebachiensis)*
- Red sea cucumber *(Parastichopus califormicus)*

Inorganic extractive species

- Arctic kelp *(Laminaria solidungula)*
- Sugar kelp *(Saccharina latissima)*
- Winged kelp *(Alaria esculenta)*
- Dulse *(Palmaria palmata)*

4.6 Suitable areas for IMTA: Important considerations

4.6.1 Physical characters of the Artic

Sea temperature, salinity and photoperiod are major parameters determining a species´ range and thus the suitability of a geographic area for farming.

Sea surface temperatures show great natural variation depending on the influence from ocean currents, thereby contributing to a very heterogeneous marine environment in the Arctic [25] (Figure 9). Also, climate change affects sea surface temperatures (see also chapter 4.7).

Figure 9. Surface ocean currents in the Arctic.

Simplified; Warm currents originating from the Atlantic and Pacific Oceans are flowing north to the Arctic regions, while cold currents flow out of the Arctic.

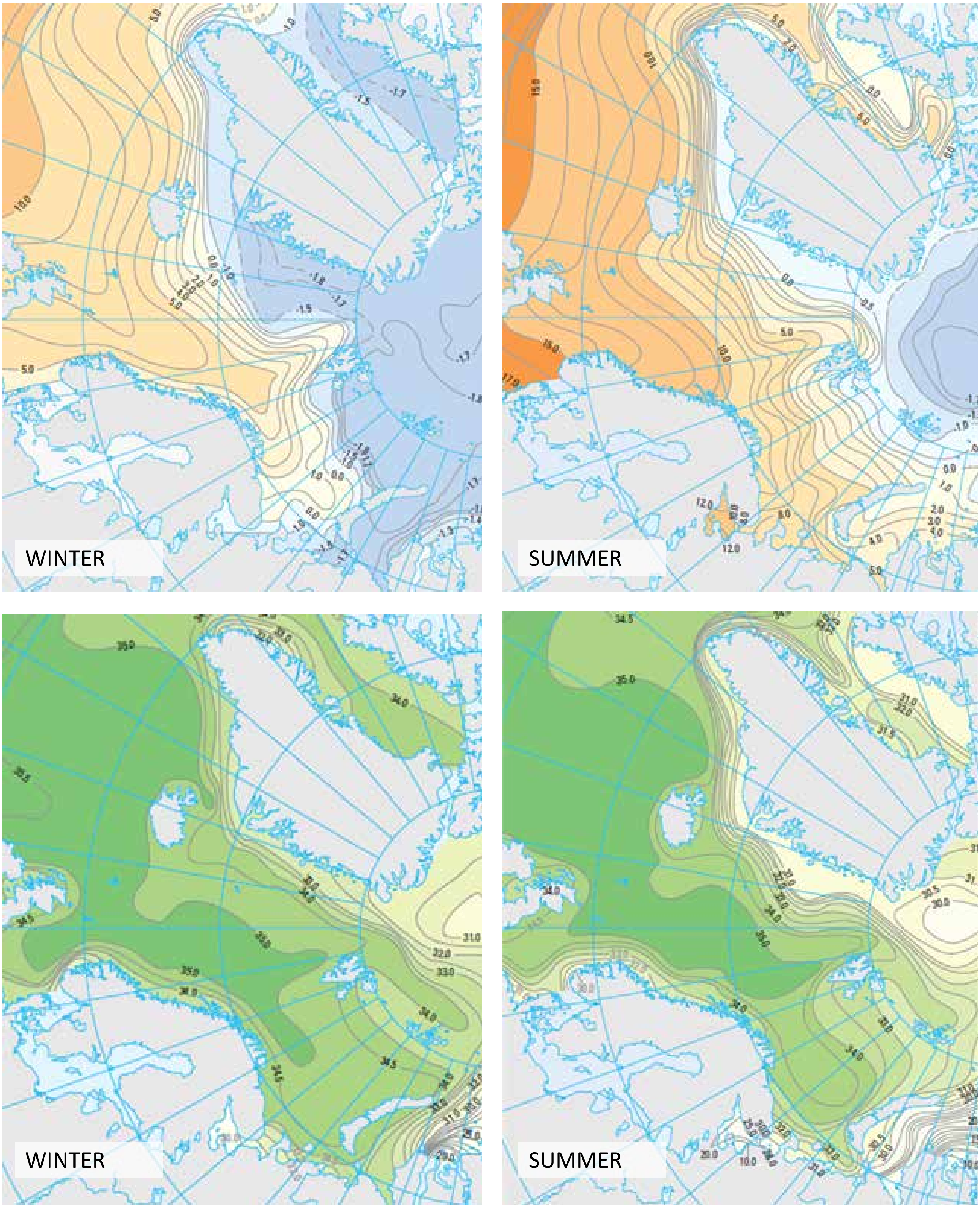
Most of the water in the Arctic Ocean originates from the Atlantic Ocean, with only a very modest inflow through the Bering Strait.

