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Climate risk mitigation in Longyearbyen, Svalbard

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Abstract
The Svalbard Archipelago has experienced the fastest and highest temperature increases in recent decades, due to man-made greenhouse gas emissions, reinforced by the melting of sea ice, which exposes, in particular, the west coast of Svalbard to the warmer temperatures of the ocean, also during the winter. This increase in temperature has effects on the weather patterns, precipitation and thawing of the permafrost, all of which expose settlements and critical infrastructure to a different risk picture and a subsequent need for climate change adaptation. Some of these threats have already materialised in Longyearbyen, the largest settlement on Svalbard, as the town witnessed an increased frequency of landslides, rockslides, snow avalanches, erosion, receding permafrost and floods. However, the scenarios concerning both future temperature increase and climate change impact on society are uncertain since this is the starting point for assessing climate risk and developing risk-based climate change adaptation methodologies. This paper discusses the risk-based approach to climate change adaptation in Longyearbyen. More precisely, the paper aims to discuss how a changing climate reflects risk- and vulnerability analysis and urban planning in Longyearbyen. Data is collected through document analysis and interviews with stakeholders in Longyearbyen. Findings indicate that the authorities the last decade have implemented both short- and longer-term measures to adapt to a changing climate, but also the uncertainty related to the physical and social consequences of a warmer climate.

Keywords: Climate change, Risk- and vulnerability analysis, Mitigation, Climate Change Adaptation, Disaster risk reduction. Longyearbyen

1. Introduction

The climate is changing, and the Svalbard Archipelago in the High Arctic has experienced the fastest and highest temperature increases in recent decades, some 3 to 5 °C during the last 4 to 5 decades (Hanssen-Bauer et al., 2019). Svalbard is exposed to an increasing number of heavy winter rainfalls, the fjords along the west coast are now mostly ice free most of the year, glaciers are melting, and the permafrost has warmed considerably (ibidem). The increase in temperature has effects on the weather patterns, precipitation and thawing of the permafrost, all of which expose settlements and critical infrastructure to a different risk picture and a subsequent need for climate change adaptation. Some of these threats have already materialized in Longyearbyen, the largest settlement on Svalbard, as the town witness increased frequency of landslides, rockslides, snow avalanches, erosion, increased active soil level due to tawing of permafrost during the summer, floods etc. The paper aims to discuss how a changing climate reflects risk- and vulnerability analysis and urban planning in Longyearbyen. Data stems from document studies, interviews and own observations.

2. Conceptual framework

While climate change is accelerating in the Arctic (IPCC, 2021), the change itself is more creeping in nature, with many negative aspects for society and ecosystems that society need to mitigate, both to reduce disaster risk, but also to adapt to the climate change at hand. Thus, the conceptual framework is formed around the concept creeping crisis, in relation to disaster risk management, disaster risk reduction and climate change adaptation.

2.1 Creeping crisis

"Traditional crises" are often described as events with a relatively clear starting point and ending. Creeping crisis on the other hand, are more slowly developing events with accumulation of latent conditions (Turner, 1976) in the pre-crisis phase, making communities and society at large more vulnerable. They unfold, in the initial phase, under "the radar" so to speak and with less attention than a fast-burning crisis ('t Hart and Boin, 2001) such as an earthquake or an avalanche. A creeping crisis is a threat to widely shared societal values or life-sustaining systems that evolves over time and space, is foreshadowed by precursor events, subject to varying degrees of political and/or societal attention, and impartially or insufficiently addressed by authorities (Boin et al., 2020:7). Thus, it is not obvious when an escalating problem becomes a creeping crisis. Authoritative decision-makers may need to define when we move from a precrisis phase to an acute crisis phase. When a creeping crisis is defined, we are still struggling with how to handle the situation at hand because even recognized societal problems may be hard to deal with by policymakers, politicians and other decision-makers.

