Social and environmental conditions for mining in Greenland

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Cryolite: Lessons from History for Contemporary Practice

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Abstract

The June 1963 issue of *World Mining* announced that the ore body of the cryolite mine in Ivigtut, Greenland had been mined out. This marked the first major ore mineral to be completely depleted in the modern world. Although cryolite exists in small quantities elsewhere Greenland was the only major commercial source of the mineral. In the early 20th century cryolite was used in the manufacturing process of aluminium and was essential to the war-time production of aircraft. During the Second World War several multi-national companies took an interest in both cryolite and Greenland itself. Once corporate reliance on cryolite abated, so too did its interest in the island. Drawing from the closed company archives of the Aluminum Company of Canada (Alcan – now RioTintoAlcan) this paper will highlight lessons that can be learned from the history of cryolite for contemporary industry.

Figure 1: Ivigtut cryolite mine 1940

1. Introduction

In mid-July 1963 Fraser Bruce, the President of the Aluminium Company of Canada (Alcan), received a letter from the Director of Aluminium Laboratories Limited. The letter stated that the Cryolite mine at Ivigtut had been completely mined out. Although stockpiles would permit shipment for several more years, cryolite was the first major ore mineral to be completely depleted (Alcan Archives, 1963).

Alcan had a long standing interest in Greenlandic cryolite. In the first half of the 20th century cryolite from the Ivigtut mine was vital to production of aluminium at Alcan. This reliance became a global geo-political issue when Germany invaded Denmark during the Second World War. On the day of the invasion Alcan notified the Canadian government of the potential impact the German invasion could have on Denmark's colonies, including Greenland. The German occupation of Denmark would likely affect annual shipments of Cryolite from Greenland which would have a major effect on war-time aluminium production (an essential component in munitions and aircraft manufacture) (Berry, 2012). Over the course of the war Alcan played a significant role on the island. It became the official purchasing agent for the colony's imports during the war supplying Greenlanders with food, clothing, machinery and even ammunition for hunting (Campbell, 1989). The company was dependant on natural cryolite shipments from the island between 1940 and 1942, but they did not request additional supplies of

the mineral in 1943 because over the course of the war Alcan developed a cost-effective synthetic alternative to cryolite. This development meant a significant decrease in the corporation's interest in both Greenland and its main export cryolite. By the time the cryolite supply had been completely depleted twenty years later in 1963 Alcan had not used cryolite for years and not refined its own cryolite for a significant period (Alcan Archives, 1963)

An examination of the history between Alcan and the Greenlandic cryolite industry highlights a number of issues which should be remembered in industry today. This paper will discuss the ways in which Alcan's relationship to Greenland during the Second World War reveals aspects of the Greenlandic cryolite industry in the 20th century that should inform Greenlandic mining practices in the 21st century particularly with respect to staffing, corporate-community engagement, and the effects of market forces on corporate interest in Greenland.

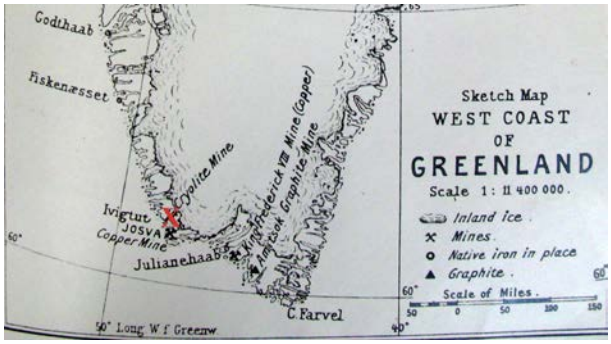

Figure 2: Map of Greenland with Cryolite Mine

2. History of Cryolite and Cryolite Mining in Greenland

Cryolite is a mineral that was commercially mined in Greenland from the mid 19th to mid 20th century. Although it has been found in small quantities in other locations the only large commercial deposit of cryolite was found near the town of Ivigtut on the south-west coast of Greenland. Although it has been found in small quantities in other locations the only large commercial deposit of cryolite was found near the town of Ivigtut on the south-west coast of Greenland. Nicknamed "ice-rock" because of its ice-like appearance, cryolite was discovered in 1800 and first developed commercially in the mid 1850s by the Royal Greenlandic Company (KGH) of Denmark which held a monopoly of the mining, refining and trade of the mineral. It was originally used in the production of soda and later for iron enamelling and the production of opaque glass (Friis, 1937). In 1865 the Pennsylvania Salt company (PennSalt) was granted an exclusive North American distribution contract for cryolite which was mined in Greenland and refined in Denmark (Campbell, 1965).

Cryolite became particularly commercially important in the aluminium production process. In the early 20th century the most cost effective manufacturing process of aluminium required two materials: bauxite and cryolite Bauxite is one of the most abundant materials on earth and can be found on nearly every continent. In contrast cryolite was only found in Greenland (Berry, 2012).

In the Hall–Héroult process of aluminium production which was used by Alcan, bauxite – an aluminium ore that is a composite sedimentary mineral rock – is heated and filtered to produce aluminium oxide. The aluminium oxide is then heated and cryolite is added as a flux and charged with an electric current to produce the metal (Carr, 1952). It was possible to use a synthetic alternative to cryolite, but at the time it was more expensive and less effective than natural cryolite.

At the time of the German invasion of Denmark the town of Ivigtut had a population of approximately 150 people. The population was comprised exclusively of Danish miners (without their families) and mining officials. Until the mine was nationalised by the Greenlandic governors, the mine employees were responsible only to the shareholders of the Ivigtut Kryolite Mines and did not fall under the jurisdiction of Askel Svane, the Governor of South Greenland. In addition, the living standards of the town were Danish and Ivigtut's European expat residents had almost no

contact with local Greenlanders (Mount, 1985). Although the revenues from the cryolite mine constituted a significant proportion of Greenland's economy there was a popular saying that "Ivigtut is not Greenland." (Dunbar, 125).

When Greenland was cut off from Denmark as a result of the German invasion there was significant concern on the part of industry in both Canada and the United States that the cryolite exports would be disrupted. Alcan, however, was concerned about Greenland's cryolite supply long before the German invasion. A number of company executives were worried about the security of shipments from Greenland to North America. As mentioned most of the global cryolite supply had been refined in Denmark and North American supply was managed and distributed by PennSalt. The war in Europe meant that shipping the unrefined cryolite to Denmark was increasingly dangerous as a result of German u-boats and surface raiders in the North Atlantic.

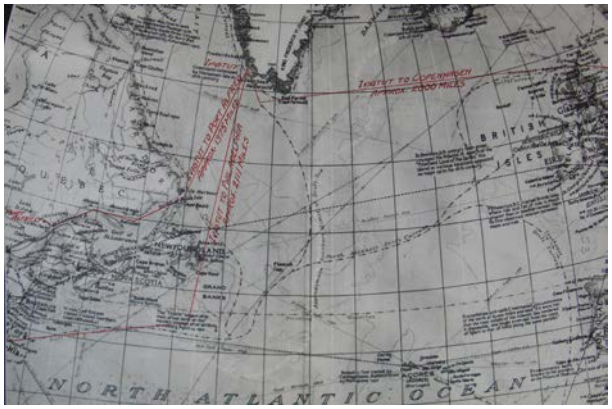

Figure 3: Map of cryolite shipping routes from Greenland to Europe, Canada and the United States

Although the United States was officially neutral in the early stages of the war there was no guarantee that their shipments would be secure.

Greenland's climate only allowed cryolite to be shipped from the island for a brief period each summer when the harbours were ice-free. The harbours had been iced over since the war began in September 1939. Though there had not yet been any war-time shipments of the mineral out of Greenland the sinking of a cargo of bauxite elsewhere by Germany in early 1940 caused Alcan to give serious consideration to the security of that year's cryolite shipments, "the loss of which would be a serious blow." (Alcan Archives, 1940).

Figure 4: Abandoned section of Ivigtut cryolite mine 1940

More significantly, however, Reports had been circulating in the mining community that the Ivigtut mine was nearing exhaustion and the quality of the mineral that was being extracted was considerably reduced in comparison with previous years. (Alcan Archives, 1939-1940).

Alcan's president was cognisant of the fact that aluminium production would inevitably be disrupted if an alternative to natural cryolite was not quickly developed. When Germany invaded Denmark Fraser Bruce's first action was to encourage the formulation of a cost effective alternative to cryolite as soon as possible. Cognisant of the fact that an alternative to natural cryolite would take time to produce, he entered negotiations with Canadian government officials to ensure the safety of the cryolite supply from Greenland to preserve the company's production schedule for the year.

Greenlandic Governors Eske Brun and Axsel Svane, in conjunction with the mine manager, nationalised the mine on June 26, 1940 for the Greenlandic government. The mine managers negotiated separate agreements with both PennSalt and Alcan. Over the course of the war Alcan assisted with the distribution of cryolite to the United

Kingdom and the British Commonwealth. As mentioned, they also began acting as a purchasing agent for the colony (Alcan Archives 1940-1945).

At the end of the war the re-privatised mine requested the cessation of Alcan's distribution of cryolite to its pre-war European markets. In addition, in recognition of Alcan's assistance to Greenland during the war, the Danish Government presented the King Christian X Liberty Medal to Alcan's Director of Purchases and Chief Purchasing Agent. After the war ended, however, Alcan had little more to do with the island or its mining industry and the aluminium industry's interest in the island abated for decades.

3. Issues raised by the example of the Ivigtut mine.

The experience of Alcan's trade with Greenland during the Second World War reveals both positive and negative aspects of the mining industry at the time. Although some of these issues have been addressed many still persist in Greenlandic mining industry today.

3.1 Staffing

One of the most striking aspects of the Alcan-Ivigtut relationship during the war was the structure of the town and the composition of its workforce. None of the mine's employees were local and those who worked in the mine had almost no interaction with the local community. While it could be argued that as a Danish colony Danish workers in Greenland should not be considered foreign, it was a company policy not to employ Greenlandic employees. According to corporate records from the time Greenlanders were "neither employed at the mine, nor allowed to enter the settlement, except once a week for the purpose of trading fish and other native produce for rye bread, coffee, tobacco, etc" (Alcan Archives 1940).

Although the paternalistic regulations that guided polices during the war are no longer acceptable practice the issue of staffing is one that persists in the Greenlandic mining industry today. Although studies from the 1980s predicted unemployment would be an issue for Greenlanders in future (Lyck, 1989) the rapid growth in the extractive and other industries on the island have not born this prediction out. With a current population of only 57,000 inhabitants Greenland will not have a sufficiently large national workforce to draw from to satisfy industry's growing demands. Recently the Greenlandic Parliament has passed legislation that allows for projects valued at more than $900,000 to use imported contractors and labour. This move has been criticised by the international community because the legislation will allow companies to pay low wages to the temporary workers (Plogander, 2012). The legislation also has the potential to re-create the corporate-community divide that existed on the island in the early 20th century. Greenland's government and mining companies will have to continue to work in conjunction to ensure Greenlanders are represented in industry as much as possible and foreign workers are treated fairly.

3.2 Corporate-Community Engagement

Second, the there was little to no direct engagement or benefit between the mining company and the community. Prior to the war a portion of the profits from Greenland's cryolite industry were sent to Denmark which helped to offset the administration costs of the colony. Although this indirectly provided government services for the people of Greenland there was little contact between the mine and the local community and the mine's operations did not benefit the people living on the island. While Alcan did assist both the mine's employees and local Greenlanders with the acquisition of necessities during the war it had no contractual obligation to do so.

Greenland was recently ranked 14th in the Fraser institute's annual global mining survey which is based on a composite index which takes into account a variety of factors including taxation and government regulation (Wilson, 2013). Greenland's strong international reputation will continue to attract multi-national involvement in the island its mining industry matures and the

opportunities for profits on the island continue to be affirmed.

Corporations continue to have a vested interest in maximising profits and minimising expenditure and have little interest in engaging the local community without legislation to do so. Over the past decade Greenland has implemented policies with the express purpose of attracting small companies which are less adverse to risk than larger multi-national corporations in order to stimulate the development of the mining industry on the island (Greenland, 2009). The willingness of these small companies to invest in Greenland has not only helped engage a greater number of Greenlanders in the industry and affirmed the wealth of resources on the island, but also helped to establish the industry itself. Both of these results have directly impacted the community. As increasingly large projects are approved and foreign workforces imported policy makers will need to ensure that the benefits of foreign investment continue to be more than strictly financial.

3.3 The effects of market forces on corporate interest in Greenland

The most significant lesson that can be gleaned from the history of the relationship between Alcan and the Greenlandic cryolite industry is the finite nature of the mining industry and the effects of market forces have had on corporate interest in Greenland. At the outset of the war global demand for cryolite increased as a result of fears for the reliability and quality of the supply. Although Alcan assisted the people of Greenland during the war the company's interest in the island faded when its reliance on Greenlandic cryolite waned and cryolite stores were exhausted. Alcan and the mining industry lost interest in Greenland both as a result of issues with the cryolite supply and advances in the industry that were making cryolite obsolete.

It is a seemingly obvious point that Greenland's minerals are finite and non-renewable and prices are contingent on demand. Geological surveys have revealed abundant quantities of copper, zinc, lead, precious gems, uranium, and recently rare earth metals (Greenland, 2013). It is tempting to view the wealth of Greenland's minerals and potential for investment as unlimited. Global commodity prices, however, are volatile. The historical example of cryolite has shown Greenland that neither supply, nor demand are guaranteed in the extractive industries.

This concern was reflected in Greenland's 2009 mineral strategy. The government stated that the financial crisis had had only a limited affect on investor interest in the island, but acknowledged that market forces might reduce mineral exploration on the island to a "disappointing level." They asserted that it might be necessary to monitor the global economic situation in order to "identify the best possible ways of mitigating undesirable consequences" (Greenland, 2009).

4. Conclusions

At first glance the history of Alcan's interest in Greenland's cryolite industry can seem far removed from the current issues of Greenland's mining industry. An exploration of 20th century staffing practices, corporate-community engagement and the effects of market forces on Alcan's interest in Greenland, however, reveal that many of the issues persist today. Greenland is in the fortunate position of having a variety of natural resources to exploit, but the industry will continue to face a number of challenges, particularly with respect to labour in the near future.

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Utilization of waste fractions from the TANBREEZ deposit

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TANBREEZ Mining Greenland A/S is expected to start mining in the Ilimaussaq intrusion in 2015. The current inferred resource is more than 4.3 billion tons of eudialyte ore, which contains variable contents of extractable rare earth elements (REEs). Along with REE, Zr, Nb, and Ta will be extracted. Along with eudialyte the main minerals in the ore are feldspar, nepheline, and arfvedsonite.

As part of the REEgain project (Innovative permanent magnet production, recovery and reuse), a 41 mio. DKK budget project supported by 18 mio. DKK by the Danish Agency for Science, Technology and Innovation, it is sought to develop methods for utilizing all products from the mining process, hence limiting waste. Environmentally friendly methods are being developed to extract lithium from a fraction which predominately contains arfvedsonite. Although low in concentration, the process when combined with the ongoing extraction process, could yield a scenario in which potentially 4 megatons, corresponding to 10% of the world's known natural lithium reserves, are utilized. If arfvedsonite can be utilized in this way, a unique situation where all mined minerals from a deposit will be used, has arisen with both large economic and environmental benefits.

Utilization of the tailings of the mining operation, which in composition are close to the ore, are investigated mainly from a technological perspective, where possible concentration processes for the very fine powder are being developed.

Industrial development, indigenous peoples' rights and public participation

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Abstract

Since large scale industrial projects started being planned in Greenland, involvement of the public has been a topic of discussion in several forums.
Inuit Circumpolar Council (ICC) Greenland has since 2010 started building up capacity to take part in the public consulting procedures, and, in 2012 studies were initiated about the issue of public involvement in resource development in Greenland.
Through the studies we will try to get a better understanding of the validity of the rights of indigenous peoples in Greenland, including the principle of free prior and informed consent, common ownership of land, public involvement in decision making through e.g. environmental (EIA) and social (SIA) impact assessment hearings.
As part of the studies ICC Greenland has held public meetings in seven Greenlandic towns informing about indigenous peoples' rights and having people discuss their validity in the Greenlandic society.

1. Introduction

The United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) describes, among other issues, the right to be heard about projects potentially affecting indigenous peoples, and the right of indigenous peoples to collective ownership to land.
With a wish for increased industrial and financial activity in Greenland, exploration and exploitation of non-living natural resources have increased substantially over the past years. Exploration expenditures have experienced a growth of 390 % in the years 2006-2010. In the same period, the number of exclusive mineral licenses has risen from 30 to 100. As presented in figure 1, the licence areas are mostly spread along the west coast of Greenland.

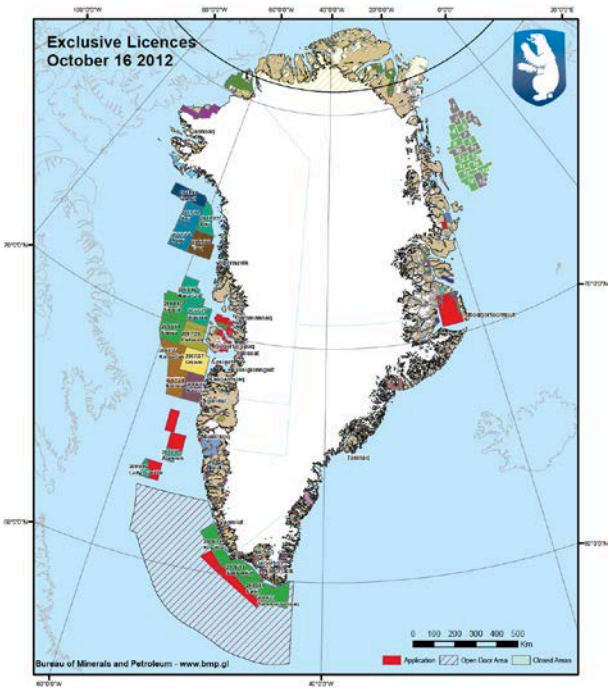

Figure 1. License areas in and off the Greenlandic coast (BMP 2012)

Increasing activity is however also expected

along the East coast in the coming years.
The possible presence of hydrocarbon and minerals has long been known in Greenland, but the harsh environment and remoteness has limited the returns on extracting the resources. Today, growth of major international markets, such as the BRIC (Brasilia, Russia, India and China) countries has severely increased the global demand for carbon fuels and scarce minerals. This has brought new possibilities for industrial activities in Greenland, as resource-prices in a near future will make extraction in the remote and hostile Greenlandic environment economically feasible (Secher 2005).

The Greenland Government has assigned Open Door zones, where international corporations are invited to conduct exploration activities. Due to an increased industrial interest in exploring the Open Door zones, their size was more than doubled since 2008 and is now the largest exploration and exploitation area. These areas are characterized by a special application procedure – the applicants can apply on a yearly basis andare treated on a „first served" basis. In addition, the licensee attains the licenses to exploit whatever they find. As in the case of terrestrial mineral projects, the Open Door zones have no „No Go" areas, which leave the Open Door zones a Greenlandic exploration and exploitation "wild west", where the investigation of oil and minerals has no bounds. (Mineral Resources Act 2009)

This study consists of several ongoing projects, including case studies of ongoing and emerging activities, and a practical application of public involvement through public meetings in some Greenlandic towns.

2. The ongoing study

Through this study, ICC and WWF will collect and analyse historical data on a range of industrial projects in Greenland. A wide range of data is accessible and this case-based study will collect and summarise data of these projects to create a complete overview of the intensity, extends, duration, financial value and environmental and social impacts.

2.1 Recent industrial activities

In the years from 2002 to 2011, the number of licenses for mineral exploration has grown from 17 to 94 licenses (BMP 2011a). The number of hydrocarbon exploration and exploitation licences has now reached 20 (BMP 2011b), and the extent of seismic exploration activities has increased ten-fold over the past ten years (BMP 2011c). Major potentials for hydropower create increasing interest from energy intensive industries such as aluminium production.
A significant tool in Greenland introduction to hydrocarbon industries has been the so-called Open Door procedure (Naalakkersuisut 2011). The procedure has been implemented to invite and motive industrial actors to invest in the very resource demanding exploration activities. The procedure has been applied along the South-western shore where data coverage and knowledge of the area is fairly low. Exploration in these areas is therefore associated with a high level of risk in terms of disturbance and damage to the marine environment. In addition to these difficulties, the areas are associated with a high level of pack ice and relatively deep waters. Thus, there are both high economic as well as environmental risks hidden in these waters. With oil wells as deep as 1.530 meters, it can take up to 50 days to drill a release well in the event of blowout (Capricorn 2011, Government of Norway 2011). Such an accident would be devastating in the sensitive arctic marine environment.
The study will collect data on mineral activities over the past 10 years, and the social and environmental implications of the projects. Focus will be on how the mineral activities have been managed and what were the terms given by the administration?

2.2 Assessing the environmental and social impact

Impact assessments have been performed in Greenland since the early 1970s and when the Self-Government gained full administration of minerals and hydrocarbons, it was required that all exploration applications should include

Environmental Impact Assessments and Social Impact Assessments (EIA and SIA), and that these reports should be available to the public.

Greenland is not legally committed to conduct Strategic Environmental Assessments (SEA), but Greenland has consented to the United Nations Economic Commission for Europe (UNECE) protocol on SEA. National legislation on EIA and SIA are being developed by the Ministry of Internal Affairs, Nature and Environment.

The effective influence of these assessments, however, can be discussed. One study indicates that these assessments and public consultation have limited effect. In the case with the major aluminium producer Alcoa, decisions were not made through the formal public procedures, but rather through informal dialogue with key members of the staff in the Greenland Government (Merrild Hansen 2010).

Another example of the insufficient implementation of public consultation is the licensing application for oil exploration drilling for the field season 2011. The material counted an Environmental Impact Assessment (EIA) of 1.777 pages and a Social Impact Assessment (SIA) of 340 pages both made available only in English. Summaries had been translated into Danish only; none had been translated into Greenlandic (!). 42 days were given to comment on this large amount of material, and the project was to be initiated only 1.5 months after the consultation term. Therefore, oilrigs were already on their way to the exploration site before the public consultation had been properly processed. This proves strong indications that the actual influence of the consultation is non-existent and that public participation is not implemented. ICC and Kommuneqarfik Sermersooq have previously advocated for longer and earlier consultation terms.

Based on Merrild Hansen's study on the Alcoa case, there is reason to believe that decision making related to industrial licensing is not always made through the formal processes. The study will therefore include a component that focuses on the informal decision processes. In reference to the complexity of the power distribution in Greenland, the study will include a "power-mapping" of the power structure and balance within the Greenlandic society and administration as well as an analysis of the power-distribution between the Greenland Government and the industrial actors that have, or wish to initiate projects in Greenland. With a comparative analysis of legislation and procedures in Greenland and other countries, ICC and WWF will develop recommendations for improvements of the Greenlandic administration.

2.3 Land use

The vast open lands of Greenland have left the population with unclear definitions of land use and property rights. For centuries, people have lived off the resources provided by nature, through hunting, gathering and fishing. With the traditional Inuit culture and lifestyle, there has not been a need for owning land, to use it and therefore Greenland still has collective property rights. However, industrial development brings challenges as hydrocarbon and mineral activities brings forward the need for exclusive rights to land use. Greenland has vast territories, but only a small proportion of this is ice-free and with access to the sea, which serves both as a resource in fisheries and hunting and as vital in transportation. As exploration and exploitation licences are issued, exclusive rights for land use are granted in neglect of local and traditional land use. A case example is the conflict in Qeqertarsuatsiaat, where locals were refused access to a mountain rich in red rubies as exclusive exploration rights had been issued to a Canadian corporation (Information 2008).

Land use is usually referring to the way land and sea is used and maintained both physically and spiritually by indigenous peoples. This study aims to analyse the present legislation on collective property rights in relation to industrial licensing, and the procedures for including "usage of land" in the impact assessments. The study is performed on a case based approach, targeting cases that present implications of present and coming industrial activities.

Greenland still has collective property rights. The present industrial development, however, pose a situation that threatens to discriminate the human rights of the Greenlandic people. The lack of regulatory limitations to the geographical range of industrial projects is destroying hunting fields, and threatens to leave peoples without game and without alternative income. Greenlandic legislation and licensing procedures lack to address this issue.

2.4 Main activities of the project – concretization

Mining activity and public involvement

Output 1.1: Mining activity between 2002-2012

- Mapping historical mineral activities as an introduction to the mapping of the past 10 years.
- Mapping the past 10 years of mineral resource activities in Greenland.
- Description of 3-5 selected mining activities.
- Issues: Consequences for nature and environment.
- Consequences for communities and Greenland.

Comparative study of management in Greenland, Canada, Alaska, Iceland (and Norway)

Output 1.2: Legislation

- Experience with consultative processes for mineral resource and energy intensive industries.
- Description of the regulatory framework, management and practice of licensing and preparation of Environmental Impact Assesment (EIA), Social Impact Assesment (SIA) in Greenland.
- Issues: Consultation processes, public involvement

Mining activity and public involvement

Output 1.3: Collective ownership in Greenland between 1950-1979 and 1979-2013.

- Historically hedge ownership of the subsoil, the collective ownership since introduction of home rule. The discussion on ownership and mining industry.
- Description of 2 selected mining activities.
- Issues: Mining activities positive and negative effects towards use of land.
- Sustainability
- The right to land use and Greenlanders' rights

The study will evaluate interrelations and possible discrepancies between national and international legislation. In addition to these international declarations, the study will look into other international bodies, such as UN Permanent Forum on Indigenous Issues (UNPFII), UN Environment Programme (UNEP) and in the Arctic Council Sustainable Development Working Group (SDWG). This study will support the development of recommendations that respects international standards as a minimum requirement, and will strengthen the argumentation as it is the declared intent of the Greenland Government to respect these standards.

3. Some observations

In the Government coalition program for 2009-2013 by the three political parties Inuit Ataqatigiit, Demokraterne and Kattusseqatigiit Partiiat, mining, oil and mega industries are mentioned, along with tourism, as being the key business areas that will play a significant role in the economic development in Greenland (Coalition Agreement 2009). This ambition is followed by the statement:
"We accept exploitation of the non-living resources as an important potential – though not at the expense of our environment.
When Self-Government is a reality and Greenland takes over responsibility for the non-living resources, it will be important to have legislation that ensures people direct influence and involvement in the decision-making processes."
It is, however, the experience of ICC and

WWF that the Greenland Government has yet to establish the procedures and capacity for meeting this ambition of balancing the sustainability of the industrial development.

4. Public meetings

As part of the study ICC has conducted public meetings in four West Greenlandic towns in October-November 2012.
The headline of the meetings was *"Industrial development and Human rights".*

The public meetings were held in the towns of Nuuk, Aasiaat, Upernavik and Maniitsoq. These towns are central in the current and future, mineral and oil exploration and exploitation development in Greenland.

Meetings consisted of a presentation of ICC, it's history, organisation, goals, and its involvement in UN and Arctic Council. Then the projects about public involvement in resource development, were presented, a short introduction to ILO 169, UNDRIP and the Inuit Declaration of Ressource Development Principles, (paper copies of the last two (UNDRIP and Inuit Declaration) were freely available for the attendees in both Greenlandic and Danish).

Finally a diagram of a mining project history was shown to demonstrate where and when public is involved, and where we think it should be involved, in the decision process.
After the first meeting in Nuuk we also included a short overview of two hearing answers about mining and oil exploration and exploitation projects, given by ICC Greenland.

Following the presentations, which took about one hour, the floor was open for questions and comments. Generally ICC was criticized for not being more open to the Greenlandic public, but most people said that these meetings were much needed.

Apart from Nuuk where there was Greenlandic - Danish translation, all public meetings were held in Greenlandic.

During the public meetings, it has been important to emphasize that the ICC is not opposing industrial development, but only wants to avoid possible damages of the environment, to secure direct and meaningful participation of the civil-society and respect of human rights and the rights of indigenous peoples.
Meetings were advertised through national TV advertisements and, after Nuuk, National Radio, posters and local radios in Aasiaat and Maniitsoq.
The average attendance to the public meetings at the community halls were between 15 to 20 persons in all towns. These people were interested in listening to the presentations and to get news regarding industrial development as well as to be part of the dialogue on those huge projects.

4.1 Opinions expressed at the meetings

In regards to peoples' knowledge about the industrial development and the on-going public debate, Maniitsoq is different than other towns. This is due to the possible establishment of the ALCOA Smelter Project close to Maniitsoq, which has been presented to the citizens at a very early stage through official consulting processes done by the authorities and the company ALCOA. It shows that the knowledge among these people is considerably higher, and on this stage it is dividing the people in two blocks with those in favour or those against the ALCOA project.

During the meetings some participants requested to hear more about impacts from existing and closed industrial development experiences from Greenland and abroad. This will give better knowledge to the public and will be included during the next phase of the ICC information tour to South and East Greenland in 2013.

Brief summary of common positions expressed during all meetings:

- A clear wish was expressed that it is necessary to establish a cross-

organizational and political forum for people who want to express their views without being bound to their respective organizations or political parties. ICC was asked to be at the forefront in establishing such a body.

- One of the most important and common positions expressed during the public meetings is the problem of a high rate of unemployment in all the towns we visited. Therefore, the expectations by people are quite high in regards to the possible resource development, which they hope in the very end will result in new employment opportunities.

- The citizens are in general concerned about possible damage to the environment. The general wish is that any possible environmental damage caused by industrial development should be at the very lowest and minimum rate as possible. The aim is to continuously be able to utilize the land and water resources as a way of living in the future to come and for the upcoming generations.

- It was criticised that the public hearings convened by the authorities and the companies regarding industrial development projects, and specifically regarding the large scale projects nearby Nuuk and Maniitsoq, were mainly held in the respective towns. The argument is that the public hearings should be decentralized and held all over the country because these huge projects will influence the whole country and its citizens and is therefore a concern for all citizens.

- One example raised several times was the issue of taxation and royalties on minerals and other products, which are brought of the country before refinement. ICC was reluctant to get involved in discussions during our public meetings on certain issues like this, since they are part of an on-going internal political discussion in Greenland.

4.2 Public involvement

At each meeting the participants were asked to fill out a 2 pages evaluation questionnaire, asking a little about their background and opinion on the meeting and it's content.
In total 49 questionnaires were filled out in the four towns, 19 in Nuuk, 9 in Aasiaat and Maniitsoq each, and 12 in Upernavik.
Figure 2 shows a distribution of answers to a question about the involvement in debates about resource development. It clearly shows the attendees in Nuuk and Maniitsoq being more active in debates, while the attendees from the towns in the north (Aasiaat and Upernavik) have participated in fewer debates.

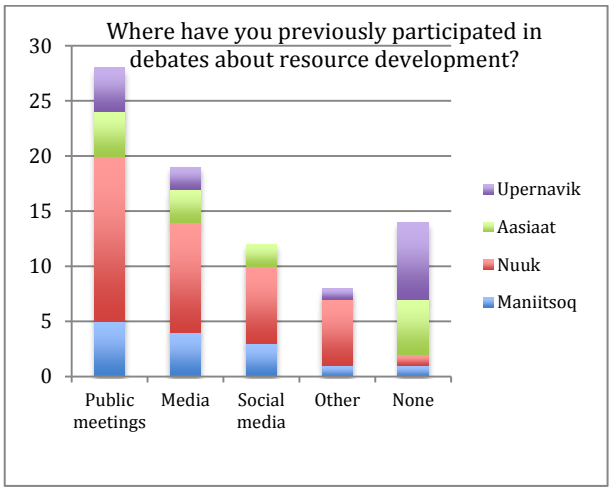

Figure 2: Numerical distribution of answers to a question about the attendee's previous involvement in debates about resource development, some marked more than one option.

Although the attendees represents about 1 percentage of the towns' populations, the observations from the public meetings suggest that a substantial part of the public is actively following the development and wants to be actively part of the decision making.

5. Conclusions

Four years has gone since the Greenland Government took the responsibility of its non-living resources, and the land and seas are wide open for utilisation by extractive industries. Despite the government's intention on the opposite, the public participation in the decision making still has long way to go, but the public is following the development and wants to be involved.

Acknowledgements

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Water management - a challenge for mining industry in cold climates

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Abstract

Mining in the Arctic and Near Arctic areas puts special demands on management of water, both supply to production and handling of drainage and effluents. Water pollution from mining operation stems from the minerals themselves, from not detonated explosives and from chemicals used in connection with ore processing and hydrometallurgical processes. Global warming, more extreme weather conditions make for example sudden snow melting an extremely difficult situation to handle in the tailing pond. On the other hand extremely low temperatures restrict access to water.

Disposing mining residues and mine drainage in a tailing pond is a long term environmental responsibility and alternatives to this traditional method might contribute to solving water supply issues for the mining operation as well as reducing the post closure financial risks. Technologies exist making the mine 'neutral' from a water consumption point of view and at the same time reducing the environmental impact and risk dramatically.

1. Introduction

Water plays a key role in industrial production. Today, with increasing demand for water resources and uncertainty about the amount and quality of supply, the competition for water resources is being felt across all sectors of society. Awareness of the ways water-related risks can disrupt business has also increased.

Mining operations use water to mill ores, process concentrates and mineral products; cool or wash equipment; manage waste tailings; suppress dust; and supply onsite needs for consumption. Although the minerals industry generally speaking is a small user of water, it can be a large user at a local level if located in a water-scarce area. Many mining operations try to recycle water onsite because of limited resource but also because discharge is subject to comprehensive regulatory and legal requirements.

As the mining industry is increasingly scrutinized on its stewardship of the natural environment, beneficial use of available water is often sought. The amount of water that is "lost" to the voids in the stored tailings, to seeps from the tailings impoundments is something being increasingly viewed by critical regulatory and public eyes that insist on evaluating whether there are viable alternatives for any given proposed mining development. This puts pressure to seek alternative approaches.

2. Mines in the cold and often remote areas

The fragile ecosystem is a concern when establishing mines in the cold and remote regions. The local communities are often economically dependent of the land and water for hunting or fishing and being in the nature is their greatest interest. Changes to the natural environment brought on by mining projects are therefore worrying the locals. On the other hand mining exploration and development often offers attractive economic spinoffs. The local communities therefore struggle with

the potential impact of mining projects on their land.

Mining is an old industry and historically little attention has been paid to the effects mining could have on the environment. During 15th and 17th century Sweden was on a global scale a major copper miner and copper producer. Copper was mined as sulfide mineral and tailings from this period are still a major environmental issue in this specific region. There are in one County 3,643 potentially contaminated areas and of these approx. 750 are related to old mines (Bäckström, 2012).

Over the last couple of decades companies have worked hard to reduce pollution from mining activity. Investments have been made in new mining processes and technologies, however focus have been on the production itself and unfortunately many new mining projects see traditional tailing ponds implemented. Of course with safer structural design but still with the same function.

The mining industry can significantly contribute to the prosperity of these remote areas including Greenland. Opportunities created throughout the mining cycle, from exploration to production, provide local communities with occupation and income. However because of the nature of this industry the mines at some stage will close causing great financial impact on the communities, and if not properly managed also a long term effect on the environment. Greenland has one unfortunate example from which we all can learn.

3. Tailings Management

Tailings management often represents the most significant environmental challenge associated with mining projects. Tailings storage facilities typically represent the most significant environmental liability associated with mining operations.

For tailings and waste-rock management, BAT decisions are among others based on:

- environmental performance
- risk
- financial viability.

The tailing pond is basically mineral containing residues being long term stored in water where the surrounding environmental factors as, temperature, wind, snow, ice, microorganisms etc. continuously are influencing on the physical and chemical conditions for the material stored. Redox potential in the water phase is very different when there is an ice cap on the pond compared to when there is open water surface provided with mixing by wind or sun. Also at low temperatures microorganisms function and microorganisms' involvement in solubilization of minerals is well known though not always thoroughly explained.

In particular, the consideration of risk is a very site-specific factor.

The pursuit for a solution to the mine waste problem begins where the problem is created – right at the start of planning for the mine.

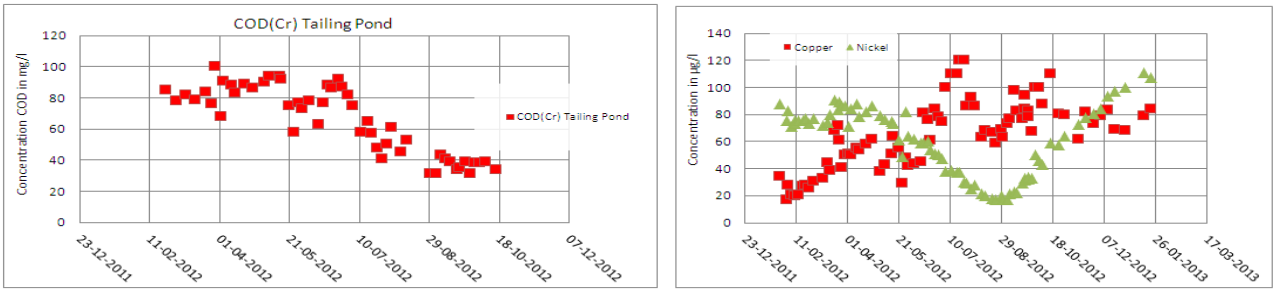

Figure 1: Yearly variation of COD, Ni and Cu concentration in a tailing pond in Northern Sweden.

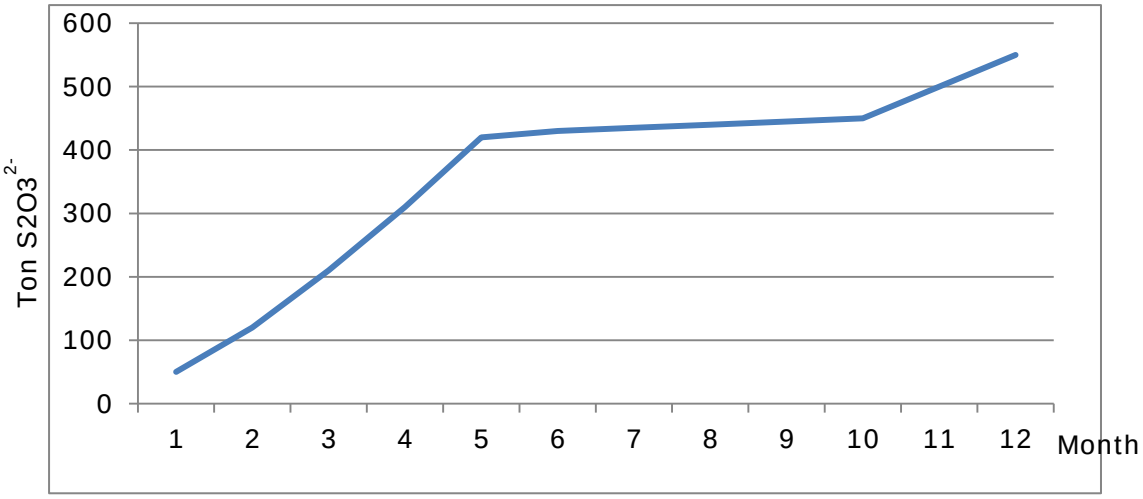

Figure 2: Accumulated Thiosulfate release in a tailing pond over one year (Sundqvist JE)

Figure 1 and 2 demonstrate what chemically can take place in a tailing pond and is by no practical means possible to control during the lifespan of the pond including the post closure situation.

Instead of mine waste being an issue to be dealt with at the end of the mine's life, it should be on the table for discussion at prefeasibility stage or earlier. In the beginning of a mine project the design factors are most open and flexible. Mining operations are only temporary, but the effects can last for many decades if not addressed properly.

Waste (tailings) containment facilities must be designed to provide the best environmental solutions for today and for the future. Over the past 50 years, unprecedented rates of change for both temperature and precipitation have been recorded and future predictions agree with the current trends (Furgal et al., 2008). Climate change is occurring and it is vital to include these effects in the design of future waste containment facilities. Like snow sliding off a roof on a sunny day, the Greenland Ice Sheet may be sliding faster into the ocean due to massive releases of melt water from surface lakes, according to a new study by the University of Colorado Boulder. Storage of mine waste must take these factors into consideration.

Environmental concerns must be addressed and future disasters must by all means be avoided especially in the Arctic, where remoteness constrains clean-up operations and the cold climate results in slow decomposition of pollutants (Pearce et al., 2011).

Dry stacking has in the last couple of decades grown rapidly in popularity (Davies et al., 2010). The main arguments for choosing this method over other tailings disposal methods are the environmental benefits and water conservation.

Some advantage of dry stacking over other storage techniques:

- Involves smaller storage volumes (low water content ~ 15%). Smaller footprint.
- Conserves water.
- Easily accessible in the event of a need for additional mitigation measures.
- Easy accessible to reuse for back fill if the mine requires
- Relatively low capital cost for preparation of storage sites
- May prove more cost effective over the life of the mine and permanent closure periods.

4. Water treatment

Often one of the main reasons to select dry stacked filtered tailings as a management option is the recovery of water for process water supply. This is particularly important in regions where water is an extremely valuable and limited resource. Filtering the tailings removes the most water from the tailings for recycle. This recovery of water has a cost benefit to the project, which offsets the capital and operating cost of the tailings system.

Some potential issues related to water management at a mining site:

- Metals leaching from waste rock or tailings
- Residual content xanthate and other flotation agents in water
- Residues of solvents
- Ammonia/ammonium and nitrate in drainage from mine, waste rock and/or tailings (from explosives used)
- Suspended solids in excess water to be discharged

In addition in cold regions a further challenge can be to manage water balance during sudden snow melting.

4.1 Nitrogen

Undetonated explosives present an environmental problem connected to mining, which not until recent years has caught attention. In warm climates natural biological oxidation and reduction "neutralizes" to a big extent these nitrogen compounds. In cold climate the low average temperature prevents the complete processes to occur meaning that both ammonia and nitrite, two compounds toxic in natural environment, escape in intended and unintended aqueous discharges from the mining site.

Toxicity for trout: NH_3: LC 50 = 0.5 mg/l and NOEC = 25 µg/l,
NO_2-N: LC50=0.2 mg/l and NOEC = 10 to 50 µg/l (depending on Cl content)

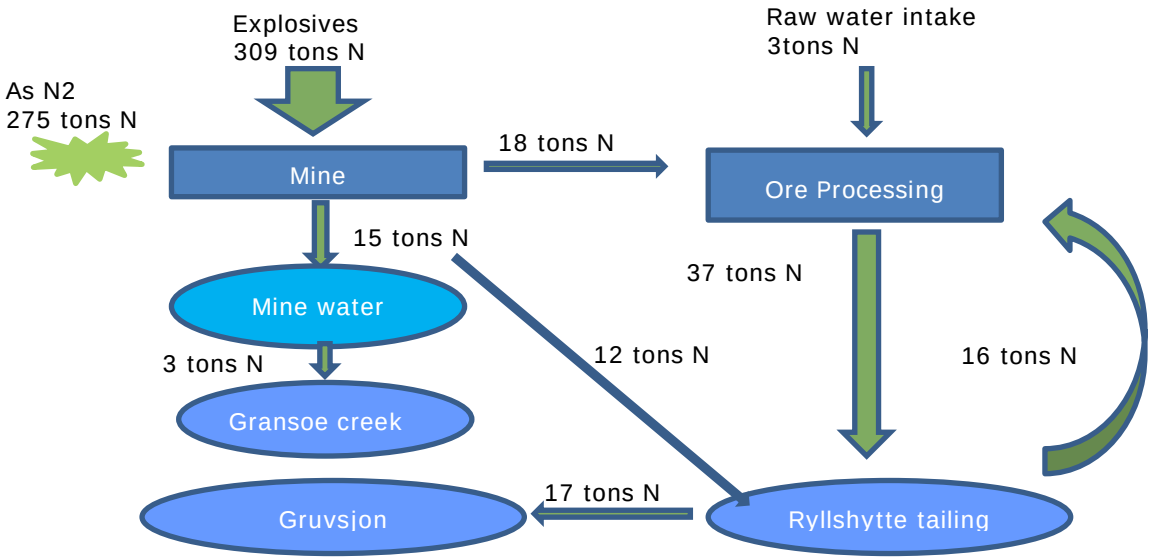

Figure 3: Nitrogen Balance Boliden Garpenberg Mine (Lindestrom)

MBBR (Moving Bed Bio Reactor) a specific fixed film biological technology has proven to be able to remove these nitrogen compounds in mine water down at temperatures as low as 2 °C.

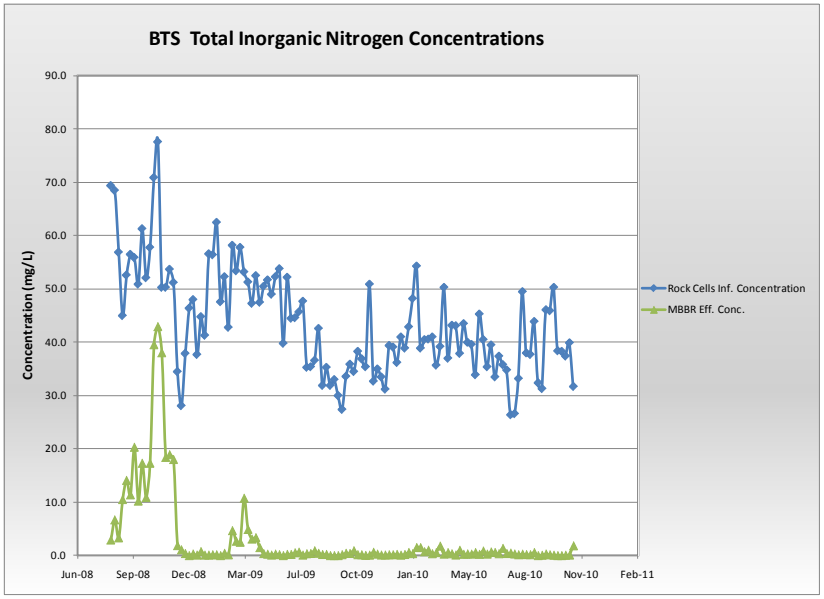

Figure 4: Nitrogen removal in AnoxKaldnes™ MBBR at East Boulder mine.

