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Resilience-based Monitoring of Climate Adaptation

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Climate change is happening today, so we have to build a more resilient tomorrow. This is especially true for Longyearbyen in Svalbard, as the climate is changing more rapidly in the Arctic regions than anywhere else in the world. This paper describes a resilience-based approach for monitoring of municipalities' work on climate adaptation, using Longyearbyen as a case aiming at making it climate resilient. It is based on the method Critical Infrastructure Resilience Assessment Method (CIRAM) but adapted for the follow-up of work on climate adaptation using indicators. This new method is named CLimate Adaptation Indicators Method (CLAIM). The paper describes the development and use of the method, which was carried out in close collaboration with the local government. Climate adaptation indicators can help Longyearbyen local government, and municipalities in general, to visualize, report and communicate the work and effort made on climate adaptation to inhabitants, local politicians, and central authorities. Additionally, they can provide continuity in the work on climate adaptation covering both short-term and long-term measures against the effects of climate change. Establishing a system for monitoring the status of climate adaptation work is demanding, but the alternative – not knowing the status of climate adaptation work – may prove to be far more costly.

Keywords: Climate adaptation, climate resilience, resilience, resilience indicators, risk, risk governance.

1. Introduction

"Climate change is happening today, so we have to build a more resilient tomorrow." (EC 2021).

1.1. *Nature and scope of the problem*

Understanding and adapting to climate change is one of the greatest ongoing societal challenges. The primary objective of the Arct-Risk project[a] (Risk governance of climate-related systemic risk in the Arctic) is to develop knowledge and tools to make sense of and deal with effects of climate change on society's ability to protect the life and health of its citizens and to maintain critical infrastructures and functions.

The response to the threat of climate change include two main pillars, the reduction of greenhouse gas emissions and climate adaptation (UN 2015), the latter related to the fostering of climate resilience. Climate adaptation is defined by IPCC (2014) as the process of adjustment to actual or expected climate and its effects. The link between climate adaptation and climate resilience is provided e.g. by EC (2021) in the new EU strategy on climate adaptation (and further by IPCC, 2014). Here it is concluded that "the new EU Adaptation Strategy paves the way for a higher ambition on climate resilience: in 2050, the EU will be a climate-resilient society, fully adapted to the unavoidable impacts of climate change. For this reason, climate change adaptation is an integral part of the European Green Deal [EC 2019] and its external dimensions and firmly anchored in the proposed European Climate Law [EC 2020a]." Climate resilience is achieved by reducing loss of critical functions for society.

1.2. Purpose and case

The purpose of the paper is to show a resilience-based approach for monitoring municipalities' work on climate adaptation. Longyearbyen, the administrative center of Svalbard at 78 degrees

[a] https://www.ntnu.edu/iot/arct-risk

north has been used as a case in the study. Few other places in the world experience such an increase in annual mean temperatures as Longyearbyen, which has led to changes in natural hazards and societal safety.

1.3. *Resilience-based approach*

The resilience-based approach is illustrated with the resilience curve (cf. Figure 1) which by an extreme weather event depicts loss of critical functionality from nominally 100% to a certain minimum functionality over a certain time period until recovering to full functionality (Øien et al. 2018). This approach applies to both the original CIRAM method and the new CLAIM method, developed as part of the Arct-Risk project (Øien & Albrechtsen 2024).

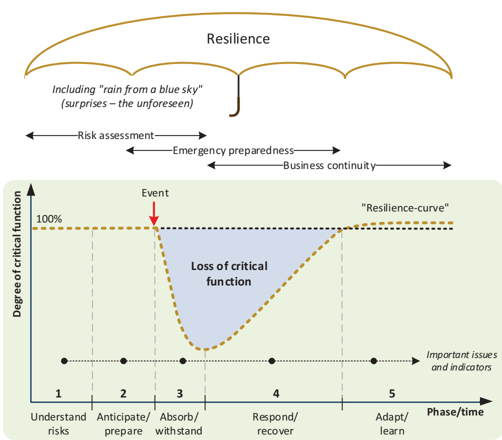

Fig. 1. Resilience as an umbrella term (based on Øien et al. 2018)

Resilience can be measured directly using the resilience curve or indirectly with resilience indicators for phases before, during and after an extreme event. Both CIRAM and CLAIM use resilience indicators to measure resilience levels indirectly.