A complication factor is the development of the creeping crisis, i.e. do we foresee a steady linear increase of a crisis, or will we face a non-linear tipping point? In his book on everyday life sociological changes, Gladwell defines a tipping point as "the moment of critical mass, the threshold, the boiling point (Gladwell, 2000:12). In the Earth's climate system, a tipping point is a mechanism that causes the climate to change from one stable state to another, if certain threshold values are exceeded by climate change (Hessen, 2020). A tipping point marks the transition between gradual development and sudden escalation. The Arctic is experiencing at least 19 of these tipping points (Arctic Council, 2016).

2.2 Risk and disaster risk management

With this discussion of creeping crisis, as events develop in silence, under the radar, a critical task in the pre-crisis phase will be risk management related to climate change. Risk is essentially about the future, about events or activities that may occur in the future and their possible consequences (Aven, 2012). Thus, risk may be defined an uncertain consequence of an event or an activity with respect to something that humans value (IRGC, 2005) or a combination of possible events/consequences (outcomes) and associated uncertainty (will the events occur, what will be the consequences) (Aven and Renn, 2009).

According to the United Nations Office for Disaster Risk Reduction (UNDRR), disaster risk reduction (DRR) is aimed at preventing new and reducing existing disaster risk and managing residual risk, all of which contribute to strengthening resilience and therefore to the achievement of sustainable development (UNDRR, 2024c). Disaster risk reduction is the policy objective of disaster risk management (ibidem).

According to (UNDRR, 2024) disaster risk management (DRM) is the application of disaster risk reduction policies and strategies to prevent new disaster risk, reduce existing disaster risk and manage residual risk, contributing to the strengthening of resilience and reduction of disaster losses. Thus, to lessen the impacts of extreme events, disaster risk management, according to the Sendai Framework for Disaster Risk Reduction 2015-2030 (United Nations, 2015), are actions within all crisis phases, from prevention, mitigation, but also preparedness and response, in addition to recovery and learning in the post-crisis phase. Such comprehensive actions are to be well-thought-out and coordinated according to development plans, resource allocations and programme activities (UNDRR, 2024). Approaches toward the management of climate change impacts also must consider the reduction of human vulnerability under changing levels of risk. A key challenge and opportunity therefore lie in building a bridge between current disaster risk management efforts aimed at reducing vulnerabilities to extreme events and efforts to promote climate change adaptation.

UNDRR distinguishes between prospective disaster risk management, corrective disaster risk management and compensatory disaster risk management (also referred to as residual risk management) (UNDRR, 2024b).

Disaster risk management could also have a community-based focus promoting the involvement of potentially affected communities at the local level, and a local and indigenous peoples' approach recognising and utilising traditional, indigenous and local knowledge and practices to complement scientific knowledge in disaster risk assessments.

Finally, as demonstrated in the Sendai Framework for Disaster Risk Reduction, DRR and climate change adaptation are two strategies aimed at reducing disaster risk. Thus, the UNDRR aim to integrate DRR and CCA in the UN Sustainable Development Cooperation Framework (UNDRR, 2020).

Whereas DRR focuses on many different risks, including man-made risk, climate change adaptation focuses on risks emerging from climate change. Climate change adaptation refers to actions that help reduce vulnerability to the current or expected impacts of climate change like weather extremes and hazards, sea-level rise, biodiversity loss, or food and water insecurity (UNDP, 2024), or climate change adaptation may be understood as adjustments in natural or human systems in response to actual or expected climatic stimuli or their effects, which moderates harm or exploits beneficial opportunities (IPCC, 2007).

3. Methods

Data stems from the results presented in Climate in Svalbard 2100 – a knowledge base for climate adaptation (Hanssen-Bauer et al., 2019), which goal is to provide information to effect studies concerning climate change and CCA (climate change adaptation), on document studies related to climate change and impact on Svalbard, on studies of risk- and vulnerability analysis in Svalbard and in Longyearbyen (see 4.1 and 4.3). Furthermore, data is collected through meetings and discussions with representatives of the authorities and other stakeholders in Longyearbyen during the ArctRisk-project, and, finally, on own observations from Longyearbyen over a period of five years (see 4.2).

4. Results

This section presents the status of climate change in the region, more specifically in Longyearbyen and how this reflects risk- and vulnerability analysis and urban planning in Longyearbyen.