Source: Murray et al. 1998. AMAP

The warm, North Atlantic currents reach high latitudes and thereby largely moderate the coastal temperatures in the Arctic region. This is especially notable during winter, giving these regions milder winter temperatures as compared to similar latitudes in the continental Arctic. As a result Iceland, the Faroe Islands, Northern Norway, southern parts of Svalbard, the Kola Peninsula and even the west coast of Novaya Zemlya have unusually high temperatures in winter despite the high latitudes/northerly location. Some unexpected consequences are for instance that the surrounding waters of Svalbard are open and navigable most of the year, and that the southern parts of Iceland have July temperatures of 10-13°C. In contrast to the warming effects of the North Atlantic currents, the coast of Greenland is surrounded by cold currents that flow out of the Arctic, as is illustrated in figure 9 [25].

In addition to these strong influences from the main oceanic currents, the sea surface temperatures vary with latitude and season, the latter also affecting salinity. Combining maps showing sea surface temperatures and salinity [25], gives a good basis to evaluate potential sites for aquaculture activities (Figure 10): The area east of Novaya Zemlya (Kara Sea) and the White Sea show varying and relatively low salinity during summer due to input of freshwater from rivers and ice melt. Though, areas with stable and relatively high salinity are overlapping with areas in the North- and Barents Sea with sea temperatures that make some of these areas potentially suitable for aquaculture purposes.

Figure 10. Winter and summer surface temperatures (°C, top) and surface salinity (bottom) in the Arctic Ocean and adjacent seas. (USSR Ministry of Defence 1980). Figures from Murray et al., 1998. AMAP.



Together with temperature and salinity available sunlight influences biological productivity in animal as well as plant organisms. In the Arctic, seasonal variations in photoperiod and sea temperatures are rather extreme. As illustrated in figure 11 the most extreme seasonal variations in insolation occur at the North

Pole (90° North). Considering the Arctic region lies in between approximately 66.5 and 90° North, it is shown that during the time period around the June solstice, the Arctic receives more potential incoming solar radiation than any other location graphed. In contrast, there is a dark season with polar nights between the September equinox and the March equinox with no or little direct sunlight north of the Arctic Circle [26].