In the new method (CLAIM), we do not measure the resilience level of individual extreme events as in CIRAM. Instead, we assess the progress of climate adaptation efforts across all relevant climate-related events, defining climate adaptation indicators as indicated in the bottom part of Figure 1. Similarly, to standardize the use of CIRAM, CLAIM defines indicators for five phases: 1) understand risks, 2) anticipate and prepare, 3) absorb and withstand, 4) respond and recover, and 5) adapt and learn.

These phases are also reflected in the definition of *climate resilience* used in CLAIM, i.e., "climate resilience is the ability to understand the climate risks that may threaten society, prepare for anticipated and unanticipated climate related events, absorb or withstand the effects, respond and recover from them, and adapt society based on learning after events." In general, resilience is not a straight-forward term. It has many different applications and a broad scope. A helpful review paper providing insights into the term and its history is Alexander (2013).

The IPCC (2014) definition of *climate adaptation* is elaborated in the Norwegian government white paper Meld. St. (2022-2023): "Climate adaptation involves understanding the consequences of climate change and taking measures to, on one hand, prevent or reduce damage, and on the other hand, take advantage of the opportunities that the changes may bring."

1.4. *Relevant previous work*

Various initiatives have been introduced to measure municipalities' climate adaptation efforts using indicators, such as Menon (2018), Sivertsen et al. (2021), and Depina & Øien (2021). These initiatives are generic and not tailored to specific municipalities. Menon (2018) and Sivertsen et al. (2021) use different types of indicators, while Depina & Øien (2021) employs a hierarchical model with six levels also described in Øien et al. 2018). This paper primarily builds on Depina & Øien (2021), adapting it to Longyearbyen and incorporating some indicators from Menon (2018) and Sivertsen et al. (2021).

1.5. *Principal results and conclusions*

The result is a method for developing indicators to monitor municipalities' climate adaptation efforts both short-term and long-term. Longyearbyen is used as a case study to demonstrate the method's application.

Climate adaptation indicators can help Longyearbyen's local government visualize, report, and communicate their climate adaptation efforts to inhabitants, local politicians, and central authorities. They also ensure continuity in climate adaptation work despite changing responsibilities, making it easier for new employees to familiarize themselves with ongoing efforts. This is particularly important for Longyearbyen, given its high turnover of inhabitants and employees.

2. Methods

The original method, Critical Infrastructure Resilience Assessment Method (CIRAM) (Øien et al. 2018), has been adapted to establish indicators for measuring climate adaptation, resulting in the CLimate Adaptation Indicators Method (CLAIM). CIRAM is detailed in Section 2.1, and the development of CLAIM is described in Section 2.2.

2.1. *CIRAM*

The original method, CIRAM, provides an umbrella approach (illustrated in Figure 1) that extends the focus from critical infrastructure protection (CIP) to critical infrastructure resilience (CIR) (Setola et al. 2016). This aligns with EC (2020b) reflections that national approaches are increasingly informed by resilience thinking, where protection is one element alongside risk prevention, mitigation, business continuity, and recovery. Thus, resilience in critical infrastructure encompasses a broad time perspective, including risk analysis, emergency preparedness, and business continuity (as shown in Figure 1). It complements rather than replaces these analyses.

The five phases are shown at the bottom. The first two phases occur before an event, and the last phase occurs after recovery to full or improved functionality, as illustrated by the dashed curve. The critical functionality curve, often called the "resilience curve" (e.g., Poulin and Kane 2021), is a conceptual illustration of an event's impact. The curve can take various forms, and its dashed representation indicates that its shape is irrelevant for indirect resilience measurement using indicators. Unlike direct curve assessment, this method measures resilience levels regardless of the curve's shape, allowing for tracking changes in resilience over time, independent of specific events. The figure also illustrates that resilience covers unforeseen events, metaphorically described as "rain from a blue sky." This distinguishes resilience assessments from risk analyses, which focus on foreseen events. Addressing the unforeseen requires capabilities like adaptive capacity, flexibility, and improvisation.