4.2 Sulfate Reduction

Mining of sulfide minerals results in a mine water containing sulfates. Sulfates discharged into fresh water aquifers are no longer acceptable and the requirement that water discharged shall more or less meet local drinking water standard of 250 mg/l is coming up. Nanofiltration (NF) has been successfully applied to reduce sulfate concentration in water from tailings treatment facility.

NF is followed by the precipitation of calcium sulfate from the NF reject stream. The use of NF membranes generates a reject solution with a high concentration of sulfate ions. The subsequent addition of calcium ions with the basic objective to create the calcium sulfate reaction, followed by flocculation and settling of the precipitate, creates treated water low in sulfate. 75% to 80% recovery of water is possible.

4.3 Removal of suspended solids and metals

Suspended solids and heavy metals in discharges from a mine is the traditional problem. Hemlo mine (Barrick Gold Corporation), located in northwestern Ontario, closely monitor its water usage for ore processing, dust suppression, blasting rock, and other activities. Water supply is from surface and groundwater sources and they also capture storm water captured on-site. The mine strives to take only the minimum amount of fresh water and to maximize reclaim/recycle water usage wherever feasible. They installed ACTIFLO® high-rate, microsand ballasted clarification system to efficiently convert reclaimed tailings water into process water for the entire mine site.

The process is successful in removing regulated metals well below the current Certificates of Approval (C. of A.) limits. The ACTIFLO also treat water below potential future C. of A. limits, as well as meeting and/or exceeding the effluent criteria regarding metals and suspended solids. It also has a very small footprint.

This installation has meant that they have been able to reduce their withdrawals from the nearby creek to approximately five percent of its permitted amount.

Coagulant-lime addition sequence			Simultaneously	Coagulant : 5 min Lime : 5 min.
Coagulant	Type	--	$Fe_2(SO_4)_3$	$Fe_2(SO_4)_3$
	Dosage	µL/L	325	325
		mg/L Fe	60	60
Lime	Dosage	mg/L	120	120
Polymer	Type	--	Magnafloc 10	Magnafloc 10
	Dosage	mg/L	0.5	0.5
pH	ETP	--	7.46	7.46
	CWW		6.90	7.10
Turbidity	ETP	NTU	1.39	1.39
	CWW	NTU	0.28	0.31
	Removal	**%**	**79**	**77**
Total Arsenic (As)*	ETP	mg/L	0.009	0.009
	CWW	mg/L	0.002	0.001
	Removal	**%**	**77**	**88**
Total Antimony (Sb)*	ETP	mg/L	1.96	1.96
	CWW	mg/L	0.22	0.17
	Removal	**%**	**88**	**91**
Total Copper (Cu)*	ETP	mg/L	0.23	0.23
	CWW	mg/L	0.05	0.01
	Removal	**%**	**78**	**95**
Total Lead (Pb)*	ETP	mg/L	< 0.01	< 0.01
	CWW	mg/L	< 0.01	**< 0.01**
	Removal	**%**	--	--
Total Mercury (Hg)*	ETP	mg/L	< 0.1	< 0.1
	CWW	mg/L	< 0.1	< 0.1
	Removal	**%**	--	--
Total Molybdenum (Mo)*	ETP	mg/L	1.61	1.61
	CWW	mg/L	0.24	0.42
	Removal	**%**	**85**	**73**
Total Nickel (Ni)*	ETP	mg/L	0.24	0.24
	CWW	mg/L	0.16	0.06
	Removal	**%**	**33**	**75**
Total Zinc (Zn)*	ETP	mg/L	0.03	0.03
	CWW	mg/L	< 0.01	< 0.01
	Removal	**%**	**> 66**	**> 66**

Figure 5: Performance ballasted for a mine water

4.4 Zero liquid discharge ZLD

Many mines are weighing the different options for upgrading their treatment capabilities due to stricter effluent limits. As the need grows to remove larger portions of the dissolved constituents in mine-water effluent, ZLD may become the only practical option.

For Greenfield applications, the addition of ZLD systems in principle eliminates the need for permits for liquid waste disposal, allowing projects to be fast-tracked for regulatory approval. For existing operations facing new permits, ZLD systems may be retrofitted into a mine's existing treatment system, reducing capital costs. These mines could use the existing conventional treatment for the removal of metals and suspended solids, and then add a MULTIFLO™ softener, RO system and evaporation/crystallization system to achieve ZLD.

The wastewater from Rio Tinto Kennecott's Eagle Mine located in Michigan undergoes treatment using Veolia's patented OPUS™ process, resulting in effluent suitable for reuse in the mining process or to be released to the environment as ground water through the treated water infiltration system. This site was the first to utilizing OPUS™ technology in a mining application, creating Zero Liquid Discharge (ZLD) and in accordance with Rio Tinto's sustainability goals. This ZLD process employs chemical precipitation softening, clarification, filtration, ion exchange softening and a final two-pass reverse osmosis polishing step. They selected the process for the high water recovery rate and ability to remove boron. They produce 2,725 m3/d of high quality permeate with a resultant 240 m3/d waste stream consisting of ion exchange regenerant and reverse osmosis reject. These waste streams are combined and sent to evaporator(s)/crystallizer(s). The resultant solids are disposed offsite as non-hazardous waste, and the evaporator/crystallizer distillate is returned to the process as discharge quality water.

5. Concluding remarks

The trend to implement significantly sustainable solutions is becoming more prevalent in the mining industry. Environmental concerns are of major interest to the local communities.

Any discharge of water from a mine in cold and environmentally sensitive regions shall not only meet, but preferably exceed, the most stringent water quality standards.

Where in a mining project handling of mining residues is considered parallel to water supply for the mining operation, efficient solutions can be created resulting in minimum water resources withdrawn from the environment and dramatically reduced pollution load to the aquatic environment.

In cold regions global warming could result in local changes in the water cycle with effects which we cannot foresee on for example manmade ponds for waste storage. Mining operations have long term influence and playing safe in design is safer for all, local community, operators, investors and the environment.

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Balancing the Traditional Iñupiat Lifestyle & Resource Development for a Vibrant Arctic Economy: Experiences from the NANA Region of Northwest Alaska

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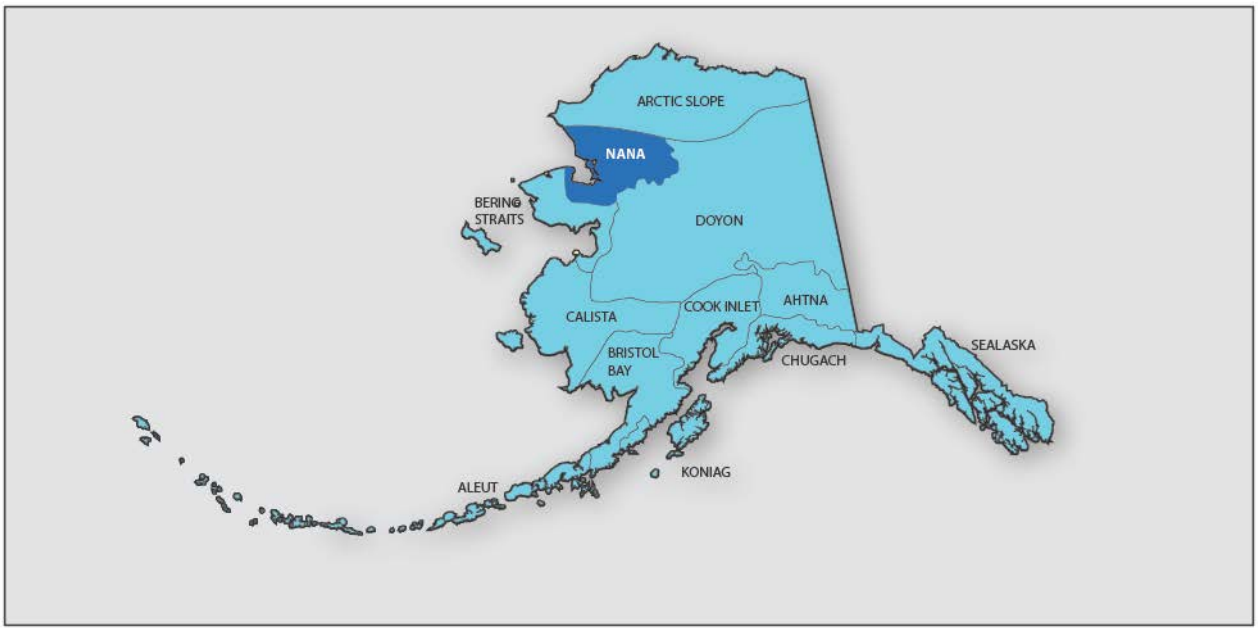
Abstract

NANA Regional Corporation (NANA) is owned by more than 13,000 Iñupiat shareholders of Northwest Alaska. Created pursuant to the Alaska Native Claims Settlement Act (ANCSA) of 1971, NANA owns 2.2 million acres of land and generated $1.8 billion in revenue in 2012. NANA's mission is to improve the quality of life for shareholders by maximizing economic growth and to protect and enhance NANA lands. Subsistence hunting, fishing and gathering is the highest and best use of NANA-owned lands; NANA conducts responsible resource development in alignment with this policy. Through an innovative 1982 agreement between NANA as landowner and Teck Alaska, Inc. as operator, production of zinc, lead and silver began at the Red Dog Mine in 1989 after years of consultation with area villages. In 2010, Red Dog contributed 73% of U.S. zinc production and 4.4% of global production. In 2012, the mine created 573 direct jobs, paying $73.6M in wages. NANA shareholders comprised 53% of the workforce and earned approximately $33.9M. A 2010 state of Alaska study found the mine has a total economic impact of creating 2,800 jobs yearly statewide, paying $166M in wages. From 1989-2012, NANA distributed $515M to other Alaska Native Corporations through ANCSA's 7(i) sharing provision. In 2011, NANA and NovaCopper Inc. partnered to begin the new Upper Kobuk Mineral Project (Cu, Zn, Pb, precious metals) to explore the Ambler Mining District. NANA funds grassroots mineral exploration on both NANA and adjacent lands for base and precious minerals, and is working to encourage onshore oil and gas exploration to reduce the high cost of energy in Northwest Alaska.



1. Introduction to NANA

Owned by over 13,000 Iñupiat shareholders originating in northwest Alaska, NANA Regional Corporation, Inc. was founded in 1971 as a result of the Alaska Native Claims Settlement Act of 1971 ("ANCSA" or "the Act"). An historic settlement of Alaska Native aboriginal claims to their homelands, ANCSA called for creation of twelve Alaska Native owned corporations established generally according to traditional cultural borders. These state-chartered corporations were to gain fee simple title to 44 million acres of land and payment of $962 million from the federal government. ANCSA was the result of a real threat to Alaska Native land ownership: upon passage of the Alaska Statehood Act of 1958, the newly forming State of Alaska was entitled to select 103,350,000 acres from the public domain, much of which constituted lands used and occupied by Alaska Natives. Additionally, in 1968, oil exploration on Alaska's Prudhoe Bay oilfield in northern Alaska produced wildly successful results. As the state worked to secure a pipeline right-of-way to transport this newfound wealth to the ice-free ports in Valdez, Alaska Native people became increasingly determined to maintain legal rights to their ancestral homelands, which were of critical importance to maintaining indigenous lifeways as well as developing economic sustainability. A group of young Alaska Native leaders, many from the NANA region, worked diligently and strategically to make certain Alaska Natives' fate rested in their own hands.

Through ANCSA, NANA received title to 2.2 million acres of Iñupiat ancestral lands. As an Iñupiat corporation, NANA values subsistence as the highest and best use of our traditional lands. All development projects must be in concert with this perspective. NANA's mission is the following:

> We improve the quality of life for our people by maximizing economic growth, protecting and enhancing our lands, and promoting healthy communities with decisions, actions, and behaviors inspired by our Iñupiat Iḷitqusiat[1] values consistent with our core principles.

[1] The Iñupiat Iḷitqusiat (translation: "those things that make us who we are") are the foundational principles that guide NANA and the Iñupiat of the NANA region. The seventeen values that comprise the Iḷitqusiat were developed through what is now known as the "Spirit Movement" of the 1980s. During this time, regional leaders met with Elders and community members in each village to hear what qualities had enabled the Iñupiat to thrive for thousands of years in one of the harshest climates on Earth. The result of the meetings were the Iḷitqusiat, a reference point all Iñupiat may use in their daily lives.

NANA lands share the same border as the Northwest Arctic Borough. As of 2012, the population of the Borough was 7,810, 80 percent of which is Iñupiat (compared to a 15 percent statewide Alaska Native population).[2]

ANCSA authorized the Secretary of the U.S. Department of the Interior to create a list of Alaska Natives[3] eligible to receive up to 100 shares in one of the 12 regional corporations and one of the 203 village corporations.[4] These shares remain inalienable; they may be inherited or gifted but they cannot be sold.[5]

NANA had 4,828 original shareholders. In 1989, NANA shareholders became the first to vote to issue life estate stock to Alaska Natives born after December 18, 1971. Because of the choice to include additional generations, NANA's shareholder base continually expands.

Each of the 11 communities in the NANA region incorporated a village corporation. In 1972, 10 of the village corporations combined resources with NANA by merging (all but Kikiktagruk Inupiat Corporation located in the town Kotzebue). NANA was initially governed by a 13-member, elected board of directors. As a result of the merger agreement, the board is comprised of 23 members, two of whom reside in each of the 10 region villages, one from Kotzebue, and two at-large members who may reside anywhere.

[2] United States Census Bureau, State & County QuickFacts, available at http://quickfacts.census.gov/qfd/states/02/02188.html (last viewed Mar. 22,2013).

[3] ANCSA defines "Native" as a "citizen of the United States who is a person of one-fourth degree or more Alaska Indian . . ., Eskimo, or Aleut blood, or combination thereof." 43 U.S.C. § 1602(b).

[4] 43 U.S.C. § 1604; 43 U.S.C. § 1606(g) and 1607(c).

[5] 43 U.S.C. § 1606(g)(1), (h)(1)(B) and (h)(2)(A).

2. Partnership for Success: Red Dog Mine

The subsurface of NANA land is mineral-rich and NANA is working with partners to unlock its potential to benefit shareholders. All exploration and development is conducted in alignment with NANA's guiding principles on subsistence.

The Red Dog Mine is comprised of 119 million tonnes of rock containing zinc, lead and silver in three deposits, including the Main Deposit, and the Aqqaluk and Qanaiyaq Deposits. In 1989, mining commenced at the Main Deposit, which produced ore containing 17% zinc, 5% lead and 2.4 ounces per ton of silver. In 2011, the Main Deposit was closed and mining began at the adjacent Aqqaluk Deposit. The mine is expected to produce until 2031. NANA and industry partners are actively engaged in exploring future mine sites to ensure the economy of the NANA region and state remain vibrant and healthy.

In 1970, pilot Bob Baker noticed mineralized streaks as he was flying his bush plane over the present-day Red Dog Mine. He notified the United States Geological Survey, which confirmed the presence of zinc, lead and silver. This land was within the traditional territory of the Iñupiat of the NANA region yet the land had become part of the North Slope Borough. NANA was entitled to select lands to fulfill our entitlement under ANCSA, so in 1974, NANA filed a selection application that included the Red Dog area. This selection was followed by a number of challenges that required resolution prior to developing the mine. First, NANA needed to secure the property, which necessitated the garnering of support of the state, Local Boundary Commission, and carving the land out of the North Slope Borough. Northwest Alaska lacked a borough, so it became necessary to create the Northwest Arctic Borough. To transport ore concentrate from the mine to the port, where it would be loaded onto ships for transport to smelters around the world, trucks would need to cross the Cape Krusenstern National Monument. Uniquely, the State of Alaska agreed to invest in and own the road and

port, which kick-started the future success of the Alaska Industrial Development and Export Authority. Finally, to develop the mine, it was imperative that the people of the NANA region agree to it. For thousands of years, the Iñupiat people have utilized a consensus-based decision making process. This traditional process reflects the spirit of Article 32(2) of the United Nations Declaration on the Rights of Indigenous Peoples, which provides that indigenous peoples have the right to free and informed consent prior to the development of mineral resources affecting their traditional lands. Initially, the people of the NANA region opposed development of the mine. For approximately 10 years, NANA consulted with the 11 communities to ensure the peoples' voices were accounted for in the decisions made. In 1980, the shareholders voted to approve development of the Red Dog Mine.

In 1982, NANA and Cominco Limited, a Canadian mining company with considerable experience working in the Arctic, signed an innovative operating agreement that would guide their work at Red Dog. In July 1987, the work to create a common vision of success paid off and construction of the mine and port sites and the 52-mile road connecting them commenced. With a total capital investment of $414 million operations at Red Dog began in December 1989.

The NANA-Cominco Operating Agreement - now an agreement between NANA and Teck, Cominco's successor in interest as of July 2001 - was a progressive and visionary covenant, based on a cooperative long-term partnership that continues to evolve. The Agreement memorialized Teck and NANA's commitment that operations at the mine must:

- Protect subsistence and the Iñupiat way of life;
- Create lasting jobs for NANA shareholders;
- Provide opportunities for NANA's youth; and
- Serve as a catalyst for regional economic benefits and sustainability.

Prior to the start of construction at Red Dog, a Subsistence Committee of residents from the villages closest in proximity to the mine, Noatak and Kivalina, was created. The Committee plays an important role in guiding hunting and fishing protection activities at the mine. One of the Committee's first tasks was to select a route for the road connecting the mine and port sites that considered the migration of the Western Arctic Caribou Herd (approximately 400,000 caribou), fish spawning areas and bird nesting sites. The Committee directs a regional caribou monitoring program. During the herd's migration, the Committee has the authority to close the road to reduce potential risks to the herd. At the port, shipping schedules are planned to minimize possible impacts to whale and seal hunts. Discussions are held annually between mine representatives and whaling crews, and schedules are agreed to that meet the needs of all parties.

The mine is subject to the full panoply of federal and state laws and regulations. Red Dog operates under more than 70 permits. Teck's environmental management system focuses on five key areas: discharges to water; emissions to air; impacts to land and wildlife; consumption of energy and materials; and product and waste handling, storage and disposal. Where issues have arisen, Teck has expeditiously acted to mitigate them. For example, a 2001 National Park Service Study found evidence ore concentrate dust was escaping from the trucks used to transport the ore from the mine to the port site. In 2001 and 2004, the Alaska Department of Health and Social

Services concluded the dust posed no risk to wildlife or human health. Teck took significant actions to prevent the escapement of the dust, including changing to hydraulically operated, hard covered truck trailers to transport the concentrate and redesigning and upgrading the port concentrate transfer and loading facilities.

The Red Dog Management Committee (RDMC) consisting of six representatives from NANA and six from Teck was formed pursuant to the Operating Agreement. It is responsible for "safeguarding the physical, cultural, economic and social needs and Subsistence Needs of the Natives of the NANA region." The RDMC meets at least four times per year, during which time decisions regarding operation, budgets and other topics are made.

The Operating Agreement provides that in contracting at the mine, NANA companies that submit competitive bids shall have contracting preference. The Agreement also provides that NANA shareholders shall have employment preference at the mine, and that job training and development opportunities be afforded to them. Recent statistics demonstrate the commitment NANA and Teck have to shareholder employment: More than 600 full-time positions are located at the mine site in an area of Alaska where steady, well-paying jobs are scarce; as of February 2013, the Northwest Arctic Borough had a 15.6 percent unemployment rate.[6] NANA shareholders make up 53 percent of the mine's workforce and earned a total of $33.9 million in 2012.

3. Local, Statewide and National Benefits

The Red Dog Mine is a key contributor to the NANA regional economy, responsible for an estimated $66.1 million in total annual economic benefits resulting from wages, taxes and payments to local businesses in Alaska. From 1990-2008, Red Dog provided $1.9 billion in benefits to the regional and state economy, including wages to shareholders, contracts and Payments in Lieu of Taxes (PILT) the Northwest Arctic Borough. Since mining began, Red Dog has paid approximately $118 million in PILT to the Borough; the annual PILT ranges from $7-11 million. In 2009, Red Dog Mine purchased $172 million in goods and services, including work with 10 Alaska mining support companies.

Alaska Native people throughout the state benefit from the mine through the ANCSA section 7(i) sharing provision. 7(i) requires the 12 land-based regional corporations to share 70 percent of revenues from subsurface resource and timber development with the other regional corporations, which in turn share 50 percent of the funds with the ANCSA village corporations in their region pursuant to

[6] State of Alaska Department of Labor and Workforce Development, Research and Analysis, available at http://live.laborstats.alaska.gov/labforce/index.cfm (last viewed Mar. 22, 2013).

section 7(j) of ANCSA. In 2012, NANA distributed $76.4 million through the 7(i) provision.

Zinc is needed all around the world for everything from galvanization to boosting the immune system. Northwest Alaska helps supply the world with the much-needed metal.. In 2010, Red Dog represented 73 percent of U.S. zinc production and 4.4 percent of global zinc production. Also in 2010, Red Dog ore was 82 percent of the state's mineral export and 25 percent of its total export.

4. Upper Kobuk Mineral Project

On October 19, 2011, NANA entered into an Exploration Agreement and Option to Lease with NovaCopper U.S., to commence exploration in the Ambler Mining District. What is known as the Upper Kobuk Mineral Project (UKMP) in the Ambler Mining District includes NANA-owned land at Bornite and Nova-patented land at the Arctic Deposit and nearby state claims. The UKMP is part of a belt of rocks containing a volcanogenic massive sulfide (VMS) deposit, which contains mostly copper, zinc, lead and some precious metals. The UKMP Agreement builds upon the 20 years of experience at Red Dog and uniquely aligns NANA and NovaCopper's interests to create greater opportunity for both. The UKMP Agreement formalized NANA and NovaCopper's commitment to promoting a sustainable regional economy by agreeing to: hire NANA shareholders, contract with NANA companies and create an educational scholarship fund. An Oversight Committee comprised of representatives of each party meets regularly to ensure the UKMP activities benefit NANA shareholders, protect the Iñupiat way of life and uphold NANA's land use policy that resource development must protect subsistence. It takes approximately 20 years for a mine to enter the production phase. Prior to entering into this project, NANA engaged in 15 years of consultation with the villages, with emphasis on engaging with the villages closest to the UKMP: Ambler, Kobuk and Shungnak.

5. Social and Cultural Programs

Maintaining a sustainable economy means more than funding basic infrastructure; to NANA, it means supporting the social and cultural programs that are important to NANA shareholders and that improve their quality of life. Each year, NANA contributes millions of dollars to such programs. These programs include culture camps; post-secondary education and vocational training scholarships; staff in each village to serve as resources to community members; Elders' programs; financial assistance to shareholders in times of crisis; and language renewal projects.

5.1 The Aqqaluk Trust

In order to "Empower the Iñupiat people of Northwest Alaska through language, culture and education," NANA founded the Robert Aqqaluk Newlin Sr., Senior Memorial Trust, a non-profit organization serving northwest Alaska. It was named in honor of Robert Aqqaluk Newlin, Senior, a great leader of the Iñupiat people and NANA. In 2012, NANA contributed more than $3.5 million to the Aqqaluk Trust.

In 2012, the Aqqaluk Trust awarded $780,000 in scholarships to 340 NANA shareholders, dependents and descendants. This is an important funding source for students pursuing vocational and university programs.

Each summer, the Aqqaluk Trust hosts Camp Sivunniigvik, a cultural camp, during which children and Elders come together to

learn and share the skills of hunting, fishing and gathering essential to the Iñupiat way of life. The camp is also used in the winter for educational and Elders programs.

The Aqqaluk Trust supports the Regional Elders Council, which meets regularly to discuss issues and provide guidance to NANA and other regional organizations.

The Iñupiaq language in the NANA region remains endangered, but there are efforts to help reverse this unfortunate reality. The Aqqaluk Trust maintains several language revitalization programs and in 2004 created the Iñupiaq Language Commission (ILC). The ILC is an important advocate for perpetuating our language and is an convener of forums on language revitalization. In partnership with the world-wide language-learning company Rosetta Stone, the Iñupiaq Language Commission developed two interactive Iñupiaq language CD-ROMs, one for the Coastal dialect and one for the Upper Kobuk dialect. NANA contributed additional funds to the Aqqaluk Trust to ensure each shareholder household access to received this special tool

5.2 Village Staff

NANA employs Resource Technicians (RTs) in each of the 10 NANA region villages. RTs serve as liaisons between the village governments - often two, a city incorporated under the laws of the State of Alaska and a sovereign tribe - and organizations or individuals wishing to come to the village for a wide variety of purposes. This helps ensure the village is prepared to manage hosting the various visiting groups. The RTs assist village residents with many different administrative tasks, such as filling out job applications, preparing resumes and filling out government forms. RTs are a critical link between village residents and the organizations and agencies that seek to work with and serve them.

5.3 Responsibility to Tribe

One of the Iñupiat Ilitqusiat is “Responsibility to Tribe.” In furtherance of this value, NANA provides funding to non-profit organizations and events that benefit NANA shareholders and the region. Examples of programs NANA contributes to include: the Boys and Girls Club; state basketball tournaments; the Alaska Technical Center, which offers vocational education programs; Village Economic Development grants to coordinated efforts by city and tribal governments; and the Kobuk 440 Dog Sled Race. NANA also assist shareholders and communities in coping with natural disasters and search and rescue operations when hunters or travellers go missing out on the land or water. Finally, NANA provides burial, medical and disaster assistance to shareholders in times of need.. The NANA region is very remote and it is the combined effort of community members that enables the villages to persevere through challenges. NANA is grateful to be able to assist community members through these difficult times.

6. Ongoing Communication to Build a Better Future

NANA provides a variety of opportunities for community input to ensure accountability to our more than 13,000 Iñupiat shareholders. NANA hosts many meetings throughout the year, including: the annual shareholders meeting, annual "informal" meetings held in each village and other locations where we have a high number of shareholders, and special meetings to discuss current projects and important happenings. NANA provides regular updates to shareholders, business partners and policy makers through our news publication, "The Hunter" and actively engage in the social media sites Facebook and Twitter. NANA purchases air time on KOTZ Radio, the regional radio station, and Resource Technicians make important announcements over VHF radio, a primary communication tool in the villages. NANA conducts a shareholder survey every three years to gauge shareholder opinion about various aspects of the corporation and issues that affect their lives. NANA leadership set an important precedent of consultation before shareholders voted to develop the Red Dog Mine. The investments NANA continues to make in consultation and communication allow our projects to succeed and enable NANA to fulfill our mission to improve the quality of life for our shareholders in a manner that is firmly rooted in our Iñupiat identity and the Iñupiat Ilitqusiat.

7. Conclusion

It is no accident that NANA's logo is the Great Iñupiaq Hunter. Many of our corporation's founders were raised on the land and water, living in sod houses, and moving with the seasons and animals. They were hunters of nutritional and cultural sustenance. Today, many of NANA's people remain hunters in the traditional sense, but are also Modern Day Hunters. As Modern Day Hunters, we are moving agressively toward a successful future in a vast, beautiful and sometimes harsh world. This is NANA. In our region, NANA is all of us together as one hunter, successful if we are of one mind and purpose, hungry if we are split by doubts. As one hunter is small and insignificant when compared to our environment so is NANA when compared to the ever changing global environment in which it must hunt successfully to survive. The same qualities of courage, confidence, humility, respect, integrity and sharing that have allowed our people to survive as great hunters in a harsh climate are necessary for NANA to be successful. We are grateful for the bounty of the natural resources in our region that allow us to provide for our shareholders and communities, and we welcome partnerships throughout the Arctic as we continue our work to develop a sustainable Arctic economy in which our communities may continue to thrive.

Acknowledgements

Quyanaqpak – thank you very much – to our ancestors who have worked hard to perpetuate the culture and spirit of our People, the Elders past and present who have and continue to guide us in our work, and the children who continue to inspire us to work toward a future in which they may thrive as Iñupiat people in the global society. We thank the conference organizers for the opportunity to present at "Sustainability in Mining in the Arctic."

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Creation of a 20 billion DKK loan guarantee by the Danish Government to secure investments in hydropower for supplying large scale projects in Greenland.

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Abstract

Using the West Greenlandic hydropower potential of 2,000 MW in supplying large scale mining- and aluminium projects has very substantial advantages, environmental and financial. Controlling the use of this potential is very important for Greenland and The Kingdom of Denmark. Coordinated control safeguard the optimal use of the resources. Greenland by itself has no possibility of funding the hydropower development investment (more than 2 times the Greenlandic BNP), but a loan guarantee from The Kingdom of Denmark will make funding available. It is imperative that the Government of Greenland neither de jure, de facto or morally will be liable for the loans. Establishment of hydropower by Greenland will be welcomed by investors in mining- and aluminium projects. Investment in hydropower is a strain on their financials, which they want to avoid. The Government of Greenland can of course force the use of hydropower on the projects, but the consequence may very well be that projects are abandoned to the disadvantage of the Greenlandic community.

1. Introduction

The Kingdom of Denmark has a considerable interest in reducing the CO2 emission from Denmark as well as from Greenland, especially if it is possible within an attractive economic framework.

There is an unused hydropower potential in Western Greenland of app. 2.000 MW, which is more than double the capacity needed for the large scale projects identified so far. Potential electricity production is app. 15 billion KWh per year.

This large hydropower potential is a very significant resource for the Greenlandic society, and it is of vital importance, that the resource is used to the greatest benefit for Greenland.

The value of the resource, depending on the actual use of the electricity will be in the magnitude of 10 billion DKK per year.

On top of that the use of hydropower reduces the emission of CO2, which as mentioned is of great importance for The Kingdom of Denmark.

In general, there are several obstacles to reach a solution, which will benefit the highest possible use of hydropower and the optimal solutions to the Greenlandic Society and to The Kingdom of Denmark.

2. The agenda of the interested parties

The main interested parties in the in use of hydropower are the following.

- The Government of Greenland
- The mining Projects
- The aluminium project
- The Kingdom of Denmark

2.1. The government of Greenland

The government of Greenland has a major interest in getting the highest possible yield on the hydropower resource. The financial yield of course is a major concern, but not the only one. Employment of the Greenlandic workforce is another major concern, meaning that hydropower can support enterprises, which will give employment to part of the Greenlandic workforce. The reduction in CO2 emission by using hydropower replacing conventional electricity production is also a concern, even as Greenland for the time being has avoided being part of any convention on reduction of CO2.

Finally it is imperative for Greenland to avoid investment in hydropower for large scale projects, due to the fact that the investments are very large compared with the BNP and the debt capacity of Greenland.

2.2. The mining projects

The mining projects have in general a positive attitude towards hydropower, but are not willing to make the related investments. The major problem for the mining projects is the relative short lifespan of the mines compared with the very long lifespan of the hydropower projects.

In general financing of a mining project is based on pay back times between 3 and 5 years and internal interest calculation over 20%. These financial key numbers are essential for making finance available to the projects, and are not consistent to major investments in hydropower.

Conventional electricity production for the large scale projects will on the other hand enlarge the CO2 footprint of Greenland very significantly, which is a concern for the mining projects. Finally the costs of conventional electricity production are very high. The price level is about 1,8 DKK per KWh, which is 5 to 10 times higher than the hydropower alternative.

2.3. The Alcoa aluminium project

The Alcoa project is based on obtaining a competitive price on electricity. The Greenlandic project is competing with other hydropower facilities all over the world, and with coal or natural gas based electricity production, which is subsidised in varying degrees around the globe.
The Greenlandic project is only viable based on hydropower. Although it is not a main interest for Alcoa to invest in hydropower, it has up till now been imperative, as there is no other investor available. On this basis Alcoa is seeking the best possible conditions for the investment in the aluminium smelter as well as in hydropower.

Up till now the Greenlandic government has accepted options on several hydropower potentials to Alcoa as part of the negotiation process, and the Greenlandic Parliament has given the Government a very wide authorisation for the coming negotiations with Alcoa.

2.4. The Kingdom of Denmark.

The major concern of The Kingdom of Denmark is the CO2 footprint of the large scale projects in Greenland. Although The Kingdom of Denmark so far has avoided formal limitations on the CO2 emissions of Greenland, there are concerns related to the item, especially related to the high profile the Kingdom of Denmark keeps on green growth and reduction of emissions.

3. Facts and figures

3.1. Potential and demand

The hydropower potential in the south western part of Greenland is well documented although it looks like the potential is higher than in the general reports (Nukissiorfiit 2005).

The geography of the major documented potentials are seen at figure 1.

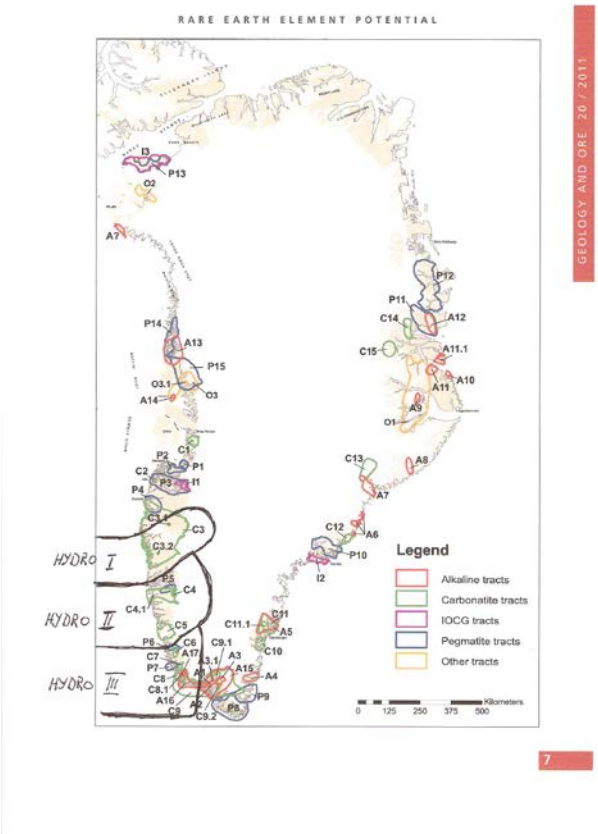

Figure 1. Hydropower potentials

Figure 2. Hydro I area

Hydro I potential 965 MW
Hydro II potential 450 MW
Hydro III potential 400 MW

In connection to the aluminium project, there has been made new evaluations, which upgrades the potential of two specific sites app. 40%. As many hydropower potentials depend on melting of the icecap, global warming means higher potentials than forecasted based on historical data.

For the time being there are several large scale projects in the pipeline in the Hydro I and Hydro III areas, but no actual projects in area II.

The specific conditions in the Hydro I area is seen at figure 2.

Of the potential of 965 MW the two large scale projects the Alcoa aluminium smelter and the ISUA iron mine in total have a demand of app. 775 MW. On top of that the town of Maniitsoq demands app. 5 MW.

3.2. Relations and ownership

In hydro area I there are two large scale projects, which at present are in a competitive situation, depending on the options of Alcoa to use specific Hydropower potentials. This situation is at present and in the actual structure, a major obstacle against the use of hydropower at the ISUA iron mine project.

London mining, the owner of the ISUA project is quite happy with the situation, as they are not interested in making the investment in hydropower, due to the specific demand for a short payback time for the mining project and some considerations for the time frame for a hydropower project.

On the other hand they have shown interest in buying hydropower in the long perspective, but without taking up ownership.

As the hydropower potential in the area is big enough to supply the two projects, it is the financial structure and ownership, which

are the main problems in establishing the best possible solution for all involved parties.

4. Solutions

4.1. Ownership

To be able to coordinate all interests in hydro area I there is a need of concentrating the ownership in one organisation. As mentioned before, there is no possibility of ownership of the Government of Greenland, on normal conditions, due to the lack of financial capacity.

Comparing the Greenlandic and the Icelandic situation illuminates this situation. The Icelandic power company Landsvirkjun has a production of app. 13 TWh per year and a balance of 26 billion DKK. Landsvirkjun is owned by the Icelandic Government (Landsvirkjun 2011). The Icelandic BNP is app. 80 billion DKK. The investments in Greenlandic hydropower to large scale projects are app. 20 billion DKK and the Greenlandic BNP is App. 10 billion DKK.

Landsvirkjun has by itself financed very big investments in connection to aluminium industry, latest an investment in a 690 MW hydropower station for delivering electricity to an Alcoa aluminium smelter in the eastern part of Iceland. The investment is app. 7,5 billion DKK.

The relation to Alcoa is based on a delivery contract, of which there are no details public available, but a major element is a connection between the electricity price and the world market price for aluminium.

The ownership alternatives are, due to the limitations of the Greenlandic financial capacity, limited to the following possibilities

- Public Private Partnership (PPP) will be complicated and time consuming. One must expect a rather high price on this model, but the main objection is difficulties in finding a suitable partner.
- Investment from a major electric utility. This solution is a special case of the PPP with the same problems and lack of opportunity.
- A special financial structure supported by The Kingdom of Denmark. This solution is based on a loan guarantee from the Kingdom of Denmark to finance the investments. The ownership of the hydropower stations and transmission lines is in a company owned by the Greenlandic Government, but totally depending on the special guarantee structure.

4.2. Financing

As mentioned earlier it is imperative to the Government of Greenland to avoid investments in hydropower due to lack of financial capacity. The special financial structure based on a Loan guarantee from The Kingdom of Denmark has to secure that the Government of Greenland neither de jure, de facto or morally will be liable for the loans.

An irrevocable and unconditioned guarantee from The Kingdom of Denmark will make financing available from international institutions as well as from Danish pension funds etc.

The relations between the Government of Greenland and The Kingdom of Denmark in that relation depends partly on the will of the two parties and partly on the actual conditions of the cooperation. Based on a Greenlandic company owned by the Greenlandic Government it should be possible to agree on the specific conditions, and at the same time secure the Greenlandic interests in the whole venture.

4.3. Organisation

As mentioned the construction is based on a Greenlandic company owned by the Greenlandic Government. The share capital, fully paid in, is expected to be rather low, between 10 and 100 mill. DKK.

Appointment to the board of directors will depend on agreement between the

Greenlandic government and The Kingdom of Denmark, but with a clear majority of Greenlandic appointed members.

The key element in the organisation and administration of the activities, will be a guarantee committee, which based on recommendations from the administration make primary decisions on establishment of specific loan guarantees. Members to this committee shall be appointed by the Greenlandic Government and the Danish Government with equal numbers from each party.

The final decision on actual loan guarantees will based on recommendations from the Guarantee committee be made by the Danish Government.

Nukissiorfiit, the national Greenlandic water and electricity utility, can take care of the day to day management of the company and the operation of the hydropower stations. Nukissiorfiit is experimented in building and operating hydropower stations in Greenland up till 45 MW.

4.4. Politics

Around the world, it is quite common that governments provides loan guarantees to major hydropower projects. A resent example is the Canadian federal guarantee to the CAD 7,4 billion Muskrat Falls project. The guarantee has a maximum of CAD 6,3 billion and a timeframe of 35 to 40 years (Taber 2012).

A Kingdom of Denmark guarantee to Greenlandic hydropower projects is in this context not an unusual activity. As mentioned earlier The Kingdom of Denmark has by itself an interest in the highest possible use of hydropower to large scale projects in Greenland. On this basis, and related to the political debate in Denmark, and on the comments from leading Danish ministers, it should be possible to get an accept from the Danish Government to establish a framework for loan guarantees to Greenlandic hydropower projects.

From a Greenlandic point of view, guarantees from The Kingdom of Denmark gives the maximum influence and financial benefits, and at the same time as the structure will make it easier to attract further large scale projects to Greenland. Furthermore the guarantee structure means very little interference with the Greenlandic rights and possibilities to make the relevant decisions concerning hydropower projects and related large scale projects.

In general this structure of cooperation between Greenland and Denmark, is of mutual benefit, and therefore should be a realistic way of developing the Greenlandic economy and development.

5. Conclusions

This paper draws up a framework for a mutual beneficial cooperation between The Greenlandic and the Danish Governments on environmental and financial matters. Furthermore the framework defines a basis, which makes Greenland more competitive in connection to large scale projects. Taken at face value one should expect a great interest, from the Greenlandic and Danish governments, to substantiate the framework to an operational structure.

Unfortunately experience shows that there are great many difficulties in catching the eyes of governments to a proposal like this one, which means, that first step in the process is to find sponsors, who are in the right position and thereby are able to further the process.

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Overview of the environmental effects of the 5 largest mines in Greenland.

Ivittuut, Mestersvig, Maarmorilik, Seqi, and Nalunaq

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In 1982 it was found that blue mussels and seaweed over a large part of Arsuk Fjord near Ivittuut had very high concentrations of lead. This was a surprise. It was soon discovered that the quay constructed at the cryolite mine was the source of this lead. This quay was made of discarded cryolite ore with low content or no content of cryolite but containing galena (lead sulphide). Unfortunately, as the tidal currents moved up and down and in and out of this quay material, conditions were optimal for oxidizing and dissolving of the galena. There is still lead pollution of the Arsuq Fjord but it is gradually diminishing.

Also at the lead mine in Mestersvig, northeast Greenland, environmental investigations have proved a pollution of the sea with lead. Here, spills of lead concentrate with appr. 70% lead at the beach and in the shallow waters close to the harbor at Mestersvig was the source of pollution. Whole barges filled with galena were in one or more cases lost in the sea. Another source of pollution was (and is) the tailings deposited on a hill side. This deposit is not op to present day's standard. Material containing zinc and lead is gradually washed down the hill side by rain and snow-melt and ends up in the river and further down to the sea (Kong Oscars Fjord). The tailings deposit is primarily a source of zinc pollution.

The Black Angel mine at Maarmorilik is a classic example of inappropriate tailings deposition. In 1972 the tailings were expected to be chemically inert, and therefore safe to dispose in the nearby fiord Affarlikassaa. But already at the first environmental investigation in 1974, few months after the opening of the mine, very high and completely unexpected concentrations of lead and zinc were found in the water from the fiord where the tailings were deposited. Later investigations showed that this pollution was spreading to blue mussels, seaweed, prawns, and fish in a large area south and west of the mine. This well investigated case further showed that the deposition of lead-containing waste rock, partly in the fiord, also resulted in dissolution of lead sulphide (as at Ivittuut). Today, 23 years after the closure of the mine, there is still lead pollution of the area. Today, however, it seems that the lead-containing dust released during mining is still a major contributor to the pollution of the area. The pollution originating from the tailings seems to have stopped.

The Seqi olivine mine only operated a few years. This mine was operated much better with regard to the environment. Here, the only observed negative environmental effects were the spreading of dust. The dusting problem was very local and was mainly associated with the content of nickel and chromium in the dust.

Similarly, the Nalunaq gold mine has been operated more safely from an environmental point of view. Here, the only observed negative environmental effect is dusting. Again the dusting is very local and only observed close to crushing activities and close to the road leading from the mine to the harbor. The gold mine uses sodium cyanide to extract the gold from the ore. A major goal of the environmental regulations is to prevent dangerous release of cyanide to the environment with risk of killing all life in the river flowing past the mine. So far, the cyanide content in the water running out of the mine has been below the max-concentration set by the authorities, and the arctic char living in the river seem to be unaffected by the mine.

Monitoring of metal dispersion near former mine sites in Greenland

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Monitoring the dispersion of pollutants near mines is important to evaluate the environmental impact and if needed address measures to reduce it. In Greenland, the Danish Centre for Environment and Energy (DCE - formerly named DMU/NERI) has conducted environmental research near mines since the 1970s. Significant pollution with mine-derived elements (metals have been of main concern) has been observed at several former mine sites in Greenland. Important sources of pollution from the mines include dust, waste rock and so-called mine tailings originating from the ore-treatment process. In order to monitor the dispersion of mining-derived pollutants near the mines, samplings of water, dust and marine sediment has been used in addition to more alternative techniques. These techniques include a range of indicator organisms such as lichens, seaweed, mussels and fish that concentrate metals and reflect the dispersion in different environments. In addition, geochemical tracers such as element ratios and lead isotopes have been applied to further trace the mine-derived elements. This presentation will focus on monitoring of metal dispersion near two former mines in Greenland; the lead-zinc mine in Maarmorilik and the olivine mine in Seqi in Southwest Greenland. New research and techniques for monitoring metal dispersion will be presented. Furthermore, the results will show the present and past dispersion of metals at these two mine sites and highlight some important lessons learned.

Soil amendments and native nitrogen-fixing species for mine site restoration in northern Canada

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Abstract

The development of soil amendment technology and practices for the restoration of mine impacted soils is strongly needed in northern Canada. The nitrogen cycle is highly sensitive to pollutants and restoration of this biogeochemical pathway is essential to ensure long-term sustainable ecosystems. We examined various soil amendments and native nitrogen-fixing species to determine optimal formulations that improve soil conditions and promote long term re-vegetative success. Soil amendment treatments including biochar, mulch, calcium bentonite and lime were applied to tailings at a mine site in Yukon Canada. In a greenhouse trial, the growth and nitrogen fixation rates of four local native nitrogen-fixing herb species (*Dryas drummonii*, *Hedysarum alpinum*, *Oxytropis campestris* and *Lupinus arcticus*) were determined in both tailings and cover soils. The biochar and lime treatment resulted in significantly higher rates of germination and aboveground biomass in the tailings in-situ. *Lupinus arcticus* had the highest biomass and all species with the exception of *Dryas drummonii* showed nitrogen fixation in both tailings and cover after 3 months. Very few native seed mixes are commercially available for use in Yukon and northern Canada. Development of suitable soil amendments and incorporation of local nitrogen-fixing species into restoration efforts can help to improve restoration success, plant species diversity and nitrogen availability in mine impacted soils.