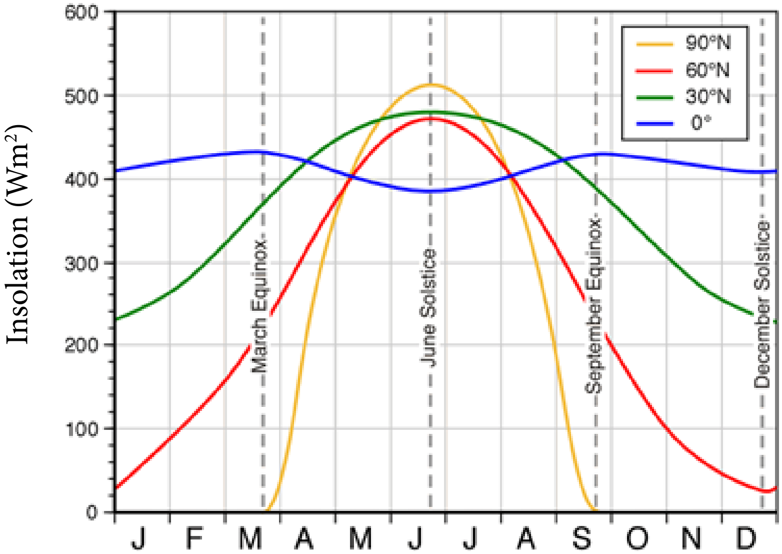


Figure 11. Monthly values of available insolation in Wm-2 for the equator, 30, 60, and 90° North over a one-year period.

The calculated insolation take into account the combined effects of angle of incidence and day length duration.

Source: Pidwirny 2006 [26].

Species in the Arctic therefore inhabit properties to cope with cold waters, short growing seasons, long periods of darkness and extensive ice presence.

Organisms can react by triggering an unusually fast/rapid growth following periods of environmentally induced growth depression (e.g low sea temperatures and/or little or no sunlight), a phenomenon named compensatory growth [27]. Even though the underlying mechanisms are different in feeding organisms, such as fish compared to primary producers, such as algae – this phenomenon leads to explosive growth in the Arctic following cold and dark winter periods.

As a result of this, fish in temperate ecosystems undergo about 90% of their annual growth in the summer months because food availability tends to be the highest and water temperatures approach growth optimum [28]. This indicates that the productivity during the summer half year in the Arctic can be close to productivity during a complete growing season in warmer latitudes, and that the effective growth seasons in the Artic are short of character.

4.6.2 Protected areas and area conflicts

In addition to the physical characteristics defining the range for cultured species, available and suitable area for aquaculture activities is a prerequisite. There are several protected and vulnerable areas in the Arctic where aquaculture practices should not be allowed or considered (Figure 12).