CIRAM is structured in six levels from area to indicators, as shown in Figure 2. Indicators are defined top-down, while the overall resilience level is calculated bottom-up by entering values at level 6. Both scores and resilience levels can be provided for each model level.

Calculated resilience levels can be visualized using TreeMaps. Regular measurements (e.g., yearly) allow for trend analysis and visualization (Shapira et al. 2019; Øien et al. 2021).

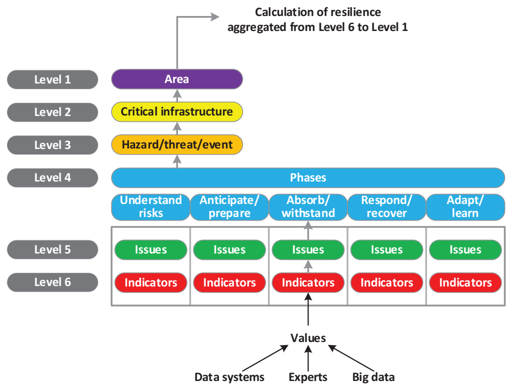

Fig. 2. Hierarchical model/framework (based on Øien et al. 2018)

CIRAM consists of 10 method steps: the first six correspond to the levels in Figure 2, three are for preparing and performing measurements and calculations, and the final step presents the results.

2.2. *CLAIM development*

The 10 method steps of CLAIM is shown in Figure 3.

Short description of steps		Level
Define the scope of the assessment		
1	Select area	Level 1
2	Select infrastructures and societal functions	Level 2
3	Select relevant climate related natural hazards/damages	Level 3
Establish issues and indicators for all phases		
4	Consider each phase for each climate related natural hazards/damages	Level 4
5	Identify issues within each phase	Level 5
6	Identify indicators for each issue	Level 6
Prepare and perform measurements and calculations		
7	Determine the range of values for each indicator, assign weights and roles	6
8	Assign values to the indicators (perform the measurement)	6
9	Perform the calculations (score and resilience level)	1-6
Present results		
10	Present results (status and trends)	1-6

Fig. 3. CLAIM method steps

The main adaptations of CLAIM are in steps 3, 5, and 6. In step 3, instead of selecting a few relevant extreme events, we cover all natural hazards negatively affected by climate change. This climate profile must apply to the selected area, in this case, Longyearbyen, as illustrated in Figure 4 based on NCCS (2019).

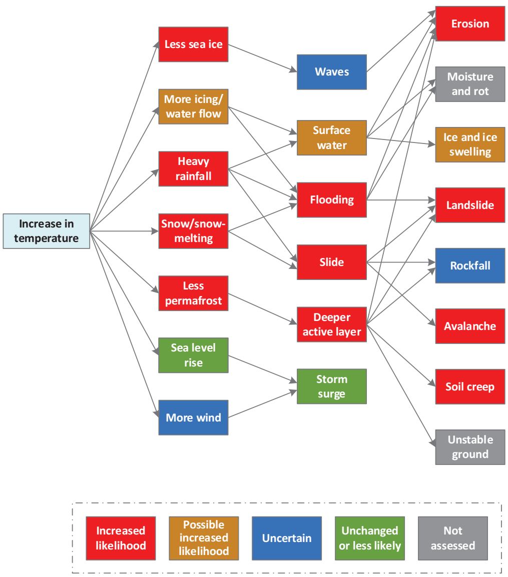

Fig. 4. Climate change and natural hazards in Longyearbyen (based on NCCS 2019)

Particular attention should be paid to natural hazards with increased likelihood due to climate change (red boxes in Figure 4). Dependencies, such as reduced permafrost leading to deeper active layers and soil creep in avalanche slopes, must also be considered. Soil creeps may reduce the effectiveness of avalanche barriers.