1. Introduction

With the expansion of mining in northern Canada there is an increasing need for appropriate cost-effective reclamation and restoration technologies. Northern restoration has unique challenges relating to cold-climate soil chemistry, short growing seasons and geographical isolation. Reclamation failures have been common despite extensive research over the last decade (Haigh, 2000; Moreno-de las Heras et al., 2008). One of the potential causes of reclamation failure is that traditional reclamation treatments generally do not increase biodiversity and may limit the potential for long-term establishment of pre-disturbance ecosystems. Grasses, for example, are easily established and thus often viewed as a nurse crop for early vegetation establishment. The seeding of uniform agronomic grass and legume communities can however result in plant communities that inhibit shrub and tree regeneration and remain successionally stagnant (Sheoran et al., 2010). Initial plant cover should allow for the development of diverse self-sustaining plant communities (Shu et al., 2002; Sigh et al., 2002; Hao et al., 2004; Sheoran et al., 2010) and failure to reestablish natural successional trajectories on reclaimed areas can result in degraded ecological conditions. Indigenous or native species are preferable to exotic species because they are most likely to fit into fully functional ecosystems and are climatically adapted (Li et al., 2003; Chaney et al., 2007; Sheoran et al., 2010).

This may be particularly important in harsh climates typical of northern Canada. In Yukon, a lack of precipitation and higher latitude lead to variable success rates of revegetation efforts and revegetation techniques used with success in more southern locations are often unsuccessful (Snow et al., 2009). However, very few native seed mixes are commercially available for use in Yukon and northern Canada. Commercial revegetation seed mixes that do contain only species that are native to Yukon, have often been propagated outside the territory and will contain non-native genotypes (Matheus & Omtzigt, 2012).

The nitrogen cycle is highly sensitive to pollutants and restoration of this biogeochemical pathway is essential to ensure long-term sustainable ecosystems. Boreal forest soils are nitrogen limited; therefore including local native nitrogen-fixing species into seed mixes used in northern restoration may promote plant community growth while reducing the application rates of artificial fertilizers (Myrold & Huss-Danell, 2003). Determination and selection of native plant species that promote nitrogen availability and nitrogen cycling is crucial.

Due to the lack of organic matter, low pH and high metal content the conditions on many mine sites may be too harsh for vascular plants to establish. Hence, the use of soil amendments may be necessary to allow for successful germination and growth. Several studies have found biochar, a product that results from the oxygen limited pyrolysis of various biological ingredients, can result in significant decreases in the bioavailability of heavy metals associated with mine impacted soils (Namgay et al., 2006; Beesley & Marmiroli, 2011; Fellet et al., 2011) and simultaneously improve physical, chemical and biological soil properties (Laird et al., 2010). Biochar has many benefits for the environment and has been investigated extensively in southern climates, but very few studies have examined its use in northern reclamation and restoration.

The purpose of this study is to examine (a) formulations of soil amendments that improve the condition of the soil and promote germination and growth of native Yukon species and (b) the potential to include local native nitrogen-fixing herb species in seed mixes.

2. Methods

2.1 Site Description

The Keno Hill Silver District is one of the world's highest-grade silver districts located 330 km north of Whitehorse, Yukon, Canada. The mining district comprises 233 km of numerous mineral occurrences and over 35 mine sites with a history of silver, lead, and zinc production (Alexco Resources, 2013). Past mining activities have left the area honeycombed by small workings, open pits, a large tailings impoundment and an altered drainage pattern. It is estimated that approximately 4,050,000 tonnes of tailings were deposited at a 130ha site, known as the Valley Tailings, located in the the McQuesten River Valley (63°55'26.4N, 135°29'76.1W). The tailings are highly variable with a pH ranging from 5.7 to 8.4 and texture varying from silt loam to sand. The tailings exceed the Canadian Council of Ministers of the Environment (CCME) industrial soil quality guidelines for allowable levels of Antimony (Sb), Arsenic (As), Cadmium (Cd), Copper (Cu), Lead (Pb), Silver (Ag), Titanium (Ti) and Zinc (Zn).

The original site consisted of boreal vegetation including small trees (*Picea glauca*, *Picea mariana*, *Populus tremuloides*, and *Populus balsamifera*), as well as, shrubs (*Salix* spp.) and vegtative moss mats (*Sphagnum* spp., *Pluerozium* spp.). Vegetation in the Valley Tailings area was eventually covered by tailings, which range from 0.1 to over 4m in thickness (Keller et al., 2010).

Mean January temperature in the Keno area is -26.9°C, while mean July temperature is 15.6°C. However, summer temperatures in the region can exceed 25°C and winter temperatures -50°C. The average total precipitation is 322 mm and discontinuous permafrost is found throughout the area (Clark & Hutchinson, 2005).

2.2 Tailings Soil Amendment Trial

We examined 8 soil amendment treatments and 1 control treatment (fertilizer and seed only). Soil amendments were applied to the Valley Tailings using a randomized block design with 14 blocks (5m x 10m). Leaving at least 1 m^2 between treatments, the 9 treatments (1 m^2 each) were randomly assigned within each block. Each soil amendment treatment had 14 replicates for a total of 126 plots.

The soil amendment treatments included the following materials: biochar (1 kg/m^2), smectite (calcium bentonite) (750g/m^2), dolomite lime (54.6% $CaCO_3$, 41.5% $MgCO_3$) (484g/m^2), wood mulch (193 g/m^2) and the tackifier Guar Gum (12.7g/m^2). The biochar (BC) was a Phosphorus-rich bonemeal biochar (2-14-0) pyrolyzed at a temperature of 450°C for 6 hours. The grain size of the finished product was ≤ 2mm. The 8 soil amendment treatments were: biochar (BC); biochar and smectite (BCS); biochar and lime (BCL); smectite and lime (SL), biochar, smectite and lime (BCSL); mulch (M); mulch and lime (ML); biochar, smectite, lime and mulch (BCSLM). All soil amendement treatments were fertilized (19:19:19) at a rate of 110 kg/ha and seeded at a rate of 30kg/ha with a native grass seed mix, containing Violet Wheatgrass (*Agropyron violaceum)* (40%), Sheep Fescue (*Festuca ovina)* (23.3%), Rocky Mountain Fescue (*Festuca saximontana)* (23.3%) and Glaucous Bluegrass *(Poa glauca)* (13.4%). Guar Gum was present in all treatments. All of our amendments were applied as a slurry to simulate delivery via hydroseeding using 7.5L of water per m^2.

Plots were established between July 1-3, 2012. Germination was determined by counting the number of emerging stems in 0.25m^2 subplots for each replicate from July 25-26, 2012. Above and belowground biomass were sampled from August 27-29, 2012 in 0.5m^2 subplots for each replicate. All biomass was dried at 90°C for 36 hours before determining dry weights.

2.3 Greenhouse Nitorgen-Fixing Herb Trial

Soil amendments and nitrogen-fixing herb species were examined in a greenhouse trial at the Yukon Research Centre, Whitehorse, Yukon. We used a full factorial design with 2 soil types (Cover and Tailings), 4 local native nitrogen-fixing species (*Dryas drummonii*, *Hedysarum alpinum*, *Oxytropis campestris* and *Lupinus arcticus*) and 4 soil amendments. Each treatment combination had 12 replicates for a total of 384 samples. Each sample comprised on an individual container that was 3.8cm in diameter, 21cm deep and had a volume of 164 ml (Ray-Leach Tubes, Stuewe & Sons, Tangent, Oregon).

Cover soils from Husky SW (63°54'18.9 N, 135°31'45.1W) and Valley Tailings (63°55'16.2N, 135°29'36.9W) were collected on August 29, 2012 for the greenhouse trial. The Husky SW soil is currently being used in trials as a cover soil. The pH of these soils ranges from 8.0 to 8.4 and they have a loam texture and organic carbon content of 47%. The soils exceed the CCME industrial soil quality guideline for allowable limits of As. Seeds from 4 local native nitrogen-fixing species (*D. drummonii*, *H. alpinum*, *O. campestris* and *L. arcticus*) were collected throughout August 2012. In addition, for each species the belowground systems of a number of plants were excavated, examined and sampled for rhizobia or frankia nodules between August 29-September 3, 2012. Nodules were kept in the fridge without light at 4°C until used.

Three different soil amendments and a control treatment were used: biochar (BC), Rhizobia (R), biochar and Rhizobia (BCR) and a control with fertilizer only (C). The same biochar as used in the previous trial was mixed with deinonized (DI) water and 5 ml of biochar slurry was added to each container. Nodules previously collected were masticated in DI water to create Rhizobia slurries or for *D. drummonii* a Frankia slurry. Seeds receiving the the R and BCR treatments were soaked for 3 hours within the slurry prior to planting. Slurries contained 1.4mg/ml of masticated nodules (wet weight). Containers receiving the R treatment were given 2.5ml of slurry and 2.5ml of DI water. All containers received 2 seeds of one of the 4 species and fertilizer (19:19:19) at a rate of 110 kg/ha. The trial was initiated on September 11, 2012.

The greenhouse conditions and watering were controlled to reflect typical summer growing conditions in the Keno area. Temperature was 11°C with no light from 22:00-4:00 and 16°C with 175 µmol/m^2/s of light from 4:00-22:00. Each replicate was watered every second day with 6ml of DI.

From December 6-13, 2012 containers were sampled for germination rate, number of observable nodules, above and belowground biomass and nitrogen fixation. Measurements of N_2-fixation were made using acetylene reduction assays (ARA) (Stewart et al., 1967). Plants were harvested from each container (with belowground systems kept intact) and placed in a separate 60 ml amber glass vial with a teflon septa cap. Each amber vial was injected with 10% (v/v) acetylene gas (C_2H_2) and incubated in the dark at 20°C for 4 hours. Ethylene concentrations were measured with a portable gas chromatograph (SRI 8610A, Wennick Scientific Corporation, Ottawa, ON, Canada) fitted with a Porapak column (Alltech Canada, Guelph, ON, Canada) and a flame ionization detector.

Data from both the soil amendment trial and greenhouse trial were examined to ensure the assumptions of Analysis of Variance (ANOVA) were met and log transformations were performed on some variables. Soil amendment trial data was analyzed using a blocked ANONA and greenhouse trial data was analyzed using a full factorial ANOVA. All analyses were conducted in R (R package version 2.1.50).

3. Results

3.1 Tailings Soil Amendment Trial

Of the 8 amendment treatments examined the BCL treatment had significantly higher germination rates (Figure 1) and significantly higher aboveground biomass (Figure 2a) when compared with the fertilizer only control treatment (CT). The BCL treatment also had higher germination rates than treatments that included mulch (i.e. M, ML and BCSLM).

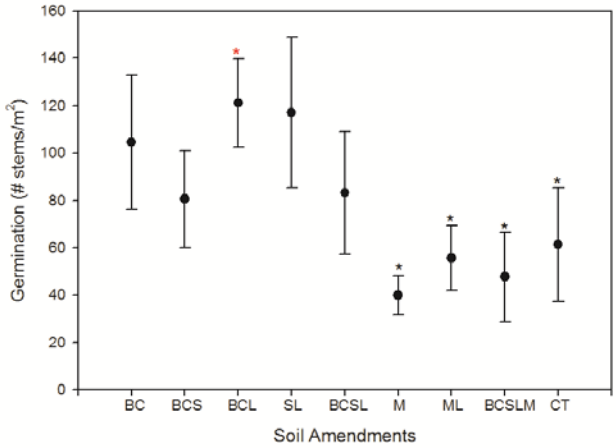
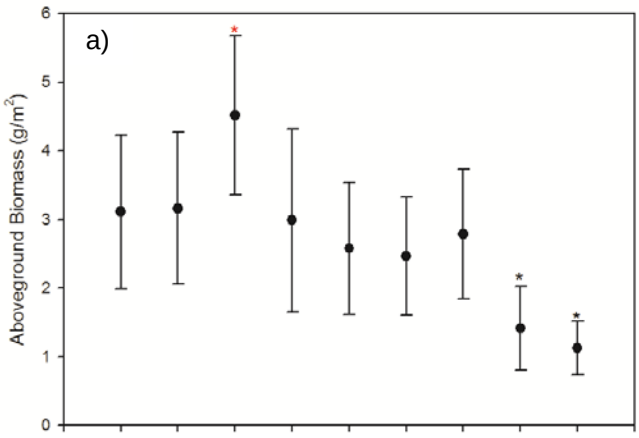


Figure 1. Germination of native grasses with different soil amendments 22 days after application at the Valley Tailings, Keno, Yukon. Soil amendment treatments are Biochar (BC), Biochar and Smectite (BCS), Smectite and Lime (SL), Biochar, Smectite and Lime (BCSL), Mulch (M), Mulch and Lime (ML), Biochar, Smectite, Lime and Mulch (BCSLM) and Control with fertilizer only (CT). Germination of the BCL treatment is significantly higher (*) than the M, ML, BCSLM and CT treatments (*) (ANOVA, $p<0.05$ for all comparisons).

None of the soil amendment treatments had significantly higher belowground biomass compared with the control. Average belowground biomass was slightly higher in the BCL treatment (2.9g/m^2) compared with the control (2.0g/m^2), however not significantly. The SL treatment had significantly higher belowground biomass compared with BCS, BCSL, ML and BCSLM (Figure 2b).



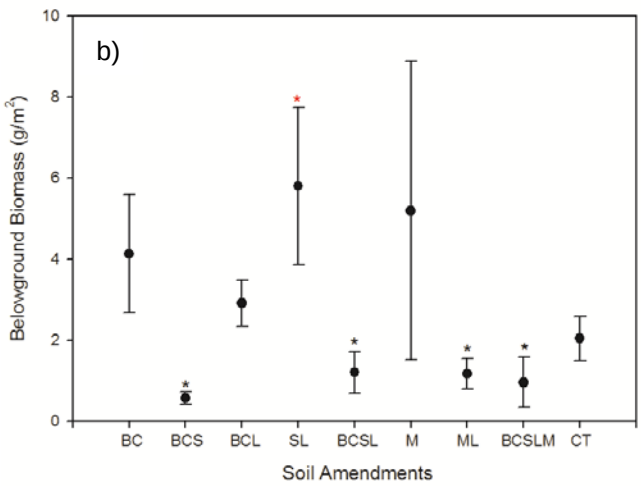


Figure 2. Aboveground (a) and belowground (b) biomass of native grasses with different soil amendments after 2 months grow on the Valley Tailings, Keno, Yukon. Soil amendment treatments are Biochar (BC), Biochar and Smectite (BCS), Smectite and Lime (SL), Biochar, Smectite and Lime (BCSL), Mulch (M), Mulch and Lime (ML), Biochar, Smectite, Lime and Mulch (BCSLM) and Control with fertilizer only (CT). The aboveground biomass of the BCL treatment is significantly higher (*) than the BCSLM and CT treatments (*) (ANOVA, p<0.05 for all comparisons). Note: Belowground biomass was only sampled within 5 plots per treatment.

3.2 Greenhouse Nitorgen-Fixing Herb Trial

Overall cover soils had significantly lower germination rates (42% versus 53%, p<0.01), but higher rates of nodulation (3.8 nodules versus 0.3 nodules, p <0.001) and nitrogen fixation (209 µmol ethylene/m^2/hr versus 23 µmol ethylene/m^2/hr, p<0.001) compared with tailings. Aboveground and belowground biomass were not significantly different between the two substrate types (p=0.47 and p=0.63 respectively). However, average root length was significantly longer in the tailings (11 cm) compared with cover soils (9 cm) (p<0.001).

O. campetris had significantly lower germination rates compared with all other species (Figure 3), which did not differ significantly from each other. The BC treatment (34%) had lower germination compared with all other soil amendment treatments (BCR= 54%, F=51%, R=52%, p<0.001 for all comparisons).

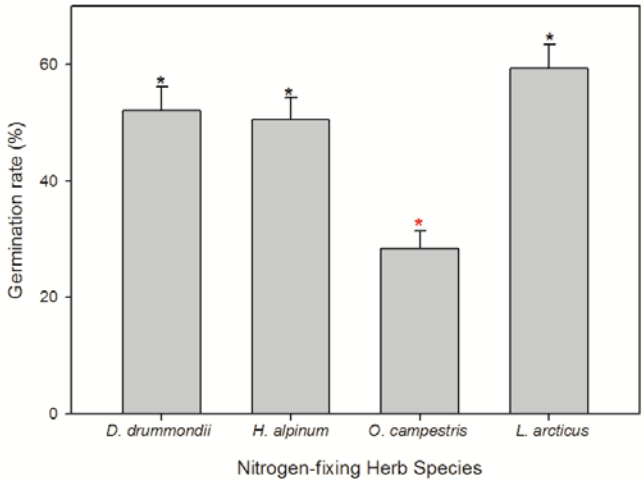


Figure 3. Germination rates of nitrogen-fixing herb species on both cover soils and tailings in a greenhouse trial. O. Campestris had significantly lower germination (*) compared with all other species (*)(ANOVA, p<0.001 for all comparisons).

The R (4.7 nodules) and BCR (3.6 nodules) treatments had higher average rates of nodulation than the BC (0 nodules) and F (0.02 nodules) treatments (p<0.001). *L. arcticus* had the highest average rate of nodulation (3.9 nodules) and was significantly higher than both *O. campetris* (1.3 nodules) and *D. drummondii* (0 nodules) (p<0.05 and p<0.001 respectively). *H. alpinum* had the second highest average rate of nodulation (3.1 nodules).

All species with the exception of D. *drummondii* demonstrated active nitrogen fixation after 3 months. Only those samples treated with the rhizobium innoculum (i.e. CR, TR, CBCR and TBCR) had nitrogen fixation above our detection limit (10 µmol ethylene/m^2/hr). *H. alpinum* had significantly higher mean rates of nitrogen fixation (288 µmol ethylene/m^2/hr) compared with both *O. campetris* (50 µmol ethylene/m^2/hr) and *L. arcticus* (11 µmol ethylene/m^2/hr) (p<0.001). Average nitrogen fixation was significantly higher for the BCR treatment (188 µmol ethylene/m^2/hr) than the R treatment (45 µmol ethylene/m^2/hr) (p<0.001). The

highest rates of nitrogen fixation occurred in cover soils with the BCR treatment (Figure 4). Specifically, *H. alpinum* had higher nitrogen fixation than *L. arcticus* in CBCR and *O. campetris* had higher nitrogen fixation in cover soils than in tailings for the BCR treatment (Figure 4).

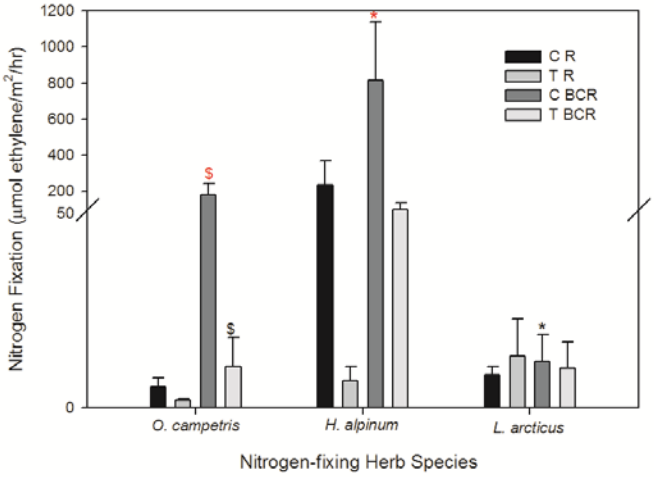


Figure 4. Nitrogen fixation by three herb species in four different treatments after 3 months. The treatments are cover soils with rhizobia (CR), tailings with rhizobia (TR), cover soil with biochar and rhizobia (CBCR) and tailings with biochar and rhizobia (TBCR) Bars are means with SE. H. aplinum CBCR (*) has significantly higher rates than L. Arcticus CBCR (*) and O. campestris CBCR ($) has significantly higher rates than O. campetris TBCR ($) (ANOVA, p<0.01 and p<0.05 respectively).

L. arcticus (62g/m^2) had significantly higher average aboveground biomass compared with all other species (*D. drummondii*=1.3g/m^2, *H. alpinum*=11g/m^2, *O. Campetris*=3.5g/m^2, p<0.001 for all comparisons). The BC soil amendment treatment (8.7g/m^2) had lower aboveground biomass compared with all other soil amendments (BCR=24g/m^2, R=19g/m^2, F=26g/m^2, p<0.05 for all comparisons).
L. arcticus (153 g/m^2) had significantly higher average belowground biomass compared with all other species (*D. drummondii* =0.7g/m^2, *H. alpinum*=31g/m^2, *O. Campetris*=5.0g/m^2, p<0.05 for all comparisons). *H. alpinum* had significantly higher average belowground biomass than *D. drummondii* and *O. Campetris* (p<0.05 for both comparions). The BC soil amendment treatment (28g/m^2) had significantly lower average belowground biomass than the BCR (61g/m^2) and R (56g/m^2) treatments (p<0.05 for both comparisons).

4. Discussion

Phytostabilization of mine tailings is highly difficult, not only due to phytotoxic effects of elevated heavy metal concentrations, but also due to extreme pH values, low fertility, low water-holding capacity and unfavorable substrate structure (Fellet et al., 2011). The BCL treatment promoted both germination and growth of the native grass seed mix at the Valley Tailings. There are a number of potential mechanisms by which biochar may have influenced germination and growth including retention of soil moisture, increased temperature at the surface due to the black colour of the biochar, increased nutrient retention and reduction in bioavailability of heavy metals. Biochar has a high surface area and porosity and can increase the water-holding capacity of the soil (Fellet et al., 2011). Biochars with a high volume of macropores greater than 50nm diameter can make water available to plants (Lehmann & Joseph, 2009). Higher moisture availability at the surface may have contributed to both higher rates of germination and initial growth.
Biochar also has a high cation-exchange capacity and can reduce nutrient losses in the soil. The functional groups of biochar influence the sorption process depending on the nature of their surface charge so that both transition metals and non-transition metals can be sorbed onto the surface of biochar particles (Amonette & Joseph, 2009). Several studies have found reduced availability or leachability of heavy metals following the application of biochar to contaminated soils (Beesely et al., 2011).
Lower rates of germination were observed for soil amendments that included mulch. Although mulch may act to retain moisture at the surface, the layer of wood fibre may have inhibited germination of these native grasses.
Surprisingly, in our greenhouse trial we found the biochar (BC) treatment had lower

rates of germination, however, we also observed lower rates of germination in the cover soils compared to the tailings. Under less harsh environmental conditions and in soils with higher water-holding capacity, biochar may play a less important role in promoting germination.

High variability was observed in belowground biomass and no soil amendment treatment was significantly different than the fertilizer only control treatment (CT). However, the SL treatment did have higher belowground growth in comparison to other treatments. Reduction of heavy metal bioavailability may promote belowground growth in plots treated with a combination of lime and calcium bentonite. For example, Zinc is retained through bonding to bentonite surfaces and retained Zn can diffuse into cavities and transform increasingly to residual forms (Ma & Uren, 1998). High pHs (> 6.9) generally result in greater specific adsorption of Zn (Ma & Uren, 1998). Therefore, the combination of lime and calcium bentonite may be most effective at promoting Zn retention in the Valley Tailings.

In situ immobilization of metals using soil amendment processes is increasingly being considered as an effective and low cost remediation alternative (Mench et al., 2007; Kumpiene et al., 2008; Fellet et al., 2011). While liming is one of the oldest and most widely used metal immobilizing soil treatments, the effects of liming gradually reduce over time due to the dissolution and leaching of the liming agent, especially in highly acidic soils (Ruttens et al., 2010). Biochar however, is highly recalcitrant (Steiner et al., 2007) and its effects may persist over long time periods. In addition most biochars tend to have neutral to basic pH and therefore commonly have a liming effect. However, it should be noted that this liming effect has been shown to increase As mobility and restrict re-vegetation (Beesely et al., 2011). Care should be taken to determine how various types of biochar may interact with the elements and conditions at a given site.

Determining the most appropriate closure and reclamation option is heavily dependent on site characteristics; however, development of soil amendments that are effective on both tailings and soil covers could significantly increase re-vegetation success. Although, the BCR soil amendment was most effective at promoting nitrogen fixation in the cover soils, we still observed relatively high rates in the tailings. Therefore, a combination of both a rhizobia innoculum and biochar may best promote nitrogen fixation and hence N input on mine impacted sites.

Nodulation and nitrogen fixation only occurred in samples that were given a rhizobia innoculum, indicating that nodulation in these soils is unlikely to occur naturally and the use of nitrogen-fixing species in northern reclamation may require microbial amendments. Robertson et al. (2012) did not find any differences in the rate of nodulation of lodgepole pine (*Pinus contorta var. latifolia*) or sitka alder (*Alnus viridis ssp. sinuata*) in sub-boreal forest soils amended with biochar. However, nitrogen fixation was observed to continue for longer in biochar-treated systems versus non-biochar treated systems. We found nitrogen fixation for both the R and BCR treatments, but the BCR treatment had significantly higher rates.

L. arcticus had the highest above and belowground biomass and no differences in biomass were observed between the two substrate types. Therefore, of the species examined here, *L. arcticus* may be an important species to consider in restoration efforts aimed at promoting biomass accumulation and nitrogen input. Further studies are needed to examine a wider variety of species on a number of substrate types common on mine impacted sites.

5. Conclusion

Development and identification of soil amendments and native species directly impacts eco-restoration re-vegetation success while simultaneously helping to remediate soils affected by pollutants. Currently there are very few native species available for restoration in northern Canada. Our study indicates that native nitrogen-fixing herbs demonstrate a strong potential for use in restoration efforts. Further, soil amendments are needed to promote nodulation and nitrogen fixation by these species. We demonstrated that biochar positively influences germination and growth of native grass species in tailings. However,

further studies are needed to develop a stronger understanding of the specific mechanisms by which biochars retain or release contaminants over time.

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Caribou, individual-based modeling and mega-industry in central West Greenland

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Abstract

The dynamics and spatial distribution of the caribou (*Rangifer tarandus groenlandicus*) population in West Greenland result from both short and long term changes in the Arctic landscape. To assess their present distribution satellite collars were deployed on 40 female caribou in the Akia-Maniitsoq herd, central West Greenland in 2008. Detailed information on spatial distribution prompt opportunities to use statistical models to understand the drivers of the distribution of the caribou in West Greenland. In a newly started PhD-project the focus will be on analyzing caribou population dynamics using a spatially explicit individual-based model (IBM). The project relies on existing knowledge on caribou behavior and feeding ecology along with data on variations in the vegetation. By relating vegetation, snow distribution and caribou in a realistic "virtual world" of an IBM it is possible to examine the plausible effects of different environmental impacts on the population dynamics of caribou in West Greenland. The simulations will include introduction of mega-industry, roads, and transmission lines in an area. Further, enhanced or lowered hunting pressure, and changed weather conditions can be studied using IBM. Thus, both short and long term changes in the landscape will be studied and provide insights into how specific spatial changes impact caribou in West Greenland.

1. Introduction

The use of individual based models (IBMs) is a new and powerful tool for studying hypotheses relating to the causal drivers of system behavior e.g. how caribou numbers are affected by changes in vegetation, anthropogenic disturbances etc. Further, IBM can be used to study interactions between individual organisms at different trophic levels. For instance it is possible to link individual-based models with the current monitoring of caribou in West Greenland and thereby gain insights to understanding how changes in time (e.g. climatic changes, changes in hunting pressure and the establishment of mega-industry) relates to caribou movement in the landscape (movement related to e.g. optimized foraging).

2. Scientific background

2.1 Caribou ecology

Caribou (*Rangifer tarandus*) are widespread over most of West Greenland. The population has fluctuated greatly during the past centuries (Meldgaard 1986). Data from i.e. hunting statistics have shown that the fluctuations are cyclic, coincide along the entire west coast, and lasts between 65 and 115 years. The difference in numbers at population maxima and minima can be tremendous. Generally speaking there are three factors that are thought to drive the fluctuations: hunting, overgrazing and climate. Historically, hunting has been most important (Melgaard 1986) but newer data suggest that overgrazing (Cuyler et al. 2005) and climate (e.g. Meldgaard 1986, Cuyler et al. 2005, Tyler 2010) are almost

equally as important. The effect of migration for individual herds is not well known but it is expected to have a synchronizing effect on fluctuations across populations.

The seasonal migration patterns of the caribou depend on the population density given that caribou disperse over larger areas in periods when the population is large. Migrations towards the coastal areas during the winter season primarily take place in years with many caribou. When the population size decreases the migrations cease and the caribou primarily stay inland all year round (Meldgaard 1986).

Studies in both Greenland and elsewhere in the Arctic show that migrations are related to the selection of vegetation that allows animals to optimize their food intake (Johnson et al. 2002, Tamstorf et al. 2005).

The caribou in West Greenland are divided into 5 herds (Cuyler and Linnell 2004). The population size of the caribou in the Akia-Maniitsoq herd (figure 1) is estimated every five years, most recently in the winter of 2010 (Cuyler et al. 2011). Population size as well as herd structure and recruitment were recorded (Cuyler et al. 2005, 2011). During recent years the population has been decreasing, presumably due to declining recruitment related to increased calf mortality and lower female fecundity (Cuyler et al. 2005). Further, the vegetation appears to be overgrazed in certain areas and in combination with an increased snow cover during winter it may result in increased winter mortality (Cuyler et al. 2005, Tyler 2010).

Topographic variations in the landscape are crucial for the distribution of snow and vegetation types. The influence of this variation on changes in caribou behavior and feeding ecology remains unclear. By coupling individual-based modeling with the current monitoring of the Akia-Maniitsoq herd the expected outcome will provide insights to how temporal changes (e.g. climate variation and changes in hunting pressure) affect the movement of caribou in the landscape (vegetation, plants and foraging).

Figure 1: Map of Greenland with a marking of the area where the Akia-Maniitsoq herd is located.

2.2 A new tool: Individual-based modeling

The spatial element can be studied in several ways. IBMs are powerful tools that can simulate real-world phenomena to provide a unique and relatively cheap tool for studying how changes in the landscape and thus in the distribution of forage (scaling from seasonal changes to long term changes) affect population dynamics.

Individual-based modeling has been introduced to the ecological world during the past decades. IBM's are fantastic tools to study interactions between individual organisms on various trophic levels (Huston et al. 1988). An IBM is a computer simulation model with the ultimate output

resembling "the real world" (Grimm et al. 2005, Railsback og Grimm 2009). It describes a system of individuals and their surroundings (local resources) where changes at the population level are the result of changes in behavior at the level of individuals. The behavioral changes are dependent on the local availability of resources and interactions between individuals. (Grimm og Railsback 2005). Within the virtual world of IBMs it is thus the individual being in center in contrast to e.g. the classical population models that are based on a non-mechanistic top-down approach.

Individuals with adaptive behavior will give rise to so-called ”emergent properties” (Railsback 2001), especially if the ability to adapt to new surroundings affect the fitness of the individuals. Emergent properties are characteristic of the model output that cannot be directly foreseen based on the input. An example is mortality in caribou. You construct (a) an IBM where the risk of dying is equal for all individuals in the population and (b) an IBM where the risk of dying varies and depends on the behavior of the single individuals. In model (a) the mortality of the population will be constant and can be predicted based on the mortality rate of the individuals. On the contrary, in model (b) the mean mortality rate emerges from the animals’ behavior, responses to environmental cues (e.g. behavior towards a hunter or other anthropogenic disturbances) and location (e.g. prime foraging areas). In model (b) the outcome is thus more complex than the input given to the model.

Hence, an IBM can be used to analyze interactions between caribou, vegetation, anthropogenic disturbances etc. while it takes into account both spatial and temporal aspects.

3. Methods

3.1 Data

The data to be used in the IBM work is already available in different forms. Figure 2 provides a simplified view of the data types that can be used.

Important data for the IBM work was gathered during studies in relation to baseline studies prior to the possible establishment of an aluminum smelter and hydropower plants in the Maniitsoq inland area. The company ALCOA has co-financed several studies mapping vulnerable areas for i.e. caribou and vegetation. A subproject involved fitting 40 satellite collars on female caribou in the Akia-Maniitsoq herd. The collars were deployed in May 2008 and have logged data (GPS-position) with 1-3 hour intervals (Cuyler 2008). Another subproject has dealt with vegetation and snow distribution. The compilation of data has formed the basis for making high resolution vegetation- and snow maps covering the entire area (GRAS 2009).

Thus, interconnected data on individual caribou, their location in the landscape, the vegetation composition and snow coverage in the local area exist. Further, data on caribou population size, herd structure and other parameters on population ecology (Cuyler 2005, 2011) are also available. This makes it possible to perform different model simulations by e.g. simulating longer snow free periods equaling better access to forage due to longer growth season and hence, provide better forage for the caribou.

3.2 IBM

During recent years several IBMs for a variety of objectives and systems of varying complexity have been developed (e.g. JABOWA simulating forest growth [Dale et al. 1985], ALMaSS – The Animal, Landscape and Man Simulation System [Topping et al. 2003]). The current project will primarily make use of the NetLogo software (http://ccl.northwestern.edu/netlogo/) since it is able to handle the required degree of complexity (Railsback et al. 2007). The program has the added advantage of being very user-friendly and well-documented. The model will be documented using the ODD protocol developed specifically for documenting IBMs (Grimm et al. 2006).

3.3 Population dynamic analysis of IBM data

Coupling of the emergent population dynamics generated by the IBM with our current understanding of the population

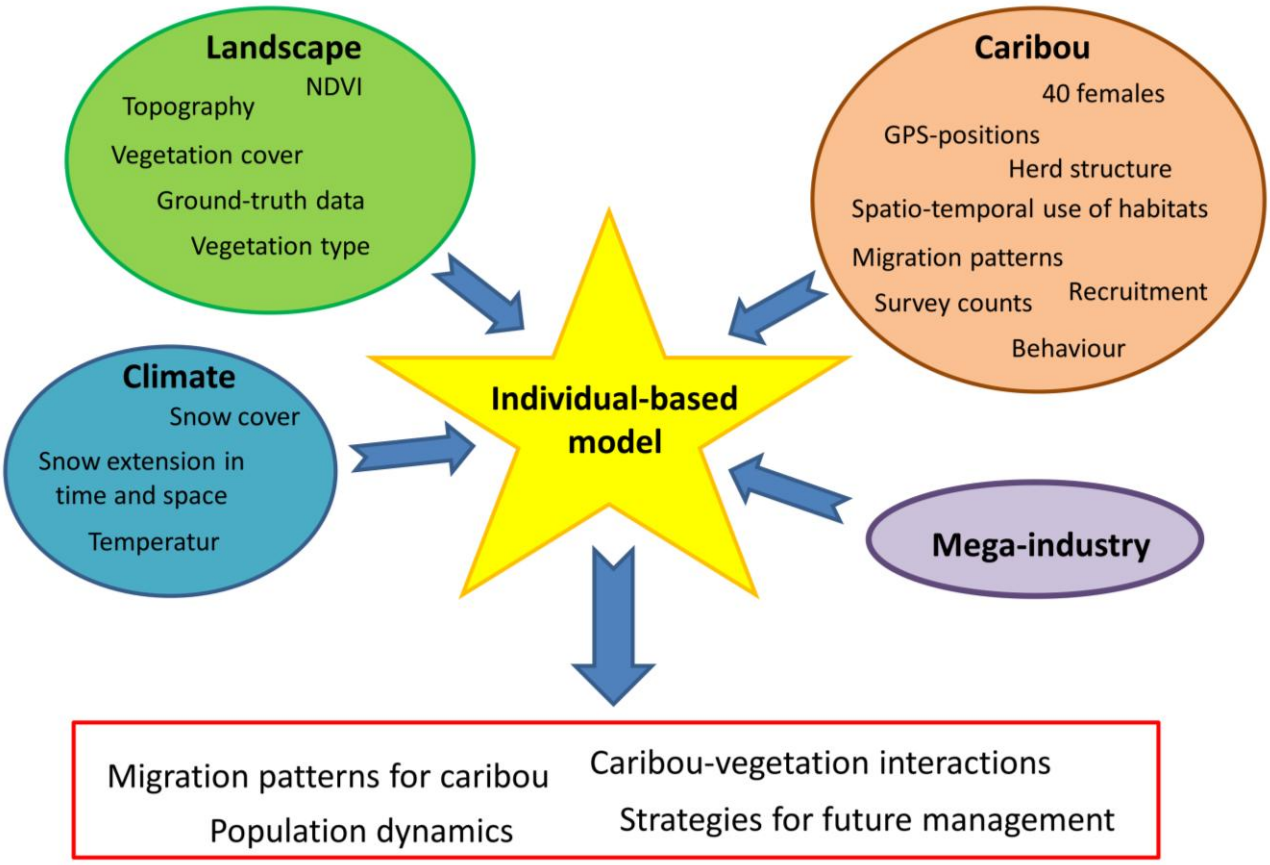

Figure 2. Data types that can be used in the modeling

dynamics is a valuable outcome of the entire project.

Changes in the landscape and how they affect the dynamics of caribou populations can be analyzed by using the Maynard Smith - Slatkin population model,

$$N_t = \frac{N_{t-1}R}{1+\left(aN_{t-1}\right)^b},$$

where N is population size, R is the fundamental reproduction rate of the population, while (a = (R-1)/K) explains the degree of competition with a stability factor K; b explains the type of competition (Maynard Smith and Slatkin 1973; Bellows 1981). The structural parameters as R, a and b can be estimated and compared with the "emergent properties" from the IBM at different landscape scenarios.

3.4 Mega-industry

Caribou and other mammals are known to respond to anthropogenic disturbances in a variety of ways. The disturbances range from people walking on foot to the establishment of industry in an area occupied by caribou.

4. Expected outcome and Conclusion

The project has 4 goals: (1) using IBM's to describe interactions between caribou and vegetation in a spatially and temporal framework (2) analyses of how changes in the environment (e.g. hunting) affect the movement of caribou in the landscape, (3) population dynamic analyses of data generated by the IBM to study how changes in characteristics in the landscape affect structural dynamics in the caribou population, and last but not least (4) a unifying description of management aspects for caribou in West Greenland using the data generated in (1)-(3).

A very important part of (4) is the modeling of how caribou react to e.g. increased or lowered hunting pressure, virtual roads, power lines and other types of anthropogenic disturbances, further decline

in population size and changes in selected vegetation types vital for caribou. Environmental consequences of mega-industry at present under consideration in the area (e.g. London Mining's iron mine at Isua and ALCOA's aluminum smelter close to Maniitsoq) will be included in the model.

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Calling mining companies – watch out for sustainability

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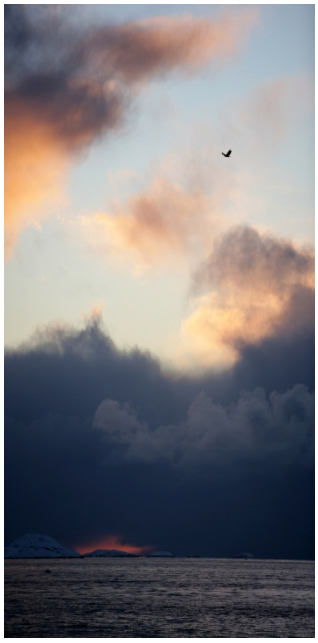
Abstract



"Investments in social responsibility ultimately translate into the ability to bring projects on-stream more rapidly or avoid production interruptions caused by community unrest."
Deloitte: Tracking the trends: top ten trends mining companies may face in the coming year

From a sustainability perspective, mining is a challenging industry. Many different issues regarding the social, economic and environmental impact of mining are relevant, and in each location, they play out differently. In the Greenlandic media, focus has mostly been on the social and economic impact of foreign workers in the establishment phase and on finding the right economic benefit models. The issues at hand, however, are much broader. Our work is an analysis of the different risk and opportunity aspects for the extraction projects in Greenland focusing on certain key issues in the sector such as the extremely high cost of minerals production, local impacts on water, biodiversity, regulatory risks, public unrest and instability and the rise in global CO2 levels.

1. Development of Sustainability in the Mining Sector

As mining company activity catches the international spotlight, industry stakeholders find themselves subject to higher levels of activism than ever before.

Similarly, community involvement is on the rise; beyond demanding higher levels of local investment, community stakeholders expect an open and transparent dialogue, longer-term social commitments and enhanced environmental performance. Companies that fail to deliver risk facing more vocal opposition, difficulty obtaining project approvals and even riots similar to those that broke out in Papua New Guinea and Peru this past year.

Environmental stewardship is equally important. Companies increasingly must access coastal water suppliers, mandating investment in sophisticated pumping technologies and desalination plants.

Concerns relating to carbon also continue apace. In response, monitoring and standards-setting authorities continue to tighten their regulatory mandates. Mining companies must now comply with several significant guidelines such as those from the International Council of Mining and Metals (ICMM), the Global Reporting Initiative (GRI), the UN Convention on Human Rights (which is endorsing the adoption of FPIC, the principle of free, prior and informed consent), the International Cyanide Code and the Extractive Industries Transparency Initiative (EITI). The complexity of these implementation requirements and the lack of integration among the various standards-setting bodies are having a profound effect on management's ability to track and deliver on all their performance expectations.

Ignoring the risk of environmental degradation?, negative bio-diversity and social impacts, health and safety issues and large carbon emissions are all factors impacting the companies' performance and risk of losing reserves or having to abandon projects due to civil unrest and subsequent political reluctance. Companies that do not manage issues adequately, face significant hurdles which may result in a high risk of negative economic performance and value loss.

These general challenges apply to companies mining in the Arctic. But since each mining activity is different and has its particular risk and challenges, companies need to fully grasp the local context, before starting their operations. The meaning of sustainability in mining highly depends on the ore, the type of operation, the geophysical conditions and the legal structure and culture of the local community. This is why that also companies with sustainability policies and experience from other locations ought to start with a thorough mapping and understanding of the specific conditions of sustainability in the Arctic.

2. Mining and the Future of Greenland

The mining opportunities and developments seem the road forward for Greenland in order to achieve economic growth and gain increased independence from Denmark. Hence, it is a general local political ambition to transform the local economy from fishery and hunting to the mining of natural resources which in turn can be used to develop local skills. Mining, which is not a new activity in Greenland, may in other words play a significant role for the future of Greenland, when explored in a larger scale. Greenland's main export is seafood, which constitutes up to 85% of total exports. 50% of the export alone is shrimp making this the most important income source. Remaining exports come from tourism, water, gold, fur etc.

Hunting and fishing have been the dominant occupations in the smaller settlements, but both trades are undergoing dramatic challenges. The market for sealskin has almost vanished with the EU ban (despite an exception for Greenlandic skins), reducing seal hunting almost solely to subsistence purposes. In fishing, a change is taking place with larger boats and combined with decreasing quotas, it leads to a decline in the number of people living of fishing. Thus, new jobs are needed, and many see mining

and in particular the supporting industries as a potential for job-creating. However, few communities are close enough to benefit. The Isua iron mine will be relatively close to Nuuk, the ruby mine close to Fiskenæsset and Kvanefjeldet close to Narsaq, but it is unclear if other communities will benefit. Still even with operations close to the communities, few of the local inhabitants have the right education or skills to work on the operations.

2.1 Tourism and mining

Tourism in Greenland is today fairly concentrated around the Disko Bay area in North Greenland, with some activities in Kangerlussuaq, Sisimiut and South Greenland. It is still unclear how mining activities will impact tourism, but at a first glance there will not be any dramatic conflict.

Visit Greenland, the Greenlandic Tourism Organisation, is highlighting the experience from other mining countries where mining has helped developing infrastructure and in turn supporting tourism. However, this will only be a benefit if there is a strong environmental and social performance from the mining activities.

The transformation is long term. Although, expectations of the possible deposits of rare earths and oil are high, companies are challenged by harsh and difficult conditions for exploration and project development, e.g. Greenland has very limited infrastructure today with no roads linking any towns and each town being an island in itself, meaning that operating costs are often high. Furthermore, a short operating season and scarcity of local labour force are other challenges.

2.2 Local communities and benefits sharing

Often, mining company investment in local communities does not address the full spectrum of stakeholder needs. In some cases, this signals a broken link between a company's intentions and its outcomes. Communities are becoming increasingly sophisticated in their engagement strategies and now expect investments that extend beyond mere financial commitments. Instead, they are demanding that mining officials engage in meaningful dialogue to understand their citizens' needs and include local representatives in the planning process.

One of the most contentious topics is the use of customary lands and associated economic and social impacts on indigenous communities. Mineral development in the Arctic has often occurred in situations where the rights of indigenous peoples were not recognized or respected – resulting in the majority of economic benefits accruing to industry and governments. Indigenous peoples have often been excluded from decision-making, with the result that industrial development has occurred without full consideration of the social, cultural and environmental implications.

In the case of Greenland it is central to understand that its population is predominantly Inuit. As Greenland is a self-governing territory with its own government in charge of mineral development, a mining company should understand the special conditions of the local population. Contrary to operating in Canada or Alaska, this is not a situation where the mining company is doing something particular for the indigenous minority. Greenlanders are the majority and have the right to decide alone.

In recent years, indigenous peoples in the North have exercised their power to grant companies a 'social licence to operate' by demanding compensation and royalty payments, often in the form of Impact and Benefit Agreements (IBAs). They have also capitalized on the fact that mining sector activities are dependent on a wide range of supplier of goods and services. Many efforts on the part of governments, industry and northern businesses, including indigenous-owned business, has been devoted to expanding the supply and service sector in the Canadian North. One focus has been on fostering joint ventures with southern suppliers, especially when the product or material of interest, is under patent or protected by licensing requirements. Another focus has seen mining companies foster the emergence of specialized

northern-owned and operated environmental consulting, ice road construction and work site security businesses, including some who provide ”polar bear intrusion” monitors at work sites.

2.3 Regulation and anti-corruption

Known as the “resource curse”, resource-rich countries often have low diversity in their economies and similarly small pockets of wealth, consequently the mining companies may represent a large portion of the economy, raising concerns of “state capture”, which creates distortion in the legal framework of a country.

To a large extend Greenland has the relevant legislation in place, but generally speaking, legislation tends to be poorly implemented or enforced since the local authorities are stretched thin..

The Tax and Welfare commission report from 2010 points out that the high employee turnover in public administration is a risk in terms of enforcing legislation as well as ensuring legal consistency. This is supported in a report by the Nordic Consulting Group from 2012, which points to the fact that whereas large-scale corruption is not widespread today, there are few structures, institutions and processes in place to prevent corruption and to protect the environment. Reducing the negative impacts of mining operations is consequently a task left to the companies to manage. A strong pressure on national and local administrations to push things through could lead to frameworks not being in place or lack of proper engagement with stakeholders – making a backlash later a much greater risk.