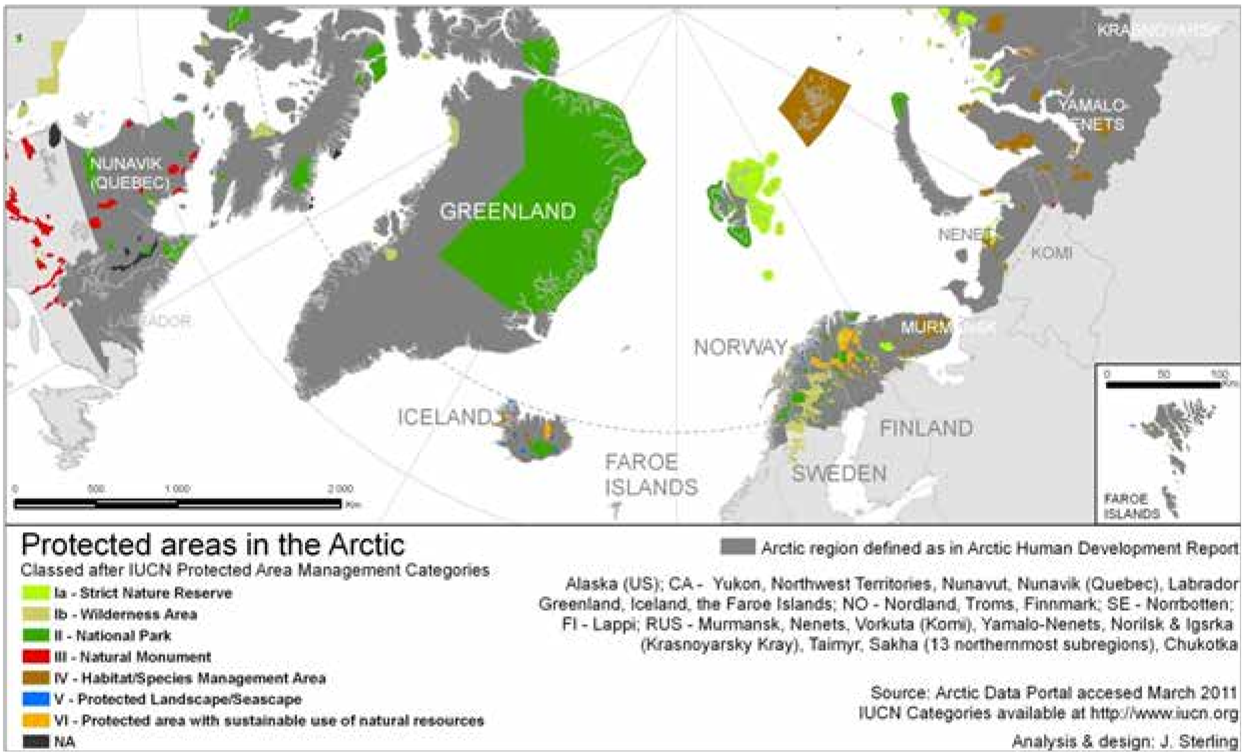


Figure 12: Protected areas in the Arctic. Source: Nordregio at www.nordregio.se.

Access to (new) areas defined for aquaculture practices is presently a point of discussion in all areas with aquaculture activities relating to future possible development.

Provided performed within the carrying capacity of the environment; mariculture is the most resource and area effective way of producing food and has great potential to increase food security and value creation in Arctic areas. Sufficient and suitable areas for these means should therefore be prioritized alongside with other important marine activities.

It is estimated that aquaculture activities in Arctic Norway occupy approximately 0.03% of the sea area within the baseline of the three northernmost counties [11]. Considering the rather limited use of area combined with the fact that Norway presently by far is the largest aquaculture producer in the Arctic region, illustrates the area efficiency of seafood production and the vast area potentially (and theoretically) available in other Arctic regions.

When it comes to area for aquaculture purposes it is not only sufficiently large areas that need to be prioritized, but also the suitability an area.

Alongside aquaculture, also fisheries, the mineral industry, renewable energy, tourism and the petroleum industry are all area-intensive users of the coastal zone. Access to suitable areas is a challenge for several of the industries [11].

There is a need for improved planning and area management – considering all these potential users. Authorities dealing with resource management will also face increasingly competitive use of marine ecosystems and have to balance/consider among options for the greatest good for the greatest number of people.

Because of the predicted sea ice retreats in the Arctic resulting from climate change, a major concern is also how this will open the way for a significant potential increase in maritime activity, as illustrated in figure 13. The map shows the complexity surrounding the future of the Arctic Ocean area in respect of access to resources and where new activities are expected to take place.