In steps 5 and 6, issues and indicators for resilience against specific extreme events are typically identified. In CLAIM, however, the focus is on identifying issues and indicators important for climate adaptation. These indicators measure the status of climate adaptation efforts, not resilience against specific extreme events.

Additionally, step 2 now includes important infrastructures and societal functions, not just critical ones. Step 7 has a minor adaptation to include the selection of responsible roles for indicators. The method steps of CLAIM are described in Section 3.

In addition to adapting the CIRAM method, the results are based on document reviews on climate change (NCCS 2019; NCCS 2021) and indicators (Menon 2018, Sivertsen et al. 2021), as well as a series of workshops with Longyearbyen's local government (LL) and an open climate café with its inhabitants.

3. Results: The CLAIM Method Applied Step-by-Step

The method is highly participatory, with each step carried out in one or more workshops with LL (Øien and Albrechtsen 2024).

3.1. *Step 1: Select area*

The area is limited to developed areas in Longyearbyen, excluding unregulated areas. This boundary, along with the delimitations in steps 2 and 3, can be adjusted later if needed.

3.2. *Step 2: Select infrastructures and societal functions*

Included infrastructures and functions are buildings, roads, water and sewage, power supply, district heating, fiber networks (telecom, electronic communication), hospitals, airport, ports, fire and rescue, emergency functions, critical functions at the Governor, and schools.

3.3. *Step 3: Select relevant climate related natural hazards/damages*

Based on the climate profile (Figure 4), the selected natural hazards and damages include landslides, rockfall, avalanches, river flooding, storm surges, erosion, soil creep, unstable ground, and moisture and rot.

3.4. *Step 4: Consider each phase for each climate related natural hazard/damage*

This step structures the resilience assessment into five predefined phases, as used in CIRAM.

3.5. *Step 5: Identify issues within each phase*

In the original method (CIRAM), the process begins with identifying and selecting key issues (factors) and then determining the relevant indicators to ensure comprehensive coverage of all important issues.

In this project, we built on previous work measuring climate adaptation in municipalities. Indicators were proposed without linking to issues (Menon 2018; Sivertsen et al. 2021). Depina and Øien (2021) connected these indicators to issues, deriving issues within each phase from the indicators. Table 1 shows examples of the 22 identified issues.

Table 1. Issues for each phase (examples)

Phase 1: Understand risks
1.1 Knowledge about climate adaptation challenges
Phase 2: Prepare/anticipate
2.1 Accountability and involvement
2.2 Foundation in planning and regulations
2.3 Inclusion of climate adaptation in projects
2.4 Monitoring of buildings and infrastructure
Phase 3: Absorb/withstand
3.1 Location of buildings in relation to exposed areas
3.2 Requirements for buildings (climate-related)
3.3 Location and redundancy of infrastructure
3.4-3.9 …
Phase 4: Respond/recover
4.1 Emergency plans
4.2 Emergency drills and real incidents
4.3 Availability of electricity, water and sewage, etc.
4.4-4.5 …
Phase 5: Adapt/learn
5.1 Learning from climate-related events
5.2 Adaptations after incidents
5.3 New solutions

3.6. *Step 6: Identify indicators for each issue*

The existing indicators were evaluated for relevance (yes/no), adjusted as needed, and new or alternative indicators were considered for each issue. Irrelevant indicators were removed during the initial screening.

A second screening assessed relevance (low, medium, high) and data availability (low, medium, high), using a prioritization matrix. Out of 102 indicators, 57 were first priority, 41 second priority, and 4 un-prioritized. Only four indicators were removed, resulting in 98 indicators being brought forward.

Examples of indicators for phase 1 and issue 1.1 (three of seven) are:

- *1.1.1 Has an overall risk and vulnerability (ROS) analysis been prepared?*
- *1.1.2 To what extent are climate-related events part of LL's overall ROS?*
- *1.1.3 Is future climate taken into account in LL's overall ROS?*

3.7. *Step 7: Determine the range of values for each indicator, assign weights and roles*

To determine if an indicator's value is 'good' or 'bad,' we must first set threshold values for the 'worst' and 'best' values. We also assess the importance of indicators and issues using weighting. We start by looking at threshold values and then weighting. Additionally, we identify who is responsible for each indicator, as this responsibility is distributed among many roles in LL.