3. Environmental impacts across the mining life cycle

Minimization of environmental impact at every stage of a mine’s development is now a prerequisite for doing business. Given the uniqueness and sensitivity of northern ecosystems, protection of the physical environment is foremost for greenfield and brownfield ventures alike, with strategies to avoid/minimize impact across the exploration/feasibility, construction, operation, closure and reclamation phases. Two of the most significant issues are metal leaching and acid generating waste (i.e. Acid Mine Drainage) and cumulative impacts. AMD can result in contamination of rivers and water bodies, damage to aquatic life and impacts on the indigenous communities that rely on these ecosystems for fishing, hunting and other cultural/spiritual activities. Cumulative impacts refer to the effect that new mining operations may have at a local and/or regional level. Seen in isolation, a new mine’s impacts may not be deemed substantial; however, when examined in combination with the impacts of other existing and/or planned developments, the effects may in fact be significant to habitat values, water quality and the socio-economic characteristics of the area.

3.1 Climate change adaptation

Climate change impacts are more pronounced in northern latitudes. Key projected changes include sea level rise, permafrost degradation, increased melting of sea ice and reduction of sea-ice cover as well as more frequent and intense extreme weather events. For the mining sector, the impacts will offer benefit in the form of increased accessibility of northern mineral deposits. Negative implications include compromised safety of infrastructure, potential failures of mine tailing retentions due to permafrost degradation and/or extreme precipitation leading to water levels exceeding the design parameters of water treatment ponds/treatment plants and failure of frozen soil containments of hazardous waste.

3.2 Integration of science with traditional indigenous knowledge

Consideration of local traditional knowledge in environmental decision-making is increasingly a requirement for any mining development occurring in the Arctic. In Canada’s North, the consideration of traditional ecological knowledge (TEK) alongside western science is entrenched in

the environmental assessment, land and water approval processes in the Yukon, NWT and Nunavut (as well as a requirement of the federal Canadian Environmental Assessment Act). Mining companies will both face pressure to ensure that TEK is given adequate prominence in the decision-making process, but also to foster the 'bottom-up' capacity development of local communities so that they are able to meaningfully participate in decision processes.

4. Conclusion

The sustainability imperative is present for mining companies and consequently they need to approach sustainability initiatives with greater rigour than in the past.

Explorations in the Arctic are high-risk projects, financially, socially and environmentally, which calls for heightened sustainability standards applied to mining projects in this particular region. Thus, two approaches need to be combined in order to ensure long term commitment, efficient compliance, and a road map for integrating sustainability into all phases of the mining:

On the one hand, mining companies must set out to understand the local context for sustainability and mining, address key stakeholder activity, assess relevant local social, environmental and governance issues, on the other hand mining companies must take into account the direct costs/benefits (value creation) and the value of mitigating risks such as delays in planning, construction and operations, lawsuits or potential project cancellation (value protection), before they decide on an optimal portfolio of sustainability investments.

The outcome of combining these two approaches will ensure a long term mutual value creation for the operating company and the Greenlandic society.

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The organization of mineral exploitation and the relationship to urban structures and local business development

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Abstract

The key question of the paper is how to organise mining projects to involve the local workforce and support the potentials of mining projects for development in Greenland. This paper explores the concept of flexible settlements in relation to develop socio-economical sustainability. A major challenge for Greenland is the on-going decoupling between existing settlements and the main export industry based on marine living resources. In praxis Greenland, as other Arctic regions, is divided into relatively isolated island economies with only modest trade between the settlements, limited possibilities of commuting, and where a number of settlements are left without a substantial industrial base. Administering the settlements often is the most important wage based occupation and the society in general struggles with unemployment and widespread social problems.

Mineral extraction is seen as a key to overcome the contemporary economic challenges. But few mineral resources are located in proximity to existing settlements. Many of the mining companies envisage potentials for a fast extraction of the resources using immigrant and migrant labourers that work intensively over a period of time while living in shantytowns. Both local and international experiences show that such an organization of work and everyday life is not very attractive for those parts of the population that still have alternative option, and that these forms of mining activities often end in significant human and social challenges also for the surrounding community. The historic experiences of Greenland tell that a different and long-term organisation of exploitation of mineral resources can contribute to a socially better organised, socially functional and innovative society. Therefore there is seen a need for further research regarding the possibility of re-establish the coupling between settlements and local resources and thereby trade possibilities primary linked to mineral extraction. When extraction only last for a decade or two there is a demand for incorporating flexibility in how the settlements are constructed. The focus in the research will be whether it is possible in such temporary mine-related settlements to create an attractive and sustainable alternative with a reasonable population and economic diversity.

1. Introduction

This article is based partly on a PhD study that, among other things, analyses the Greenlandic economy for different types of habitats, and partly on knowledge developed through the teaching of Arctic engineering students associated with Sanaartornermik Ilinniarfik in Sisimiut and the Technical University of Denmark.

First, the introduction presents the central framework of understanding regarding the Greenlandic settlement pattern, economic base and Greenland's economic situation. Section two shows the increased interest in

exploiting Greenland's mineral resources, and section three discusses experiences with work organization. Finally, in section four, the article discusses the need for a new approach to work organization of the mining industry in relation to urban structures and business development.

1.1 The link between residence and business bases

As many other Arctic communities, Greenland is characterized by a very small population in relation to its size, and the country's settlements are widely dispersed. At the same time, all Greenlandic settlements practically operate as islands without roads or any other option for daily commuting between settlements. This means that the Greenlandic economy in reality is not a coherent economy, but a number of interconnected island economies. One of the major challenges of the island economy structure is that there is an extremely modest trade between the individual settlements. Only around 15 % of ship cargo is between Greenlandic settlements, while around 50 % is import from Denmark, and approx. 35 % is export to or through Denmark.

Facts

Population (January 1st 2013): 56,370
Of these 6,270 were born outside Greenland

Population in cities: 48,151
Population in settlements: 7,775 (Grønlands Statistik 2013)

However, the difference between towns and settlements is unclear and is primarily based on historical and administrative status. Based on this, there are currently 18 towns ranging from 452 (Ittoqqortoormiit) to 16,454 (Nuuk) inhabitants, and 58 settlements ranging from 22 (Qassimiut) to 512 (Kangerlussuaq) inhabitants. Moreover, there are a series of sheep farms and technical / scientific stations.

There is a remarkable deficiency of women with 89 women per 100 men in all of Greenland, and similarly in the reproductive age (defined as 18 to 42 years) with 92 women per 100 men.

For island economies without the possibility of daily commuting, having a locally based livelihood becomes vital to the financing of the settlement. For the Greenlandic settlements, the primary commercial basis has traditionally been the exploitation of marine living resources, but for decades it has not been able to fund community service, which is why Greenland has been and still is entirely dependent on financial transfers (subsidies) from Denmark. Greenland also has a large education gap, which is why a large part of skilled labour and labour with higher education is exogenous and mainly from Denmark.

For both the individual settlements and Greenland as a whole, over time there has been a growing disconnection from the exploitation of marine living resources because, in growing proportion, these resources are being caught by large ocean-going trawlers, processing or freezing on board, which then sell directly to ports outside Greenland, or sell in Greenland, where most of the raw materials are exported unprocessed. This means that the impact on employment, and thus added value for the communities where there still exists a seafood buyer, is modest, and that the settlement's localization in reality will be decoupled from the local resource utilization.

For major towns, the primary industrial base has become the maintenance of the settlement's operations, including administration, health, education, retail, construction, etc. In contrast to this trend, there still exist a number of smaller settlements where the primary existent and occupation base continues to be linked to the exploitation of marine living resources and the vast majority of the inhabitants and workforce is of Greenlandic origin (Hendriksen 2013).

1.2 The Danish government's economic contribution

Currently, the Danish government contributes almost half of Greenland's government budget (577 million out of 1.261 million EURO in 2011) (Statistics Greenland 2013) and approx. one third of the disposable gross national income. At the same time, Greenland have the same demographic challenges as a number of other Arctic areas, with increased life expectancy, a declining birth rate which is down to 1.8, and migration from Greenland, which together result in an increased dependency ratio, with consequent growth in public spending. Public spending is also challenged by expectations of increased welfare, education and health, while export incomes are declining, overall resulting in an expected increase in the deficit in public finances. The autonomy agreement with Denmark implies that the Danish transfers (subsidies) to Greenland are regulated by the Danish price index without compensating for rising costs.

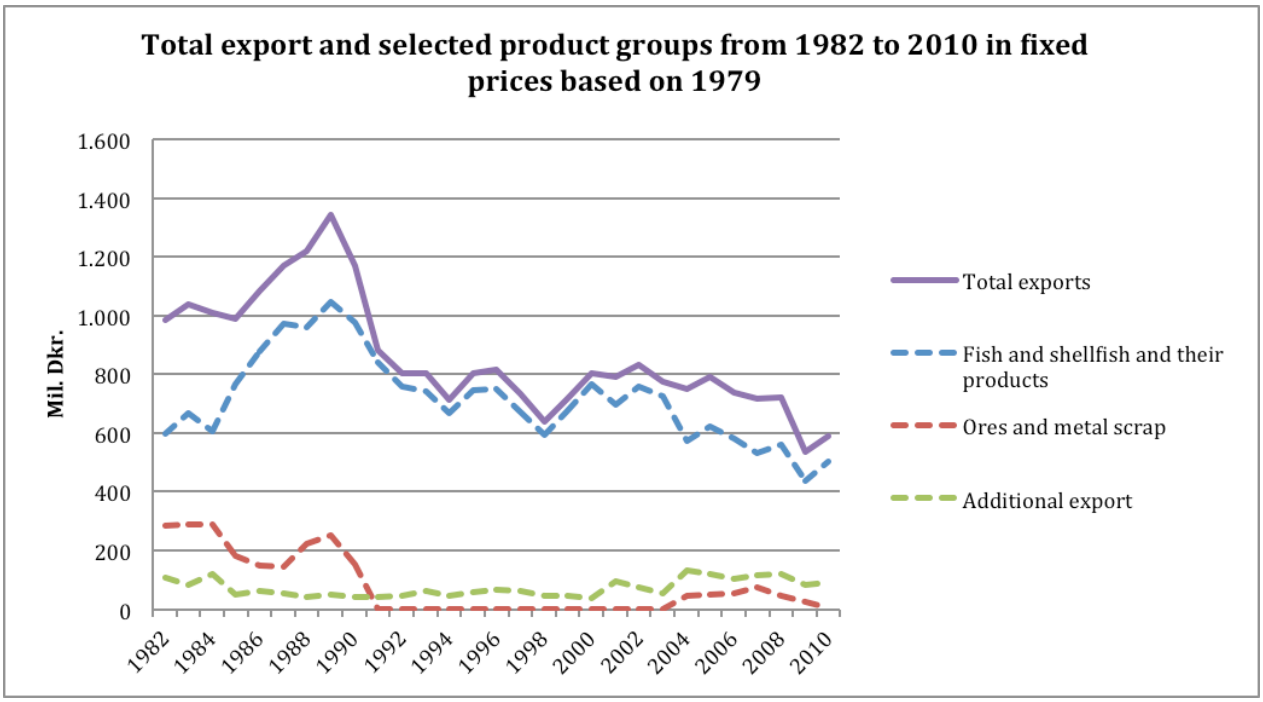
1.3 The desire for increased differentiation in the industrial base

The political desire in Greenland for increased political and economic autonomy creates an obviously untenable situation, and it is in this light that the growing interest in the country's mineral resources has to be seen.

That is why there is a massive political desire to develop new business areas and thus expand the export incomes to more areas than just living marine resources. Over the past decades, the value of mineral exports has been quite modest, while fish and shellfish account for the predominant share of exports.

2. Potential mineral resources

It is noteworthy that most of the known mineral deposits have been known for decades, but has not been exploited because no one has found it profitable. The increasing global resource shortages of certain raw materials and consequent expectations of price increases is a major explanation for the increased international interest in some of the Greenland mineral potentials. Another explanation is more intensive Greenlandic marketing of these potentials, combined with increased flexibility of the rules. Additionally, there may be political considerations of the superpowers behind, for example, the Chinese interest in mineral exploration in Greenland, where a geographically rooting in Greenland can help legitimize a Chinese seat in the Arctic Council and other international bodies, thus making China an 'Arctic nation'.



In recent years, a large number of exploration licenses have been extended, and currently, the exploitation licenses for a handful of projects are being negotiated. However, currently only one relatively small project is close to being realised.

3. The use of local manpower

Apart from the so-called rare earth elements (REE) in Kuannersuit (Kvanefjeld) at Narsaq, none of the current potential mines are directly linked to an existing settlement. Currently, it is uncertain whether a mineral exploration in Kvanefjeld will be undertaken, as the mountain contains uranium, and both the Greenlandic autonomic government and the Danish government has a zero-tolerance policy in relation to uranium based on both environmental concerns for the local area and population, as well as security considerations with regards to non-proliferation of nuclear materials and the ratification of international conventions. Abandoning the zero-tolerance policy is currently being debated in Greenland.

The general strategy for mining companies is to make a relatively quick extraction and a subsequent closing of the activities, balancing the cost of equipment and the development of market price for the resource in question. There is an emphasis on migrants or immigrant labour boarded for the period in shantytowns at the mine itself, interrupted by shorter furloughs at home. During the work period, working will typically be done in 12 hour shifts 6 days a week for a longer period.

The Greenlandic government announced that potential Greenlandic labour can only expect to be transported to and from the mine from a major city, while they themselves must pay for any transportation to smaller settlements, and the government encourages people to move towards the major cities.

3.1 Experience of work organization

Past Greenland experiences with this type of work organization is not particularly positive.
From 1972 to 1980, the Canadian (and later Swedish) mining company Greenex operated the zinc- and lead mine Marmorilik in the Uummannaq district (Nordregio 2009 p. 12). The work shifts were 14 days followed by 14 days off. Approximately 15% of the workers were born in Greenland (Dahl 1977: 6; Nordregion 2009 p. 15). An illustration of Marmorilik being a special community is the percentage of women, that during the years 1997-1992 only were 9% (Nordregio 2009 p. 14). Until 1977 the Greenlandic workforce was discriminated with lower salary and poorer employment and work conditions. After a work conflict the formal conditions were equalised, however the number of employees with a Greenlandic background were not elevated, according to Nordregio because of the company's right to choose who to employ (Nordregio 2009 p. 13-14).

The only currently active mine is the Nanulaq gold mine in Kirkespirdalen in South Greenland, Nanortalik district, which has been running since 2004. The mine has continuously employed 80-100 people, but only for short periods of time did it manage to have more than 50% domestic manpower and a large part of these is working with the services such as cleaning, catering and transport. It is remarkable, because the mine is located in one of the country's poorest districts with massive unemployment.

Relatively many Greenlanders have worked shorter periods at the Nalunaq mine, but few have done it for a long time. The explanation often heard is that they work in the mine for a period to raise money for e.g. a new tractor for their sheep, a dinghy or motor for hunting and fishing, consumer goods for the home or similar, but they do not want to work under the given conditions for an extended period of time (Hendriksen

2013).

Work organization do not seem to fit into the culture of Greenland, where time spent with family counts very much, just as many considers having time to get out into the countryside, hunting and fishing, to be very important. This also explains that a relatively large part of the crew on Greenlandic trawlers is recruited in the Faroe Islands, Iceland, Norway and Denmark (Nielsen 2000).

The socio-economic impact of mining may be very modest, as long as the only direct income is taxation of employees' wages, and workers from outside Greenland are exempt from council tax and only pay land tax. Because they do not live permanently in Greenland, their wages are not put into circulation in society through general consumption, and therefore there is a limited multiplier effect for this part of the workforce.

3.2 Experience with other work organizations

From 1924 to 1972 there was an active coal mine in Qullissat, which was organized as a real community with school, shop, hospital, administration, etc., and where there was a fairly even gender distribution. Although Qullissat's primary industrial and existence base was mining, a broad occupation base of hunting, fishing, construction companies, etc. emerged, and the city developed into an attractive habitat that attracted people from all over the country, and for a period of time, Qullissat was Greenland's second largest city with about 1,200 inhabitants. Qullissat was an innovation centre and the birthplace of the Greenland trade union movement, as well as a cultural centre for music and politics.

In this context, it is key that the Greenlanders were a very large part of the mine workers, and that there was a community which was also seen as attractive for citizens who did not work in the mine.

There is thus a historical example of mining in Greenland being successfully combined with an attractive community with great diversity.

On the other hand, the closing of the settlement of Qullissat stands as no success. In 1972, Greenland was formally an integrated part of Denmark, and it was the Danish Government which decided to close the mine. The closure was based on the fact that the coal grade was low, that it was more difficult to produce coal, because the easily accessible part had been extracted, and that Qullissat had no port, so coal had to be lightered out to the ships that sailed it to Denmark. Another key factor was that Polish and South African coal was cheaper, making world prices crucial to the closure of the mine. It gave rise to some political discussion in Denmark, since the closure took place during the Cold War, where not everyone found trade with Poland opportune, and many found it unacceptable to buy coal from the apartheid system in South Africa, where miners lived and worked under miserable conditions.

The decision was made without consulting enough with locals, and people saw it as a decree. There was not put enough thought into alternative economic opportunities or phasing out the mining activities over a period of time. Inhabitants of the community were forcibly relocated and scattered to the winds. The decision became a politicizing factor in Greenland and was an important political mobilization leading to the Home rule Government in 1979. The closing of Qullissat is still traumatizing in Greenland, and it may be some of the reason that the establishment of actual settlements in connection with mining operations is not on the political agenda?

4. Exploring alternatives

As mentioned above, Greenland faces a number of challenges of an economic nature in relation to education and to re-establishing a link between residence and commercial basis, if the vision of economic self-dependence must be met.

The Greenland Government's plan that people should move from the smaller settlements and gather in large cities, from which some of the men should commute to the mine's shantytowns for stays of 3-4 weeks followed by a week or two at home, seems, in light of experience, not very realistic.

It should not be seen as an argument against increased mining, as there may be good reason to increase the country's revenue base on the exploitation of mineral resources. It is only a question of how it is implemented environmentally and in terms of securing a socio-economic and socio-cultural sustainability.

This complex area has for some years been taken up in the engineering education. In an attempt to shed light on alternatives to the mining industry's dominating work organization with immigrants and migrant workers in shantytowns, we organised a special course with groups of students from the engineering education to work more systematically with this problem complex. Their work has resulted in the exhibition material for the Danish exhibition at the 2012 Venice Biennale International Architecture Exhibition. These preliminary studies indicate that among parts of the population there is a great interest in discussing alternatives.

As an example we have looked at a potential mine on the east coast of Greenland at Kangerlussuaq, midway between Ittoqqortoormiit (Scoresbysund) and Tasiilaq (Ammassalik). There has already been a settlement at Kangerlussuaq, which was closed during the Danish Government's efforts to centralize the population. Kangerlussuaq is one of the best hunting spots in Ammassalik district, and every summer around 30 families sail the 300 km up to Kangerlussuaq, where they camp and hunt, among other species, narwhals and polar bears.

Ammassalik district is one of the country's poorest, and the base for hunting and fishing and fish purchasing capacity is inadequate to effectively secure the district's existence, which is why a part of the population is dependent on social transfers.

The students' interviews indicate that there exists a connection between interests in working at the mine, and whether there will be the establishment of a proper settlement at Kangerlussuaq, including room for women and children. There is also a desire for the work to be organized with normal operating hours, allowing time for family and leisure, which is typically spent on hunting and fishing. In this context, there is a desire for flexibility, allowing for holidays or other forms of free time in the periods where this is e.g. narwhal catch, something that cannot be planned and predicted in the longer term.

If mining is organized as a slightly less intensive and lengthy process, there can be established a residence with about 200 inhabitants, a quarter to a third are employed in the mine and the other of working age ensures the settlement's operation and operates catch. Under these assumptions, it is estimated that there are resource potentials for at least 30 years of operation. New business opportunities may develop around the mining settlement related to fishing and tourist, creating a more diverse economic base.

There will obviously be some societal costs of (re) establishing a proper settlement at Kangerlussuaq, but the alternative may result in the classic Greenlandic problem where major projects are based on outside labour and wage money circulation will take place outside Greenland and the majority of secondary multiplication is thus absent.

4.1 Sustainability challenges

Preliminary studies indicate a central problem in relation to sustainability. First, there is of course the challenge of running a given mine in an environmentally acceptable manner, an issue not examined more closely here. In addition, the challenge of ensuring that mining gives socio-economic and socio-cultural benefits to the Greenlandic society.

In recent decades, several hydropower stations and runways have been constructed by external contractors primarily using

outside labour, and local job creation has been extremely modest. And there are indications that the next big mining projects can quickly end up creating the same problem. At the expected iron mine at Isua in the bottom of Nuup Kangerlua (Godthåbsfjord), alone, there are expected a workforce of up to 1,000 during the operational phase. It may be asked whether it seems realistic to find this manpower within the country when we consider the failure to find more than approx. 50 % resident labour for a mine with 80-100 employees. If labour is not Greenlandic, how does the mine benefit the country? Although there is not charged royalties for mineral extraction, it can of course be expected that some modest income tax revenues will be generated from the outside labour. Experience shows, however, that there is no evidence to suggest that mining companies will have to pay business tax at any significant rate, and thus the social contribution remains small. This means that the overall positive momentum through the generation of jobs for the surrounding communities also remains modest, and this challenges the overall sustainability.

Traditionally, the population of Greenland has a very high mobility and there is still a relatively high mobility of the population, and, most surprisingly, there is a relatively high mobility of the population engaged in hunting and fishing (Nordregio 2010). The question is whether this mobility can be exploited for mineral extraction, if the work is organized and arranged in accordance with social and cultural frames of reference.

4.2 Need for more research

There is a great need for more research in this area, involving experience from similar projects in areas with indigenous peoples in and outside the Arctic.

It is essential to explore how local people can be involved positively in the Greenland mineral extraction projects, and how work can be organized so that it is attractive, and will not undermine the existing cultural context, but will be included as a positive element in sustainable development dynamics. In this context, it is necessary to analyse the socio-cultural implications of establishing settlements with an expected service life limit, and how the settlements can be soundly closed when livelihoods are exhausted. Already in the start-up phase, should it be assessed whether the site has other potentials that can enable a long-term establishment and continued run of the settlements or parts thereof. Inuit is originally a nomadic culture, and parts of the population have maintained a high mobility. It should therefore be examined to what extent the general mobility can be included as a positive factor in the establishment of settlements, which is of temporary nature.

In addition, an assessment of the individual mines socio-economic potentials under different operating modes is needed, where it is necessary to analyse much broader than just the financial return for the mining company.

Finally, there are a number of technical challenges to the establishment of settlements, which are expected to have a limited lifespan, so that most elements can be reused at another settlement, and so that the settlement also environmentally becomes sustainable in the operation phase, and that there may be an environmentally sound dismantlement.

Acknowledgements

This paper is partly based on interviews and results from our students' work on flexible settlements from 2009-2012. We also want to thank the many interviewees that have contributed to our exploration of this idea.

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Pollution of the Arctic and its effects on human health and ecosystems; with special focus on local Arctic industries

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Abstract
The Arctic Monitoring and Assessment Programme (AMAP) is a working group under the Arctic Council with mandate to monitor and assess the pollution and the climate change in the Arctic, and hereby to document levels, trends and effects on human health and ecosystems. This presentation gives an overview about documented levels, trends and effects of long range transported pollutants like persistent organics (pesticides and industrial chemicals), mercury and radionuclides, in addition, special focus on observed levels, trends and effects due to local Arctic industrial activities like oil and gas, smelters and mining industries. The presentation also cover some information about the latest observations made in the Arctic related to the climate change and how this leads to new challenges and opportunities for the peoples living in the north.

1. Introduction

AMAP was initiated in 1991 by Ministers from the eight Arctic countries (Canada, Denmark, Finland, Iceland, Norway, Russia, Sweden and USA) as part of the Arctic Environmental Protection Strategy (AEPS). In 1996 the Arctic Council was established based on and including the AEPS. The Arctic indigenous peoples have a special seat and say in the Arctic Council as Permanent Participants. AMAP is one of the 6 working groups and has been tasked to monitor and assess the pollution of the Arctic, including effects on ecosystems and humans. In 1993, AMAP was asked to include assessments of climate change - including UV/ozone and its effects on Arctic ecosystems and humans. The main geographical area for the AMAP assessments is shown in figure 1.

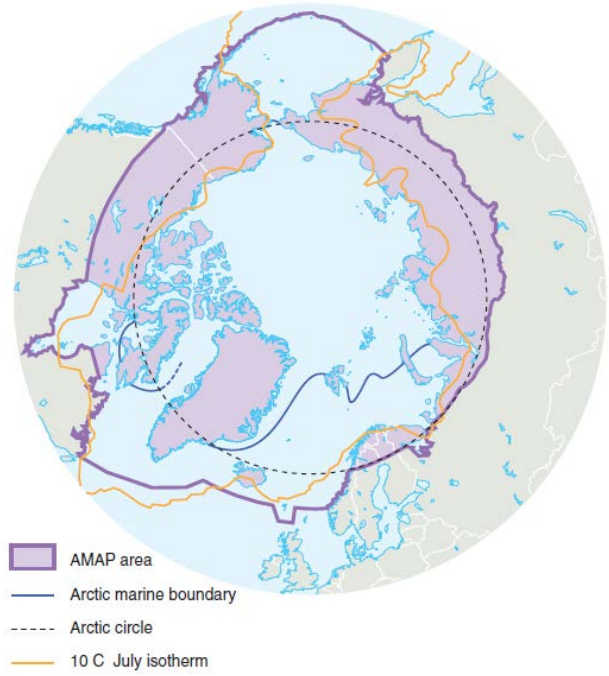

Figure 1. The main geographical area for AMAP assessments. (AMAP, 1998).

Since 1991 AMAP has delivered more than 30 scientific and technical assessments. During the first ten years the main focus was on

contaminants like persistent organic pollutants (POPs), heavy metals (especially mercury, lead and cadmium), radionuclides (mainly due to military activities in the North and accidents like the B52 at Thule in 1968, testing of nuclear bombs and releases from European reprocessing plants - Sellafield), acidification (especially forest death around smelters) and petroleum hydrocarbons. During the following ten years, the climate change got increasing priority, and today it is the climate change and the combined effects of climate, pollutants and other stressors that have the main focus. Over all the years, the effects due to pollution and climate change on humans, especially the situation for the indigenous peoples has been a high priority area in relation to the food security, life style and to provide advice to health workers.

2. Materials and methods

AMAP has developed strict operating guidelines for the work to be done, both for the monitoring part, the assessment, data handling/storage and publication. AMAP recommend methodologies accepted by international scientific communities and other international organization to achieve comparable data. There are special requirements for QA/QC programmes and reporting to Thematic Data Centers. The Guidelines are updated when new components are added or new methods accepted. All of the AMAP Programmes and Guidelines are available from AMAP web site www.amap.no .

3. Results

The assessments have documented that a range of contaminants: POPs, heavy metals like mercury and lead, radionuclides and acidifying components have been and still are transported into the Arctic area and deposited in the environment. The fastest transport into the Arctic is by the wind (it may take less than a week from Southern Europe), then significant amounts are carried by the large rivers (normally within a year or two along the longest ones) and finally the slowest transport is by the ocean currents (it may take 3-4 years from Central Europe).

Some of these contaminants accumulate in food chains, and some also bio-magnify in species that feed high in the food chain, including humans. POPs accumulate mainly in the marine food web and are bound to lipids/blubber (fat), with potential to affect high trophic level predators such as polar bears and killer whales, but also indigenous human populations that consume significant amounts of marine mammals as part of their traditional diet. The same goes for mercury which also accumulates in fish and marine mammals. For radionuclides, the terrestrial food chain is the most affected and thereby indigenous peoples living on reindeer meat are the most exposed groups (AMAP, 1998, 2002).

Effects due to the exposure to POPs and methyl mercury have been documented in Arctic animals (e.g. polar bear and glaucous gulls) and humans since the 1980-ties (AMAP, 1998). For some of the “classical” POPs (e.g. DDT, PCB, HCH) there has been observed a decreasing trend over the last years, see figure 2. However, at the same time new POPs has been observed – brominated and fluorinated products (figure 3), (AMAP, 2009).

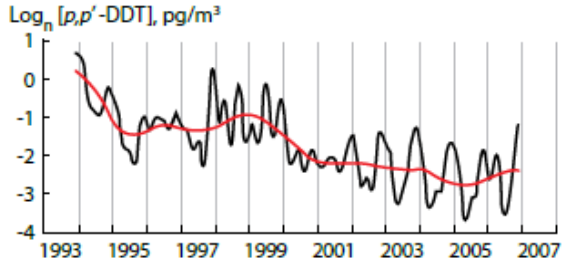

Figure 2. Decreasing trends in DDT in air at Svalbard. (AMAP, 2009).

This paradoxical situation - where Arctic people that hardly used and/or had little benefit from products containing these harmful contaminants, are among the most highly exposed groups to these contaminants anywhere on the planet - has resulted in the so-called “the Arctic dilemma”. The marine food chain is rich in fat, which provides energy as well as essential vitamins for humans. POPs accumulate in the blubber and

mercury in the meat of Arctic marine that can be a key to survival under the harsh conditions that exist in the Arctic.

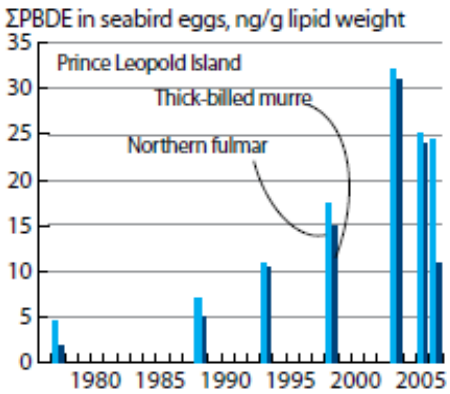

Figure 3. Trends in PBDE in seabird eggs at Prince Leopold Island, Canadian Arctic. (AMAP, 2009).

Regarding mercury, the main source for the atmospheric transport and deposition is mercury originating from burning of coal in power plants. Figure 4 shows the trend in emission of mercury, and clearly shows that in countries were stricter regulations has been introduced, e.g. North America and

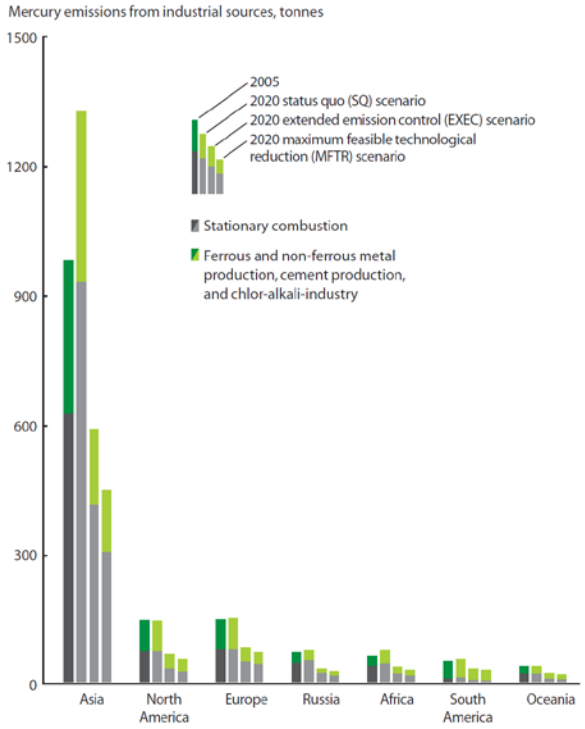

Figure 4. Trends in mercury emissions in different regions. (AMAP, 2011a).

Europe have reduced the emissions, while in areas with increasing demand for energy e.g. South East Asia, the emissions have increased.

Figure 5 shows that the increase in mercury levels in artic indigenous peoples and animals that has happened since the burning of coal increased around 1880 (AMAP, 2011a).

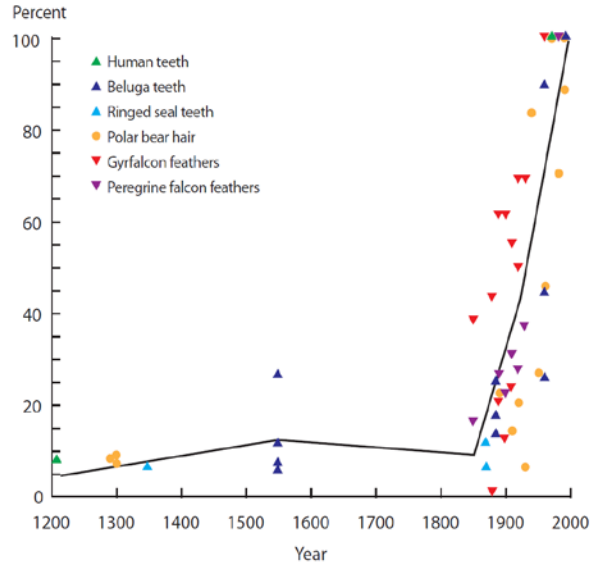

Figure 5. Trends in mercury contamination in humans and animals. (AMAP, 2011a).

Some local industrial activities have had a significant effect on local forest (forest death) and freshwater systems, especially around the large Russian smelter complex at Norilsk on the Taimyr and Nikel on the Kola Peninsula. Figure 6 shows the forest damage due to emission of SO_2 at Monchegorsk and Nikel on Kola Peninsula that also affected part of Finland and Norway (AMAP, 1998).

In all Arctic countries mining activities has been ongoing for a long period and today there are plans to increase such activities several places. Oil and gas activities have been ongoing since 1920-ties and there are also plans to increase such activity both on land and offshore (AMAP, 2008).

Discharges from the mining and oil and gas activities have affected local areas by discharges of hydrocarbons, chemicals,

particles and metals – on land, in fjords and offshore. For discharges that sinks to the bottom of a fjord or sea, one will normally observe a gradient with highest levels close to the point source and lower levels further away – how far away you may observe the discharges and any biological effects depend on several factors - the amount discharged,

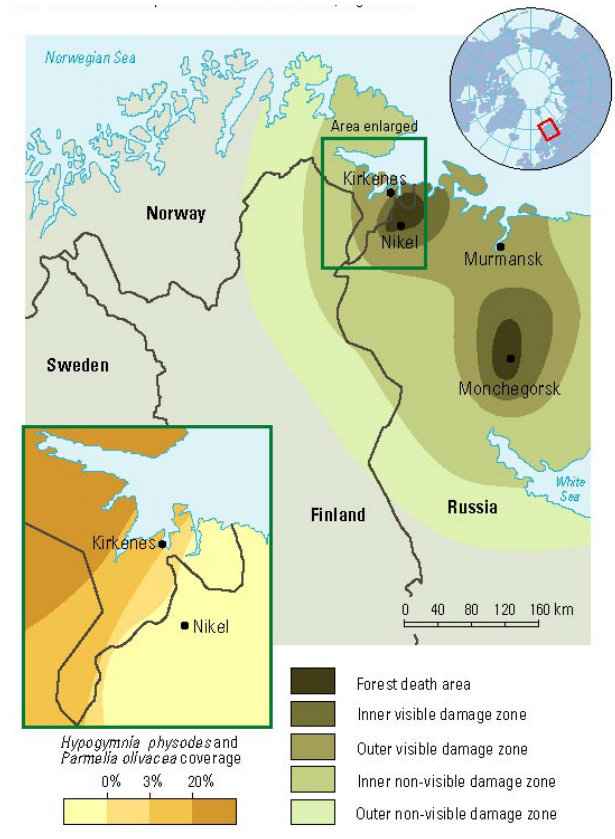

Figure 6. Extent of forest damage around smelters on the Kola Peninsula. (AMAP, 1998).

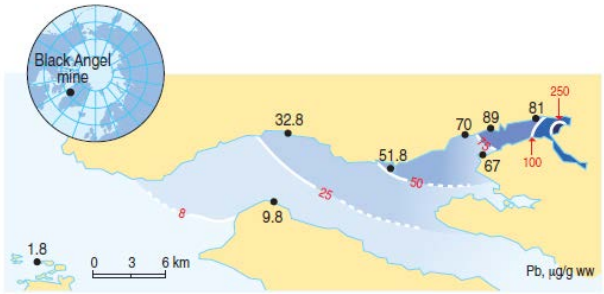

Figure 7. Lead levels in blue mussels in the fjord outside the Black Angel lead-zinc mine, West Greenland, 1986-87. (AMAP, 1998).

the weight/floating of the particles and the water current in the area. Figure 7 shows distribution of lead in blue mussels in the fjord outside the Black Angle lead-zinc mine in West Greenland in 1986-87 (AMAP, 1998).

In addition to long range transport of several types of POPs, a local use of pesticides has also been documented in some areas of the Arctic, mainly due to military activities, some households and in animal herding. Thus exposure to contaminants from local sources comes on top of the long range transported contaminants and has been shown to affect specific groups of people.

The last six years have been the warmest years ever recorded in the Arctic since 1880. In AMAP (2011b) - the SWIPA report, it is documented that the melting of the Greenland ice sheet and Arctic mountain glaciers and ice caps have increased over the last decades and is making a significant contribution to the global level rise. Furthermore, this report document that the permafrost is thawing and thereby opening for an increased emission of the greenhouse gas methane, but also affecting manmade infrastructures like buildings and roads. The sea ice has been thinner and the extent of the summer sea ice reduced since satellite observations started in the 1970-ties with the largest reduction observed in the summer of 2012. With less summer ice in the Arctic, this opening up for increased shipping across the Arctic and related to this the need for harbours and Search and Rescue services, and the chance for accidents and oil spills.

Effects due to Short Lived Climate Forces (black carbon, ozone, etc.) has been estimated in AMAP (2011c) and the report documents that sources near or within the Arctic, e.g. soot from gas flaring at oil fields and from shipping, will have larger effects on the snow and ice melt than sources further away. The feedback mechanisms due to reduced albedo that leads to increased heat adsorption have been documented in the SWIPA reports (AMAP, 2011b). Climate models predict temperature increases that may have a dramatic effect on the ice and snow conditions in large parts of the Arctic on

a time scales as short as a few decades. The melting of multiyear land ice and thawing of permafrost is remobilizing contaminants that has been deposited since emission of such compounds started. AMAP has also reported an interesting link between climate change and the transport of contaminant and precipitation over the Arctic – combined effects (AMAP, 2011d, UNEP/AMAP, 2011).

The climate change is affecting the Northern areas and it is creating challenges and opportunities. Challenges for the local people to continue the traditional life style, e.g. when sea ice is no longer close to the coast and bring seals to the hunters, and the change in snow and permafrost that are affecting terrestrial ecosystems and the way of herding, hunting and food storage. Opportunities for increased sea transport, mining and oil and gas exploration and exploitation, tourism, etc. is there, but who will be the winner and who the looser – the local people, or the new ones entering the area; the Arctic species or the new species entering the area due to warmer climate?

4. Discussion

The results from AMAP have played a significant role in the establishment of international regulations - protocols and conventions to handle pollution, e.g. the Århus protocol regarding European emissions of heavy metals and POPs and the Stockholm convention covering global use of POPs. AMAP has established a close cooperation with UNEP Chemicals with the work to achieve a better control for global emission of mercury and we have produced technical assessments together (AMAP/UNEP, 2008) and an update report to be released at the Governing Council in February 2013. The hot spot identifications that AMAP made in Russia in 1995 and 2003 has played a significant role in initiating clean-up programmes in Northern Russia partly funded by Russia and partly by the Nordic countries and USA and Canada as part of the Arctic Council and Barents Council activities. Projects have been implemented both in vicinity of villages, industries and military sites e.g. safe storage of PCB and obsolete pesticides, decommissioning of nuclear submarines - in 2012 there was only one nuclear submarine taken out of service in North West Russia that had not been decommissioned. The clean-up of the high Arctic military air bases at Frantz Josef Land of tanks and barrels with fuels, lubricants and chemicals that has been planned since 2004 was initiated in the summer of 2012.

Regarding climate, the Polar chapter of the IPCC report in 2007 built a lot on the ACIA 2005, the next IPCC report has received all the latest reports from AMAP "The Snow Water Ice and Permafrost Report (SWIPA)" and the report on "Impact of Black Carbon Arctic Climate" (AMAP, 2011b & d).

AMAP is at present implementing a scientific project assessing the combined effects of climate change and contaminants on human health – the ArcRisk project, to be presented in January 2014. In addition, we are assessing the status and effects due to increased emissions of CO_2 and its effects of the acidification of Arctic oceans – the Northern marine ecosystems and fisheries, the Arctic Ocean Acidification Assessment (AOA) is to be delivered in May 2013.

AMAP together with international organizations has put priority on analysing the combined effects of several stressors or drivers on Arctic ecosystems, the human health and the societies. We intend to perform a significant work on the effects and adaptation to the Arctic Change issue the next five years.

All AMAP assessment reports are available from the AMAP web site www.amap.no .

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Fate of mining waste in marine sediments - a pilot study to investigate biological, geo- and biochemical processes in marine tailings disposal.

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Marine tailings disposal can in some cases be the only solution to handle waste from the mining industry. Little is however known about the involved geo- and biochemical processes and how organisms living on or in the sea floor affect such processes or are affected themselves. This makes it difficult to conduct correct and sufficient decision making for authorities. In Greenland the marine environment is of particular interest, since a large proportion of food consumption and exports are based on marine resources. Without the sufficient knowledge there will be risk that marine tailings disposal can lead to detrimental effects on the marine biota and the marine ecosystem. With the growing interest in mining activity in Greenland, which could include large-scale projects, there is an urgent need for further investigations of the possible impacts of marine tailings disposal on the vulnerable and valuable Arctic environment.
The pilot project that is presented here aims to investigate chemical, physical and biological processes that are involved in the transformation of mine tailings in the ocean. This includes, for example, how sandworms affect and are affected by such processes. Column experiments are conducted in 120 l barrels with sediment, tailings, seawater and organisms in five different combinations. Sediment cores are taken at different time intervals throughout a year and pore water samples are extracted. Sea and pore water, sediment and worm samples are analysed for nutrients and metals to describe the distribution of metals released from the mine tailings to the sediment and pore water compartments.

The poster will describe the project and the results obtained at present stage of experiment.

Can a tiny shrimp tell about the environmental impact of mining activities in Greenland? - Usage of biological and ecological indicator organisms of contamination

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In the context of ongoing and closed mines in Greenland, monitoring for contamination of metals and other contaminants in the environment has been conducted by DCE - Danish Centre for Environment and Energy (formerly DMU/NERI) for many years. The species, i.e. seaweed, mussels and sculpins, that have hitherto been used as biological indicator species for monitoring the contamination load of the marine environment from mining activities do not reflect or poorly reflect load on sediment-dwelling organisms. Since metals generally have a high binding to sediment, there is a need for the implementation of sediment-dwelling organisms in monitoring programs. Furthermore, the previously used indicator species have mainly been used to assess the dispersion of metals within the marine environment and very little attention have been focused on any potential biological effects of the metal contamination. This presentation will deal with studies qualifying a small shrimp, that is highly common in Greenlandic shallow waters and well known by fishermen for stripping bait and catches, to be implemented as a biological and ecological indicator of sediment-associated contamination from mining activities in Greenland. Knowledge between toxic effects on form and function and internal metal concentrations in the organism is highly essential before this organism can be used as an indicator species for effect monitoring.

Sustainable water management within mining areas in Arctic region

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Abstract

The development of mining activities in the Arctic region generates a huge amount of wastewater, containing different kind of pollutants. However, a sustainable wastewater management includes cleaning of wastewater at the level when it can be reused for different purposes such as production processes, personal use, etc. This paper shows a new approach to wastewater treatment in remote locations and in cold regions using a hybrid submerged membrane electro-bioreactor (SMEBR). It is built as a modular system; then, it can be adapted to the flowrate and quality of influent change at any time. When mining operations end, the system can be dismantled and transported into another place. Furthermore, it can be implemented in a separate dwelling, in remote location since it does not require a high power supply. Our recent studies at lab and pilot scale in Canada, where microfiltration membrane was used, showed a very high efficiency of the system producing almost pristine water. Complete removal of phosphorous and metals, 99% removal of COD and total nitrogen as well as pathogens to acceptable level were observed. The SMEBR can be adapted to mining camp and arctic community, thereby decreasing the cost of production of water and protect the Arctic environment.

1. Introduction

The changing Arctic landscape is now opening up to new transport lanes and the exploitation of both natural and mineral resources. While this will be a benefit for the regional and global economy, it might also have an impact on the Arctic's fragile environment. The development of mining activities in the Arctic region generates a huge amount of wastewater, containing different kind of pollutants.

Many countries, including Canada and Denmark, search for new resources and promotes explorations in remote cold regions, which can lead to fast (but very often temporary) communities' developments. Furthermore, the Arctic States are concerned about sustainable development of cold regions, unknown impact of potential waste discharge and water-related services which might grow with an unprecedented rate.

Thus, treatment and polishing of wastewater produced in mining camps is inevitable but also challenging issues. Present methods of wastewater treatment (if any, Fig. 1) in the North, such as conventional sequential batch reactor (SBR), rotary biological contactor (RBC) and lagoons, do not remove harmful compounds and nutrients and are unreliable (e.g. do not maintain biomass and have operational issues), and most have variable effluent quality. In general, the biological removal of nitrogen from wastewater is restrained by winter conditions. The facilities are also permanent and they can't be applied to remote dwellings.

On other hand, sustainable wastewater management includes cleaning of wastewater at the level where it can be

reused for different purposes such as production processes, personal use, etc. Thus, we can not only protect the Arctic environment against undesired pollutants from the wastewater but also we can supply the Arctic communities with clean water.

Figure 1: Direct discharge of wastewater to the bay (Sisimiut, Greenland)

Hence, there is an undeniable need for new technologies, which would address extreme temperatures, dynamic changes in population, fluctuations in wastewater volume, challenges in transportation, and protection of the exceptionally sensitive environment in North. In this context, a sound water management is needed.

The paper describes a new cost-effective technology for wastewater treatment, namely SMEBR, which can be applied to various remote, mining and rural communities in cold regions. This technology of wastewater treatment ensures a new water source and prevents irreversible impacts of industrial developments on the environment.