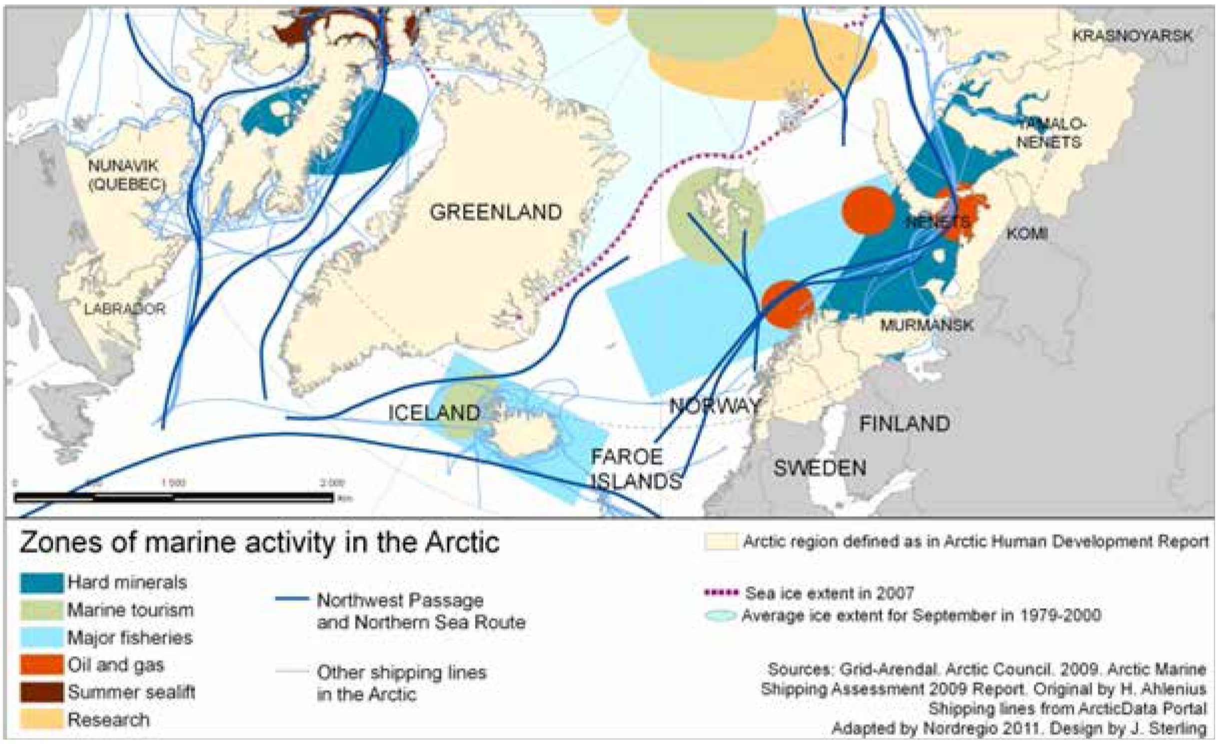


Figure 13: Zones of marine activity in the Arctic. The map illustrates the complexity surrounding the future of the Arctic Ocean area in respect of access to resources based on the Arctic Council Arctic marine Shipping Assessment 2009 Report. The major concern is what is going to happen in the coming decades as the sea ice retreats, opening the way for a significant potential increase in maritime activity. The map shows where these new activities are expected to take place and the sea routes that may become important in relation to these future activities in the region. Sources: Grid-Arendal. Arctic Council 2009. Arctic Marine Shipping Assesment 2009 Report. Original by H.Ahlenius Shipping lines from ArcticData Portal. Adapted by Nordregio 2011. Design by J. Sterling.

4.7 Climatic change: a brief overview relevant for IMTA

The effects from climate change are particularly obvious in the Arctic region. Physical changes resulting from climate change impacts are most recently and thoroughly described by The Intergovernmental Panel on Climate Change [15], and more specifically concerning the Arctic by The Arctic Climate Assessment [12]. Based on these reports, the predicted physical changes with the highest potential effects for integrated aquaculture are summarized:

Increasing sea temperature. The period from 1983 to 2012 was likely the warmest 30-year period of the last 1400 years in the Northern Hemisphere. Over the next 50 years, a further increase in sea temperatures of 1 to 3°C in the North Sea, Nordic seas and Barents Sea is likely and a minimum warming of 0.5°C is projected in the Denmark Strait. The largest changes are occurring in the northernmost regions, and the Central Arctic Ocean is projected to warm more strongly than any other region. By the end of this century it is predicted that in sea-ice free areas, the annual mean temperature will show a 4-5°C increase and the average winter temperature in the central Arctic an increase of as much as 6°C.

Sea ice reduction. Due to the increasing warming, year-round reductions in Arctic sea ice are projected. Duration of sea ice is projected to be shortened by 15-20 days within 2050, and 20-30 days within 2080. A nearly ice-free (sea-ice extent is less than one million km2 for at least five consecutive years) Arctic Ocean in September before mid-century is likely. And some models project that by 2080 the formation of sea ice in winter will no longer completely cover the Arctic Basin, with probable open areas in the high Arctic (Barents Sea and possibly Nansen Basin).

With decreasing ice duration and coverage follows more areas and longer seasons with light exposure.

Increasing acidification: Ocean acidification refers to a reduction in the pH of the ocean primarily caused by increased uptake of carbon dioxide (CO_2) from the atmosphere due to increased atmospheric levels of anthropogenic CO_2. Since the beginning of the industrial era, the pH of the ocean surface water has decreased by 0.1 (from 8.2 to 8.1), corresponding to a 26% increase in acidity (IPCC). In the Nordic and Barents sea, it is predicted that the surface water pH will be further reduced by 0.19 from 2000 to 2065 [29].