3.7.1. *Threshold values*

We use a score scale from 0 to 5, where 0 is the worst and 5 is the best, as shown in Table 2.

Table 2. Score scale and resilience levels

Score	Resilience level	Designation
4-5	A	Very good
3-4	B	Good
2-3	C	Average
1-2	D	Bad
0-1	E	Critical

Each step on the score scale (0–5) corresponds to a resilience level (E–A), with E being the worst (critical). For example, a score between 3 and 4 corresponds to resilience level B (good). Each indicator has its own measurement scale, which must be adapted to the score scale by setting threshold values. This common scale is necessary for aggregating individual indicator values.

One example of threshold values for one indicator (indicator 1.1.1) is shown in Table 3.

Table 3. Threshold values for the indicator *1.1.1 Has an overall Risk and Vulnerability Analysis (ROS) been prepared (according to the Planning and Building Act) for LL as a whole? If yes, how old is it?*

Score	Resilience level	Designation	Threshold values
4-5	A	Very good	< 2 yrs
3-4	B	Good	2-4 yrs
2-3	C	Average	4-6 yrs
1-2	D	Bad	> 6 yrs
0-1	E	Critical	No

To simplify score calculation, standard ('default') score values are mid-values at each level (e.g., 0.5, 1.5) when the indicator value falls within this range.

3.7.2. *Weights*

At all levels (except the highest), weights must be assigned to determine the relative importance of indicators and issues. If considered equally important, each unit's weight is 1/n, where n is the number of units. The sum of the weights should always equal 1.0, regardless of whether weights are equal or different.

We identified five weighting alternatives and selected the one where weights are first allocated equally among all issues, then equally among all indicators for each issue. This results in different weights between phases. For 22 issues, each has a weight of 4.55%, and each of the seven indicators for the first issue has a weight of 0.65%. These weights can be adjusted later.

3.7.3. *Roles*

Many roles in LL are responsible for various issues and indicators and must be involved in establishing and using them. Additionally, a coordinator is needed for all work related to measuring and monitoring climate adaptation.

3.8. *Step 8: Assign values to the indicators (perform the measurement)*

In this step, data is collected for the indicators to determine their actual values. These values can come from various sources, such as information systems, data analysis, or experts. The measured values are used to calculate indicator scores, and with weights, scores and resilience levels are calculated at aggregated levels in step 9. Setting threshold values often becomes easier with real indicator values, making steps 7 and 8 inter-connected and iterative.

3.9. *Step 9: Perform the calculations (score and resilience level)*

The measured value of an indicator gives a score, which corresponds to a resilience level (E-A), as shown in Tables 2 and 3. Score values for issues (level 5), s_{Fk} for the issue (factor) *Fk*, are calculated as the sum of the weighted scores of the underlying indicators, s_{kj}, as shown in Eq. (1).

$$s_{Fk} = \sum_{j=1}^{n_k} v_{kj} \cdot s_{kj} \qquad (1)$$

Sum of weights shall equal 1, i.e., $\sum_{j=1}^{n_k} v_{kj} = 1$, where v_{kj} is the weight of indicator *j*.

Similarly, score values for phases (level 4) are the sum of the weighted scores of the underlying issues, and so on, until the total score for the area (level 1) is obtained. Each level's score corresponds to a resilience level.

General formulas for calculating score values at all levels are used, as Eq. (1). While the calculations are simple and can be done by hand, using an Excel spreadsheet or another tool is more practical, especially with many indicators and repeated measurements. Such tools are also useful for presenting results.

For example, the measured value for indicator 1.1.1 was '4-6 years' in 2022, as the ROS analysis was 5 years old (updated in 2017). It was updated again in 2023, changing the value to '< 2 years' and the score from 2.5 to 4.5. Consequently, the resilience level increased from 'C – Medium' to 'A – Very good'.