2. Description of SMEBR technology

The SMEBR is a new sustainable wastewater treatment method, which addresses major Arctic needs such as: i) adjustable wastewater treatment technique for cold climate; ii) removal of nutrients that contribute to water pollution, ii) removal of emerging pollutants and metals, iii) assuring clean water resources in the North; iv) protection of the sensitive northern environment; v) fostering economical development in North, vi) assuring a sustainable development in collaboration with a local Nation; and finally, vii) improvement of water management.

Primarily, the SMEBR technology addresses the removal of major wastewater pollutants such ass nutrients, pathogens, organics (chemical oxygen demand, COD), solids and metals without using additives (Bani-Melhem et al., 2010). Since clean effluent can be reused as reclaimed water, the removal of endocrine disrupting compounds (EDC) can be also addressed. The usage of adequate membranes permits pathogen removal; no harmful for environment disinfects are used (Fig.2).

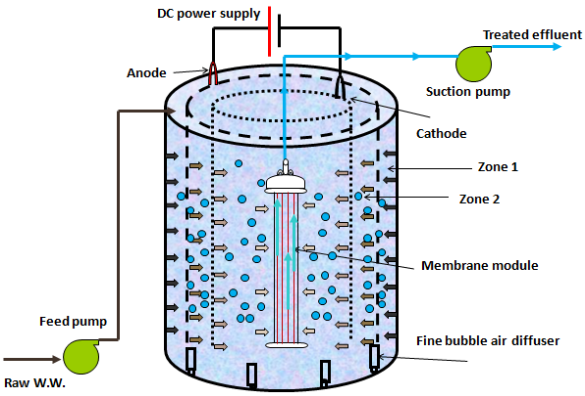

Figure 2: Schematic representation of submerged membrane electro-bioreactor (SMEBR) (Hasan et al. 2012, Elektorowicz et al., 2009a)

The SMEBR is a hybrid electro-bioreactor with submerged membranes. It combines electrical, biological and membrane filtration processes taking place simultaneously in a sole reactor (Fig 2). Depending on the type of wastewater and the user's needs, one process can prevail over another, making the technology adaptable to a large variety of conditions. Electrocoagulation (or electroflotation) is controlled by electrical operation modes to accelerate agglomerations and co-precipitations of phosphorus (Bani-Melhem et al, 2010, 2011). Flow of treated water towards the membrane module (e.g. submerged hollow membranes, Microza) is forced by the pump where transmembrane pressure is monitored. An increase in transmembrane pressure indicates the membrane fouling and cleaning takes place. In fact, the reactor

is built in a way which decrease dramatically fouling - the primary concern of conventional membrane bioreactors at low temperature. Removal of nitrogen and carbon takes place due to biological processes; then, microorganisms are exposed to an electrical field.

The creation of an "adequate electrical field" is set based on a number of interrelated factors: i) electrical parameters (voltage, electrode material, size and position of electrodes, etc); ii) influent properties (temperature, conductivity, suspended solids, the concentrations of carbon, nitrogen and phosphorus, metals, surfactants, etc); iii) microbial consortium (food to biomass ratio, microorganisms species' vulnerability, structure of their membrane); iv) exposure time to electrical field (mode of operation); v) sludge residence time in reactor (SRT). Once the technological parameters are set, the SMEBR reaches equilibrium conditions and expresses self-adaptation to wastewater quality change.

3. Results

Both investigations at bench and pilot scales showed that microorganisms responsible for the removal of COD, ammonia, and nitrate will positively respond to low DC voltage even at low temperature conditions (Wei et al., 2009,Wei et al. 2011, Ibeid et al., 2012) . Intermittent DC controlled conditions in the reactor leading to simultaneous nitrification and denitrification (Ibeid et al., 2012). Furthermore, the SMEBR changed wastewater properties, morphology of bioflocs, extracellular polymeric substances (EPSs) production, and humic substance behavior (Ibeid et al., 2011, Ibeid et al, 2012, Hasan et al., 2012a). The relationship between the electrical field and the changes in characteristics of mixed liquor suspended solids (MLSS), conditions for electrocoagulation and the electro-transport of flocs were defined (Hasan et al. 2012a).

It was proved based on lab and pilot scale tests that SMEBR removed simultaneously by more than 99% of carbon, nitrogen and phosphorus from wastewater, while membrane fouling and the footprint was many times decreased. Figure 3 shows results of one of many testing series for SMEBR efficiency. The comparative studies with conventional membrane bioreactor proved that SMEBR performance was much better in the same conditions (Hasan et al., 2012a). Furthermore, high removal rates of Pb (100%), Ni (98.1%), Cu (100%), and Cd (94.6%) were reported (Hasan et al., 2012b).

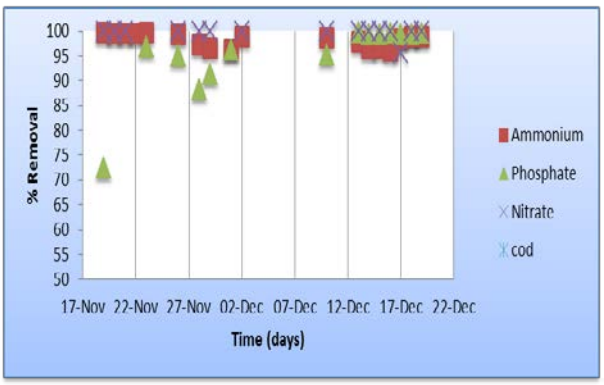

Figure 3: Result showed almost complete removal of phosphorous, ammonia, nitrate and carbon when electro-bioreactor reached equilibrium conditions after 45 days (November 17).

The SMEBR is a compact electro-bioreactor with submerged membranes, which is able to remove carbon, phosphorus, nitrogen and other trace impurities (metals, surfactants, EDCs) from wastewater produced in northern regions and which can serve as source of clean water.

It has a small footprint, since all removal processes take place in one compacted electro-bioreactor. This design permits the protection of the quality and the quantity of water resources used for various proposes (drinking, industrial, mining) and in ecosystems (fishery reserves).

The proposed SMEBR system can be modular (Fig. 4); thus, adapted to influent fluctuation (can increase or decrease its capacity following the community's needs), mobile unit or single dwelling. For example, it can operate starting from 1m^3/d and

reaching 100 000 m^3/day at the same mining camp.

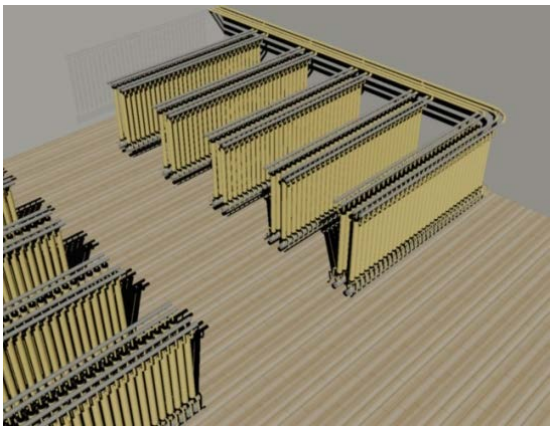

Figure 4: A representation of modular SMEBR system for a bigger wastewater treatment plant. A single module is sufficient for a remote located single dwelling

Once the technology is implemented, it will be easier to apply new regulations related to wastewater treatment, water conservation, and its reuse, as promoted by the International Arctic Science Committee and both Denmark and Canada. It decreases a potential impact on the environment and society, with emphasis on indigenious communities' sustainable development.

The SMEBR technology solves the wastewater and sludge treatment issues in cold zones, particularly in mining development conditions. Not only mining camps but also aboriginal Nations communities, settlements, temporary (e.g. exploration or military) bases would all profit from these ground-breaking technology that at the same time, preserves natural resources and the environment.

4. Conclusions

The SMEBR (submerged membrane electro-bioreactor) is a new solution for water management (treatment and supply) which also minimize the impact of human activity (including mining) on the northern environment. The screened raw wastewater without primary clarifier is exposed to simultaneous electrochemical and biological processes and subsequently subjected to filtration through a membrane module. Depending on the type of wastewater and someone's needs, one process can prevail over another, making the technology adaptable to a large variety of conditions. This hybrid system removes almost completely COD, nutrients, metals and pathogens, producing clean water. Then, its implementation can change common direct discharge of wastewater to fiords into production of water from wastewater for various purposes.

Due to modular system, SMEBR can be installed, augmented, dismantled, and transported to another location at any time. Therefore, the stems we would like to present the possibility to adapt this system to mining camp and arctic community thereby would decrease the cost of production of water and protect the Arctic environment.

The system SMEBR can be combined with a system EKDIM (Elektorowicz and Oleszkiewicz, 2009), which is capable to treat sludge electrokinetically and transform it into an exceptional quality dry soil amendment without metals and pathogens.

Acknowledgement

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Risk Informed Decision Making for Sustainable Developments

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General societal pressure on the availability of raw materials such as minerals, critical and rare earth element as well as oil and gas increasingly direct attention on the prospects of exploration and exploitation activities in the high arctic. The effect of climate change on reductions in the extent and duration of ice coverage of the arctic seas add to the focus on the arctic regions for raw materials exploitation and shipping.

One the one hand these developments open up opportunities for economical growth and improved welfare for the population in regions where at present livelihoods are under significant pressure and social problems are widespread. However, on the other hand raw materials exploitation is associated with significant risks to the fragile arctic environment, to the original cultures and as developments in many parts of the world have shown may also lead to an unintended natural resource dominated economical dependency – with significant societal problems as a consequence – an effect which is also known as the resource curse.

Effectively the management of raw materials exploitation in arctic societies constitutes a new activity where not only the technical capabilities of various industries are pressed beyond their present level but also the related processes of societal planning and governance are pushed into new land. Considering the possible gravely adverse consequences which may be associated with these activities it is obvious that the basis for decision making should be established on the basis of a thorough understanding of all relevant risks and chances.

With this outset the present paper first analyses and discusses the risks associated with raw materials exploitation in the arctic from a holistic societal perspective, including the aspects of security, social welfare, livelihoods, environment, safety and economy.

Thereafter a framework for proactive risk informed decision making based on systematic assessment and treatment of the risks and chances associated with different decision alternatives is suggested as a means of supporting sustainable societal developments in the arctic. Finally, the suggested framework is mapped on the presently ongoing developments in Greenland and it is highlighted and discussed on which issues the future focus with respect to improving the decision basis for sustainable societal developments in Greenland should be directed.

Metal attenuation via microbial sulfate reduction in sulfide mine tailings of the Russian Far North

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Microbial sulfate reduction (MSR) is instrumental in precipitating metals from mine effluents and waste streams. The sulfate reducing microorganisms produce H2S that causes precipitation of metals in the form of highly insoluble sulfides. MSR also occurs as a natural process in mine tailings. It may lead to attenuation of dissolved metals, increasing pH of the waste streams and facilitating the formation of secondary sulfide minerals.
We have studied MSR in various types of sulfide-containing wastes in the Norilsk and Kola Peninsula mining areas in the Russian Far North. Measured with the radioactive tracer MSR rates were relatively high and comparable with those known for tailings in temperate climate. The sulfate-reduction potential was high even in the upper oxidized layers of the tailings. Occurrence of secondary sulfides of biogenic origin was demonstrated by measuring the stable isotope ratio (δ34S) of reduced sulfur compounds. Psychrotolerant rather than psychrophilic sulfate-reducing bacteria (SRB) were detected in the tailings. Psychrotolerant Desulfomicrobium spp., producing substantial amount of H2S, can be important players in these arctic ecosystems. Spore-forming SRB belonging to genus Desulfosporosinus may promote metal precipitation in acidic leachates with high copper concentrations. The whole genome of one of the Desulfosporosinus strains isolated from the Norilsk tailings has been sequenced to provide insight into metal resistance mechanisms in SRB.

Suspended electrodialytic remediation for detoxification of copper-mine tailings

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Abstract

A major environmental effect of mining activities origin from the production of tailings, and the exposure of these to ambient physical and chemical conditions. In modern mining, and in particular when mining in the pristine and vulnerable Arctic environment, special precautions should be made. In this regard, special attentions should be paid to tailings handling and tailings deposition. One method in development for detoxification of tailings is electrokinetic (EK) or electrodialytic (ED) extraction of left toxic elements. Six electrodialytic experiments in laboratory scale show that it is possible to extract residual Cu from Cu mine tailings by electrodialysis in suspension independently of tailings age. Cu can be separated from other extracted elements because it is precipitated as metallic Cu directly at the cathode. From these small scale laboratory experiments a maximum energy consumption for the electrodialysis process can be calculated to < 80kWh/ton to remove half of the copper.

1. Introduction

A major environmental effect of mining activities origin from the production of tailings, and the exposure of these to ambient physical and chemical conditions. In modern mining, and in particular when mining in the pristine and vulnerable Arctic environment, special precautions should be made. In this regard, special attentions should be paid to tailings handling and tailings deposition. One method in development for detoxification of tailings is electrokinetic (EK) or electrodialytic (ED) extraction of left toxic elements.

Experimental results have shown that application of a direct current field (EK) over tailings can be used to remove Cd, Cu, Pb, and Zn from tailings soils (Kim et al., 2002; Kim and Kim, 2001); As from tailings (Baek et al., 2009; Isosaari and Sillanpää, 2012); and Cu from tailings (Hansen et al., 2013; Hansen and Rojo, 2007).

It has been shown that the efficiency increases when ion-exchange membranes are placed as barriers between electrodes and tailings (ED) for removal of Cu from Cu mine tailings. Still, however, a major concern is the long treatment-time required for element-transport through the tailings matrix. Therefore several enhancement methods have been investigated to decrease treatment time. Improvements were obtained for removal of Cu from Cu mine tailings by: pre-treatment of tailings with acid (sulphuric or citric acid) (Hansen et al., 2007a; Rojo et al., 2006); insertion of bipolar electrodes to accumulate Cu (Hansen et al., 2007b); and implementation of pulsed electric fields (Hansen and Rojo, 2007) or sinusoidal field (Rojo et al., 2010; Rojo et al., 2012). It was also shown that the energy-consumption for treatment of arsenic tailings (but not treatment time) could be reduced by combination of electrokinetic treatment and anaerobic bioleaching (Lee et al., 2009).

Figure 1: The Caren tailings impoundment at the Codelco-El Teniente Cu mine in Chile.

When comparing treatment of fresh (< 2 years old) and aged (>20 years old) tailings, it was observed that although removal of Cu from fresh tailings improved significantly by pre-treatment with acid, removal from aged tailings was even more efficient – without acid pre-treatment. This is due to the natural acidification occurring by oxidation of sulphide minerals during the aging process (Hansen et al., 2007a; Hansen et al., 2013).

It was shown for other materials such as ashes and sludge that electrodialytic treatment time can be significantly reduced by treatment in a homogenously stirred suspension, as opposed to a solid matrix (Ottosen et al., 2012). The main effect is thought to be the reduced transport distance between the material to be treated, and the electrode compartments. However energy and time may also be saved by the avoided build up of polarization phenomena, which are also the phenomena approached when applying pulsed current and sinusoidal current fields (Hansen and Rojo, 2007; Rojo et al., 2010; Rojo et al., 2012). As fresh tailings leave the mine in a liquid suspension, it may be feasible to treat those directly as such prior to deposition, and even consider the treatment as a final extraction step in the mineral extraction process. In addition, as mineral prices increase, re-mining of old tailings deposits become increasingly common. For this purpose, electrodialytic treatment of old tailings in suspension may also be a potential technological alternative. It was shown that Cu can be removed from fresh tailings by electrodialytic treatment in suspension, when suspended in sulphuric acid, and that the rate of removal increases with degree of suspension (Hansen et al., 2008). Works on other materials, however showed that when treating by electrodialysis in suspension, acid addition impedes remediation as opposed to when treating by electrodialysis in a static matrix (Jensen et al., 2007a; Nystroem et al., 2006).

The aim of this work is to further evaluate the potential of treating suspended Cu mine tailings by electrodialysis. Comparison of treatment at two different current densities with Cu mine tailings of three different ages suspended in water is the focus.

2. Materials and methods

2.1 Tailings characteristics

The mine tailings used were all from the Codelco-El Teniente Cu mine in VI Region in Chile. Three different tailings of different age were used.

a) Canal: freshly processed tailings from the ore concentrator, sampled directly from the tailings waste canal, which feeds the impoundments.
b) Caren: 5-10 years old tailings from the Caren impoundment.
c) Cauquene: 20-30 year old tailings from the Tranque Cauquene impoundment.

Figure 1 shows the Caren impoundment. Mineralogical characteristics of the fresh tailings are described in (Hansen et al., 2005).

2.2 Electrodialysis experiments

Electrodialysis experiments were made in cylindrical Plexiglas-cells with three compartments. Compartment II, which contained the tailings-slurry, was 5 cm long and 8 cm in inner diameter. The setup is visualized in *figures 2 and 3*.

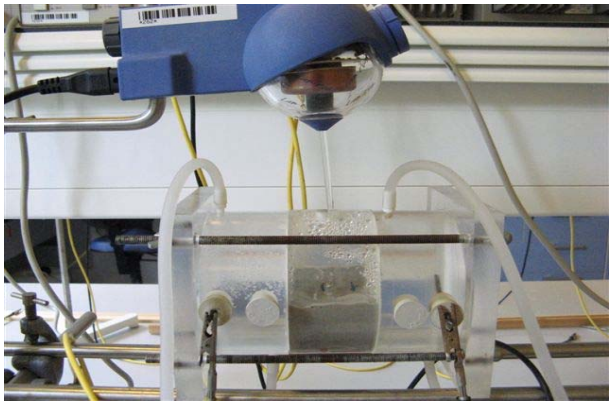

Figure 2: Picture of the experimental setup.

The slurry was kept in suspension by constant stirring with plastic-flaps attached to a glass-stick and connected to an overhead stirrer. The anolyte was separated from the soil specimen by an anion-exchange membrane, and the catholyte was separated from the soil specimen by a cation-exchange membrane (AR204SZRA and CR67 HVY HMR427 respectively.

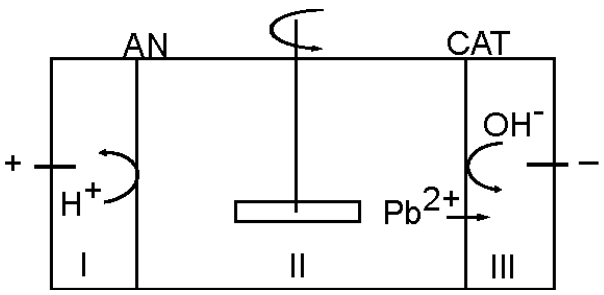

Figure 3: Schematic view of a cell used for experimental remediation of tailings in suspension. AN = anion-exchange membrane, CAT = cation-exchange membrane. I = anolyte compartment, II = compartment containing sediment slurry, III = catholyte compartment.

Platinum coated titanium electrodes were used as working electrodes. The catholyte and the anolyte initially consisted of 0.01M $NaNO_3$ adjusted to pH 2 with HNO_3. pH in the catholyte was kept between 1 and 2 by manual addition of HNO_3 (7M). The liquid to solid ratio (L/S) was 4 (25g air-dried tailings and 100 mL distilled water). All experiments lasted for one week. An overview of the experimental variables (material, suspension liquid and current density) is given in *table 1*.

Table 1: Electrodialytic experiments

Experiment	Material	Current (mA/cm^2)
Fresh 0.1	Canal	0.1
Mid 0.1	Caren	0.1
Aged 0.1	Cauquenes	0.1
Fresh 0.2	Canal	0.2
Mid 0.2	Caren	0.2
Aged 0.2	Cauquenes	0.2

After the closure of the experiments, electrodes were rinsed in 5M HNO_3, and membranes in 1M HNO_3. Samples of all liquids incl. electrolytes were saved for analysis of Cu. The tailings suspension was filtered through filter paper, and a sample of the filtrate saved for analysis. The wet tailings were dried at 105°C overnight and saved for analysis of Cu.

2.3 Extraction experiments

Reference extractions (*table 2*) without current application were made by shaking 5,0 g tailing material with 20,0mL DI water or 20,0 mL HNO_3 pH 4 on a shaking table for one week. The slurry was filtered and a sample of the liquid saved for analysis.

Table 2: Reference extractions without current application

Ref.	Material	Extractant
Fresh Acid	Canal	HNO_3 pH 4
Mid Acid	Caren	HNO_3 pH 4
Aged Acid	Cauquenes	HNO_3 pH 4
Fresh EDW	ED treated Canal	DI water
Mid EDW	ED treated Caren	DI water
Aged EDW	ED treated Cauquenes	DI water

2.4 Analytical methods

Cu was analyzed by flame AAS according to the Danish standard method DS259 (Dansk Standardiseringsraad, 2003) which includes acid digestion of 1g dry tailings material with 20.00mL of 7M HNO_3 in autoclave at 200kPa and 120ºC for 30 minutes. The Cu-content in solution was measured by AAS after filtration through a 0.45µm filter. pH was measured on all samples by a Radiometer electrode. All analysis were made in triplicate.

Analysis of the Cu in the tailings and process liquids was made prior to and after the experimental remediation. Non-acidic liquid samples were preserved with one part of concentrated HNO_3 to four parts of liquid prior to analysis.

After experimental remediation and analysis of samples, the fraction of Cu remaining in the tailings (compartment II), dissolved in the suspension solution (compartment II), transported to the cathode (compartment III), precipitated at the cathode, and transported to the anode (compartment I) were calculated.

3. Results and discussion

The mass balances for Cu understood as mass of Cu found in the ED cell system after treatment experiment in percent of the mass of Cu calculated from initial digestion and analysis of the untreated tailings were all between 91 and 101%, which is acceptable considering the standard deviations on the analysis of Cu (*table 3*). pH decreased during treatment from natural to just below 2 due to the acid produced in the ED-cell by water-splitting at the anion-exchange membrane (Nystroem et al., 2005) (*table 3*). The Cu concentration was reduced from around 1000mg/kg to around 500mg/kg in all experiments (*table 3*). No significant difference in reduction could be observed between tailings of different age in opposition to what was found when treating tailings in solid matrix (Hansen et al., 2007a; Hansen et al., 2013). Furthermore, Cu could be removed efficiently even from fresh tailings without acid pre-treatment. The removal was slightly more efficient at the lower current density compared to the higher current density. It can be seen from *figure 4* that a small amount of the Cu was found dissolved in the suspension liquid in the middle compartment of the cell in the three experiments with low current density, while no Cu was observed there at the closure of the experiments with high current density. This shows that at the high current density, the system is under pressure, and any Cu released from the tailings is immediately transported to the cathode compartment. In a system under such pressure and lack of ions to carry the current, compensation by water splitting at the cation exchange membrane can occur (Jensen et al., 2007b) with production of hydroxide ions as result. This can explain the higher efficiency of the system at lower current. However, only a slight resistance increase was observed in the experiments with high current density as the maximum voltage observed during those experiments was 3.7 independently of tailings age, while it was 2.3 in the experiments with low current density. At such low voltage drop and current density, energy consumption becomes minimal (< 80kWh/ton to remove half of the copper). Comparing with the previous work on treatment of fresh tailings in a suspended ED-system (Hansen et al., 2008), it can be seen that higher amounts of Cu were removed in this work at lower current densities and lower L/S than in the previous work where the tailings were suspended in sulphuric acid. The main reason is likely to be that when the material is suspended in acid, the conductivity increases significantly. Two consequences of this are, that when the tailings are suspended in acid: a) much current is carried by the hydrogen ions, thus higher current densities are needed to remove other ions efficiently; b) the limiting current for water splitting is increased, and less acid is produced by water splitting at the anion exchange membrane.

Table 3: pH and Cu (mg/kg ± Std. dev.) in tailings before and after ED treatment.

Experiment	pH start	pH end	Cu start	Cu end
Fresh 0.1	7.7	1.7	997±19	475±14
Mid 0.1	7.6	1.7	1059±27	435± 7
Aged 0.1	7.4	1.7	1190±13	456± 7
Fresh 0.2	7.7	1.9	997±19	506± 1
Mid 0.2	7.6	1.9	1059±27	475±11
Aged 0.2	7.4	1.7	1190±13	492±10

With no exemptions the experiment show that the Cu removed from tailings is mainly precipitated at the cathode as metallic Cu, and only small fractions are found in the liquid phases (electrolytes) (*figure 4)*. This is the typical behavior for Cu (Jensen et al., 2012), and can be considered and advantage if separation of Cu from other

metals such as Zn or Pb is the aim, as most other metals will remain dissolved in the electrolyte liquids.

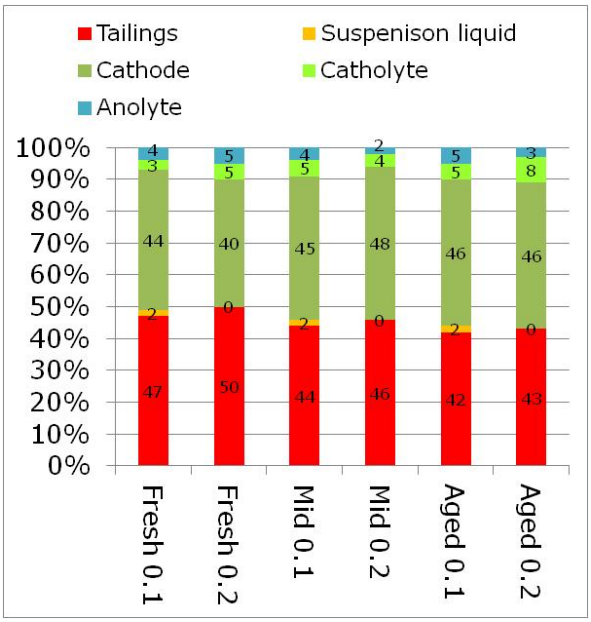

Figure 4: Results of the six electrodialysis experiments expressed as percent of the Cu found in the various compartments of the electrodialytic cell. The amount in the electrolytes include small amounts (<1%) found in the membrane material.

The reference extractions showed that independently of age of tailings, less than 1% of the Cu could be extracted from the tailings no matter with distilled water or HNO_3 at pH 4, thus the application of current significantly improved the extraction.

4. Conclusions

It is possible to extract residual Cu from Cu mine tailings by electrodialysis in suspension independently of tailings age. Faster and more energy efficient extraction is obtained when the tailings are suspended in water as opposed to acid suspension. Increasing current density to above 0.1 mA/cm^2 does not improve the extraction. Cu can be separated from other extracted elements because it is precipitated as metallic Cu directly at the cathode. From these small scale laboratory experiments a maximum energy consumption for the electrodialysis process can be calculated to < 80kWh/ton to remove half of the copper.

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Environmental regulation of mineral exploration and exploitation in Greenland

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The Government of Greenland regulates mineral exploration and exploitation in Greenland. Regulations include environmental issues related to activities carried out. The objective is to minimize the environmental impact in all phases of a mineral project.

With respect to exploration the regulations are specified in “Rules for field work and reporting regarding mineral resources (excluding hydrocarbons) in Greenland” (http://bmp.gl/images/stories/minerals/rules_for_fieldwork.pdf). regulations include rules for e.g. driving, flying and sailing, for camps, for handling of waste, for drilling and for clearing an area. Specific rules apply to areas “Important to wildlife" such as breeding and moulting areas for geese, caribou calving areas, etc.

With respect to exploitation an approval of a mineral project includes specific conditions to protect the environment such as requirements to safely store waste rock and tailings. A guidance to deal with the environmental issues during exploitation has been prepared “BMP guidelines for preparing an Environmental Impact Assessment (EIA) Report for Mineral Exploitation in Greenland” (http://bmp.gl/images/stories/minerals/EIA_guidelines_mining.pdf). The guidelines also include guidance on the baseline studies needed to prepare the EIA report of a mining project.

Oil spills in Greenland – past, present and in the future

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The last ten years intensive work with soil and groundwater contamination has been carried out in Greenland from the permafrost regions in the north to the non-permafrost regions in the south.

Hydrocarbons are the most common contaminant in soil and groundwater in Greenland. Every year huge amounts of oil products are transported, stored and handled in Greenland. In 2011, the mining industry used 7.000 m3 – a number that has been increasing since 2004. Unavoidable oil spills will happens and often there is a risk for the environment.

The consequences of oil spill are often difficult to determine and cleaning up is often very expensive due to the challenging logistic. At the same time legislation in Greenland is not explicit regarding clean up goals.

Surveys in several areas with fuel storage tanks have shown that oil spills can be spread over huge areas in a short time– especially in permafrost areas where free oil can be found in the soil and on top of the groundwater table far from the contamination source. This contamination can be a risk for wildlife in rivers, lakes, etc.

Because of the low temperatures and a low content of nutrition in the soil, hardly any degradation of the fuel takes place and the contamination remains a problem for several decades.

With proper focus, mining companies can reduce the risk of oil spills and the impact on the environment in the future.

Kvanefjeld: “Specialty Metals for a Greener World”

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Abstract

Greenland Minerals and Energy has completed a Pre-feasibility Study (PFS) on the Kvanefjeld REE-uranium project. The PFS was based on a 7.2Mtpa Mine and Concentrator, which produced a mineral concentrate which was subsequently processed at a hydrometallurgical refinery located not far from the mine. The Concentrator uses conventional phosphate flotation techniques to recover the REE-uranium rich minerals. The Refinery then applies conventional atmospheric sulphuric acid leach followed by solvent extraction to extract the uranium, which is then converted to uranium oxide. The REEs are subsequently recovered as separate light and heavy REE carbonate or hydroxide concentrates. Since the release of the PFS in April 2012, Greenland Minerals and Energy has focused on optimising the process performance with excellent results. We have improved both mineral concentrate grade and flotation recovery, as well as reduced REE recovery losses across the refining stage. As a consequence we can consider further reductions in the mining rate without sacrificing product output or unit costs. We are also evaluating the potential of moving the hydrometallurgical refinery to an off shore location where we can access cheaper energy, reagents and labour costs. As a consequence of these strategically important developments, we believe Kvanefjeld will become the largest and lowest cost producer of both heavy and light rare earths outside of China, as well as a low cost producer of uranium oxide.

1. Introduction

Greenland Minerals and Energy Ltd (‘GMEL’ or ‘the Company’) is a mineral exploration and development company operating in southern Greenland. The Company is primarily focused on advancing the 100% owned Kvanefjeld multi-element project *(both light and heavy rare earth elements, uranium, and zinc)* through the feasibility and permitting phase and into mine development.

2. History and location of the project

The Kvanefjeld project area is located in Southern Greenland, approximately 10kms away from the town of Narsaq (see Figure 2.1) and is adjacent to deep-water fjords that allow for shipping access directly to the project area, year round. An international airport is located 35km away, and a nearby lake system has been positively evaluated for hydroelectric power.

Since acquiring the Kvanefjeld Project in mid-2007, GMEL has completed an extensive exploration and scientific research program which includes over 40,000m of diamond core drilling, geological modelling and mine design, metallurgical batch and continuous piloting test work, engineering design and the development of capital and operating costs estimates all of which culminated in a Pre-Feasibility Study being published in early 2012. This follows on from the extensive historical work conducted by Danish authorities and scientists in the 1970s and early 1980s, which resulted in a Pre-Feasibility Study being published by Risø National Laboratory (Risø) in 1983.

GMEL has also completed a flora and fauna assessment for the Project area and a number of other environmental baseline studies which have been approved by the Greenland Bureau of Minerals and Petroleum (BMP). These studies were conducted by Orbicon, a Danish environmental consultancy company. A number of baseline data collection studies (meteorological, hydrological and air quality) continued throughout 2012. These studies will form the basis of the Environmental Impact Assessment (EIA).

Social impact studies have also commenced, with GMEL engaging the Danish consultancy company Grontmij to assist with the stakeholder engagement program and the development of the Social Impact Assessment (SIA).

In September 2010, the Company announced an amendment had been made by the Government of Greenland to the *Standard Terms for Exploration Licenses* the effect of which was to allow the inclusion of radioactive elements as exploitable minerals for the purpose of thorough evaluation and reporting in respect of the Project.

The Company lodged an application for an exploration license (License) under the new regulations and on 9 December 2010 received permission from the BMP to commence feasibility studies into the Project. The feasibility studies, inclusive of an EIA and a SIA for Kvanefjeld, are a pre-requisite for applying for an Exploitation Licence.

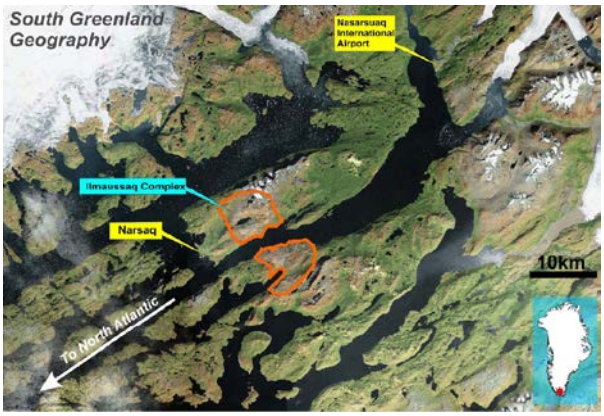

Figure 1: Location of Kvanefjeld Deposit in Greenland

3. Stakeholder Engagement conducted by GMEL

The Company has implemented a stakeholder consultation and engagement program with the purpose of keeping regulators and other stakeholders fully informed about the Project. The programme includes meetings with the BMP, NERI, SIK and EA, community open days, key stakeholder workshops and public town hall meetings.

Identifying stakeholders and developing a comprehensive stakeholder engagement plan are essential in order to ensure that relevant stakeholders are engaged in the development of the Project. An effective engagement process enables stakeholders to consult and to participate so that they are in the best possible position to make informed assessments and decisions relating to the Project.

The Company commenced the Stakeholder Engagement process in 2011, with Key Stakeholder Workshops being conducted in Narsaq, Qaqortoq and Nuuk during March/April 2011. Another workshop was held in Narsaq in April 2012.

The Company also held two Community "Open Days", the first in Narsaq in August 2010 and the second in Qaqortoq in June 2011. The objective of each Open Day was to show local townspeople the lifecycle of mining and the expected benefits. The events covered areas such as exploration, resource definition, assessments and approvals, construction, mining and processing, products and marketing, environment and culture, health and safety, job opportunities and careers. Both events were well attended, with approximately 600 residents at the Narsaq Open Day and over 1500 residents at the Qaqortoq Open Day.

In September 2011 a public meeting was held at the Greenland School of Mining's auditorium in Sisimiut which was attended by both students and local residents including the Mayor. The objective of the meeting was to give an update on the Project, discuss recent achievements and to explain the EIA and SIA process.

Figure 2: Images from the Open Day at Qaqortoq.

4. PFS completed, Q1 2012

GMEL recently finalized a comprehensive pre-feasibility program that has focused on identifying and evaluating the best possible process flow sheet for the Kvanefjeld project, taking into account economic metrics, environmental considerations, technical and market risk. The outcomes were extremely positive and reiterate the potential for Kvanefjeld to become one of the largest rare earth producing mines globally, occupying a dominant position at the low end of the future production cost-curve. A large heavy REE output and significant uranium output differentiate Kvanefjeld from many other emerging RE projects.

The Kvanefjeld project is centred on the northern Ilimaussaq Intrusive Complex. The project includes several large scale multi-element deposits including Kvanefjeld, Sørensen and Zone 3. Global mineral resources now stand at **956 Mt** (JORC-code compliant). The deposits are characterised by thick, persistent mineralisation hosted within sub-horizontal lenses that can exceed 100m in true thickness. Highest grades generally occur in the uppermost portions of deposits, with overall low waste-ore ratios.

While the resources are extensive, a key advantage to the Kvanefjeld project is the unique rare earth and uranium-bearing minerals. These minerals can be effectively beneficiated into a low-mass, high value concentrate, then leached with conventional acidic solutions under atmospheric conditions to achieve particularly high extraction levels of both heavy rare earths and uranium. This contrasts to the highly refractory minerals that are common in many other rare earth deposits.

The April 2012 PFS highlights are summarized below:

- Mine capacity of 7.2 Mt ore/annum;
- GMEL has identified a preferred processing flowsheet based on;
    - beneficiation of the mined ore to produce a high grade REE-U mineral concentrate; then
    - conventional atmospheric acid leach, followed by solvent extraction and precipitation to separate the uranium and rare earths;
- This flowsheet delivers low unit costs across all product streams: less than US$8/kg TREO and US$31/lb U3O8; and
- The plant capacity chosen delivers globally significant heavy rare earth and uranium production: ~4kt/a HREO, 10kt/a MREO, 26kt/a LREO & 3Mlbs/a U_3O_8 over 33 years of mine life.

5. Recent Developments

The 2012 PFS was a great result however it does come with a set of challenges:

There are physical challenges in Greenland	• Topography • Climate
Approvals	• The project will break new ground in Greenland, no standards or guidelines exist
The hydrometallurgical process is complex	• Access to resources – skilled labour, maintenance, chemicals?
REE production will affect the REE market	• At full capacity will result in over supply of LREOs
The size of the investment required	• At full capacity capital investment hurdle too high

These challenges lead us to question some of the fundamental PFS assumptions, and in particular:

- Is there an alternative configuration for the plant, which will reduce implementation risk, improve economics and provide a "Greenland" sensitive solution?; and
- Are we working with the appropriate scale of production, given the type of project and its location, the demand for the products and the cost of financing?

Taking into account some of the issues raised by the local communities during the community Open Days, the various town hall meetings, as well as those captured at the "Key Stakeholder Workshops" in 2011 and 2012, consideration was given to separating the refinery facility from the mine and mineral concentrator. The refinery facility could either be built somewhere else in Greenland, or overseas.

Another Refinery location in Greenland may:

- reduce the social impact of the project;
- reduce the approvals risk for the project; and
- increase the capital cost.

An overseas Refinery **will mean a smaller Greenland footprint** and may:

- reduce social and environmental impact;
- reduce approvals risk; reduce project risk;
- reduce capital costs; and
- increase financial returns.

By separating the refinery from the mine and concentrator, and thus reducing the need for expensive refinery infrastructure, the Project becomes more economically scaleable, and the Company is currently conducting studies to determine the optimal start-up capacity. For instance the Project development could be built in stages:

Stage 1: Build a smaller mine and mineral concentrator only in Greenland with the refinery and REE separation plants built off-shore. The REE and uranium would be shipped as a mineral concentrate.

Stage 2: The project could be expanded over time with the expansion being funded out of cash flows from Stage 1.

The following criteria have been chosen in order to evaluate relocating the refinery off-shore:

- **Operating Costs** - higher transport costs are offset by lower reagent and power costs
- **Capital Costs** – considerable savings are expected as infrastructure and acid plants not required
- **Geo-political risks** – reduced by operating in a well regulated, established heavy industrial location
- **Social and environmental impacts** – reduced as project footprint and complexity reduced

- **Permitting and implementation schedule** – improved as project complexity reduced
- **Market and pricing** – risk reduced by building smaller project initially and expanding as market and pricing dictates
- **Financing and reliance on JV partners** – financial hurdles reduced, project more attractive to major, strategic partner

The Company expects to complete these studies by mid 2013.

6. Conclusions

Kvanefjeld - "Specialty Metals for a Greener World" and the answer to the global rare earth supply crunch – Why?

- ✓ The world's largest rare earth resource, and one of world's larger uranium resources (NI 43-101 or JORC-code constrained)
- ✓ Direct shipping access to Project area year round
- ✓ Large, outcropping orebodies allow for simple, low cost, open-pit mining
- ✓ Unique and highly favourable ore-type conducive to simple, cost-competitive processing
- ✓ Clear scope to be the largest producer of heavy rare earth elements outside of China
- ✓ Uranium revenues allow for highly competitive cost structure for rare earth production
- ✓ Technical studies well advanced, process methodology developed by respected metallurgical team

Put simply – Kvanefjeld holds the clear potential to break the rare earth supply monopoly

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Environmental and ethical aspects of sustainable mining in Greenland

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Abstract

The increased use of scarce metals in combination with climate changes pave way for extensive extraction of mineral resources in Greenland. The focus of this study is on the environmental ethical aspects of mining activities in a vulnerable and unspoiled arctic nature. Mining can have several economic and social benefits for Greenland. On the other hand the environmental impacts from mining are well-known. Through DPSIR-(Drivers, Pressures, States, Impacts, Responses) and Stakeholder analysis we assess how future mining in Greenland can be sustainably implemented. The analysis revealed that numerous stakeholders have to be taken into consideration with a wide range of different interests. The DPSIR analysis clarified the availability of various potential political responses that could affect the drivers, pressures, states and impacts of mining mainly focused on implementation of effective environmental regulation strategies. Our findings revealed a number of different environmental ethical dilemmas of which the most critical is how Greenland can open up for mining, gain economical revenue while averting destruction of unspoiled regions and aesthetic impairment. We recommend strict environmental legislation involving use of the "polluter pay principle", continuous monitoring of pollution and establishment of an industry-funded catastrophe trust fund. These initiatives can ensure economic benefits while environmental impacts remain negligible.

1. Introduction

Climate change is currently an inevitable fact (Artic Council, 2011). It is not only the climate that has changed during the last 100 years – the need for natural resources has been steadily increasing. The Greenlandic subsoil contains a range of different natural resources such as gold, lead, platinum, nickel and diamond. It is assumed that the waters surrounding Greenland holds some of the world's unknown resources of oil and gas. Some of these areas have previously, and some still, not been easy to access due to rough and icy climate. Climate changes can hence pave the way for increasing extraction and investigation of natural resources both on land and at sea (Climate Greenland, 2012). Today Greenland is economically dependent on Denmark and around half of the Greenlandic budget is financed by the Danish block grant (Nanoq, 2010) but establishing a successful mining industry in Greenland could reduce the economic dependency on Denmark.

No doubt that mining can entail many economic benefits and maybe even independency from Denmark but mining has historically also been known to cause adverse environmental effects. In this paper, we focus on the environmental and ethical dilemma potentially associated with widespread mining in Greenland by using Stakeholder and DPSIR analysis to derive at a set of recommendations. The combination of the two analytical tools makes up a great support in a decision-making process.

2. Applying a Stakeholder Analysis

Via Stakeholder Analysis we identified key stakeholders, assessed their importance, influence and interests in order to lay the fundament of the development of a stakeholder strategy plan.

2.1 Stakeholder identification

In this paper, we define stakeholders : *"Stakeholders are people, groups, or institutions which are likely to be affected by a proposed intervention (either negatively or positively), or those which can affect the outcome of the intervention"* (Rietbergen-McCracken *et al.*, 1998, according to Lienert, 2012a).

Using this definition, a number of key stakeholders were identified; Government of Greenland, mining companies, Greenlandic people, Greenpeace (or related NGOs), Chinese labour force, resource craving companies, Government of China, Government of Denmark and EU, United States and Arctic Council countries.

Stakeholders can be divided into primary, secondary and external stakeholders. Primary stakeholders are characterized as direct beneficiaries or direct concerned persons of an intervention. The secondary stakeholders are intermediates in assisting to primary stakeholders in processing the intervention, whereas external stakeholders are identified as decision makers and policy makers (Lienert, 2012a). The key stakeholders are considered to be Government of Greenland, mining companies, Greenlandic people, China, Denmark and EU, United States and Greenpeace and related NGOs (See Table 1). Only key stakeholders are analyzed further in the following sections.

2.2 Key stakeholders' importance, influence and interests

The importance and influence of a stakeholder is analyzed in order to optimize the involvement of stakeholders. Determining the influence of stakeholders will indicate the power he or she has to impact the given project. Finally the interests of different stakeholders are important to identify in order to clarify the motives and expectations for the given project. Interests can be hidden and hence harder to determine (Lienert, 2012b).

2.2.1 Government of Greenland

The Greenlandic Government is undoubtedly one of the most important key stakeholders given that they have the power to accept mining in Greenland. It is not possible for any mining companies to begin mining before establishing an agreement with the government. Their interest for implementing mining is obviously to gain economic independency and growth with solving social problems currently evident in the country. An example of their power is the country's previous zero-tolerance uranium policy, which prohibits mining of uranium in Greenland in spite of big expected uranium reserves (Weaver, 2012).It should however not be disregarded that the Greenlandic Government in some cases will have trouble utilizing its power due to their interest in mining and the Greenlandic Government may not be prepared for big international agreements due to lack of experience (Mogensen 2012).

2.2.2 Mining companies

It is inevitable that the mining companies are essential to involve in negotiations on establishing a framework for a future mining industry. The mining companies have a great power to affect the implementation of mining activities since they can back out of the negotiations, if their demands are not met. The mining companies main interests in the access to Greenland's mineral resources are the economic profits related to extraction and sale of scarce metals.

2.2.3 Greenlandic people

The Greenlandic people as a stakeholder can be affected both negatively and positively by mining. The positive aspects are creation of new jobs and improvement of infrastructure in the municipalities (Angel Mining PLC, 2012). Furthermore the population could benefit from an improvement of health- and educational system based on a general increase in tax revenues to the Government. A negative consequence from mining could be if the wealth that emanate from mining do not assign the population (MPE, 2012).

In the long run the possible damage to the environment could furthermore have negative effects on the population with regard to health issues and pollution. This group of stakeholders is considered to have high importance but low influence.

2.2.4 China

China is currently producing close to 100 % of the world's supply of rare earth metals, because they outmatched other countries due to lower production cost. China's interests are to increase production and maintain their monopoly on rare earth metals, and the Greenlandic subsurface is seen as possibility to do so (Ramskov, 2012). The Chinese Development Bank, which is directly controlled by the Chinese Government, are making final negotiations regarding financing a major mining project in Greenland. London Mining is responsible for the project but the Development Bank is going to help financing it (Fastrup et al., 2012) and the Chinese Government is indirectly ensuring that the interests of China are taken care of. It is most likely that Chinese investors only want to make investments if a special law on import of cheap Chinese labor is realized (Fastrup and Jensen, 2012), which underlines that China has a high influence on intervention.