Increasing precipitation and runoff: It is likely that anthropogenic influences have affected the global water cycle since 1960. Precipitation and runoff has increased slightly and is projected to increase further by up to about 10% by the end of the century.

Changes in ocean surface salinity: Observations of changes in ocean surface salinity also provide indirect evidence for changes in the global water cycle over the ocean. Increased precipitation and (river/ melt water) runoff will contribute to stronger freshwater stratification in fjord systems (thick brackish/ fresh surface water layer). Also, in coastal areas, salinity changes will be increasingly governed by the annual cycle of freshwater runoff. North of Siberia and in the Arctic Ocean, salinities are projected to decrease by 0.5 to 1.0, and a tongue of fresher water is projected along the East Greenland Coast.

Sea level rise: Global mean sea level rose by 0.19m over the period 1901 to 2010, and the rate of sea level rise since the mid-19th century has been larger than the mean rate during the previous two millennia. In the Arctic region, the sea level in predicted to increase further with a 15 cm rise in sea level by 2050 and 25cm by 2080.

Intensity of storms: It is possible that storm intensity can increase regionally (Labrador, Beaufort and Nordic Seas). In general, winter storms will decrease slightly in intensity because the pole to equator temperature gradient decreases. In areas of sea-ice retreat, here will be an increase in wind-driven effects (currents, waves) because of longer fetch and higher air-sea exchange.

4.7.1 Potential direct effects from increased temperature

The direct influence of climate driven changes in water temperature on production species is likely the most profound parameter that impacts aquaculture production in the Arctic. As opposed to land living production animals, farmed marine species like finfish and mussels are so called poikilotherm; thus their body temperatures are largely varying and governed by the surrounding sea water temperature. Physiological processes like metabolism and growth are strongly related to temperature in these species. Hence, sea temperature will (together with salinity) define a species´ ideal area of production considering biological performance (feed intake, growth, reproductive success) but also lower and upper lethal temperatures. In principle, growth is positively correlated to temperature up to an optimum range, which is species-specific [22, 23, 24] (see also chapter 4.5.2). Therefore, provided temperature changes are within optimum range of a species, potentially positive effects from warming waters are increased growth rate/ productivity, extend growing season, extended geographic range suitable for certain aquaculture species and reduced winter natural mortality [13, 30, 31].

Increasing growth rate related to increasing temperatures also leads to increased metabolism and need of oxygen. Since the solubility of oxygen decreases with increasing temperature, stocking density of production organisms need to be planned accordingly. Maximum oxygen demand should not exceed available soluble oxygen at any time.

4.7.2 Potential indirect effects and other variables

Direct and indirect effects from climate change are hard to predict, and it can be difficult to discern the causative links, and often the changes are caused by a combination and/or a chain of effects [32] (Figure 14).

Due to increased ice melting and reduced sea ice as a result of increasing temperatures, land and water surface area available for production purposes is also likely to increase. Though, more or less ice-free conditions are required since ice can damage aquaculture equipment.

Decreased sea ice also results in more exposure to light and increased vertical mixing and upwelling of nutrients. In a positive sense, this combination is predicted to result in a two to five times increased primary production over present levels which would provide more food and increase productivity of filter-feeders in cultured systems, such as mussels. Though, it could also result in increased risk of harmful algal blooms (increased human health risks by eating molluscs) and increased risk of invasive disease. Compared to more southern latitudes with higher water temperatures, development and transfer of disease will likely be slower/less aggressive in the Arctic waters considering the relatively cold sea temperatures [13, 30, 31].

Indirectly, changes in water temperature will also affect availability of feed ingredients like fish meal and fish oil (imported feed resources from fisheries). Though, as is outlined in chapter 4.3.2, this issue could be addresses by development of IMTA practices.