4.1. Climate change

Climate in the past: The average annual temperature is calculated to -8.7°C for "Svalbard total" (Hanssen-Bauer et al., 2019) and has a range of variation of 11.4 °C. The cooling at the end of the 1970s is followed by an increase by 3-5°C during the period 1971-2017 (ibidem). The 30-years annual mean precipitation in the Longyearbyen area is considerable low; 189 mm (1961-1990) and 196 mm (1971-2000) and the difference between seasons are small. Since 1912, the observed annual precipitation has increased by 3-4% per decade at Svalbard airport and the largest increase is registered for autumn (Hanssen-Bauer et al., 2019). The last two decades the frequencies of high intensity precipitation events have increased (ibidem). As the winter-, spring- and autumn-temperatures rise, the probability of precipitation falling as rain instead of snow increases. The consequence at Svalbard Airport is that during the period 1958-2017, the winter season covered by snow is one month shorter (Hansen et al., 2014).

Climate in the future: Projected climate changes regarding temperature, precipitation, sea level and wind towards 2100 are based on assumptions about future greenhouse gas emissions, where the emission scenarios are input into the global climate models (GCM). However, there is great uncertainty related to the climate projections at global, regional and local levels. Three main sources of uncertainty in climate projections exist: (1) Internal variability uncertainty; (2) Model uncertainty; and (3) Emissions scenarios uncertainty (Wu et al., 2022, Moise et al., 2024). How our society contributes to future climate change is tied to the latter uncertainty. IPCC (2014) describes four distinct Representative Concentration Pathways (RCP) for the future concentration of greenhouse gases with the corresponding estimated global average temperature rise by 2100 compared to the pre-industrial period:

RCP2.6: very low future emissions, 1.6 °C
RCP4.5: low/moderate future emissions, 2.4 °C
RCP6.0: moderate future emissions. 2.8 °C
RCP8.5: very hight future emissions, 4.3 °C

These estimates also consider the uncertainty surrounding population growth, economic development, and the development of new technologies.

For Svalbard area the GCM project an increase in annual mean temperature from 1971-2000 to 2071-2100 of about 3°C(RCP2.6), 6°C (RCP4.5) or 10°C (RCP8.5) (Hanssen Bauer et al., 2019). For RCP8.5, for Svalbard Airport, improving the models by different small-scale Regional Climate Model (RCM) modelling and Empirical Statistical Downscaling, the simulated ensemble median values are calculated from 6.5°C to 8.7°C. These results show that the annual mean temperature at Svalbard Airport and Longyearbyen will increase to above 0°C at the end of the century (ibidem). Compared to 1971-2000, the projected changes in the number of frost days are roughly 50% reduction towards the end of the century. The reduction will be substantial during the winter, though the largest reduction is expected in the spring and the autumn. Until today, at Svalbard Airport, the average number of zero crossing days have occurred most frequently in spring and autumn. In the future, there will be a reduction in summer and an increase in winter (Hanssen-Bauer et al., 2019).

Rain is projected to become the dominant form of precipitation in the Artic region, an increase in cold-season precipitation of 30-50% is projected (AMAP, 2017), and the frequency of rain on snow (ROS) is likely to increase (Hansen et al., 2014). Small scale simulations indicate that the number of days with snow cover will be reduced all over Svalbard, an increase in the snowline up in the slopes, the timing of maximum snow storage will shift from June (1971-2000) to May (2071-2100) and an increased tawing of the upper permafrost layer will be experienced in coastal and lower lying areas.

The small-scale model simulations show that the dominant wind direction in the Isfjorden and throughout Svalbard area will be fairly unchanged towards the end of the century. However, the wind speed will increase over the sea in the northern part and in the mountain area east of Longyearbyen.