2.2.5 Denmark and EU

Denmark and EU are here considered as one highly important stakeholder due to the Danish link between Greenland and EU. It would be in the interest of EU to take part in the economic benefits arising from extraction of rare earth metals in Greenland and EU could play an important role due to historical ties to Denmark and hence Greenland. However EU is, compared to China, currently falling behind regarding the influence in Greenland (Harvey, 2012).
Even though Greenland has attained Self-Governance in 2009 and is exclusively responsible for their raw material resources, the Greenlandic immigration policy is still assigned to the Danish legislation. Hence a Danish special law is required if Greenland wish to import cheap Chinese labour force for the ISUA project (Fastrup and Jensen, 2012). Denmark thereby has a high influence on the outcome of intervention.

2.2.6 Greenpeace and related environmental NGOs

From an environmental point of view Greenpeace and related environmental NGOs, such as the Greenlandic environmental campaigning group Akavaq are identified as important stakeholders in the Greenlandic mining industry. However such organizations have poor political power and cannot be considered as main key stakeholders, due to low importance and influence on the outcome of intervention. The interests of the organizations are environmental protection of the Arctic nature. The arctic expert, Jon Burgwald, from Greenpeace states that mining activities can cause "*very harsh environmental consequences*" and the chairman of Avataq, Mikkel Myrup expresses his concerns for the consequences of mining operations: "*It's a real worry, and we don't think that the Greenlandic government has the capabilities to regulate this in the way that's needed – they can't stand up to these multinational companies. The public haven't been given the full picture*" (Harvey, 2012). This said the environmental organizations could turn out to be of paramount importance during negotiations if they succeed in postponing decisions, win peoples sympathy or brings critical facts into light.

2.3 Stakeholder strategy plan

According to Lienert (2012c) a Stakeholder strategy plan *"can guide one on how to interact, communicate and involve with each identified stakeholder during different phases of a project".* Such a plan will secure a positive connection to each stakeholder. A way to include the Greenlanders from the local communities is through public hearings and information meetings. The hearings should be dialogues between the decision-makers and the community, which should enable an agreement between different stakeholders.

Table 1 The key stakeholders divided in primary, secondary and external stakeholders, their influence on the outcome of intervention, whether they are affected positively or negatively by intervention and their interests, importance and influence regarding mining in Greenland.

Key stakeholders		Influence the outcome of intervention (Yes / No)	Affected by intervention (Positively / Negatively)	Interests	Importance and influence
Primary stakeholder	Government of Greenland	Yes	Positively	Gain economic growth and independence	High importance High influence
	Mining companies	Yes	Positively	Economic revenue	High importance High influence
	Greenlandic people	No	Positively, negatively	Employment, independence, social status, environmental protection	High importance Low influence
Secondary stakeholder	Greenpeace and other NGO's	Yes / No		Environmental protection	Low importance Low influence
External stakeholder	Government of China	Yes	Positively	Economic revenue, sustain monopoly on rare earth metal market	Low importance High influence
	Government of Denmark and EU	Yes	Positively	Economic revenue	High importance High influence
	United States	No	Positively, negatively	Economic revenue, avoid Chinese monopoly on rare earth metal market, secure safety on Arctic territory	Low importance High influence

3. Applying a DPSIR Analysis

The DPSIR framework was developed to help decision makers manage and conserve the environment the best way possible. The tool is used to structure different factors that might influence the surroundings and identify possible ways to solve or minimize the given problem (Tscherning *et al.*, 2012). The DPSIR framework is a five-step chain of events that consists of driving forces, pressures, states, impacts and responses. The DPSIR model is presented in Figure 1.

3.1 Driving forces

In the case of mining in Greenland driving forces are resource consumption, economic independency, employment, and social status. The resource consumption is rising all over the world, which increase the need for mining industries. Research for new places to extract natural resources is constantly taking place (Secher, 2005).

3.2 Pressures

The major pressures from an operating mining industry are emissions of metals to water, soil and air, changing land use, exploitation of resources, and waste generation. Emissions of metals from mine tailings, waste rock dumps and emission of dust particles to air are pressures on the environment resulting from mining industry. Implementing a new mine will also put pressure on the environment by the change of land use. It is not only the mine itself that takes up land. London Mining for instance wants to build new roads, a port and an airstrip (London Mining, 2011). Another important pressure is the exploitation of limited resources in the Greenlandic subsurface.

3.3 States

The pressures will change the state of the environment. It is a combination of physical, chemical and biological conditions (Smeets and Weterings, 1999). The states that are affected by pressures are soil quality, water quality, air quality, ecosystems, and humans. The states of soil, water and air quality could be affected both locally and regionally depending on the degree of pressures. Ecosystems might also be

affected locally with regard to biodiversity and vegetation. Depending on the extent of pressures, humans might also be affected.

3.4 Impacts

When the state of the environment changes due to mining activities, it might have positive and negative social, economic or environmental impacts (Tscherning *et al.*, 2012) such as better living standards, better health care, destruction of habitats, heavy metal accumulation in plants and animals, and negative effects on human health. The positive impacts are social and economic improvements of society. There are no positive improvements of the environment related to mining activities. For instance, habitats are destroyed when land is changed into a mining area and there is a release of heavy metals from mine tailings that consequently pollutes the water, which again accumulates in plants and animals (impacts). Negative impacts on human health can arise from intake of contaminated fish or surface water. However when it comes to humans, it is the health of mineworkers, which are of most concern, as they could be impacted from exposure to dust containing metals which might lead to lung diseases and cancer.

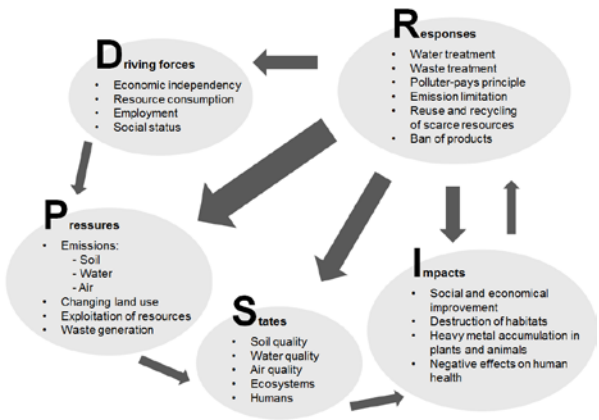

Figure 1 The DPSIR model in relation to mining activities in Greenland. The arrows indicate how the different steps affect each other. The size of the arrows symbolizes the degree of the effects.

3.5 Responses

There are a number of potential adaptive or mitigative responses or actions that society and decision-makers could take to minimize the negative impacts of mining (Ness *et al.*, 2010) as for instance setting emission limitations, implementing mandatory water and waste treatment, use of the polluter-pays principle, reuse and recycling of scarce resources and ban of products.

In general, the Greenlandic Mineral Resources Act §53 already states, that it is important to limit the amount of pollution, emissions and waste as much as possible and that waste, wastewater and other polluting materials have to be disposed in an appropriate way (Greenland Self-Government, 2009). Limitations of water and air emissions are relevant in order to reduce local pollution but also, with regard to air emission limitations, to reduce CO_2 contribution to global emissions.

Mandatory waste and water treatment are two important responses that should be implemented in order to preserve the environment as much as possible. Waste and water treatment is already being implemented in an Environmental Impacts Assessment (EIA) from London Mining and the company plans to construct a waste incineration plant and a wastewater treatment facility that can clean water with a capacity of 3.000 people (London Mining, 2012). It is however important with regular governmental inspection to ensure that the treatment facilities are complying with limit values.

Another potential response could be the adoption of the polluter-pays principle (PPP) which states that the one that pollutes is also the one to pay for the clean-up (Luppi *et al.*, 2012). By applying this principle in the Greenlandic legislation mining companies have to ensure clean-up of waste rock dumps and contaminated water in relation to tailings. The PPP is together with Best Available Technology incorporated in the Greenlandic environmental legislation (Sommer, 2011), which however does not cover mining activities. The Mineral Resources Act comprises some elements of the PPP as Paragraph 69 states that the one responsible for an environmental damage and causes a contamination in relation to an

activity covered by law, have to compensate the damage originating from the contamination, even if it occurred as an accident (Greenland Self-Government, 2009). Thus the Mineral Resources Act comprises some of the same elements as the environmental legislation. A way to ensure that costs of potential damage are eventually covered would be to have a well-defined trust fund, administrated by the Government, where a percentage of the royalties and corporate tax are collected (Andersen and Lynge, 2012).

A final and more sustainable response could be to have an increased focus on reuse and recycling of scarce resources to minimize the need for extracting new minerals. This response has to be implemented on a global scale, as reuse and recycling in Greenland only will not have any influence on the demand for minerals. The response will decrease the driving forces of extracting minerals, and result in a decrease of the pressures on the environment together with the impacts. Though it will influence the environment positively, the solution will not be beneficial for Greenlandic economy.

4. Discussion and recommendations

Based on the analyses above, we recommend that a range of changes are made to the Mineral Resources Act in general and specifically in regard to EIA and PPP.

4.1 Environmental Impact Assessments

According to Chapter 15 § 73 in the Mineral Resources Act a company applying for permission to start mining activities has to conduct an EIA, which will be approved or rejected by the Greenlandic government (Greenland Self-Government, 2009). Three inadequacies have been identified in the legislation regarding limit values on water and air emissions and renewable energy.

The DPSIR analysis emphasized that general emission limitations on water and air are essential in order to minimize the environmental impacts of mining. As stated in the Mineral Resources Act, a mining facility should be placed where pollution is limited as much as possible (Greenland Self-Government, 2009). However, only guideline values on water quality for seawater and freshwater are available in the BMP guidelines for preparing an EIA on mining operations in Greenland (Bureau of Minerals and Petroleum, 2011). As guidelines are only instructive, the Act appears ambiguous, which can lead to cases of doubt regarding interpretation of the law. A consolidation Act on EIA is in preparation at the moment (Frederiksen, 2012) and it is recommended that the act introduce water quality guidelines as legal requirements.

Contrary to the water quality there is no specific guidelines for air quality (Bureau of Minerals and Petroleum, 2011). As previously mentioned the Mineral Resources Act simply states that emissions should be limited as much as possible, which is not very specific (Greenland Self-Government, 2009). As a future local increase in air pollution could increase global warming in the region (Law and Stohl, 2007), the recommendation is hence to develop strict air quality limit values before approving mining operations in Greenland. This will minimize possible health impacts connected to air pollution.

4.2 Polluter-pays principle

One response from the DPSIR analysis is PPP. Even though PPP is stated in the Mineral Resources Act (Greenland Self-Government, 2009), it is unclear how comprehensive it is. Not even Greenlandic politicians agree on the clarity (Kristensen, 2012). It is however important that both mining companies and locals can understand the legislation in order for them to know the legal requirements. Since Greenland may not have the resources to clean up after pollution resulting from mining operations, as they still depend on Denmark in economic terms (Andersen and Lynge, 2012), it is important that the PPP is applied for the mining industry. Thus the principle has to be specified in details, which could be done in a consolidation Act. This should be elaborated, so it cannot be questioned, who decides when the mining area has to be cleaned up and which limit values should be obeyed. Moreover it is important to state, what should happen if a company is going bankrupt. Implementing a trust fund could

solve that dilemma. It seems that a mineral resources fund already exists to ensure the Greenlandic economy. However, it is not specifically stated, what the means should be used for, and international experiences reveal that to function as intended, a precise scope of the usage should be provided (Andersen and Lynge, 2012). Furthermore it seems that a bank guarantee already exists, but only covers an amount of millions kroner (Kristensen, 2012), which might not be enough for clean-up of pollutants emerging from mining activities. Former international oil spills have amounted in billions, as for example the BP's Deepwater Horizon accident in 2010, which had to pay a fine for the contamination of 26.5 billion kroner (Bloch, 2012).

4.3 Denmark and EU

It is important for Denmark and EU to take action regarding the Greenlandic natural resources in order to ensure that China does not get monopoly of the world supply of raw materials, to maintain the environmental standard, and finally to ensure social benefits for the workers (Halskov and Davidsen-Nielsen, 2012). The Greenlandic Prime Minister, Kuupik Kleist has commented the Danish lack of action and requests the Danish Government to join the race for raw materials (Hannestad, 2012). That point of view is shared with the Communication Director in Grundfos. He acknowledges the importance of competition on the global market regarding scarce resources and states that the company might be willing to collaborate and invest in mining projects in Greenland (Halskov and Davidsen-Nielsen, 2012).
In order to enforce equal rights for the workers, whether it is Greenlanders or Chinese, the Danish Government should prohibit the special law allowing for import of cheap Chinese labor. Such an act will furthermore induce a chance for Denmark and EU to take action.

4.4 Tax havens

It has come into light that the mining companies applying for starting up mining operations in Greenland are having shell companies in tax havens. This can make it possible for the companies to deprive Greenland for billion-sized revenues (Fastrup and Hannestad, 2012). This is a highly urgent issue, as the foundation for approving a mining industry is the massive Greenlandic economic revenue allowing for Greenland to obtain independency from Denmark. However, suggesting solutions for this problem is beyond the scope of this study.

4.5 Rejecting or postponing mining in Greenland

An entirely different approach regarding mining in Greenland is to refuse any mining operations in the country. This will undoubtedly be most beneficial for the environment since pollution of water, land and air will be avoided. Furthermore biodiversity and ecosystems will not be disturbed and possible health effects prevented. However, a rejection of mining does not necessarily need to be permanent. The value of metals such as iron together with Rare Earth Elements will continue to increase in the future (Bielitza and Lindstädt, 2011; Humphries, 2012). Furthermore development in greener and more efficient technologies is expected in the future. Greenland can hence postpone the decision on whether to extract their natural resources until legislation, technology and tender from the mining companies ensures significantly decreased environmental impacts. This could be accomplished through an agreement of a political moratorium, which at the same time could give Denmark and EU time to take part in the debate.

4.6 Conclusion and recommendations

The overall recommendation is that the Greenlandic Government should agree on a moratorium of implementing a mining industry in Greenland. The moratorium should ensure a completion of a consolidation Act for the EIA and PPP, which clearly states limit values and regulations that has to be obeyed. Furthermore it is recommended that the Danish Government reject the special law on immigration to ensure acceptable working conditions. This rejection will hence give an opportunity for Denmark and EU to enter the negotiations.

The drawback of these recommendations is obviously that the economic independency that Greenland is seeking will not be fulfilled in the nearest future. In the long run however, Greenland might be better off both economically and environmentally if they postpone mining.

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Increased shipping in the Arctic: Challenges and safety

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Abstract

During the last decades the Arctic has experienced one of the most rapid temperature increases on Earth. A consequence of this warming is a reduction of the sea ice extent, particularly in the summer, and decreased ice thickness. This may lead to a longer navigation season for Arctic shipping and eased access for commercial seaborne cargo transport along the margins of the Arctic basin. This includes e.g. a more extensive use of the Northern Sea Route. Another important aspect is the mineral and hydrocarbon resources in the Arctic. We clearly see a trend of increased activities related to industry, population and transport in a vulnerable area. Especially exploration of hydrocarbons in Arctic waters has an increased focus among several oil companies and thus an increased activity level. The paper focuses on the challenges related to ice actions, marine operations including ice management, communication, weather forecast, marine icing, emergency response and oil spill preparedness and response.

1. Introduction

Traditionally the ship traffic sea lanes in the Arctic have been those indicated in Figure 1. However, the world will soon face an era of energy scarcity. Under these circumstances, the Arctic will surely play a paramount role in meeting the expected needs of the energy sector and this will lead to an increased shipping in the Arctic.

The resources of the Arctic should be exploited in a sustainable way with the safest and best available technology for finding, assessing and producing the resources, especially in the case of oil and gas. Finally, the resources have to be transported over great distances to market. This transport involves ship traffic, including supply and/or tanker traffic.

For operations conducted in Arctic waters, it is vitally important to have extensive knowledge of the conditions that naturally occur. This includes previous experiences of ice pilots and navigation in the Arctic as well as new knowledge from current projects.

Because of the great commercial and environmental relevance of the region, it is of vital importance to gain this fundamental knowledge about the physical environment in the Arctic region, particularly for its ice-covered seas.

2. Vessel activity

According to AMSA (2009a) approximately 6000 vessels were reported operating in the Arctic in 2004. This includes vessels travelling on the North Pacific's Great Circle Route between Asia and North America through the Aleutian Island chain. Great Circle Route vessels account for half of all the vessels reported. Excluding the vessels plying the Great Circle Route, the most vessels in one category were fishing boats, at slightly less than 50 % of the total, with the next largest vessel category being bulk carriers at about 20 % of all vessels.

The AMSA database identified four types of vessel activities as most significant in the Arctic in 2004: community re-supply, bulk cargo, tourism and fishing vessel activity operations. Figure 1 gives a geographical overview of the vessel activity in 2004.

Also Arctic marine tourism is developing and causing an increased cruise vessel traffic in the High North.

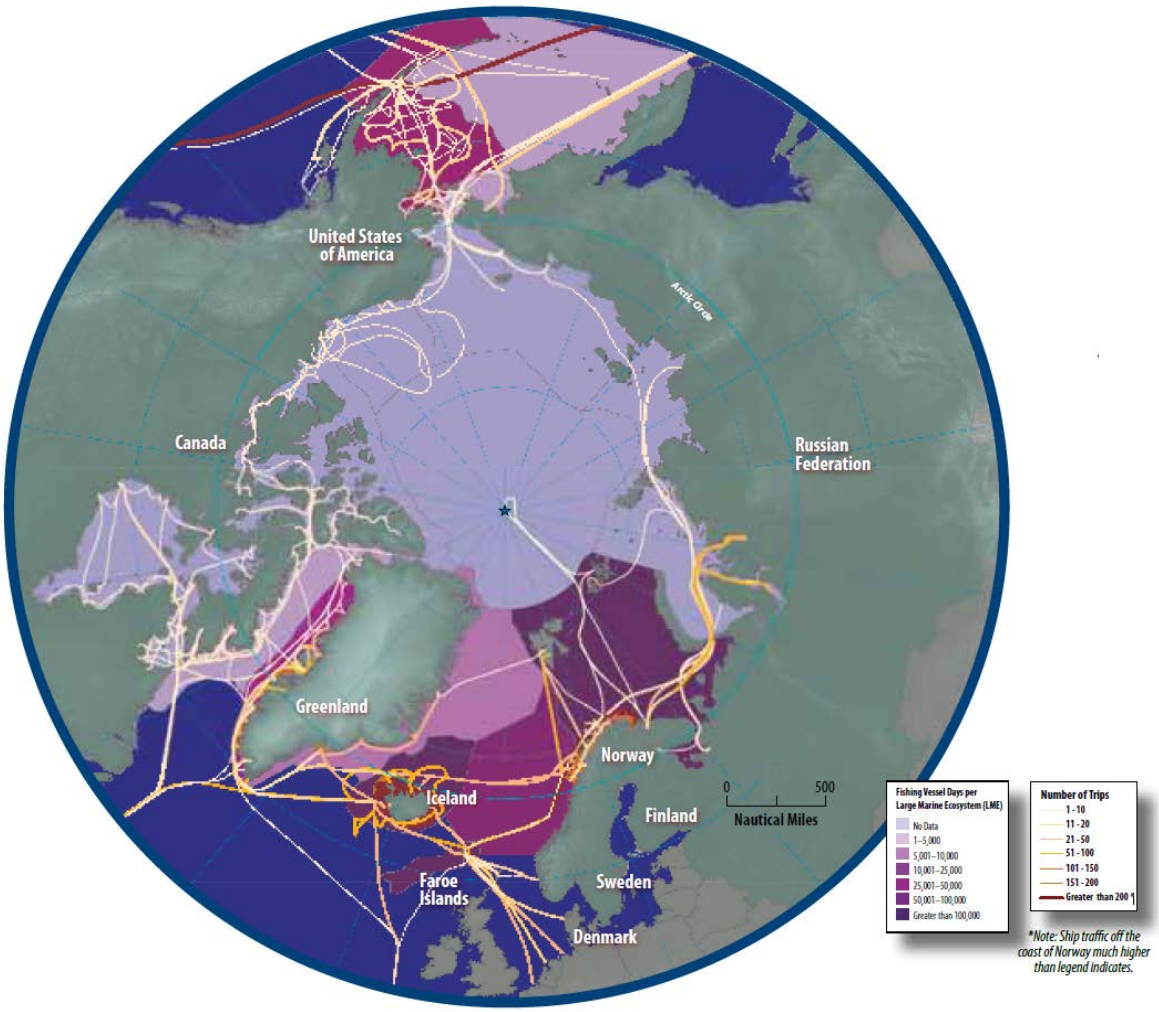

Figure 1. Arctic vessle activity for 2004 (AMSA, 2009a).

3. Perspectives of the energy sector

Stress on the environment from a potentially growing energy use is set to rise. Without doubt, the energy resources in Arctic regions will be developed (Figure 2). An important goal will be to exploit the resources offered by e.g. the Barents Sea as a new European energy province and to do that in accordance with the principles of sustainable development that have successfully been used e.g. in the North Sea.

Exploration and exploitation of these resources pose significant challenges for industry, especially in the assessment and management of risks along the whole production chain, avoidance of disruptions arising from potentially manageable accidents, and the need to minimise costs arising from adverse environmental impacts.

Figure 2. Arctic oil and natural gas provinces (geology.com, 2013).

Presently the level of knowledge about physical Arctic environment loads is insufficient to adequately address these challenges. Another aspect causing an increased growing demand for natural gas in the Far East (FE) which will necessitate increased import of Liquefied Natural Gas (LNG). Norway is the second largest exporter of natural gas and continues to develop gas fields. High natural gas prices in the FE compared to the European markets create a potential economic opportunity in shipping and selling LNG from Norway to the FE. Shipping LNG from Norway to the FE on the Northern Sea Route (NSR) may be a financially attractive option in carrying out this trade.

The NSR is also becoming a more viable and favorable option for shipping with reductions in the sea ice cover. The major benefit of trading in the NSR is that it provides up to a 50% reduction in distance compared to the Suez Canal Route (SCR) for Europe to FE trips. This can lead to substantial fuel savings. However, there are other costs associated with trading on the NSR; chiefly among them is the additional cost of an ice-classed vessel.

In additon to hydrocarbons, the Arctic contains substantial deposits of minerals including rare earths, uranium, iron ore, lead, zinc and gemstones.

4. Challenges

The activity in the marine Arctic represents a number of new challenges compared to activities further south. Most of them relate to ice actions, marine operations including ice management, communication, weather forecast, marine icing, escape, evacuation and rescue (EER), and oil spill preparedness and response.

These operations are affected by presence of sea ice and glacial ice, long distances, lower temperatures both in air and sea, marine icing and bad visibility due to fog and darkness parts of the year.

Currently, vast areas of the Arctic have insufficient infrastructure to support safe marine shipping and respond to marine incidents in the Arctic. This includes such critical infrastructure components as the accuracy and availability of timely information needed for safe navigation; availability of search and rescue assets and supporting shoreside infrastructure to respond appropriately to marine incidents, port protection facilities for ship-generated waste, availability of deep water ports, places of refuge and salvage resources for vessels in distress (AMSA, 2009b).

5. Marine operations in ice

The presence of sea ice is really what makes a difference to navigation and marine operations in the Arctic. Massive observations indicate a decrease of the ice cover both when it comes to areal extent and thickness. Further, the amount of multi-year ice is reduced. However, the threat from sea ice is not reduced for at least two reasons: 1) the traffic lanes just follow the retreat of the ice cover ice into more remote waters; 2) the opening of new accessible areas may lead to new findings and thus an increased activity.

This does also cause new possible marine operations in relation to petroleum activities such as dynamic positioning in ice for exploration drilling. Such an operation needs to be supported by *ice management*. Figure 3 shows a picture of the icebreaker *Oden* during OATRC2012 when breaking ice to demonstrate such a capability (Lubbad et al., 2013). *Oden* was equipped with different instruments to collect the navigation and propulsion data. Meteorological data were accessible from the weather station on-board.

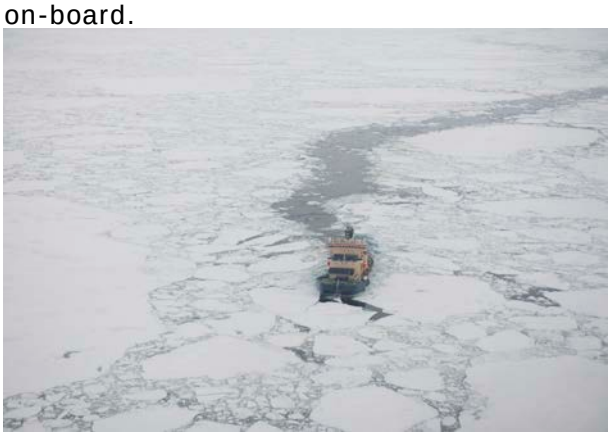

Figure 3: Oden off NE Greenland.

During OATRC2012 a 4-hour ice management test was performed to analyse the efficiency of an ice management

scenario where *Oden* was used to protect a vessel on station keeping. The procedures of this test were as follows:

- The position of the Protected Vessel (PV) was fixed at (N78° 33.6', W013° 06.3').
- The captain was told to manage an area upstream as shown in Figure 4.
- The captain used the long stroke technique; namely run up- and down-stream with some criss-crosses. One leg of these long strokes took about 30 minutes; see Figure 4 for the dimensions of the planned region.
- Helicopter surveillance took off 15:12 (UTC) to survey the unmanaged area and landed 15:32. The ice management had partly started when in the air.
- Second helicopter mission took off 17:21 and landed approximately at 17:40.

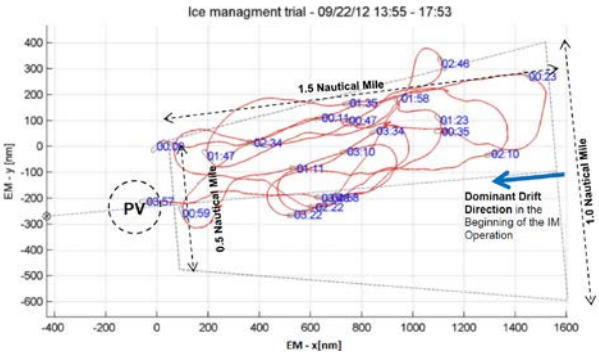

Figure 4. The trapezoid illustrates the boundaries of the area to be managed with the PV shown to the left in the figure. The track of Oden is shown in red (Lubbad et al., 2013).

As shown in Figure 4, the managed ice drifted to the North and did not envelope the PV as originally intended. This is mainly due to the unforeseen change in the direction of sea currents. Consequently, one could conclude that a successful ice management scheme is hardly reachable without at least a now-cast of the ice drift (Lubbad et al., 2013).

6. Icing

Another major difference compared to the South is the effects of low air and water temperatures – icing. This phenomenon has been a well-known hazard to traditional operations in northern waters, such as fishing and sealing (Løset et al., 2006). According to Shellard (1974) about 80 vessels capsized due to icing in northern waters in the period 1955–70.

Icing in the ocean can be divided into two main categories:

- sea spray icing;
- atmospheric icing.

Accumulations of ice and snow on structures will increase the gravity load. It should be treated as environmental actions. Icing in general can change the aerodynamic properties of structural members leading to adverse effects. Adverse effects due to ice and snow accumulations on topsides are factors that affect personnel and equipment operations, emergency evacuation procedures and communications.

Ice accretion is ice growth occurring when impinging liquid droplets freeze on a surface as a result of latent heat transfer mainly to the atmosphere. Sea spray icing is either caused by interaction between waves and the structure or structure members or from wave crests of breaking waves. This is now thoroughly studied by e.g. Kulyakhtin et al. (2012a) and Kulyakhtin et al. (2012b).

Atmospheric icing is caused by freezing rain or drizzle, freezing fog, or cloud droplets mostly depositing on the super-structure. Snow accumulation is caused by snow accreting mostly on horizontal surfaces on the superstructure. Ice that can form on the structure may be assumed to have a density of 920 kg/m^3 at most while snow may have a density as low as 100 kg/m^3.

Ice accretion generated by wave-structure, collision-generated sea spray is by far the dominant source of ice accretion due to the intensity and frequency of spraying events. Borisenkov and Panov (1972) provide the following breakdown for the relative frequency of sources of ice accretion on ships in non-Arctic seas:

- spray alone, 90%;
- spray with atmospheric ice accretion, 7%;
- atmospheric ice accretion alone, 3%.

In Arctic seas, atmospheric ice accretion plays a larger role, and the percentages are as follows:

- spray alone, 50%;
- spray with atmospheric ice accretion, 41%;
- atmospheric ice accretion alone, 9%.

The amount of ice accretion from atmospheric sources tends to be much smaller than that from sea spray because of the short duration and relative infrequency of the associated weather events.

7. SAR and communication

Ships and manned offshore structures are required to have access to evacuation at all times so that in an emergency situation, people on board may be quickly and safely evacuated. Search and rescue (SAR) is a major issue for ship traffic in the Arctic. Evacuation from an offshore structure may be direct by means of helicopters if possible. Alternatively, people may be evacuated by vehicles to move them away from the emergency or hazard at the offshore structure to a safe location where they and the vehicle may be picked up by a rescue vessel.

For offshore structures in waters that may be ice-infested for some parts of a year or on a permanent basis, such as in the Arctic ocean, a vehicle may be required to move through open water, partly ice-covered water, ice, snow and/or land. Currently, adequate vehicles in use for evacuation (EER) comprise conventional life boats or life rescue craft. These vehicles have difficulties to break ice and cannot be manoeuvred effectively in water with more than 40% ice cover.

Another challenge in the Arctic is communication. VHF is still largely used for communication at sea, but only over short distances (line of sight).

The most widely used maritime communications systems are based on geostationary (GEO) satellites that orbit the earth above the equatorial line, such as Inmarsat and VSAT systems. The problem with GEO satellites is that they have little or no coverage at all in the Arctic, and their low angles of elevation makes them more vulnerable to external influences. The theoretical limit of coverage for GEO systems is 81.3° north, but instability and signal dropouts can occur at latitudes as low as 70° north under certain conditions. Many factors influence the quality of service offered by GEO systems, and they have different effects depending on the system design.

The only satellite system that currently provides full coverage in the Arctic is Iridium, which offers digital capacity via Iridium OpenPort services. However, problems with Iridium have been reported by maritime operators in Arctic areas. The system occasionally shuts down and it can take several minutes to reconnect.

We may conclude that current maritime digital communication systems were not designed to cover the Arctic, and maritime operators lack sufficient knowledge and information about the real quality of service they can expect when they are operating in the far north.

8. Conclusions

A milder and shorter ice season in the Arctic does clearly give the opportunity of increased shipping traffic. This may lead to:

- A longer navigation season for Arctic shipping and eased access for commercial seaborne cargo transport along the margins of the Arctic basin.
- The opening of new accessible areas and petroleum licenses may lead to new findings and thus an increased activity.
- A general trend of increased activities related to industry, population and transport in a vulnerable area.

Especially exploration of hydrocarbons in Arctic waters has an increased focus among several oil companies and thus an increased activity level.

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Arctic Technology: from Localization to Local Appropriation

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Abstract

The interaction between advanced technology, environment and local culture, between newcomers and aboriginal population is one of the most important issues of future arctic development. The on-going technological invasion has already seriously harmed local environment and, consequently, partly destroyed the traditional lifestyle, which is essentially dictated by nature. This, in fact, is a complex problem, which requires special expertise that could incorporate indigenous knowledge and modern science into action and decision-making for generating new kinds of culturally appropriate innovations in the Arctic. The paper goes through following points:
1. The concept of Localization, which sets the development of technology apart from its practical enactment, is not appropriate to design objects, especially for the extreme environment of the Arctic.
2. The concept of Local Appropriation is suggested, which promotes the action of taking technology for one's own use in a variety of ways, usually beyond the designer's expectations. It is essentially a creative process, based on affordances of the environment and materials, where users' creativity implies not necessarily innovation but improvisation.
3. It is suggested to design technology for the Arctic (e.g. transport vehicles) as a "do-it-yourself kit", i.e. to supply users with a set of modules/components instead of ready-made objects.

1. Introduction

Modern technology[1] changed the entire world radically over the past few centuries. However, the effects of such changes are not uniform: for example, environmental impacts are greater at higher latitudes than in the tropics ("Technologies for Adaptation to Climate Change" 2006). They are likely to be particularly acute in the Polar Regions with vulnerable nature, severe climate and indigenous inhabitants.

During the last few decades, the Polar Regions have experienced the greatest rates of warming compared with other world regions (Solomon 2007). This, in turn, has provided opportunities for extensive exploitation of natural resources and occupation of territories that have been partly or even totally inaccessible before. At a societal level, a 'mosaic' community of newcomers, i.e. migrants, mobile workers, etc. has emerged and evolved into the most numerous subpopulation of today's Arctic (Stammler and Eilmsteiner-Saxinger 2010). Moreover, according to demographic forecasts (see e.g. "Arctic human development report" 2004; Vishnevsky 2004), the pressure of migration flows from the South to the North is expected to be increasing from year to year.

[1] From now on I refer to the conventional understanding of the term "technology" as the tangible products developed from scientific knowledge, such as constructions, machinery and equipment ("Technology" 2013).

At an industrial level, the Arctic, along with the Outer Space and marine environment, gradually turns out into a 'springboard' for future-looking innovations (e.g. new solutions for transport, equipment, construction, healthcare, food, etc.). With adequate technology, the challenges of ongoing climate change can be transformed into opportunities. However, these opportunities will only be fully realized if technical innovations are simultaneously human-, cultural- and environmental-centric. Thus, in the Arctic market, there is a specific demand for locally appropriated technology that can keep the land and its people intact, ensure successful adaptation for newcomers and provide an ultimate quality of sustainable working and living (Bravo & Triscott, 2011; Garin, 1991; Pelto, 1987; Rey, 1981; Soukup, 2006; F. Stammler & Wilson, 2006; Usenyuk, 2011).
While the critical role of innovative technology in the Arctic has been widely acknowledged in policy-making and strategic planning, it also entails some crucial challenges for existing technical knowledge and design.

However, history shows that most of the technological breakthroughs take decades to get to the mass-market. Whatever the level of technology, its application is likely to be a long-term iterative process rather than a one-off activity. Since irreversible climate change is already upon us, there is obviously no time to sit and wait years for great innovations to find their way toward everyday use.
Meanwhile, in many cases people adapt to different environmental changes by themselves: simply by changing their behavior. Even where adaptation requires the application of technology, some of the methods are fairly basic, often using measures that would have seemed familiar to people living decades or even hundreds of years ago ("Technologies for Adaptation to Climate Change" 2006). The best objects to serve human beings are emerged through one's own subjective individual experiences and learning processes (Ingold and Kurttila 2000).

In this paper the historic case studies of the Arctic technological development are presented with reference to the Russian North. However, before going into the research process per se, let us specify the relevance of the Soviet/Russian experience with regard to developing sustainable mining industry in Greenland. It stems from two main points, as follows:

1) Long-term tradition of mining (though on different scales and by different means)
   In both Russia and Greenland, mining has long been an important element of the exploitation of the countries' natural resources, and the mining tradition extends far back in their history (Secher & Burchardt, 2000; *The Perspective Transportation Systems*, 2011).

2) Opportunities provided by climate change
   As one of the most influential players in the field of Arctic exploitation, Russia will definitely benefit from the upcoming climate change in terms of increasing accessibility of resources. The potential of Russian Arctic is still largely unexploited, and the hopes and expectations are growing correspondingly with the prices for oil, gas and other mineral resources on the global market. On the other hand, however, there is a serious lack of efficient infrastructure for extraction and distribution of resources: the techno-heritage from the 'dark era' of forced industrialization is not able to fulfill contemporary needs and requirements. Therefore the main orientation in Arctic development has to be made on importing technologies. There are plans, for example, to build entire cities on the mainland to support oilrigs offshore (Niinistö, 2012; *The Perspective Transportation Systems*, 2011).
   In case of Greenland, although it has no mineral or metals production so far, the country aims at making mineral resources one of its primary industries ("Invest in Greenland" 2009).

Thus, to date, both Greenland and Russia are facing a unique opportunity to set up a

completely new infrastructure 'from scratch', i.e. to develop and establish new – *environment- and human-friendly* – technology. And here comes the difference: in Greenland, it would be one of the largest *international* projects on industrial development, with all the ensuing consequences, involving multicultural workforce, imported technology etc.
In this instance, 'learning from past', i.e. from the world-largest experiment on creating 'global Arctic technology', with focus on transport sector, can provide invaluable insights into actions that have to be taken for a more sustainable future.

The paper consists of two parts: first, it provides an overview of the localization approach to designing technology for the Arctic conditions, with reference to the state-initiated industrial development of Russian North. The second part introduces the concept of local appropriation of technology illustrated with a case study of creating personal transport vehicles. Finally, some conclusions are drawn with the aim of outlining the perspectives for designing Arctic technology.

2. "Arctic Implants": Localization of Technology

Generally, in Russia, since Soviet Era, Arctic design expertise has been exercised on two different levels, as follows:

- Professional, i.e. national R&D organizations, where scientific knowledge is coupled with engineering practice; and
- Non-professional. This level involves enthusiastic amateurs, i.e. self-taught engineers, such as local dwellers of polar areas (though not aboriginal people, but the offspring of first waves of northern immigrants), participants of scientific expeditions, ordinary tourists, etc.

But before diving into analyzing the activities on these levels, let us take a look back at the history of Russian Arctic exploration.

2.1 "At Any Cost!": a Brief History of Technological Conquering of the Arctic

Historically, the process of development of the Russian North has always involved blood and sweat: exploratory, trade and military expeditions were inevitably accompanied with great expenses as well as human losses.
Since the beginning of northern expeditions, it became clear that the 'conquest of the Arctic' could not succeed without adequate technology and equipment, i.e. transport vehicles, shelters, clothing, etc. In the late XIX – early XX centuries, the interest in resource exploration and development increased and the first permanent settlements of newcomers in Siberia were established. Consequently, a need for the special planning of working and household activities of explorers was realized and became particularly relevant,
At the same time, the approach of tackling all these emerging issues was initially based on the idea of *localization*: it was believed that means and methods from the "Great Land" could be adapted to new and unfamiliar environment. In fact, it was an entirely experimental approach, step by step, by trials and errors. For example, the first winter dwelling units were designed like northern European houses: with a gable or flat roof. To reduce heat loss chimneys were stretched across the room, during polar winter the temperature inside such a house did not rise above 9°C. It was the same case with transport technology: for instance, the main body of an aircraft was made of veneer or percale, the cabin was open and untight, therefore, during the flight, inside the plane it was as cold as outside. Aircrafts of that era had skis with wooden runners covered with metal to ensure good sliding, but in fact such an improvement was totally impractical: the metal was freezing to the ground, hampering the plane's takeoff.
In extreme conditions, the process of using technology and equipment was difficult per se: because of the constant freezing, it could take several hours to install a tent, and sometimes the tent was carried away by a strong gust of wind, therefore participants of an expedition had to spend the night under the open sky. It was also extremely

difficult to open bags and cans with food; the fuel (kerosene) turned out into a certain kind of jelly; and, due to the frost, the tin soldering of the fuel cans was crumbling to dust. Communication equipment, i.e. transmitters, receivers, radio masts, etc. were too bulky and immobile.

The first northern explorers also wore inappropriate clothes. In the 1930s, the typical outfit consisted of woollen underwear, a thick sweater, fur suit and shirt, wool socks, dog stockings, high fur seal boots, woollen gloves and spacious fur mittens. In addition to that, pilots used to have deerskin caps and fur facemasks, as well as protective spectacles and huge heavy fur coats.

Nutrition and mode of living were also critical for adaptation as well as for working performance. The importance of special arrangements aimed at physical and psychological comfort of team members has been widely recognized by experienced Northern explorers, such as Nansen, Amundsen, etc. In Russian expeditions these aspects were usually ignored in order to save time and money. As a result, numerous cases of scurvy and utter exhaustion were a common occurrence among Arctic explorers. Also, quite often, because of the exceptional physical and psychological stress, members of expeditions became mentally deranged.

There were several fatal northern exploratory expeditions. The in-depth analysis of those tragedies led to a profound change in strategies and methods of approaching the Arctic: a special “Northern Sector” was established within the state-centralized system of research and development.

2.2 The Concept of Localization

On the state level, Arctic design was established in 1919, when the Organizational Committee for Designing and Manufacture of Aerosleds (a type of propeller-driven snowmobile, running on skis, see Fig. 1) was founded. It was responsible for technical research, development and testing of aerosleds, in order to utilize them for military purposes.

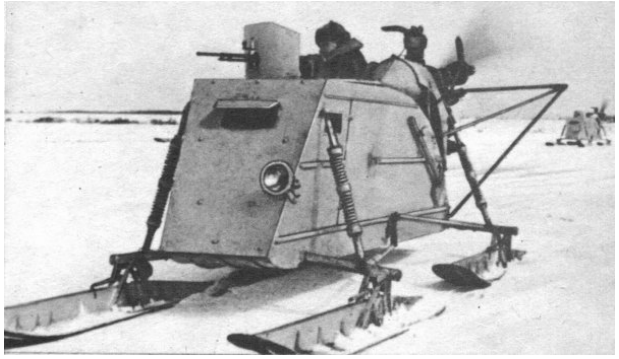

Figure 1. The NKL-26 armoured aerosled, 1942 (image source: Wikimedia Commons)

Later, professional Arctic design as a sector of industry moved to large defence factories and different smaller R&D organizations.

In early 1960s the large-scale industrial development of the Russian Arctic officially started with the Decree No. 1208 of the Council of Ministers, "About Organization of Preparatory Work for Industrial Development of Discovered Oil and Gas Deposits and about Further Geological Exploration in Tyumen Region". As a result of this developmental policy, there were two large organizations established in the field of Northern design and development, i.e. the State Research Institution of Technical Aesthetics (Russian acronym *VNIITE*) and Leningrad Zonal Research Institute of Standard and Experimental Design (Russian acronym *LenZNIIEP*). Their area of expertise encompasses research, standard and experimental design of transport vehicles, consumer goods, clothing, housing and civil construction, for the northern areas of the entire country. Both of these organizations aimed to facilitate ambitious national megaprojects related to the development of Arctic natural deposits.

The most popular and advanced sector of Arctic design was transport: nearly every R&D organization with a technical design department produced numerous projects of aerosleds, all-terrain vehicles, marsh buggies and snowmobiles for the Arctic areas (see Figures 2-4). The state leaders were the Gorky Automobile Plant (Russian acronym GAZ), the Likhachev Factory (Russian acronym ZiL) and the All-union Scientific Research Automobile and Automotive Engine Institute (Russian acronym NAMI).

Figure 2. GAZ-71, the all-terrain vehicle on tracks, 1968 (image source: http://www.vsevezdehody.ru)

Figure 3. ZiL SHN-1, the screw-driven all-terrain vehicle, 1968 (image source: http://www.vsevezdehody.ru)

Figure 4. ZiL-131NS, the northern modification of a standard production model, 1986 (image source: Wikimedia Commons)

At the same time, there was a serious lack of professional attention and expertise in designing clothing and household equipment for the conditions of the North. For instance, there were attempts to incorporate traditional clothing design of the Arctic indigenous peoples. However, these attempts resulted only in a superficial copying of traditional fur coats, where reindeer hides were replaced with new insulation materials. Therefore, the final products lost the efficiency and practical value of original samples, without gaining any new competitive advantage.

Based on the brief overview of the history of professional Arctic design in Russia, let us outline the main characteristics of localization as a predominant approach:

1) Centralized system of research and development

Usually, design, development, testing and mass-production were carried out within one state-owned entity. Generally, this phenomenon could be called “decree design” (Azrikan 1999), due to the solid belief in governmental decree. This belief, however, became a serious obstacle for innovations.

2) Profound theoretical investigations

Systematic studies of materials, development and testing of new technologies were carried out by state enterprises with a strong scientific and technical foundation, i.e. profound database, all-state network of libraries, scientific and technological centres, architectural and engineering design workshops, facilities for research and experimentation. However, all investigations were mainly theoretical, with short-term studies and experiments ‘in situ’. Therefore, projects developed by professional town-planners, architects, designers and engineers were in fact too formalized and idealistic: based on scattered factors of the environment and/or superficial analysis of indigenous artifacts, they mainly failed to cope with real challenges on site.

3) Modernization rather than innovation

Defence enterprises as primary manufacturing sites determined product design by providing restricted resources and technological capacity along with a narrow-oriented strategy of implementation. The main goal was to adapt outdated military technology for a new – civilian – need, i.e. passengers’ and cargo transportation in remote regions with lack of roads. At a first glance, the modernization/adaptation

seems to be a relatively easy and cost-effective way to create special 'material environment' for the Arctic, since it implies only moderate improvements of the existing construction. But the number of those improvements is objectively infinite: while placing such a technology into intensive use, under the real climate, socio-cultural and other conditions of the North, one would continuously discover new drawbacks and weak points that, in turn, would force new waves of costly improvements.
Also, due to the inert virtue of Soviet defence industry in general, the special sector of Arctic technology evolved very slowly. Thus, the process of mass-production was aimed not at innovation but at local adaptation of technology, i.e. incorporating local traits into existing product platform.

4) Quantitative objectives
The strategy of modernization/adaptation has resulted into the continual improvement of technology. However, most of improvements related only to technical characteristics, i.e. engine power, carrying capacity, frost resistance, fuel efficiency, etc., and did not consider the holistic appropriateness of the products.

5) Aesthetics as a minor subject
The specialization of the defence industry determined the engineering priorities and promoted a purely 'technical' understanding of the 'ideal machine'. Functionalism was the main design consideration. Thus, the issues of human-machine interaction, aesthetic and ergonomic qualities of products were ignored; and it was believed that there was no reason to reorganise manufacturing for 'design extravagances'.

6) Twisted logic of causes and effects and lack of holistic vision
The narrow focus of scientific investigations, i.e. only on technical issues, led to a contradiction between final products and the environment as well as between users and machines. For example, a wide variety of propulsive elements of machines emerged in order to find the most efficient way of moving off-road, without any consideration of the ground pressure in terms of fragile tundra soil and permafrost. Most projects were developed in urban environment, this lead to major arctic environmental considerations not being included in the design. Designs were based merely on 'dry' facts and measurements, without taking into account social and cultural dimensions of the products under development.