Direct effects from storm intensities, can be relatively well anticipated, but uncertainty regarding how these parameters will change is high. If the storms become more intense, it can cause structural damages and loss of equipment as well as farmed organisms. Future aquaculture might therefore require increased strengthening of equipment as well as searching for sheltered production sites/localities [13, 30, 31].

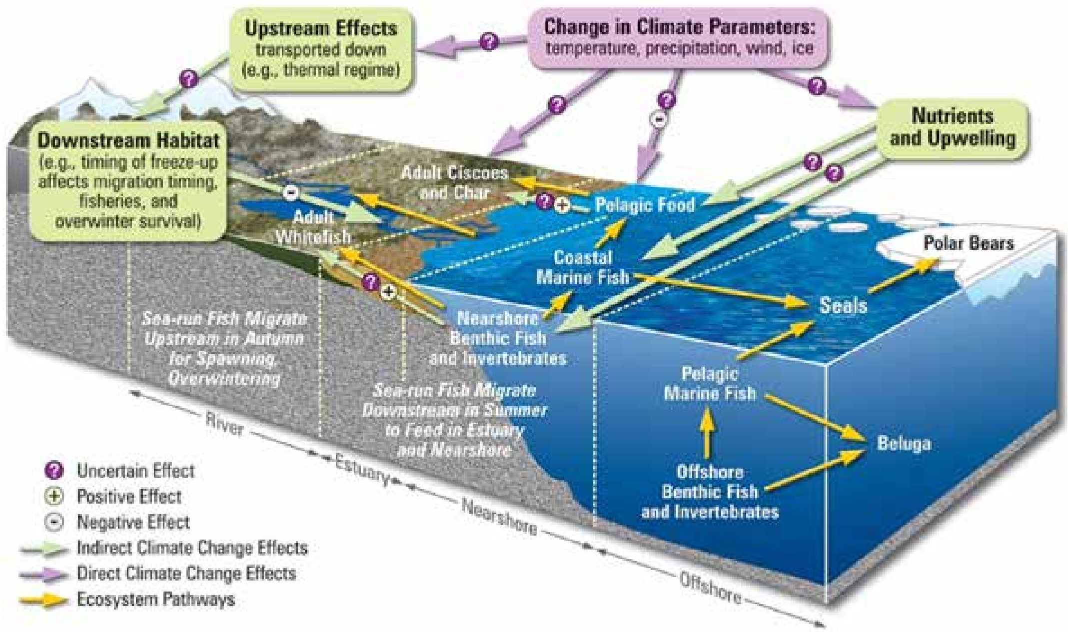


Figure 14. A stylized portrayal of some potential direct effects of climate parameters on arctic aquatic environments and some potential indirect effects on aquatic organisms (such as anadromous fish). The complexity of interactive effects raises great difficulties in projecting climate change effects on these fishes. Source: Reist et al.2006. [32]

Increasing atmospheric carbon dioxide concentrations are reducing ocean pH and carbonate ion concentration, and thus the level of calcium carbonate saturation. This can have serious consequences for marine organisms that form calcium carbonate shells or skeleton. Relevant to IMTA systems is that species like molluscs and echinoderms are more sensitive than crustaceans and fishes [15, 31, 33]. Though, we want to emphasize that all marine ecosystems, especially coral reefs and polar ecosystems, are at risk from ocean acidification. This is worsened in the Arctic since gasses dissolve more readily in cold water, and thus cold water absorbs/contains more CO_2 and has a higher acidification rate as compared to warmer waters. Also, there are likely combined effects from other global changes (e.g., warming, progressively lower oxygen levels) and local changes (e.g., pollution), leading to complex and amplified impacts for species and ecosystems [15].

It is further indicated that conditions detrimental to high-latitude ecosystems could develop within decades, not centuries as suggested previously [33].

Ocean acidification is therefore a major problem that requires global solutions, agreements and actions. The best way to reduce global ocean acidification is to cut CO_2 emissions. However, as an immediate measure, culture of algae as massive consumers of CO_2 could potentially have a local, mitigating effect.