<u>“Climate profile Longyearbyen”</u>: The results, presented in "Climate in Svalbard 2100" (Hanssen-Bauer et al., 2019) are summarized in "Climate profile Longyearbyen" (NCCS, 2019). The profile, intended as a knowledge base and aid for decision-makers and planners, provide some expectations of climate change and climate challenges for Longyearbyen:

- a high probability of an increase in heavy precipitation, permafrost temperature, flooding, erosion, avalanches, landslides and flash floods
- the potential rise in ice floes in the rivers
- the uncertainty related to strong winds, quicksand landslides, rockfalls, rockslides and mountain slides
- a constant or lower probability of storm surges

4.2. Operational consequences in Longyearbyen

Climatic changes have a profound impact on life in Longyearbyen, illustrated by the examples below. The community has over the years seen effects of these changes and made decisions to mitigate present and emerging hazards, effects also reviled by interviews by stakeholders in Longyearbyen as part of the ArctRisk-project and own observations from changing in Longyearbyen the last few years.

Changes in temperatures increases melting of the two glaciers at the top of Longyeardalen. The river, Longyearelven, cuts across the road to the airport at three points a fourth crossing, “Melkeveien”, was torn down in 2018, as it was in very poor condition. In recent years, several buildings have been built near the river, including a large dormitory for students at the University centre. The risk of flooding of the delta is a concern as an increasing percentage of the total building mass in Longyearbyen is now situated in or around the riverbed. The concern is that increased precipitation combined with high temperatures will lead to increases in the flow of water and, thereby, a threat that buildings and other infrastructure will be flooded. In 2017, a project was conducted to flood- and erosion-proof the town, which required extensive work on the riverbed to reduce the risk of flooding. The total cost was approx. NOK 50 million for the measures along the river.

Due to two major urban avalanche incidents in the same location on Sukkertoppen in 2015 and 2017, the decision was made to erect snow barriers and a stone wall to ensure the safety of the remaining houses in the avalanche prone terrain. Before 2017, there had been no reported avalanches from the top of Sukkertoppen, while there were regular reports of runoff from the lower parts. In 2005, a boy was completely buried but survived and in 2010, two people were caught but managed to dig themselves out (Brattlien, 2017). In total, 15 individual avalanche barriers situated on the west slope of Sukkertoppen were erected, combined with a 200-meter wall in the bottom, which is intended to stop any landslide or avalanche debris. The safety measures against avalanches in the area were initiated in 2019 and completed in 2023 to a cost of 170 million NOK.

A major slush ice incident in 2012, which occurred in Vannledningsdalen, destroyed a minor bridge and caused other material damage, has meant that protective barriers have been constructed in this valley. The barriers consist of 14 metal nets as well as the construction of a dike that would protect buildings located downstream. The aim is to stop, reduce the volume and possibly delay any slush avalanche coming down the valley. The measures against slush avalanches from Vannledningsdalen were initiated in 2022 and completed in 2024 at a cost of NOK 105 million.

The drinking water in Longyearbyen is being affected by permafrost degradation and the treat that saltwater can enter the freshwater supply. An outbreak of legionella disease in 2024, with an unknown source, has sparked a debate in the community as to the reliability of their fresh water supply and the degree to which the existing water pipe system is reliable. The legionella event resulted in a need to boil water or buy it from the local supermarket. The water utility currently has two sources: Isdammen and Steintippdalselva (Report to the Storting. 26 (2022–2023)). During the winter season, there is no backup source available. An assessment indicates that salt sea water may seep into the freshwater sources and thereby make it unusable as drinking water. The Norwegian government proposed in 2024 to allocate NOK 3 million for state co-financing of a preliminary project to establish an alternative drinking water source in Longyearbyen.

Permafrost melting is also affecting the stability of houses, roads and other infrastructure in Longyearbyen. Especially old buildings on wooden stakes are at risk of damage as poles are rotting (as they get exposed to moisture) and pushed by ground movements. Houses like Elvesletten North, with 46 homes on the road 500 close to the river, were supposed to be renovated to mitigate the effects of permafrost degradation. However, due to the instability of the soil in the area, the project has been dropped. Other parts of the building infrastructure have either been renovated nor removed. Roads, heating and electricity are also being affected, requiring regular maintenance, which consumes significant resources from the local and national government. The total cost of these renovations is unknown.