After introducing the concept of localization as it has been established among design professionals since Soviet era, let us move to another track of "Arctic design movement", which involved enthusiastic amateurs, i.e. self-taught engineers, such as local dwellers of polar areas, participants of scientific expeditions and ordinary tourists.

3. From Adaptation to Improvisation: Users' Creativity as a Basis for Survival in the Arctic

While the state industry proved its inability to meet users' demand for suitable technology, a spontaneous phenomenon of amateur design emerged in response. People obviously started to adapt ready-made vehicles and other techno-objects, which were imported, i.e. artificially implanted into the northern environment. In other words, this environment forced users to adjust technology in accordance with the severe natural settings.
Comparing to the professional level of developing Arctic technology, where we are stuck at the stage of 'adaptive design' (Sanders 2005), on a small-scale level users came to understanding that it would be much easier to create objects 'from scratch' rather than modifying existing artifacts. This, of course, is conventionally speaking: there is a number of objective needs, i.e. in materials, technologies, tools, etc., but it appeared more efficient to obtain them separately rather than dismantle and reconstruct ready-made things that do not properly perform their functions in their original form. At this point let us move to the case study, which is drawn from the history of Arctic development. It is a story about local innovations in transport:

assembling personal vehicles out of recycled industrial components.

3.1 'Karakat': Reinventing the Wheel

One of the major considerations for developing all-terrain vehicles for the Arctic permafrost areas is that of decreasing the pressure of a vehicle (on wheels, skis, tracks, etc.) per square unit of tundra's surface. Initially vehicles were produced that used conventional wheels. This construction has failed because of inappropriate (not specially developed) elements.

However, a quantum leap in using wheels has occurred when low-pressure tires (with an internal pressure of 0-15 psi), so-called *pneumatics*, were invented. The original idea of all-terrain vehicle on such pneumatics was not generated by professional engineers, but came straightly 'from commoners'. A so-called *karakat* (Fig. 5) was invented in early 1970s in the city of Severodvinsk (Arkhangelsk region) by a couple of friends, passionate ice-fishermen, aiming to make their travels on the ice safer and faster.

The original *karakat* is based on a motorbike, slightly modified by attaching four inner tubes taken from truck wheels. In order to prevent over-inflating of tubes during the pumping, they are bound with straps around the entire circumference. Besides maintaining the inner volume, these straps serve as grousers, i.e. prevent wheels from slipping on the snow and ice. Importantly, the ground pressure of the completed vehicle does not exceed 0.05 kg per sq. cm. *Karakat* can move rapidly – at an average speed of 25-50 km per hour. It is capable of driving upon loose snow and off-road terrain; it can also swim. Thus, in case of an accident, e.g. falling into an ice hole, the vehicle does not sink.

Figure 5. Karakat (image source: http://zima.fish-fisher.ru)

The advantages of this kind of vehicle were as follows:

- excellent cross-country ability;
- high carrying capacity; and
- relatively light weight of the unit.

However, the original light construction could not protect its driver from cold and wind, i.e. the main factors influencing human existence in tundra and taiga areas. It is well known that increasing the speed by 1 km per hour leads to decreasing the perceived temperature by 1.5 degrees. This issue forced local inventors to improve the original design by adding a cockpit. The first attempt resulted in a small all-terrainvehicle 'Nara' (Fig. 6). This type of vehicles in Russian is called a 'snegobolotokhod', which means a 'vehicle for snowy and swampy terrains'. The construction was based on a Soviet microcar, which was informally known as the '*invalidka'*, i.e. 'disabled car'.

Figure 6. The all-terrain vehicle “Nara” (image source: http://arctictrans.ru/)

Another modification of *karakat*, so-called ‘Arktika’ (Fig. 3), was designed by Vladimir Rulevich, Arkhangelsk. It had a cockpit made of a fuel tank of a Soviet fighter aircraft MiG-23. The carrying capacity of this machine was equal to its own weight.

Figure 7. The all-terrain vehicle “Arktika” (image source: http://arctictrans.ru/)

The recent stage of amateur improvements led to the creation of an all-wheel-drive vehicle on low-pressure tires with a cabin from the famous Russian car ‘Lada’. One of the main advantages of such a construction is that a driver is protected from cold and wind by a heated cabin. Another important consideration is that a driver of such a car can easily repair it on his own: a standard Lada’s engine is quite simple and intuitively understandable, also some elements can be replaced with handmade substitutes. This is critical for users from remote northern regions with an irregular supply of spare parts.

The idea of the *karakat* spread quickly through vast areas of the Russian North, including West and East Siberia, where long distances and a lack of roads are a fact of life. Nowadays these vehicles are still in active use, it is easy to find them in almost every northern settlement.

This is just one example of the numerous alternative forms of technology, developed by nonprofessionals for the Arctic environment. To summarize, the objects designed by amateurs were rather successful in fulfilling the needs of local inhabitants. They were perfectly suitable for particular activities such as fishing, hunting, carrying loads, etc. They also facilitated personal (small-scale) adaptation and survival. At this point, let us examine users’ appropriation of technology as a social and cultural phenomenon.

3.2 The Process of Appropriation: Social and Cultural Implications

In today’s Arctic the process of synthesizing new ‘material culture’ happens in a spontaneous way: when human-beings found themselves in severe environments, where the technology is not able to cope with the tasks and hopes placed on it, they have to *create* new solutions in order to survive.

At this point, however, it is important to define the term ‘creativity’. As Ingold indicates, there is a certain tendency, evident in much of the literature on art and material culture, to read creativity ‘backwards’, starting from an outcome in the form of a novel object and tracing it, through a sequence of antecedent conditions, to an unprecedented idea in the mind of an agent (Ingold 2010). But in our case such a concept does not provide any insight into social and cultural implications of the appropriation of technology: to make your own vehicle does not mean to reproduce a certain industrial pattern, or to deliberately design something, which has never existed before. It means to “join with and follow the forces and flows of material that bring the form of the work into being” (Ingold 2010). Moreover, it is argued that in the Arctic conditions the process of following the possibilities of materials and requirements of the environment is the very form of *wellbeing*.

It would be wrong to say that amateur designers are interested only in mechanical or environmental issues: the most efficient way to reach physical and psychological comfort is to make machines ‘in an owner’s image and likeness’ (Lebedev 1989; Slice 2008). The core of the process lies in the action of carefully choosing technical parts for the future vehicle on the basis of *personal identity*. Thus, despite nearly the same set of available parts, every vehicle is

born with its own 'face', remarkably similar to its creator/owner. At this point a question emerges: how to breath a life into these machines? How can the 'iron waste' (automotive components) be turned out into comfortable, durable and cost-effective means of transportation?

The answer can be found in the very essence of making, which, however, cannot be grasped through purely engineering way of thinking. More precisely, it incorporates a *spiritual content* into each thing. This content or *agency* of a thing cannot be imposed from outside, it can only be grown in the object while making it 'from scratch', i.e. to assemble technical components.

Historically, the practice of making *living things* as such has been exercised since the origin of humanity. With regard to the Arctic, let us have a look at the process of making/animating things as it still exists among Arctic natives.

A Nenets reindeer herder usually spends a considerable amount of time preparing himself and his resources in relation to the environment, before he actually starts to make a certain object. Once looking for wood to make a sledge (*narta*), a craftsman sat down under a chosen tree, smoked a cigarette, in silence, and then started his long monologue. He explained with warmth how much he needed a new sled, why he had chosen this particular tree. Finally he promised to work on it carefully, only with a good and sharp tool, so it would not be too painful for the tree, and not the slightest wood chip would be lost, and he would try his best to make the *narta* being in use as long as possible… (fieldwork notes)

In case of dealing with contemporary technology, the essence of making remains exactly the same: the animation starts from the process of finding appropriate parts, adjusting them, fitting to each other, etc. Such actions are always followed by different forms of communication between a maker and his product, such as talks, negotiations, even prayers.

This communication leads us beyond a common manufacturing process: it represents a perpetual exercise in skill and creativity inspired by locally generated needs. Moreover, craftsmen always point out that their 'clunkers' are beyond any competitions with industrial mass-produced vehicles: they are simply more than just means of transportation – the owners personify their vehicles as friends, helpers and relatives. It signifies that such vehicles are, in fact, deeply embedded in the culture.

To summarize, the main advantages of amateur design are as follows:

- Close interaction/communication between key actors, i.e. the maker and the material, as well as between the maker and the environment;
- Flexibility of the process and products, i.e. the essential ability to adapt quickly to changing conditions of the environment as well as social and cultural circumstances;
- Active sharing of knowledge and experience. For example, in Soviet times, the dialog of amateur constructors used to be a matter of publications in magazines on technical inventions, and nowadays all the discussions have moved to the Internet forums and social networks.

On the other hand, however, the following drawbacks of the amateur design, such as a lack of critical analysis and professional reflection upon technical inventions, a spontaneous 'patchwork style' of final products have made most of those objects industrially unrepeatable.

4. Conclusions

In this paper, we tried to re-consider the definition of ideal/proper Arctic technology through the lens of design imagination, i.e. images and metaphors – to inspire the reader with an appealing vision of future possibilities. By way of concluding, let us outline briefly the main points of the paper.

1. In extreme environments, technology plays a key role for human adaptation and survival. According to medical research findings (Kaznacheev 1980; Linderholm 1981), physiological adaptation to a new environment mainly depends on the adequate technology and equipment. Thus, surviving and living comfortably in the Arctic necessitates advanced and reliable technology. Therefore the concept of localization, which implies development of

technology separately from its practical enactment, by incorporating local traits to an existing product platform, cannot be applied for designing technical objects for the extreme environment of the Arctic.
In fact, in the field of Arctic technology, we cannot expect any breakthroughs until the entire strategy of development is based on the professional culture (incl. working methods, the way of thinking, the ethical attitude, etc.) of non-Arctic origin. We also must move away from the idea that non-Arctic 'thought-activity patterns' and the entire 'body of expertise' of designers, engineers and other practitioners, could be applied to any issues related to this severe and unpredictable environment.

2. The process of local appropriation, which promotes the action of taking technology for one's own use in a variety of ways (usually beyond the designer's expectations), has been examined as an existing alternative to localization. It is essentially a creative process, based on affordances of the environment and materials, where users' creativity implies not necessarily innovation but improvisation.
Encountering modern technology can be challenging, but can also serve as a 'life test' for people's personal and collective ability to adjust to new conditions. Numerous examples of local appropriation of globally acknowledged technology do not only indicate that some people are personally active, creative and skilful, but also provide fertile material for investigations by design researchers. Looking at locally adjusted technology, designers can 'read' it backwards: starting from an outcome in the form of a material object and tracing it, throughout a sequence of environmental, social, cultural conditions, to 'an unprecedented idea in the mind of an agent' (Ingold 2010).

3. It is suggested to design technology for the Arctic (e.g. transport vehicles) as a "do-it-yourself kit", i.e. to supply users with a set of modules/components instead of ready-made objects.
In the conditions of the Arctic, the process of making, i.e. flowing and following the possibilities of materials and requirements of the environment, is the very form of *adaptation* and further *wellbeing*. Using this idea as a design strategy, we can meet the specific demand of the Arctic market: solutions that can keep the land and its people intact, as well as ensure successful adaptation for newcomers.

Although the current leap in Arctic industrial development is driven mainly by technological, especially transport opportunities, it has radical implications not only for industry, economy and design, but also for the ways in which people experience and interact with the environment and each other. What we have to learn from the mentioned examples of appropriation is the fact of customizing and animating technical objects through making. This essentially interactive process, in fact, creates an unbreakable link between a thing and its owner: "Once you become a friend with a thing, it will never betray you" (Nenets proverb). Such a link entails not only social and cultural but also environmental consequences, e.g. the ideal Arctic technology, which is literally *born* in the Arctic, would never make harm to the nature.
Generally, the Arctic challenge raises substantial issues for the international community. To facilitate not only the process of *industrial development*, e.g. mining, but also the process of the *development of lifestyle* in the Arctic, all experts must reconsider their professional means and methods and generate new appropriate research models and questions. Indeed, there is a real and inevitable call for complex multidisciplinary international collaboration, where design could take a role of catalyst. To start doing this, we must turn our attention, which is currently fixed on formal and functional characteristics of technical objects, to the Arctic as a *living subject*, in all its extreme, severe and unpredictable nature.

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Social and environmental conditions for mining in Greenland

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Abstract

In preparing for large scale mining activities legal, social and environmental impact assessments are mandatory and needed for the public, political decision making concerning licences for the initiation, operation as well as closing down of mines. These impact assessments are embedded in wider legal, economic and political socio-technical regimes framing the conditions for operation and the ways mining is integrated into the local and broader society's development of knowledge, skills, economy and social living conditions and practices. EIA and SIA have predominantly been carried out on basis of international norms and practices by consultants hired outside Greenland and the specific topics covered are dominated by the conditions achieved internationally by mining companies, lacking some of the more important impacts related to the speed of economic exploitation and the options for social and educational development for the local population.

International experiences demonstrate that the legal and ownership condition for operation are crucial for the economic and developmental outcomes of mining operations in small societies with only limited regulatory capacity and economic strength. The paper and presentation explores these basic conditions for mining operations based on historic and contemporary examples from Greenland and other societies that have experienced a recent and fast modernization and still operates with a limited knowledge and experience base.

1. Introduction

The discussion and envisioning of raw material exploitation based on mining and large scale industrial projects in Greenland has in last decade been core in the economic development plans for Greenland and the self governments strategy to gain political and economic autonomy and independence of the financial transfers (subsidies) from Denmark.

The natural mineral and energy resources in Greenland are well researched for a long period of time by Danish state institutes like GEUS and the former Greenland Technical Organization. This implies that the rather scarce exploitation of raw materials and hydropower energy is more related to costs, accessibility and global market conditions for exploitation than lack of knowledge and potential resources. The growing need for CO^2 neutral energy and raw materials as well as the changing climate in the Arctic has opened new options though most of these are at a pre-project state.

First, the introduction presents the challenge for a rather small population to cope with large scale mining and industrial activities concerning the needed competences, the regulatory capacity, the challenge to culture and society related to potential large numbers of emigrant workers and to gaining an economic benefit from activities based on especially the exploitation of non-renewable mineral resources.

In the following section historic and contemporary experiences with mining, the use of workers from Greenland and the regulatory frameworks are presented to illustrated the diverse and rather complex societal challenge that face Greenland and that the society will have to cope with to avoid being reduced to just another raw material rich and dependent developing country.

This is followed by an analysis of the regulatory frameworks based on social and environmental impact assessments that have been copied by Greenland from the international scene as means to cope with the future challenges of mining and large industrial activities. The question raised is whether these frameworks are sufficiently precise and adapted to the societal problems they are expected to handle.

The article ends with some questions to the implicit assumptions and seemingly lack of basic demands put forward in negotiating the conditions for mining and large scale projects in Greenland.

1.1 Asymmetries and adaptive capacity

In economic theory on agency emphasis is put on the distribution of knowledge between economic agents including the eventual regulators of economic exchanges. While typified ideal economic models at large build on the idea of distributed and available knowledge, more sociological based approaches emphasise the unequal – or asymmetrical – distribution of knowledge making providing the involved economic and regulatory agents with very different capacities to negotiate and intervene.

Typically producers have a much larger knowledge of the technologies and market conditions of relevance while some times the knowledge on environmental conditions resides with regulatory authorities and local people as well as the experiences with social structure might reside within the local communities. Besides the uneven distribution of knowledge and experiences the big challenge is whether these different forms of knowledge are at all made relevant and useful for e.g. negotiations of what could be called the 'social license to operate' when it comes to large scale projects with potential large social and environmental impacts.

This also emphasize the importance of the interplay between periphery and centers of policy and economy that may create new challenges for the local population that they may have limited experience in handling (Keskiltalo et al. 2011, Keskitalo & Kulyasova 2009). Not only the local knowledge is of importance, but the ability of the local population to organize and respond to policies and knowledge defined from the outside being it the central government or impacts from large scale projects and economic globalization. The local community draws on its experience – sometimes defined as 'social capital' – and its ability to form collective action and respond to the different adaptation arenas at play (Hovelsrud and Smith 2010).

When it comes to mining activities and the political and regulatory actions needed such an experience is lacking opening for the government administration to build rather independent competence units dependent on knowledge and principles brought in from the outside and lacking the local competences for building a countering perspective.

1.2 Work force competences

Greenland has through a long period of time build a work force capable of running core parts of the country's infrastructure and maintenance activities. This has been the result of the government funded basic education system, the contribution of infrastructure companies like Royal Arctic Line and Air Greenland by providing internal technical education systems providing skills at all levels, a structure of technical schools providing skills for the main occupational areas in Greenland now supplemented by courses in mining activities, and a still relatively small system of high schools and including the university in Nuuk and the Arctic Engineering education in Sisimiut.

But when it comes to the types of specialized knowledge needed at all levels to

run a mining operation only few have those skills today. What might become a more serious problem is that mining operations are generally run based on global work practices where mining is often carried out in remote areas and with a high degree of migrant workers accepting long working hours and a high degree of isolation in barack towns.

Therefore the workforce competences are not just related to the technical skills of the workforce but to the workers adaptation to the specific social conditions that mining activities share with other 'remote' and not settled types of technical work like the building of railroads, bridges, pipelines, oilfields etc.

1.3 Regulatory capacity and economic vision

Following the problem of asymmetric knowledge one of the important challenges to the Greenland society originates from the limited capacity of the administration when it comes to understanding the detailed technical and market based conditions for mining compared to the involved companies that typically operate globally and have a lot of established knowledge and skills and also have access to international networks of knowledge institutions, consultants, etc.

While often the limited capacity of the Greenland administration concerning legal and regulatory instruments is emphasized this defines a too narrow scope for the discussion of the regulatory capacity. The continued flux in the administrative work force and the problem of attracting regulators with specific competences in the field of mining and industrial regulation does though also pose a serious problem.

The argument from the Greenland central administration has generally been that it was possible to include and use expertise from international legal advisors and consultant companies who were working with similar problems on a global scale. This is a necessary and basically sound strategy as international experience and references are crucial for regulators in this field. It does though not remove the need for a basic competence in asking the right questions and being able to assess the advice and solutions proposed.

Two of the major instruments for the societal and regulatory preparation of mining activities besides legal conditions of ownership, fees and taxation are the impact assessment within the social and the environmental field (SIA and EIA), where the first also influence the 'social license to operate' by forming the basis for IBA's (Impact Benefit Agreements). This framework has been adopted in Greenland based on experiences from global regulatory efforts in relation to large scale industrial projects.

In this respect two problems seem to be core to the way guidelines are developed and implemented:

- The guidelines are just mere frameworks defining core elements to be considered and giving advice on processes of analysis, public consultation and implementation. As in all other regulatory and management standards they are dependent of a body of crucial knowledge about the use and implementation that is carried primarily by consultants working for companies as well as governments.

- The analysis of social impacts is culturally dependent as the definition of impact is basically local and dependent of experiences and economic as well as political conditions. The opens for impacts for beyond the obvious ones related to employment, wages and housing.

In this paper the analysis will be focused on the application of social impact assessments and the topics handled within these.

2. Experiences from historic and contemporary mining activities

In more than a century there has been mining in Greenland. The most profitable was the cryolite mine in Ivittuut being active for more than 130 years until it was closed

in 1987. The cryolite was mostly used as a catalyst in the production of aluminum.

Ivittuut was operated by Danish companies and was in most of the period deliberately by the Danish government kept as a 'closed society' in relation to the rest of Greenland with a typical Danish workforce. The Danish colonial administration saw these mining activities as part of the colonial economy and at the same time a way of protecting the traditional way of living in Greenland. Other mining activities were carried out as e.g. a graphite mine in South East Greenland and a zinc and led mine in Mestersvig also maintained as activities independent of the Greenland society.

2.1 Qullissat coal mine and city

The only exception from this was the coal mine in Qullissat on the north side of the island of Disko. This mine developed from a small mine with a barrack town in 1924 to a Greenland settlement with a diverse business community of 1400 inhabitants of which on third were employed in relation to the coal mine. The Danish government decided to close the mine and the city in 1972 by moving all inhabitants to other places in Greenland. The reason being that the mine was not considered profitable as the price for coal from other regions e.g. Poland was lowering. The experiences from Qullissat are important as the town was seen as well functioning and performed as a cultural and political center in Greenland. The workers movement in Greenland originates from the town and the forced closing of the town was part of the political uprising that led to the start of the Home Rule in 1979.

2.2 Marmorilik at Uummannaq

From 1973 to 1990 first a Canadian and later a Swedish mining company operated the old marble pit, Maarmoriliken, as a zinc and led mine. The improved transport infrastructure in Greenland opened for operating the mine based on migrant workers, where the workers (male) lived in barracks structures with period off work in the countries they came from. Through the years also Greenland based workers primarily from the close by settlements of and Uummannaq, but this group had difficulties in adjusting to the migrant work and everyday culture, resulting in only shorter periods of employment at the mine. The mining companies were not eager to employ local workers and until 1977 the Greenland workforce was discriminated with lower salary and poorer employment and work conditions than emigrant workers. After a work conflict the formal conditions were equalised, however the number of employees with a Greenlandic background did not rise, because of the company's right to choose who the preferred to employ (Nordregio 2009:13-14).

2.3 Contemporary mining experiences

After several years with no active mining the Nalunaq gold mine in Kirkespirsdalen i the south of Greenland in 1984. At first the Home Rule was engaged through Nunaminerals with a share of 17,5% with the Canadian Crew Gold as the majority owner, but in 2006 they were bought out. At first the minerals were shipped to Spain for processing, but from 2006 to Canada (Dahl 2008). The production was closed down in 2009 based on an assessment of too low value, but taken up again by another company, Angel, in 2010. As they use a combination of mechanical and chemical methods the company is able to extract a much higher percentage (Råstofdirektoratet 2011).

The mine is small employing between 80 and 100 workers. Both mining companies have tried to recruit Greenland workforce. But despite their continued efforts they have only in very short periods been able to employ more than half of the workforce from Greenland even though the unemployment rate has been rather high (Råstofdirektoratet 2011).

The Canadian owned True North Gems Greenland has asked permission to extract rubies in southern Greenland. This mine is located close to a small settlement, Qeqertarsuatsiaat, which opens for a variety of scenarios for local development in relation to the mine activity. Even thought there are options for local development these have

not been core to the planning efforts hitherto. Part of the plan is to process a small part of the minerals in Nuuk. In total this may lead to an employment of 70 people in Qeqertarsuatsiaat and Nuuk.

3. Impact assessments as the basis for regulation

Core to the preparation for new mining and large scale industrial projects are the social and environmental impact assessment (SIA and EIA), where the first is very important for the 'social license to operate' by forming the basis for IBA's (Impact Benefit Agreements) though in combination with the licence conditions for ownership, fees and taxation principles used to maintain influence and benefits also during the periods of building, operating and eventually taking down the mining facilities and restoring the utilized area.

This framework has been adopted in Greenland from the global scene of large scale mining and complementary regulatory efforts.

3.1 Social impact assessment guidelines

The impact of large scale raw material projects in Greenland was taken up as an explicit policy issue at the end of the last century in the 1997 report: 'Impacts of large scale raw material projects in Greenland' written as part of the preparation for further independence (self rule) of Greenland (Direktoratet for Sociale Anliggender 1997).

In this report the objectives of eventual large scale mining activities were pointed out to be:

- Societal developments must be based on the demands and expectations that the Greenland population has for a good life.
- The primary male workforce in large scale project does pose a problem for the gender balance of the population.
- The negotiation strength for Greenland is the located resource base. There is a need for time to scale up projects in which training of locals can be done to avoid projects to be dominated by an immigrant workforce.
- As several mining projects have a limited life span the whole life cycle is important and the impact through the creation of supplementary business activities is crucial.
- Dedicated educational programs are needed to prepare the Greenland workforce for these new opportunities.

Though this report can be seen as one among a number of contributions to the formation of policy in the field of mining, its legitimacy was bound within its focus on the social challenges of mining activities.

Later in 2009 Greenland, as many other countries and regions, finally defined its own 'Guidelines for Social Impact Assessments' (Bureau of Minerals and Petroleum 2009) based on international guidelines. These guidelines state:

The following issues are essential in the Greenlandic context:

- *Recruiting Greenlandic labour;*
- *Engaging Greenlandic enterprises;*
- *Focusing on knowledge transfer (e.g. education programmes) in order to ensure long term capacity building of local competence within the mining industry and mining support industries;*
- *Preserving socio-cultural values and traditions.*

A way of managing the social effects from mining projects is to prepare a Social Impact Assessment (SIA) in which it is important to identify and analyse potential impacts of a proposed action or development on the human environment, and to recommend initiatives to realize both direct and indirect sustainable development opportunities as well as mitigate negative impacts. The human environment includes aspects such as business and employment, income and other socio-economic aspects, use of land and resources, health, education, infrastructure and socio-cultural features.

These demands reflect at the intentional level the need for situating the new projects within the existing societal conditions as well as staging the transformation of the society to be able to cope with the challenges and to provide the workforce and services that are crucial for an integration of the new industrial activities as alternative to their separation through the building of 'closed communities' around the large scale projects. At the same time the explicated goals all demonstrate a rather instrumental approach to the new business activities and the potential migrant workforce in the first three dots while the fourth dot reflects a rather defensive approach with the wording of preserving.

3.2 Discussion of the guidelines

It seems obvious that such a preservationist approach does not reflect the anticipated problems as demonstrated with the historic and contemporary examples. A more realistic approach might be to build scenarios for the those transformations of the Greenland society that will follow with large scale projects and ask how these can be moderated and how different groups in society can navigate in futures rather conflict based changes.

The Greenland guidelines employs a specific framework of defining the SIA through a process starting with describing the existing legal framework, the planning large scale project, the baseline conditions in Greenland and an analysis of alternatives to the project design and the potential impact of the different alternatives.

Crucial then become the baseline description, the potential impacts of the outlined project and eventual alternatives from the perspective of 'Maximisation of development opportunities and mitigation negative impacts' as stated in the guidelines.

As an outcome the defined set of specific conditions in Greenland and public participation as part of SIA is in this approach to planning for large scale projects leading to the formulation of Impact Benefit Agreements (IBA) in which the company and regulatory authority defines the responsibility of the company, its rights and duties and its interaction with local society.

There is no doubt that the outset and its intentions and visions included in these SIA guidelines for mining activities in Greenland are attempting to reach the anticipated goal of making large scale mining projects in Greenland feasible. The problem lies as in most cases in the details and in the assumptions implicitly provided in the guidelines.

A first problem is posed by the idea of a baseline conditions to form the outset for the SIA. This relates directly to an idea of impacts being related to the existing situation. An obvious alternative is to identify large scale projects as the meeting of two different cultures (worlds of logics and everyday life practices) in which either a merger resulting in a transformation of these practices is the result, or one of these cultures become hegemonic and marginalise the other to become the peripheral and dependent culture. The list of topics to be taken up in the baseline study (appendix 6 to the guidelines) includes quite a number of important and defining elements that constitute a Greenland community. Compared to this the elements included in the project description are mere technical and infrastructural issues not including the detailed presentation of the outset of the project in existing, global 'socio-technical and economic regimes' of mining.

The imbalance becomes clear in the approach to analysing 'potential impacts and alternatives' where a list demonstrates a much more instrumental set of targets (appendix 1 to the guidelines). Here local business, employment, education, public service, health, and cultural heritage are put to the fore, while 'social issues' is reduced to resettlements and changed demographics.

One of the important issues in this potential future transformation of the Greenland society is the time span and the scale of projects. This is so far left to the companies and their interpretation of the global market conditions when it comes to the balancing of cost of equipment, the scale of project, the

speed of start up activities and the development of market price for the resource in question. This must be contrasted to the impacts on Greenland where experiences from e.g. Canada and Alaska point to the need of countering the marginalisation of the local communities and the creation of artificial economies for the regions.

The Greenlandic government has announced that potential Greenlandic labour can only expect to be transported to and from the mine from a major city, while they themselves must pay for any transportation to smaller settlements, and the government encourages people to move towards the major cities. This also demonstrates a lack of consistency with the idea of creating a base for a next phase of development in the Greenland economy.

3.3 SIA implementation

The hitherto largest project that also has taken up a large part of the public debate is the iron mine in the inner part of the Nuuk fjord. The SIA report has recently been published and illustrate the problems outlined by leaving out any questions related the mining operation project and eventual alternatives and reducing the SIA to a detailed description of the existing outset and alone focusing on employment, education, taxation and settlement issues without any further consideration of the social impact of the project (London Mining and Grontmij 2013).

4. Questions to and suggestions for the future regulatory framework

It is as already mentioned, but still noteworthy that most of the known mineral deposits have been known for decades, but has not been exploited because no one has found it profitable. The increasing global resource shortages of certain raw materials and consequent expectations of price increases is a major explanation for the increased international interest in some of the Greenland mineral potentials. Another explanation is more intensive Greenlandic marketing of these potentials, combined with increased flexibility of the rules.

Also the geopolitical considerations of the involved superpowers as e.g. China and the countries interest in mineral exploration in Greenland play a part.

The basic questions that need to be asked concerning the mining activities in Greenland are:

- How does the Self Rule agreement and the Greenlandic interest in autonomy impact the decision making and would it be appropriate to include negotiation of the e.g. the Danish financial transfer to Greenland as an active part as it is providing a backdrop for the urgency of the situation?

- Why are the good intentions of SIA and EIA seemingly so difficult to enforce when it comes to the practical application and implementation side

- What role does the administration in Greenland and the international consultant play in this process of application and implementation?

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Impact of blasting on resource recovery, mining profit, safety and environment

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Abstract

If the ore loss is 15% in the process of mining, the total iron ore loss over the world will be about 461 million tons per year, corresponding to a total production of 230 iron ore mines each with an annual production of 2 million-ton iron ore. What a loss for natural resource! Based on a series of blast tests in LKAB Malmberget mine, this paper shows that ore recovery in mining process can be markedly increased by improving blast technology such as by choosing a correct primer position and by making use of shock wave collision. The paper further indicates that a high ore recovery can not only reduce natural resource loss but also lower mining cost and prolong the life of a mine. In addition, when blasting destroys ore mass in mining, it may cause the damage in the structures nearby. A strong blast may also cause or initiate a seismic event in underground mining. All these endanger mining operations in the field, particularly in underground mines. Then the paper shows an example for reducing blast-caused rock break in the roofs and walls of underground drifts (tunnels) by using scientific blasting in Malmberget mine. At last, the paper introduces how Malmberget mine has successfully reduced the ground vibrations, without downgrading fragmentation and ore recovery in sublevel caving mining.

1. Introduction

The natural mineral resources in the world are limited and they cannot be regenerated. Therefore, how to reduce mineral loss during mining production is one of most important issues for mining industry over the world. However, the fact is astonishing: Assume the ore loss is 15% in the process of mining (in large-scale mining such as sublevel caving the ore loss can be over 20%), the total iron ore loss over the world in year 2010 could be about 461 million tons according to the mineral production data by Brown et al. (2012), corresponding to a total production of 230 iron ore mines each with an annual production of 2 million-ton iron ore. In other words, each year we have probably buried 230 iron mines with an annual ore production of 2 million-tons over the world. What a loss for the world!

This paper will show that the above ore loss is just one of economic losses including direct economic loss because of ore loss, indirect economic loss due to increase in mining cost, and indirect economic loss due to shorter live of mines. Further, on the basis of a series of production tests in LKAB Malmberget mine, the paper will show that ore recovery can be markedly increased by scientific blasting from the present level to a higher level.

When blasting destroys ore mass in mining production, it may cause rock damage and rock break in the structures nearby. A strong blast may also cause a seismic event in underground mining. All these will endanger mining operations in the field, particularly in underground mines. This paper will show that blast-caused rock break in the roofs and walls of underground drifts (tunnels) can be efficiently reduced by using scientific blasting.

In the last part of the paper, the history and results of vibration control in Malmberget will be introduced where ground vibrations induced by underground blasts have been reduced by about 50%, mainly because of

two methods of vibration reduction used in the mine.

2. Total economic loss due to ore loss in mining

According to Brown et al. (2012), the iron ore production is 2 611 million metric tons over the world in year 2010. In terms of economy, if iron ore price is 150 US$/ton (the price in China in January 2013) and the recovery during mining process is 85%, the total ore loss will value 69 150 million US$ per year over the world! If we can reduce the ore loss by 50%, we may save 34 575 million US$ over the world per year! If we include other minerals such as gold, copper, zinc, coal, etc., as shown in Table 1, the total natural resource loss in mining process will be a significant figure each year. We call this kind of economic loss due to ore loss as direct economic loss in this paper. Take LKAB, an international mining company with all-time high technology, as an example, we know that the iron ore loss is 5.95 million tons per year from two mines-Kiruna and Malmberget according to the production database of the company from year 2006 to 2009.

Table 1-1. Mineral production over the world in year 2010 (Brown et al., 2012).

Mineral	Production in 2010 (1000 tons)	Mineral	Production in 2010 (1000 tons)
Iron ore (mine)	2 611 000	Gold (mine)	2.5
Coal	7 153 000	Silver (mine)	23.7
Crude petroleum	3 901 000	Tungsten (mine)	61.7
Copper (mine)	16 200	Uranium (mine)	54.2
Zinc (mine)	12 300	Nickel (mine)	1 552
Lead (mine)	4 200	Tin (mine)	276

In addition to the above direct economic loss, the ore loss can give rise to additional economic losses, as follows:

- Increase in mining cost, and
- Earlier investment in large project such as main level construction in underground mines.

Now we will show how much the mining cost is increased due to the ore loss in mining process. Assume that the total cost for mining out ore amounted to W_{m-res} (tons), which is planned to mine out, is C_{total} excluding the cost for large new projects such as main level, then the planned mining cost per ton is

$$C_{pl-ton} = \frac{C_{total}}{W_{m-res}} \quad (1)$$

Because of ore loss in mining process, we cannot mining out all the ore W_{m-res}. Instead, we can only take out one part of the ore W_{m-res}. This part is defined as W_{m-out}, meaning the ore is mined out. Thus, the actual mining cost is

$$C_{m-ton} = \frac{C_{total}}{W_{m-out}} \quad (2)$$

Assume the ore recovery in mining is 80% (based on the recovery in LKAB), i.e., $W_{m-out} = 0.8W_{m-res}$, then we get from Eq. (2)

$$C_{m-ton} = 1.25C_{pl-ton} \quad (3)$$

Equation (3) indicates that when ore loss is 20%, the mining cost per ton will be increased by 25%. This means that as ore loss in mining increases, the mining cost will increase faster than the ore loss.

For underground mines, a main level construction is usually a heavy investment, and a new main level must be built with increasing mining depth. Assume that a main level in a large underground mine costs 3000 million US$, and the main level is planned to work 20 years if ore recovery can reach 100% in mining. However, if ore recovery is 80% and annual production is kept same as planned, the ore production within the new main level will not be sufficient for 20 year-production. Instead, only enough to 16 year-production, meaning that the next new main level must be built 4 years earlier. If the company has to loan 3000 million US$ 4 years earlier, and the interest rate is 3%, then the extra cost will be

3000 mUS$ x 3% x 4 year = 360 mUS$

If the company does not need loan the money, it can be used to make any other business investment.

In conclusion, the ore loss in mining process will result in three kinds of economic losses:

- Direct economic loss due to the ore failed to mine out in mining process;
- Increase in mining cost due to ore loss in mining;
- Earlier heavy investment such as main level project.

The factors influencing the ore loss in mining process can be many such as mining method, mining planning, drilling plan and technique, blast plan and operation, loading operation and cut-off control in production, etc. Among these, rock blasting is considered to be one of most important factors. Based on a series of blast tests in LKAB Malmberget mine, we will show that ore recovery in mining process can be markedly increased by improving blast operation such as by choosing a correct primer position and by making use of shock wave collision.

3. Increasing ore recovery by blasting

Rock blasting has a great potential to make mining process more profitable. On one hand, blast operation in industry has still been dominated by experience or conventional blasting methods; on the other hand, there are both advanced theories and high technology available to largely improve the present blast operation. For example, by only changing primer position from lowest place to middle of the charged borehole, the ore extraction from 40 test rings was increased by 107% and the grade in the extracted ore increased by 7.2%, compared with 210 ordinary rings in the same drifts in Malmberget mine (2005). When the test method was applied to a whole ore body, the ore recovery from 4 drifts (JH437-2, 3, 4, and 6, see Figure 1) on one production level of a mining region has reached 82.7%, 83.5%, 114% and 154% respectively (Zhang, 2008), which is markedly higher than the average recovery 80% in the whole mine. At the same time, the grade in extracted ore has been increased too. Note that the recovery figures 82.7% and 83.5% are from two independent narrow ore bodies which usually give rise to much lower recovery than larger ore bodies, so it is certainly possible to obtain much higher ore recovery than 80% in the whole mine. We will further indicate that a high ore recovery can not only reduce natural resource loss but also reduce mining cost and prolong the life of a mine.

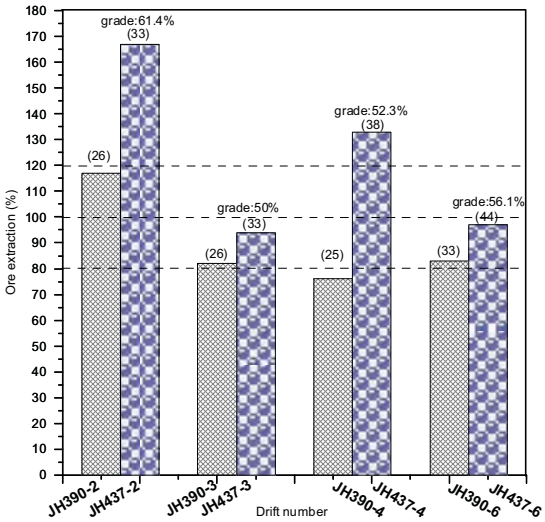

Figure 1: Ore extraction influenced by detonator/primer position. The figures in the brackets show the quantity of rings included for each drift. Four drifts JH390-2, 3, 4 and 6 with lower primer position, while drifts JH437-2, 3, 4 and 6 with middle primer position (Zhang, 2008).

One of most important reasons for the increased ore recovery in the middle primer rings is the fragmentation has greatly been improved. As shown in Figure 2, the muckpiles of the middle primer rings usually look finer than that of the lower primer rings after blasting (ore extraction has not started yet). A theoretical analysis can be found in Zhang (2005).

Figure 2: Comparison of fragmentation in ordinary ring with lowest primer (upper) and test ring with middle primer (lower). The paper in both pictures is the same paper with a size of 400x500 mm (Zhang, 2005).

Since year 2010 LKAB has continued improving fragmentation in Malmberget mine by using two methods: one is called DRB (Dividing Ring Blasting) and the other named Double-primer method. The production tests showed that the Double-primer method had given rise to much higher ore recovery than either the ordinary method used in the daily blasts in the mine, or the DRB tested together with the Double-primer method. Figure 3 is the fragmentation after the blasting of a Double-primer ring. We may see that the fragmentation is very fine. In this case, we can not only increase ore recovery in mining process but also reduce the energy consumption in the down-stream operations such as crushing and grinding. A detailed results for the double-primer tests will be reported separately in the future. In addition, a very fine fragmentation can also make extraction speed increased, as reported by Zhang (2008), meaning that mining productivity will be increased, or mining costs can decrease.

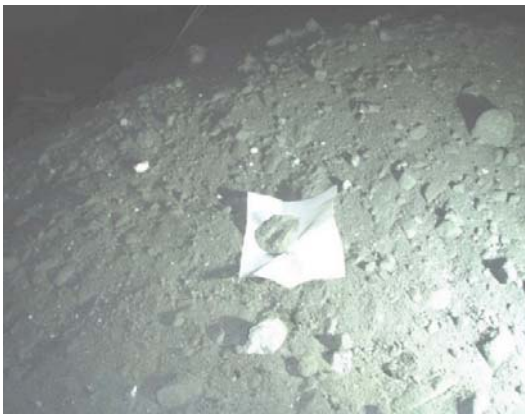

Figure 3: Fragmentation for double-primer placement AL992. The size of the paper is A4.

4. Improving mining safety through blasting

Nothing is more valuable than human beings life. Therefore, Safety First is usually the watchword of a mining enterprise. As a matter of fact, many safety problems such as rock spalling, hanging roofs, seismic events, rock fall, collapse of final slope of an open pit, fly rocks in mining are related to rock blasting either directly or indirectly. For example, rock spalling in forms of eyebrow break, drift roof and drift wall break is usually caused by tensile stress waves from rock blasting (Zhang, 2008 & 2011); hanging roofs are often induced by a bad charge or poor blast plan (Zhang, 2006 & 2008); many seismic events take place immediately after a strong blast (Eremenko et al., 2009); fly rocks and air blast are often given rise to by an incorrect charge and blast plan.

In this part we only take eyebrow break, a typical spalling, as an example to show that blast-caused eyebrow break can be largely reduced by scientific blasting rather than by empirical one.

The picture in upper Figure 4 indicates that the roof and the eyebrow of the drift are seriously broken, mainly because the primer is placed at the lowest charge place in each borehole. On the contrary, the roof of the drift in the lower picture is not broken at all, and the eyebrow break is much less than that in the upper picture because the primers are placed at the middle of charge. More results about this have been reported by Zhang (2005). In order to further reduce eyebrow break in sublevel caving, the Double-primer method using the Nonel detonators was tested in the Malmberget mine. The result is successful, i.e. the eyebrow break has markedly been reduced by this method, see Figure 5 (Zhang, 2011). After that, for improving fragmentation further, the Double-primer method was employed again in the mine, but this time electronic detonators are used. The result

Figure 4: Eyebrow and roof break in ordinary ring with lowest primer position (upper) and test ring with middle primer position (lower) (Zhang, 2005).

indicates that as fragmentation becomes better and recovery higher, the eyebrow break decreases at the same time, as shown in Figure 6. In this case, both the charge and loading operations become much safer.

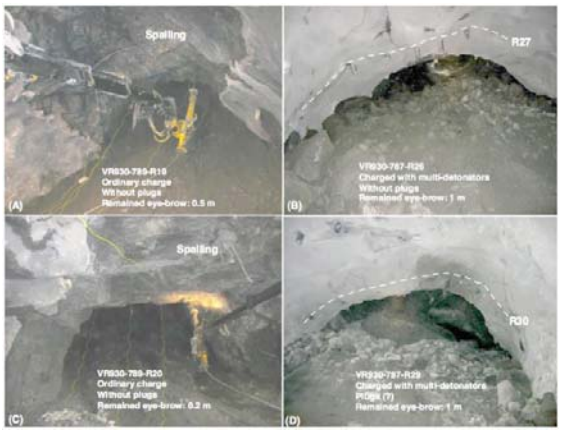

Figure 5: Eyebrow break from ViRi 930. Left: ordinary rings; right: test rings with double-primer placement with Nonel detonators (Zhang, 2011)

Figure 6: Eyebrow break from AL992 by using double-primer placement with electronic detonators.

5. Reducing blast-caused vibrations and damage to environment

Rock blasting always induces ground vibrations and causes damage to environment such as polluting underground water due to undetonated explosive. The question is whether we can reduce the vibrations and the damage while the

blasting results such as fragmentation are not worsened. The practice in LKAB's Malmberget mine has proved this. Malmberget mine is a large scale underground mine that produces 16 million-ton crude iron ore per year. In order to meet the requirement for a large scale production, a large and long blasthole is used in the mine, giving rise to much explosive to be charged in a single hole. In addition, one of the production areas in the mine is very close to the Malmberget town. The above factors make the ground vibrations induced by production blasts reach a high level. The maximum vibrations were up to 19 mm/s from 2000 to 2002. In 2002, LKAB Malmberget mine started to try a technique which can be called Stress Wave Superposition, originally reported by Blair (1987) and Hinzen (1988) and later by many scientists such as Hoshino et al (2000) and Yang & Lownds (2011). The test results from the Malmberget mine indicated that by using this method the vibrations had been reduced by 10%. But the reduction was not enough for Malmberget's situation and the method required regular single shot from production blasts, meaning the disturbance to mining production could be often, and the cost would be high. Accordingly, a new method was developed which is called Changing Initiation Sequence in Ring Blasts (CIS). The test results with the CIS method indicated that this method was efficient in vibration reduction. In addition, the third method, named Dividing Ring Blasting (DRB), was developed and then applied to some particularly-large rings with a success. All of the three methods have been reported by Zhang et al (2004), Zhang & Naarttijärvi (2005), and Zhang (2012).

Since 2004 the CIS method has been used in all of production rings in the two drifts from which vibrations are always very high. For most large rings the DRB method was applied so as to further reduce the vibrations. Both methods have been proved to be successful in vibration reduction, and they do not need additional costs. Mainly because of the two methods, both maximum vibrations and average ones have largely been reduced since 2004, as shown in Figure 7 (Zhang, 2012). According to Figure 7, the average vibration (vertical particle velocity) is 4.89 mm/s from the September of 2000 to the December of 2003, and the average vibration is 2.40 mm/s from the January of 2004 to the April of 2010. We can see that the average vibration reduction is about 50%, mostly because of the methods used.

In underground multi-hole blasts, a common problem is that some blastholes are often not detonated, resulting in that the explosives in the undetonated boreholes finally go into underground water system partly or wholly. As a consequence, the underground water is polluted and the environment is damaged. To reduce such a damage to environment, the undetonated explosive must be reduced or avoided by using advanced blast technology.