It is also likely that increased precipitation will result in increased fall out of pollutants. As is described in chapter 3, concerning mining, persistent organic pollutants accumulate in arctic ecosystem to a larger degree than further south, since this region is the fall-out for long-range transport pollutants due to prevailing sea and air currents, a process called global distillation. Therefore, unexpectedly high levels of POPs (persistent organic pollutants) are found in many Arctic species especially high in the food chain. Related to consumption of locally produced/harvested food in general, but thus also from IMTA systems, one should therefore take this in consideration.

An unfortunate combined effect of increased temperature and pollutants, is that the toxicity of common pollutants (e.g., organophosphates and heavy metals) to fish generally increases a higher temperatures [34]. This could have very negative consequences for both wild fish species as well as fish in IMTA production systems.

4.8 Key findings and recommendations

Effects from climate changes which are mainly driven by anthropogenic CO_2 emissions are especially evident in the Arctic, and result in losses of biodiversity and unpredictable changes in availability of important marine food species.

This development emphasizes the need for increased food security based on local, renewable resources and local value creation, whilst simultaneously decoupling of economic growth from CO_2 emissions.

Development of Integrated Multi Trophic Aquaculture (IMTA), provided performed within ecologically sustainable limits, offers great potential to address these issues adequately and at the same time possess environmental benefits over conventional monoculture. Potential benefits from IMTA are:

- Capture of CO_2 a in valuable biomass (reduced atmospheric CO_2 and acidification)
- Replacement of fossil hydrocarbons with seaweeds as biomass for bioenergy purposes
- Increased food production with low carbon footprint (and without increased use of feed)
- Reuse/Recycling of nutrients and recovery of valuable minerals (otherwise being lost)
- Space efficient production with less or no use of limited resources
- Local production of marine feed ingredients (reduced reliance on fisheries or import of feed)

Even though IMTA will have environmental benefits over conventional monoculture, environmental challenges with development of IMTA will naturally have some overlapping/similar potential effects as with monoculture

It is therefore crucial in future development of IMTA in the Arctic to build on experience and to secure transfer of knowledge from previous development of conventional aquaculture practices to avoid negative impact and repetition of mistakes.

Specific recommendations are therefore:

- A well-defined and knowledge based legal framework that regulates the development of IMTA that is based on/limited by environmental considerations.
- Focus on preventive fish health measures (and strictly limited use of chemical agents), e.g.,
    - Local production of seedlings, larvae and fingerlings (avoid disease transmittance)
    - Only use of naturally occurring species for production purposes (avoid introduction of new (non-native) pathogens
    - Sufficient distance between production sites (infection barrier)
    - Coordinated and efficient fallowing (areal planning and cooperation)
    - Constant use of cleaner fish (keep parasite levels constantly low)
    - Adapt stocking density to prevailing physical and environmental conditions (avoid stress)
- Promote collaborative opportunities between marine based industries and stakeholders and avoid conflict over area use
- Increased share of extractive species – as opposed to monoculture of high trophic species that need to be fed

Climate change affects fisheries and aquaculture somewhat differently. Resulting physical and biological environmental effects specific for the Arctic, and with the likely most profound effects with relevance for aquaculture practices are:

- Increased water temperature
    - positive; increased growth rates/productivity, extended growing seasons, extended geographic range, reduced winter mortality
    - negative; less dissolved oxygen, possible increase in toxic algal blooms, increased risk of invasive pathogens)
- Acidification; large anticipated negative effects, especially for molluscs and echinoderms
- Increased precipitation; likely increased fall-out of long-range persistant organic pollutants

Planning of species to be cultured in IMTA systems should be evaluated based on the functions they have in the ecosystem, natural occurrence, husbandry practices and technology is developed and their economic potential.

Seasonal variations in sea temperature and photoperiod are rather extreme. As a result, the effective growth seasons in the Arctic are explosive and short of character.

Suitable areas for IMTA should be evaluated based on ecological parameters (included possible effects from climate changes) and accessible area (not protected areas or in conflict with defined users).

4.9 References

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