4.3. Risk- and vulnerability analysis

There are three risk- and vulnerability analyses that need to be mentioned here. The first two are the Longyearbyen Community Council comprehensive risk- and vulnerability analyses from 2017 and 2023. The third is the Svalbard Governor's Risk- and vulnerability analysis.

4.3.1 C*omprehensive risk- and vulnerability analysis 2017 (LL, 2017)*

Two risk-area have been identified; (1) Risk of avalanche and (2) risk of extreme weather.

(1) Risk of avalanche

Previous events: Avalanche in Longyearbyen in 2015.

Future risk: Thawing permafrost will increase the potential for erosion and mass transport in rivers. Increased precipitation will increase the risk of avalanches. Mudslides and flash floods threaten developed area in Longyeardalen, Vestpynten-Bykaia and Adventsdalen.

Measures and prevention: Avalanche warnings and evacuations.

(2) Risk of extreme weather

Previous event: No descriptions.

Future risk: Events related to extreme weather are very likely. Very strong winds and wind gusts may have the potential to damage buildings, critical infrastructure etc. Maximum snowfall will increase for large parts of the Svalbard area.

Measures and prevention: No account has been taken of measures related to prevention and preparedness.

4.3.2 *Comprehensive risk- and vulnerability analysis 2023 (LL, 2023)*

Three risk-area have been identified; (1) risk of avalanches (2) risk of rockslides and debris slide and (3) risk of extreme weather and precipitation.

(1) Risk of avalanche

Previous events: Both avalanches and slush avalanches have been involved in several previous incidents that have resulted in material damage and fatalities.

Future risk: Three regions—Gruvedalen, the

airport road, and Bykaia—are identified as having a slush avalanche risk and one area—Nybyen—is identified as having an avalanche risk.
Measures and prevention / preparation: Safety measures like avalanche fences, avalanche embankments, trenching to channel meltwater, snow drift traps, home removal and demolition, and avalanche warning and evaluation.

(2) Risk of rockslides and debris slide
Previous events: Rockfalls in seaside area, and rockfalls and debris slide at Huset. In addition, landslides and flash floods have crossed *road 300* countless times.
Future risk: The following is expected: (a) an increasing number of incidents related to rockfalls, (b) increased probability of landslides in late summer or autumn, (c) greater risk of landslides from Sukkertoppen, (d) increased risk of rockfalls and landslides from Skjaeringa to Huset, (e) risk of landslides in Nybyen and (f) rockfalls towards the airport.
Measures and prevention / preparedness: The following have been initiated; trenching to divert meltwater from the landslide protection at Sukkertoppen, landslide embankment at Sukkertoppen, traffic bans, closure of restaurants and a population warning system.

(3) Risk of extreme weather and precipitation

Previous events: The hurricane of 1985, the storm and avalanche i 2015 as well as the incident related to avalanches in 2017. It also turns out that the permafrost has begun to thaw, which is affecting the infrastructure through greater instability and washout.
Future risk: Increasing precipitation and precipitation intensity, which may contribute to many stormwater problems including floods in rivers. Bolterelva, Endalselva and Longyearelva are pointed out as geographical risk areas. Additionally, flood landslides from the water supply valley, melting permafrost, and severe winds are mentioned.
Measures and prevention / preparedness: Dosing, digging, trenching, bottom protection across the river, erosion protection along the riverbank, overflow in the dam at Isdammen, and the construction of thresholds at bridges. Guiding the water in the appropriate direction, as well as the public notification system via cellular phone.

4.3.3 *Svalbard Risk- and vulnerability analysis (Governor of Svalbard, 2022)*

Three climate events have been analysed, (1) landslides, (2) floods, stormwater and rain on snow (ROS) and (3) strong winds.