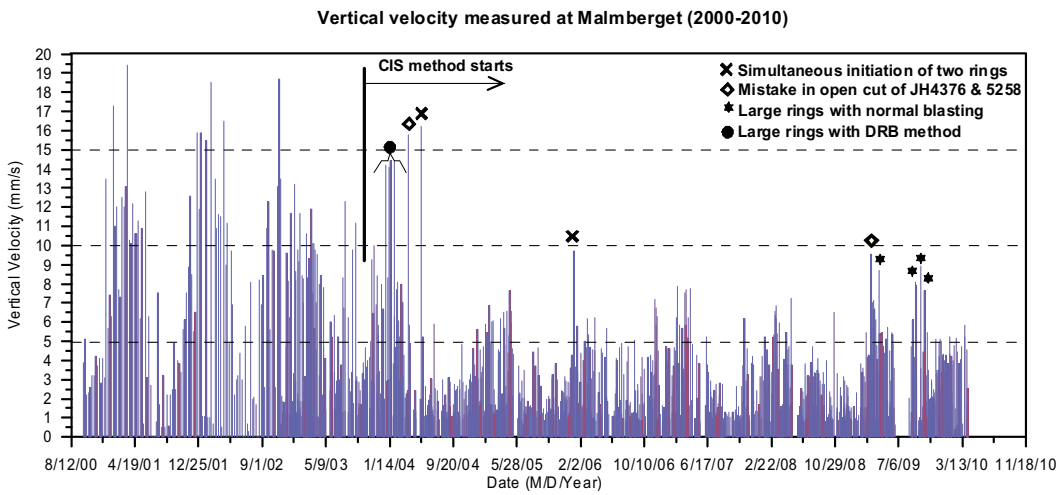

Figure 7: Underground blast caused vibrations measured at Malmberget (2000-2010).

6. Discussion

Scientifically, the yearly huge amount of mineral resource loss over the world mentioned in this paper can be largely reduced by making full use of modern science and technology. At the same time the mining safety can be improved and the blast-caused damage to environment can be reduced. However, the things are not so simple in reality. Many factors excluding science and technology usually play a large role in decelerating the applications of scientific achievements and advanced technology. For example, it is the experience rather than science that has so far dominated in mining industry; the bridge between scientific research and production is fragile in many mining companies; in some companies, a scientific person such as an engineer does not have enough power to steer the application of a new technology, or a technical decision is not made mainly by engineers but only by leaders. The fact is that the leaders who have a very good knowledge in rock mechanics, mining science, rock blasting, etc. are not so many. Therefore, in order to greatly improve this situation in mining industry, a sufficient education on rock mechanics, mining science and rock blasting to the people, especially leaders, in mining industry is necessary.

7. Conclusions

The total iron ore loss in mining over the world is about 461 million tons per year, corresponding to the total production of 230 iron ore mines each produces 2 million-ton iron ore per year. If include other minerals such as gold, silver, copper etc, we may find the mineral loss in mining is a tremendous huge amount each year in the world.

On the basis of a series of blast tests in LKAB Malmberget mine, we have seen that ore recovery in mining process can be markedly increased by improving blast technology such as by choosing a correct primer position. In addition, high ore recovery can not only reduce natural resource loss but also reduce mining cost and prolong the life of a mine. Further, mining safety can be improved by applying a scientific blasting. For example, blast-caused rock break in the roofs and walls of underground drifts (tunnels) has largely been reduced by improving the blast operation in Malmberget mine. In addition, the ground vibrations induced by blasts in Malmberget has efficiently been reduced by applying scientific blasts in sublevel caving mining.

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Risk Informed Decision Making for Sustainable Mining in the Arctic

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Abstract

The present paper addresses the quandary of sustainable raw materials exploitation in the arctic; fundamentally a tradeoff between chances and risks associated with economic growth, environmental depletion and damages, social structures, welfare, livelihoods and cultural values. Outset is taken in a discussion of sustainability and sustainable decision making from the perspective of society. It is suggested that sustainable societal decision making may be supported through a societal process in which the preferences of society are formed on the basis on information concerning their associated risks. A framework is then provided on risk informed decision making developed by the Joint Committee on Structural Safety (JCSS) and it is discussed how this framework might be utilized in a structured process of risk communication for the identification of sustainable avenues of societal developments. Finally, the suggested framework is mapped on the context of mining developments in Greenland and it is highlighted and discussed on which issues the future focus with respect to improving the decision basis for sustainable societal developments in Greenland should be directed.

1. Introduction

General societal pressure on the availability of raw materials such as minerals, critical and rare earth element as well as oil and gas increasingly direct attention on the prospects of exploration and exploitation activities in the high arctic. The effect of climate change on reductions in the extent and duration of ice coverage of the arctic seas add to the focus on the arctic regions for raw materials exploitation and shipping.

On the one hand these developments open up opportunities for economical growth and improved welfare for the population in regions where at present livelihoods are under significant pressure and social problems are widespread. However, on the other hand raw materials exploitation is associated with significant risks to the fragile arctic environment, to the original cultures and as developments in many parts of the world have show, may also lead to an unintended natural resource dominated economical dependency – with significant societal problems as a consequence – an effect which is also known as the resource curse.

Effectively the management of raw materials exploitation in arctic societies constitutes a new activity where not only the technical capabilities of various industries are pressed beyond their present level but also the related processes of societal planning and governance are pushed into new land. Considering the possible gravely adverse consequences which may be associated with these activities in especially the long term it is obvious that sustainable societal developments must take basis in a thorough understanding of all relevant risks and chances. Moreover, sustainability is not a preference of the free market mechanisms, why a strong governmental management of activities of raw material exploitation is crucial.

The present paper starts out with a general discussion on societal and preferences and societal preferences for sustainability in particular. Thereafter a process for risk informed societal decision making resting on

the concept of informed preferences is suggested as a means of facilitating sustainable societal developments. A framework is then presented for systems risk assessment which enhances proactive optimization of sustainable societal developments. The suggested framework aims to maximize benefits and reduce risks holistically with due consideration of vulnerability and robustness in the face of the manifold uncertainties associated with different decision alternatives and not least exogenous boundary conditions.
Finally, the suggested framework is mapped on the case of mining in Greenland; a preliminary system identification is outlined and suggestions are provided on where to direct the emphasis of future efforts aiming to enhance sustainable decision making for the benefit of the society of Greenland.

2. Society and Sustainability

For the purpose of sustainable societal decision making it is necessary that certain attributes of society and sustainability are identified. These include the preferences, possible exogenously given boundary conditions as well as limitations in regard to resources.

2.1 On the representation of a society

A society may be represented as an entity of people for which common preferences may be identified exogenous boundary conditions are the same and which share common resources. Considering a country as a society it is realized that such a society may comprise a hierarchical structure of societies defined at lower levels, such as communes, municipalities and communities; each society with their set of attributes partly defined through the societies at higher level. For decision making on behalf of society defined at the highest level, such as a state or a country, the societal instruments available to ensure optimal decision making are in practice limited to organizational structures, laws and regulations, taxation and subvention. The organizational structure dictates the availability or resources and thereby set the budgeting constraints for societal activities. The laws and regulations define criteria in regard to acceptable risks to persons and environment and taxation as well as subvention may be implemented strategically to direct future societal developments. At lower levels the optimization of decisions will always be subject to boundary conditions given through organizations, laws and regulations.

2.2 Considerations on sustainability

During the last three decades, is has become generally accepted that our world only has limited non-renewable natural resources such as energy and materials but also limited renewable resources like drinking water, clean air etc.. The so-called Brundtland Commission (Brundtland (1987)) concluded that a sustainable development is defined as a development ''that meets the needs of the present without compromising the ability of future generations to meet their own needs''. Sustainable decision making is now understood as decisions which take basis in a joint consideration of society, economy and environment. Seen in the light of the conclusions of the Brundtland report intergenerational equity must be accounted for; our generation must not leave the burden of maintenance or replacement of societal infrastructure to future generations and it must not use more of the natural and financial resources than are really available.
In order to assess the sustainability of a given decision in quantitative terms, and thereby to provide a basis for consistent decision making, first of all a basis must be established for the representation of what is understood as sustainability in terms of observable indicators which can be related to the preferences of society.

2.3 Risk information and sustainability

Risk assessments and risk information has significant potential in supporting the decision process for sustainable societal developments. In Faber (2011) it is highlighted that the present lack of a systematic assessment and management of risks associated with common activity loss events of small consequences but high occurrence probabilities indeed may constitute a major if not the most important barrier for sustainable societal development

– and that the consequence for the global society is catastrophic.

To some extent there is always a relationship between major societal changes and the exposure of a society to catastrophic risks. Such possible interrelations must of course always be systematically assessed, managed and communicated. Considering exploitation of raw materials catastrophic risks may be due to events of major toxic releases to the environment, major industrial accidents in relation to the processes of exploitation or refinement with consequences in terms loss of lives as well as the complete loss of cultural values and heritage.

The theoretical basis for risk informed decision making has been available since the axioms of utility theory were formulated by van Neumann and Morgenstern (1943) and the development of the Bayesian decision analysis, see e.g. Raiffa and Schlaiffer (1961). For aspects of sustainability which may be quantified and compared in a common unit, e.g. monetary consequences this framework facilitates consistent ranking of decision alternatives. However, an agreement on how to assess and compare the various attributes of sustainable societal developments has not yet been reached. According to the strong interpretation of sustainability it is not possible to assess a monetary equivalent of damages to the qualities of the environment. Whereas the weak interpretation of sustainability in principle facilitates for this, see e.g. Solow (1993), there are substantial problems associated with establishing a theoretical framework for doing this consistently.

For what concerns the attributes society and economy, a consistent risk informed framework for their joint consideration in support of sustainable societal developments seems to be available. The marginal life saving costs principle see e.g. Faber and Maes (2010) requires that societal investments into activities with an effect on life safety should correspond to and not exceed a certain limiting value. The limiting value shall corresponding to the societal preferences for life safety and be in balance with societal capacity to invest. The consistent implementation of marginal life saving costs principle is greatly facilitated by the Life Quality Index (LQI), see e.g. Nathwani et al. (1997) which allows for the quantification of the limiting value of life saving investments in dependency of demographic indicators.

In socio-economic cost benefit assessments in general it is important to account for the preferences of future generations by means of appropriate discounting of future benefits and expenditures, see e.g. Rackwitz et al. (2005).

Presently, with respect to the attributes of sustainability relating to the qualities of the environment the present direction of thinking is to formulate indicators of sustainability in regard to the environment by means of a large list of different observable environmental qualities, e.g. availability of drinking water, availability of non-recyclable resources etc. Indicators of sustainability are formulated e.g. in Altwegg et al. (2003); in European Communities (2001) a rigorous listing of indicators of the condition of the environment is also provided. In Lomborg (2001) a rather rigorous statistical investigation of a large number of indicators related to the present state of the earth is described. The results of the mentioned works form a good basis for directing the focus for decision making to the areas which really matters or where problems have already emerged.

Considering consequences to the qualities of the environment which can be related to increased mortality and morbidity for humans Lentz and Rackwitz (2004) and investigate approaches to assess the feasibility of risk reduction. The idea followed is to modify the LQI approach accounting for the possibly delayed effect of morbidity on mortality.

Considering damages to environmental qualities with no known relation to morbidity and mortality for humans an approach denoted the Environmental Quality Index (EQI) is suggested in Ditlevsen and Friis-Hansen (2004). The principle suggested there is to assess the willingness to pay for avoiding such damages in terms of the character and duration of the consequences.

In regard to damages to the eco-system which may occur as a consequence of extinction of species there is still no basis for relating these to either societal or monetary scales. So far most of the reported work has been directed to identify

species which are assumed critical for the eco-system of humans, see e.g. (Lomborg (2001)). The exploitation or non-recyclable natural resources has characteristics similar to damages in the form of extinction of species. On the short term such damages may seem unimportant but on the long term their significance are not well understood.

It should be emphasized that attributes of sustainability related to culture such as cultural values and cultural heritage in the same manner as environmental qualities are difficult to quantify. It appears that approaches like willingness to pay to mitigate loss of cultural values could be of use also in this context but little research has been reported on these aspects so far.

A final aspect which needs mentioning especially in the context of societal decision making on issues of potential geopolitical implications are the attributes of sustainability related to national sovereignty – or national security. Raw materials exploitation in the arctic presently has a marked geopolitical attention and some of the materials being sought for are of substantial strategic value in industrial and military developments. The treatment of these attributes in the context of societal decision making is a subject of security studies as addressed in e.g. Popova (2011).

In summary, it may be stated that the presently available knowledge suggests that the best that can be done in support of sustainable decision making is to assess the risks which are associated with different possible decision alternatives – in all their relevant dimensions – addressing the attributes which are associated with sustainable societal developments. Based on risk assessments it is possible to compare the consequences of different decision alternatives.

For the attributes of sustainability which cannot scientifically consistent be related to consequences on economy or life safety the total picture of the assessed risks may provide basis for a societal decision making process in which the relative importance assigned to these is assessed in terms of effects on economy and life safety. Such a decision making process is often referred to as being based on informed preferences. In the subsequent a suggestion for a protocol in support of development of risk informed preferences for sustainable societal developments will be presented.

3. The Process of Decision Making

As outlined in the foregoing sustainable societal developments may be supported by information concerning the risks associated with different strategies and options for societal developments. This necessitates that risks are understood and communicated clearly and unemotionally among societal stakeholders, i.e. subject matter experts, public decision makers, industry and the general public.

3.1 Roles in risk communication

Public decision makers and the general public need to be informed in a balanced way about the risks associated with societal developments. In the context of strategic planning of sustainable societal developments, such as in the case of assessing different possible strategies for raw materials exploitation in the arctic the risks of concern in principle include all aspects of possible changes for the involved societal stakeholders – but in particular those changes which have either a positive or negative effect on sustainable societal developments.

The responsibility for establishing and disseminating appropriate information and taking suitable precautions rests with the government. Societal decision makers are accountable and should therefore seek advice from subject-matter experts; e.g., scientists and specialized engineers. As mentioned in the foregoing, scientific risk assessments form the strongest available rationale to support societal decision making.

In the interest of the public, societal decision makers should have an adequate informed understanding of risks and best practices in risk management in order to be able to validate, confirm and assess the quality of the professional advice they receive.

Subject-matter experts shall provide their advice in accordance with the state of the art and the best practices within their area of expertise. Impartiality, objectiveness and ethical conduct in general, are to be

Risk Informed Decision Making for Sustainable Mining in the Arctic

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Abstract

The present paper addresses the quandary of sustainable raw materials exploitation in the arctic; fundamentally a tradeoff between chances and risks associated with economic growth, environmental depletion and damages, social structures, welfare, livelihoods and cultural values. Outset is taken in a discussion of sustainability and sustainable decision making from the perspective of society. It is suggested that sustainable societal decision making may be supported through a societal process in which the preferences of society are formed on the basis on information concerning their associated risks. A framework is then provided on risk informed decision making developed by the Joint Committee on Structural Safety (JCSS) and it is discussed how this framework might be utilized in a structured process of risk communication for the identification of sustainable avenues of societal developments. Finally, the suggested framework is mapped on the context of mining developments in Greenland and it is highlighted and discussed on which issues the future focus with respect to improving the decision basis for sustainable societal developments in Greenland should be directed.

1. Introduction

General societal pressure on the availability of raw materials such as minerals, critical and rare earth element as well as oil and gas increasingly direct attention on the prospects of exploration and exploitation activities in the high arctic. The effect of climate change on reductions in the extent and duration of ice coverage of the arctic seas add to the focus on the arctic regions for raw materials exploitation and shipping.

On the one hand these developments open up opportunities for economical growth and improved welfare for the population in regions where at present livelihoods are under significant pressure and social problems are widespread. However, on the other hand raw materials exploitation is associated with significant risks to the fragile arctic environment, to the original cultures and as developments in many parts of the world have show, may also lead to an unintended natural resource dominated economical dependency – with significant societal problems as a consequence – an effect which is also known as the resource curse.

Effectively the management of raw materials exploitation in arctic societies constitutes a new activity where not only the technical capabilities of various industries are pressed beyond their present level but also the related processes of societal planning and governance are pushed into new land. Considering the possible gravely adverse consequences which may be associated with these activities in especially the long term it is obvious that sustainable societal developments must take basis in a thorough understanding of all relevant risks and chances. Moreover, sustainability is not a preference of the free market mechanisms, why a strong governmental management of activities of raw material exploitation is crucial.

The present paper starts out with a general discussion on societal and preferences and societal preferences for sustainability in particular. Thereafter a process for risk informed societal decision making resting on

the concept of informed preferences is suggested as a means of facilitating sustainable societal developments. A framework is then presented for systems risk assessment which enhances proactive optimization of sustainable societal developments. The suggested framework aims to maximize benefits and reduce risks holistically with due consideration of vulnerability and robustness in the face of the manifold uncertainties associated with different decision alternatives and not least exogenous boundary conditions.
Finally, the suggested framework is mapped on the case of mining in Greenland; a preliminary system identification is outlined and suggestions are provided on where to direct the emphasis of future efforts aiming to enhance sustainable decision making for the benefit of the society of Greenland.

2. Society and Sustainability

For the purpose of sustainable societal decision making it is necessary that certain attributes of society and sustainability are identified. These include the preferences, possible exogenously given boundary conditions as well as limitations in regard to resources.

2.1 On the representation of a society

A society may be represented as an entity of people for which common preferences may be identified exogenous boundary conditions are the same and which share common resources. Considering a country as a society it is realized that such a society may comprise a hierarchical structure of societies defined at lower levels, such as communes, municipalities and communities; each society with their set of attributes partly defined through the societies at higher level. For decision making on behalf of society defined at the highest level, such as a state or a country, the societal instruments available to ensure optimal decision making are in practice limited to organizational structures, laws and regulations, taxation and subvention. The organizational structure dictates the availability or resources and thereby set the budgeting constraints for societal activities. The laws and regulations define criteria in regard to acceptable risks to persons and environment and taxation as well as subvention may be implemented strategically to direct future societal developments. At lower levels the optimization of decisions will always be subject to boundary conditions given through organizations, laws and regulations.

2.2 Considerations on sustainability

During the last three decades, is has become generally accepted that our world only has limited non-renewable natural resources such as energy and materials but also limited renewable resources like drinking water, clean air etc.. The so-called Brundtland Commission (Brundtland (1987)) concluded that a sustainable development is defined as a development ''that meets the needs of the present without compromising the ability of future generations to meet their own needs''. Sustainable decision making is now understood as decisions which take basis in a joint consideration of society, economy and environment. Seen in the light of the conclusions of the Brundtland report intergenerational equity must be accounted for; our generation must not leave the burden of maintenance or replacement of societal infrastructure to future generations and it must not use more of the natural and financial resources than are really available.
In order to assess the sustainability of a given decision in quantitative terms, and thereby to provide a basis for consistent decision making, first of all a basis must be established for the representation of what is understood as sustainability in terms of observable indicators which can be related to the preferences of society.

2.3 Risk information and sustainability

Risk assessments and risk information has significant potential in supporting the decision process for sustainable societal developments. In Faber (2011) it is highlighted that the present lack of a systematic assessment and management of risks associated with common activity loss events of small consequences but high occurrence probabilities indeed may constitute a major if not the most important barrier for sustainable societal development

– and that the consequence for the global society is catastrophic.

To some extent there is always a relationship between major societal changes and the exposure of a society to catastrophic risks. Such possible interrelations must of course always be systematically assessed, managed and communicated. Considering exploitation of raw materials catastrophic risks may be due to events of major toxic releases to the environment, major industrial accidents in relation to the processes of exploitation or refinement with consequences in terms loss of lives as well as the complete loss of cultural values and heritage.

The theoretical basis for risk informed decision making has been available since the axioms of utility theory were formulated by van Neumann and Morgenstern (1943) and the development of the Bayesian decision analysis, see e.g. Raiffa and Schlaiffer (1961). For aspects of sustainability which may be quantified and compared in a common unit, e.g. monetary consequences this framework facilitates consistent ranking of decision alternatives. However, an agreement on how to assess and compare the various attributes of sustainable societal developments has not yet been reached. According to the strong interpretation of sustainability it is not possible to assess a monetary equivalent of damages to the qualities of the environment. Whereas the weak interpretation of sustainability in principle facilitates for this, see e.g. Solow (1993), there are substantial problems associated with establishing a theoretical framework for doing this consistently.

For what concerns the attributes society and economy, a consistent risk informed framework for their joint consideration in support of sustainable societal developments seems to be available. The marginal life saving costs principle see e.g. Faber and Maes (2010) requires that societal investments into activities with an effect on life safety should correspond to and not exceed a certain limiting value. The limiting value shall corresponding to the societal preferences for life safety and be in balance with societal capacity to invest. The consistent implementation of marginal life saving costs principle is greatly facilitated by the Life Quality Index (LQI), see e.g. Nathwani et al. (1997) which allows for the quantification of the limiting value of life saving investments in dependency of demographic indicators.

In socio-economic cost benefit assessments in general it is important to account for the preferences of future generations by means of appropriate discounting of future benefits and expenditures, see e.g. Rackwitz et al. (2005).

Presently, with respect to the attributes of sustainability relating to the qualities of the environment the present direction of thinking is to formulate indicators of sustainability in regard to the environment by means of a large list of different observable environmental qualities, e.g. availability of drinking water, availability of non-recyclable resources etc. Indicators of sustainability are formulated e.g. in Altwegg et al. (2003); in European Communities (2001) a rigorous listing of indicators of the condition of the environment is also provided. In Lomborg (2001) a rather rigorous statistical investigation of a large number of indicators related to the present state of the earth is described. The results of the mentioned works form a good basis for directing the focus for decision making to the areas which really matters or where problems have already emerged.

Considering consequences to the qualities of the environment which can be related to increased mortality and morbidity for humans Lentz and Rackwitz (2004) and investigate approaches to assess the feasibility of risk reduction. The idea followed is to modify the LQI approach accounting for the possibly delayed effect of morbidity on mortality.

Considering damages to environmental qualities with no known relation to morbidity and mortality for humans an approach denoted the Environmental Quality Index (EQI) is suggested in Ditlevsen and Friis-Hansen (2004). The principle suggested there is to assess the willingness to pay for avoiding such damages in terms of the character and duration of the consequences.

In regard to damages to the eco-system which may occur as a consequence of extinction of species there is still no basis for relating these to either societal or monetary scales. So far most of the reported work has been directed to identify

species which are assumed critical for the eco-system of humans, see e.g. (Lomborg (2001)). The exploitation or non-recyclable natural resources has characteristics similar to damages in the form of extinction of species. On the short term such damages may seem unimportant but on the long term their significance are not well understood.

It should be emphasized that attributes of sustainability related to culture such as cultural values and cultural heritage in the same manner as environmental qualities are difficult to quantify. It appears that approaches like willingness to pay to mitigate loss of cultural values could be of use also in this context but little research has been reported on these aspects so far.

A final aspect which needs mentioning especially in the context of societal decision making on issues of potential geopolitical implications are the attributes of sustainability related to national sovereignty – or national security. Raw materials exploitation in the arctic presently has a marked geopolitical attention and some of the materials being sought for are of substantial strategic value in industrial and military developments. The treatment of these attributes in the context of societal decision making is a subject of security studies as addressed in e.g. Popova (2011).

In summary, it may be stated that the presently available knowledge suggests that the best that can be done in support of sustainable decision making is to assess the risks which are associated with different possible decision alternatives – in all their relevant dimensions – addressing the attributes which are associated with sustainable societal developments. Based on risk assessments it is possible to compare the consequences of different decision alternatives.

For the attributes of sustainability which cannot scientifically consistent be related to consequences on economy or life safety the total picture of the assessed risks may provide basis for a societal decision making process in which the relative importance assigned to these is assessed in terms of effects on economy and life safety. Such a decision making process is often referred to as being based on informed preferences. In the subsequent a suggestion for a protocol in support of development of risk informed preferences for sustainable societal developments will be presented.

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exercised and expected to meet the highest standards. Due to the underlying and unavoidable uncertainties, the quality of scientific advice concerning risk management cannot be judged on the success of predicting events or avoiding losses, but only on the quality of the underlying probabilistic/statistical analyses and risk assessments.

Communication of risks to the public is an important part of risk management. Consequences associated with the public perception of adverse or disastrous events depend strongly on the information disseminated before the event. Moreover, unbiased communication about risks supports the development of a risk culture and enhances rational behavior. Information symmetry among stakeholders is a well-appreciated prerequisite for collaborative efforts as needed in public risk management.

3.2 Protocol for risk communication

In the following a protocol is suggested to support communication of risk information in support of sustainable societal developments. The protocol is directed specifically on the support of societal decision making in the process of assessing and preparing for significant strategic societal changes. A protocol for risk communication in the context of disaster risk management is proposed in Faber et al. (2012).

Starting point is taken in a targeted process for the identification of the attributes of sustainability. For the attributes relating to economy, life safety and health this process may not be too difficult but for what concerns attributes relating to the qualities of the environment, the culture and national sovereignty special attention must be paid. General agreement on such issues within the general population is hardly achievable and the identification process must follow normal democratic procedures. The most important issue here is to realize that the choice of attributes constitutes the underlying rationale for the decision making process and thus to a very large extent dictate the final decisions.

Having established the attributes of sustainable societal developments, risk communication should address the situations before the societal change and after the introduction of the societal change. The communication about risks with respect to the various attributes of sustainability should encompass the entire context of risk management, at different societal levels, and should address different groups of stakeholders. The general public should, moreover, be informed about:

- Who is responsible for public risk management?
- Why is risk management essential in public governance?
- Which are the risks to which societal developments and the public presently are exposed – where do the risks come from and what can be expected if no societal change is introduced?
- Which are the different optional strategies for introducing the societal change and which are the risks associated with the different strategies – in all dimensions of the attributes of sustainability?
- Which are the major assumptions underlying the different strategies and risk models?
- How is it envisaged that strategies may be adapted or changed based on yet unknown future exogenous developments (climate change, global economy, etc.)
- How will such changes affect the risks and how will adaptations of strategies be triggered?

As a part of this communication a process shall be undertaken in which the weighing of different attributes of sustainability is varied such as to communicate and inform about the impact of different relative valuations of the attributes on the optimal choice of strategies. This iterative process in itself should be communicated from the very beginning as a means of establishing informed preferences concerning the relative valuation of attributes.

Again, following normal governmental/ democratic procedures it is decided whether or not the considered societal change should be introduced and if it is, according to which strategy.

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Again, following normal governmental/ democratic procedures it is decided whether or not the considered societal change should be introduced and if it is, according to which strategy.

During the period of implementation, based on the actual knowledge on the effects of the change, the public should be informed about:

- Actual development of the attributes of sustainable societal developments.
- Developments in the validity of assumptions underlying the choice of strategy.
- Updated projections for the development of risks.
- Possible needs for or prospects of adaptation of strategy.
- The rationale for introduced adaptations or changes.

Considering the importance of the quality of the basis for decision making for societal success it is important that risk assessments are conducted according to best available knowledge and state of the art. The risk assessments should be publicly available and subject to peer-review.

4. Risk Assessment Framework

4.1 System identification

In developing risk models to support societal decision making by means of risk information the first activity is to undertake a thorough identification of the considered societal system. At an intra-generational level the characteristics of the system consist of the knowledge about the particular society or activity considered e.g. in the present context raw materials exploitation and the surrounding world, the available decision alternatives and criteria (preferences) for assessing the benefit associated with the different decision alternatives (see Figure 1) (as discussed in more detail in Section 3.2.). A very significant part of risk informed decision making in practice is concerned with the identification of the characteristics of the system and the interrelations with the surrounding world as well as the identification of risk acceptance criteria, possible consequences and their probabilities of occurrence. Managing risks is done by “buying” physical changes of the considered system or “buying” knowledge about the system and the surrounding world such that the objectives of the decision making are optimized.

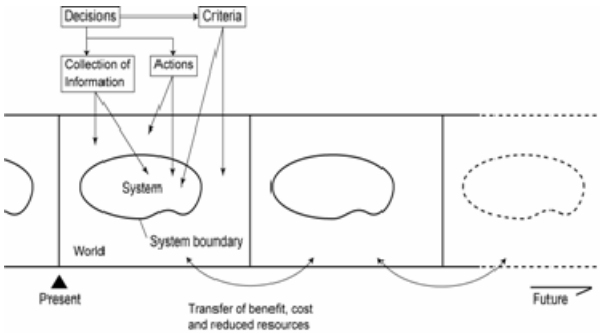

Figure 1: Main constituents of systems in risk based intra-/intergenerational decision analysis, Faber and Nishijima (2004).

A system representation, i.e. a model of reality, can be formulated in terms of logically interrelated constituents at various levels of detail or scale in time and space. Constituents may be physical components, procedural processes and human activities. The appropriate level of detail or scale depends on the physical or procedural characteristics or any other logical entity of the considered problem as well as the spatial and temporal characteristics of consequences.

The important issue when a system model is developed is that it facilitates a risk assessment and risk ranking of decision alternatives which is consistent with available knowledge about the system and which facilitates that risks may be updated according to knowledge that may become available at future times (JCSS, 2008).

The risk assessment for a given system is facilitated by considering the generic representation of the development of consequences in figures 2-3.

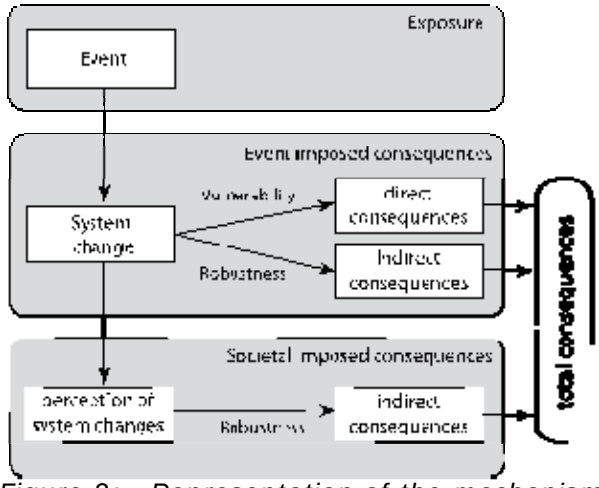

Figure 2: Representation of the mechanism generating consequences (JCSS. 2008).

Following, JCSS (2008), the exposure to the system is represented as different exposure events acting on the constituents of the system. The constituents of the system can be considered as the system's first defense with regard to the exposures. The damages of the constituents are considered to be associated with direct (or marginal) consequences.

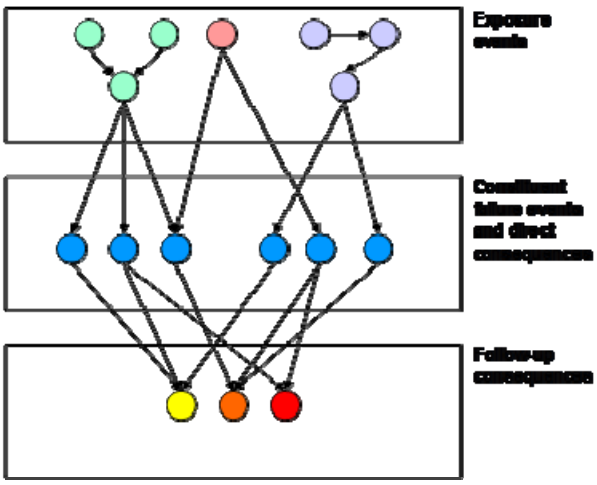

Figure 3: Logical representation of interrelations between exposures, constituent failures, sequences of constituent failures and consequences (JCSS, 2008).

Direct consequences may comprise different attributes of the system such as monetary losses, loss of lives, dam-ages to the qualities of the environment or just changed characteristics of the constituents. In consistency with (Haimes, 2004) it should be noted that very often the constituent of a given system can be modeled as a logical system comprised by its own constituents.

It is realized from Figure 3 that the scenarios represent causal relationships between events which lead to different types of consequences. Hierarchical models such as Bayesian Probabilistic Nets (BPNs) (Pearl, 1988) greatly facilitate risk analyses and assessments on the basis of such models and have been applied in a range of different contexts, see e.g. Faber et al. (2002) and Bayraktarli et al. (2005).

4.2 Indicator based risk assessment

Risk indicators may be understood as any observable or measurable characteristic of the systems or its constituents containing information about the risk. If the system representation has been performed appropriately, risk indicators will in general be available for what concerns both the exposure to the system, the vulnerability of the system and the robustness of the system, see Figure 4.

In a Bayesian framework for risk based decision making such indicators play an important role. Considering as an example the environmental risk assessment of a containment of mine tailings risk indicators are e.g. any observable quantities that can be related to; causes for releases of toxic materials out of the containment to the environment (exposure), the resistance of the containment with respect to the possible causes (vulnerability), the redundancy of the containment and the effectiveness of condition control and maintenance of the containment (robustness).

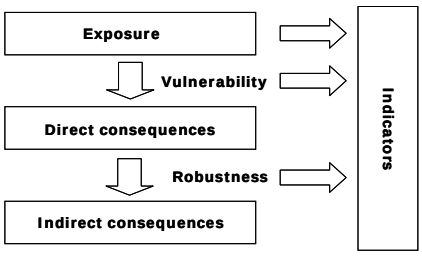

Figure 4: Risk indicators at different levels of the system representation.

4.3 Quantification of risks

Following (Faber and Maes, 2005b) the system which is considered subject to a risk assessment is assumed to be exposed to hazardous events (exposures EX) with probabilistic characterization $p(EX_k),\ k=1,\ n_{EXP}$, where n_{EXP} denotes the number of exposures. Generally exposure events should not be understood as individually occurring events but rather as the effect of relevant combinations of these. It is assumed that there are n_{CON} individual constituents of the system, each with a discrete set (can easily be generalized to the continuous case) of damage states C_{ij}, $i=1,2..n_{CON}$, $j=1,2..n_{C_i}$. The probability of direct consequences $c_D(\mathbf{C}_l)$ associated with the lth of n_{CSTA} possible different state of damage of all constituents of the system $\mathbf{C}_l$, conditional on the exposure event EX_k is described by $p(\mathbf{C}_l|EX_k)$ and the associated conditional risk is $p(\mathbf{C}_l|EX_k)c_D(\mathbf{C}_l)$. The vulnerability of the system is defined as the risk due to all direct consequences (for all n_{CON} constituents) and may be assessed through the expected value of the conditional risk due to direct consequences over all n_{EXP} possible exposure events and all constituent damage states n_{CSTA}:

$$R_D=\sum_{k=1}^{n_{EXP}}\sum_{l=1}^{n_{CSTA}} p(\mathbf{C}_l|EX_k)c_D(\mathbf{C}_l)p(EX_k) \qquad (1)$$

The state of the system depends on the state of the constituents. It is assumed that there are n_{SSTA} possible different system states S_m associated with indirect consequences $c_{ID}(S_m,c_D(\mathbf{C}_l))$. The probability of indirect consequences conditional on a given state of the constituents $\mathbf{C}_l$, the direct consequences $c_d(\mathbf{C}_l)$ and the exposure EX_k is described by $p(S_m|\mathbf{C}_l,EX_k)$. The corresponding conditional risk is $p(S_m|\mathbf{C}_l,EX_k)c_{ID}(S_m,c_D(\mathbf{C}_l))$. The risk due to indirect consequences is assessed through the expected value of the indirect consequences in regard to all possible exposures and constituent states, as:

$$R_{ID}=\sum_{k=1}^{n_{EXP}}\sum_{l=1}^{n_{CSTA}}\sum_{m=1}^{n_{SSTA}} c_{ID}(S_m,c_D(\mathbf{C}_l))\times p(S_m|\mathbf{C}_l,EX_k)p(\mathbf{C}_l|EX_k)p(EX_k) \qquad (2)$$

The robustness of a system is defined as the ability of a system to limit total consequences to direct consequences. This characteristic may readily be quantified though the index of robustness I_R (Baker et al., 2008):

$$I_R=\frac{R_D}{R_{ID}+R_D} \qquad (3)$$

which allows for a ranking of decisions in regard to their effect on robustness.

In the foregoing no mention is made in regard to the time reference period to which the probabilities and consequently also the risks have to be related. A clear specification of these is of course necessary as this will substantially influence the decision making.

5. Sustainable Mining in Greenland

The general framework for risk informed decision making in pursuit of sustainable societal developments outlined in the foregoing may be mapped in principle to any society of consideration, i.e. at national scale, municipality scale and project scale. Indeed in order to undertake a thorough risk assessment of relevance for decision making at national scale it is necessary to assess the risks with some relevant level of precision also at municipality and project scales.

The application of the methodical part of the framework, i.e. for what concerns the technical details of risk assessment, is very generic and for the trained risk engineer relatively straight forward. The system identification, however, in general constitutes the major challenge. In the following this important step will be addressed for the case of mining in Greenland.

As already mentioned the system of the Greenlandic society must be addressed and represented at various levels, such as to form a hierarchy of constituents and subsystems within the overall system. The relevant subsystems to consider should

include the possible individual mining projects, the villages, the cities, the communes and at the highest level the nation of Greenland. In the following a non-exhaustive list of different risks of relevance at these different levels will be provided together with measures of risk reduction and possibilities for exploiting chances.

5.1 The system at project level

The individual mining projects are of course subject to the law and regulations which are set at national and commune level at this also regulates the aspects of risk management. According to best practices in the industry this comprises management of occupational health and safety, risks associated with possible releases of toxic materials to the environment as well as major accidents with possible catastrophic consequences for the environment and the workers on site. Moreover, mining sites in Greenland may be exposed to natural hazards such as floods, extreme wind storms and tsunamis and may due to severe weather conditions lack the possibility for communication, supply, rescue and evacuation over extended periods of time. It is thus necessary that a certain level of self-sufficiency can be maintained by the individual mining projects. The management of such risks may not constitute a major problem in general but should nevertheless be carefully monitored. Ensuring that the best available knowledge and mining technology is applied or even further developed will facilitate that both the risks to environment and the personnel are kept at low and acceptable levels.

One issue remains a substantial challenge for the Greenlandic society in terms of capacity and that concerns provision of societal functions at the mining project sites. Enforcement of law and order, monitoring of working conditions and fulfilment of industry regulations, provision of health care, hospitals etc must be available up to national standards on the individual mining sites. If operators and working forces are of foreign origin the cultural differences will only add to the challenge. Surely some foreign operators will offer to provide most of such services themselves but this would potentially be associated with loss of sovereignty and loss of control.

5.2 The system at village and city level

The villages and the cities are subject to the strategic decisions concerning future developments defined at the level of the communes and nation. Besides these possible constraints the effects of mining activities will strongly depend on the proximity to mining project sites. However, a general challenge for all cities and villages will be to facilitate that available work force capacity may be utilized in the mining industry and at the same time ensure that traditional industrial and occupational activities are established and/or maintained at given desired levels. The desired participation of local work force and industry in mining activities may be strategically set at commune or national level and differ from city to city and village to village depending on e.g. cultural considerations and considerations on possible intensified activities in the fishing industry and tourism.

For the villages and cities within contact range of mining project sites or even established on these sites special considerations should be directed on safeguarding cultural values and management of socially transferred diseases and pandemics.

5.3 The system at commune and national level

At the level of the communes and nation the decision making with respect to mining activities is subject to relevant international laws e.g. with respect to spread of radioactive materials which might be utilized for nuclear industrial and military purposes. However, besides such boundary conditions there is substantial freedom to identify and follow the strategy for the development of the mining industry which has the highest positive impact on sustainable societal developments. A sketch of a system representation at national level is provided in Figure 5. This system representation could be relevant in the context of identifying strategies for the development of infrastructure, energy supply, industrial activities including mining fishing and tourism subject to objectives related to the

preservation of environmental qualities, cultural values, economic growth, welfare and national security.

The most important risk at this system level first and foremost concerns the management of the strategic planning process itself. If this fails substantial opportunities to support sustainable societal developments may be lost – and the opposite may result. In a small society like Greenland the governance capacity is limited and a first activity would be to strengthen this in such a manner that it facilitates the management of the societal risk informed decision process outlined in Section 3.2.

Additionally focus should be directed on strategic sustainable exploitation of raw materials on the premises of society rather than on the premises of the free market. As mentioned in the introduction sustainability is not a preference of the free market and must be enforced by government. There are of course possibilities for defining partnerships between the government and the industry and such avenues should be explored. Essentially the idea behind such partnerships would be to share risks in such a manner that the mining industry becomes less vulnerable to prosperity of resources and market chains and such that the Greenlandic society also becomes less vulnerable to possible variations in the global economy and the market for raw materials. To this end, possibilities to engage into private public partnerships not only between the Greenlandic government and the mining industry but rather by involvement of the production industry in Denmark and Europe which uses the different raw materials for manufacturing and possible also the relevant governments which may provide the necessary conditions.

Obvious strategic considerations which must be pursued concern the possibilities of a carefully identified scheme of the initiation of different mining projects at the right places and times and operating over the most optimal durations of time. This scheme should be identified on the basis of risk information as highlighted in the forgoing with a joint consideration of the development of relevant infrastructure and other, traditional and possibly new industrial sectors. It is tremendously important that the mining activities are appreciated to be short term and that the benefits of these, in financial terms, are utilized optimally to enhance a sustainable society also after the raw materials have been exploited.

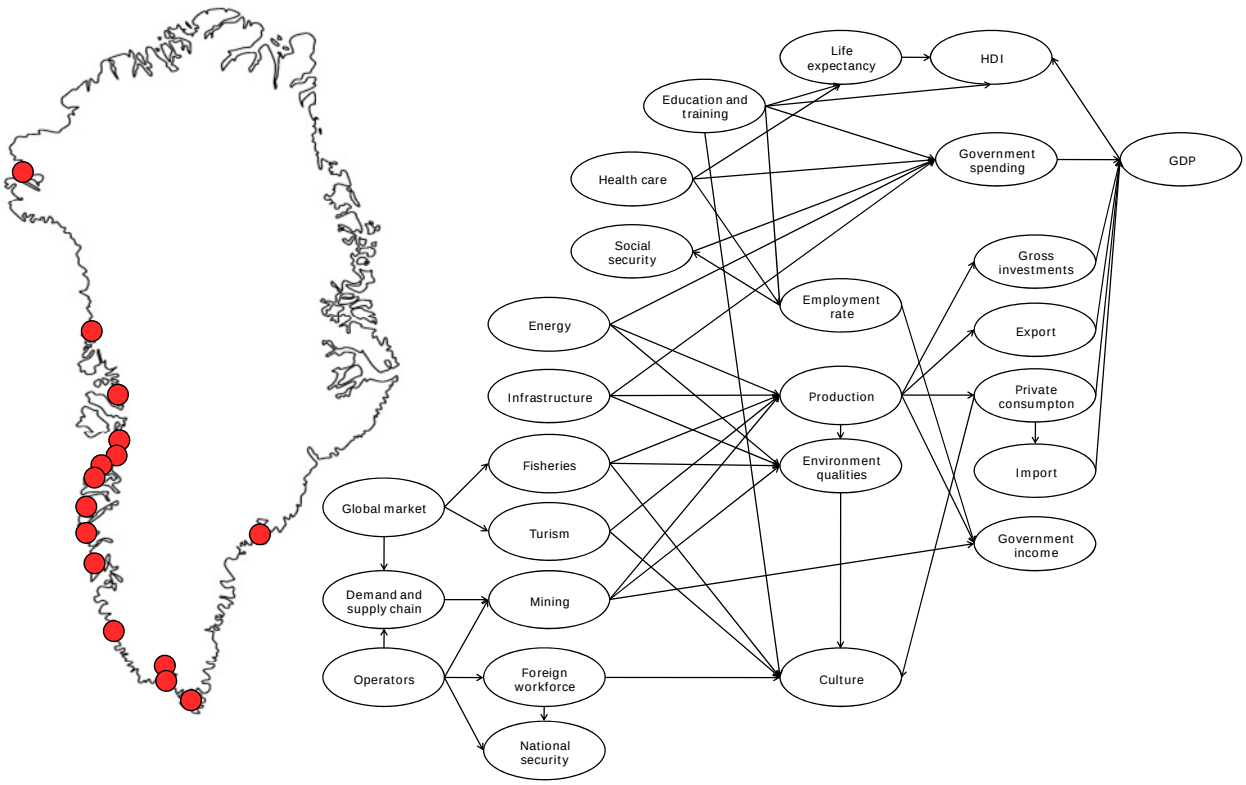

Figure 5: Sketch of a possible system representation at national scale.

A critical issue in the strategic planning will be to ensure that a clear opinion is established at societal level for what concerns cultural values and cultural heritage. Only if this is adequately handled can it be ensured that cultural values are safeguarded. If this is not handled adequately the cultural values could easily be damaged beyond recovery within a generation from now. However, by proactive and targeted action Greenland could become a showcase at international scale on how to maintain original culture and cultural values. Possibilities exist to select regions, natural habitats and villages which may be safeguarded to provide livelihoods in support of original cultural and occupational traditions. Such locations may, moreover, find synergetic effects with the future tourism industry.

A further problematic issue concerns border control. Greenland is a vast country and increased influx of people, traffic with ships and airplanes poses risks to the Greenlandic fauna, risks associated with important of prohibited substances, illegal immigration and maybe most critically risk of import and spread of pandemics. To embrace this challenge in the face of the mining activities in the future necessitates substantial capacity building and firm enforcement of the control of the borders.

Finally, the issue of national security should not be underestimated. Greenland is a very small society and engagement with the mining industry as a main instrument in strategic societal developments will easily lead to a loss of sovereignty, independent on their nationality. Geopolitical interests and raw materials as basis for possible strategic high tech and military applications add to the importance of selecting partners and defining partnerships which will respect Greenlandic independence and Greenlandic values.

6. Conclusions

The present paper addresses sustainable mining in the arctic from the perspective of strategic risk management and risk communication. It is highlighted that many of the attributes associated with sustainable societal developments are not easily defined in such a manner that facilitates traditional cost benefit analysis. Instead it is proposed that risk information concerning different options for societal developments based on mining activities is established and that the weighing of the different attributes of sustainability is supported by a societal risk communication process, with stakeholder involvement at all levels in society, which aims to build up informed preferences.

To support this process a proposal for a protocol for the risk communication process is presented and a framework for systems risk assessment suggested by the Joint Committee on Structural Safety is summarized.

Finally, some specific considerations of relevance to the important system identification for the Greenlandic society are provided which may help direct the focus on important chances and risks associated with different strategies for sustainable mining in Greenland.

It should be underlined that the present paper only outlines the top of the iceberg but that the suggested approaches and methodologies may substantially support the decision making process which has already been initiated in the Greenlandic society.

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