5. Discussion

The climate is changing, and Longyearbyen, together with the rest of the High Arctic, are experiencing fast temperature increases (Hanssen-Bauer et al., 2019), with emerging risks of events or activities that may occur in the future and their possible consequences (Aven, 2012). These changes have some of the main characteristics of a creeping crisis, i.e. “a threat to widely shared societal values or life-sustaining systems that evolves over time and space, is foreshadowed by precursor events, subject to varying degrees of political and/or societal attention, and impartially or insufficiently addressed by authorities” (Boin et al., 2020:7). The increasing temperature results in more rain on snow events, more precipitation, increased thawing of permafrost, landslides, all of which be described as signs of a creeping crisis, or as latent conditions accumulating in the incubation phase (Turner, 1976) making the Longyearbyen community more vulnerable. A triggering event may reveal this vulnerability, events such as the urban avalanches, slush avalanches from Vannledningsdalen, or permafrost degradation. The Longyearbyen Community Council comprehensive risk- and vulnerability analysis from 2017 did mention risk of avalanche and extreme weather events (LL, 2017). As detailed in chapter 3.3, considerable physical measures have been initiated the last 4-5 year, such as moving parts of the houses out of avalanche prone terrain, metal nets against slush avalanches, flood- and erosion barriers, snow fences and avalanche barriers. However, measures mentioned in ROS-analysis, such as avalanche warnings and evacuations, do only partially cover the actual measures implemented. Thus, in their disaster risk management, the Longyearbyen Community Council must have acted on other inputs in addition to the sparce measures suggested in the analysis from 2017 in their corrective disaster risk management (UNDRR, 2024b) strategies to mitigate disaster risks which are already present.

The analysis from 2023, on the other hand, is more thorough. It has a more detailed description of previous relevant events, including possible consequences and measures, in line with national expectations (DSB, 2022). Unlike the previous analysis from 2017, the 2023 analysis covers more scenarios, is more knowledge based, in line with the climate profile (NCCS, 2019) and "Climate in Svalbard 2100" (Hanssen-Bauer et al., 2019), and more stakeholders have been included in the analysis process. However, the measures mentioned in the analysis are an explanation and continuation of the measures that have already been initiated in recent years, measures that seem to be motivated and pushed forward by historical events rather than by structured risk analysis. Thus, the analysis does not explain the extensive measures put in place the last few years and does not qualify as a basis for decision-making for future measures.

The urban avalanches of 2015 and 2017 may also have acted as a tipping point, a non-linear change or a threshold from one stable state to another (Gladwell, 2000), increasing awareness of the need to mitigate disaster risk of avalanches in Longyearbyen, at "all" cost, making Longyearbyen a *gated community* against the multi-threat environment in which it is situated.

The rationale behind this increased spending in avalanche protection could, in addition to the trauma of the urban avalanches of 2015 and 2017, be because the town is still struggling to find itself in the transition from a more temporary company town/mining town to a permanent settlement.

While there are plenty of examples of communities being protected against one or two individual threats, it is less common to see developments like the ones seen in this town. Threats from above, below and from the sides has pushed the discourse towards higher, longer and increasingly more robust solutions. Here, one question is, of course, if such a strategy is economically sustainable. Another is if mitigation of climate-related risks is really a long-term strategy for communities like these. Under all circumstances such decisions must be based on a rigid analytical platform which not only addresses historical events but qualify decisions to be made in the future. Both previous analyses lacked this quality and hence served more in the role of risk identification than of a community strategic decision-making tool for planning purposes.

6. Conclusions

The aim of this paper has been to discuss how a changing climate reflects risk- and vulnerability analysis in Longyearbyen.

The findings indicate that safety measures to protect the city from avalanches, permafrost tawing, landslides and floods (i.e. the effects of climate change) are more events driven rather than driven by risk- and vulnerability analysis. That said, the approach applied to risk- and vulnerability analysis, and the risk matrix coming out of the analyses, points towards deeper concerns about creeping disasters and the long-term sustainability of towns like Longyearbyen from a risk and safety perspective.

Longyearbyen can be characterized as a laboratory for climate change mitigation where the boundaries of what is possible in terms of protecting things that humans value are tested. However, it also showcases to other Arctic communities what it takes to pursue such a strategy. While the technical solutions can be difficult to transfer, there are learning points from how the town has organized its mitigation strategies. These includes the utility of risk analysis to not only identify risks and uncertainties but also as a tool for strategic decision-making in urban planning.

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