3.10. *Step 10: Present the results (status and trend)*

The resilience assessment provides an overall status for the entire area and detailed status at each level, revealing strengths, weaknesses, and areas needing improvement. Repeated measurements over time uncover trends. An example with fictitious values is shown in Figure 5 (see Table 1 for issue names).

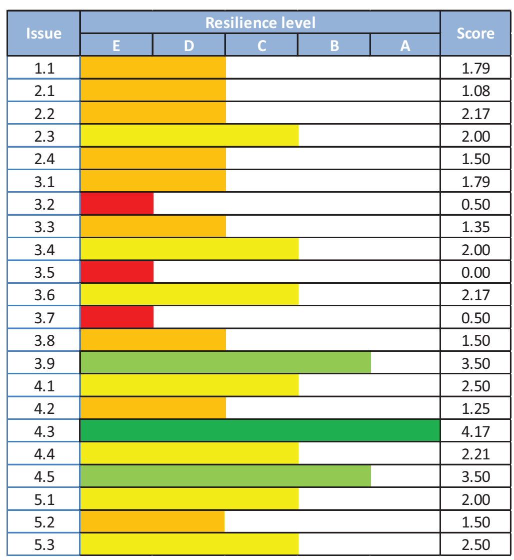

Fig. 5. Presentation of results with fictitious values

The calculations (step 9) and result presentation (step 10) are intended to be automated, for example, using a simple Excel tool. In the long term, it is practical if most data can be retrieved from existing databases.

Figure 5 shows the status for each of the 22 issues. The colours provide a quick overview of the greatest challenges and well-managed issues. The overall aggregated score is 1.89, corresponding to resilience level D.

3.11. *Summary of results*

The results are three-fold: 1) Establishing a method (CLAIM) for developing indicators to monitor municipalities' climate adaptation work, 2) Creating a set of indicators (based on CLAIM) for follow-up, and 3) Using the indicators to assess status and trends.

The method (CLAIM) is detailed in Section 2.2, with a step-by-step application in Section 3. Examples of issues are in Table 1 (Section 3.5), and indicators in Section 3.6. Figure 5 (Section 3.10) shows a status presentation. Trends can be identified from yearly measurements using the indicator set.

4. Discussion and conclusions

4.1. *General applicability*

While the method (CLAIM) is exemplified for Longyearbyen, it is applicable to any municipality. Longyearbyen's local climate profile allows for more specific indicators, covering natural hazards like erosion, landslides, avalanches, and soil creep, as well as their combinations or dependencies. For example, soil creep affects avalanche barriers on the eastern side of the Longyear valley.

4.2. *Remaining work and challenges*

Determining threshold values remains to be completed for the Longyearbyen case. It is a one-time effort, but adjustments may be needed after implementing the indicator set. The main challenges are obtaining some indicator values and allocating resources for data collection, calculations, and result presentation.

Simplifying the introduction by selecting a limited set of indicators may be appropriate. Initially, calculations and result displays can be done manually, with further development into more automated processing.

4.3. *Relation to previous work*

This work is similar to Menon (2018) and Sivertsen et al. (2021), aiming to develop indicators for monitoring climate adaptation in municipalities. While previous works are general, this paper uses Longyearbyen as a case study.

Key differences from previous works include using a resilience-based approach, categorizing indicators by phases, identifying important issues before indicators, incorporating a calculation method for aggregating indicator measurements, and detailing how results can be presented or visualized.

4.4. *Theoretical implications and practical applications*

Theoretically, this work links climate adaptation with climate resilience using a resilience-based approach, aligning with the new EU strategy on climate adaptation (EC 2021). Practically, the method and resulting indicators serve as a tool for monitoring climate adaptation in municipalities, exemplified by Longyearbyen.

4.5. *Conclusions*

The Arct-Risk project focused on both short-term and long-term climate adaptation. Longyearbyen local government (LL), responsible for climate adaptation in Longyearbyen[b], must address both short-term and long-term climate change effects and their potential interactions.

Climate adaptation indicators help LL visualize, report, and communicate climate adaptation efforts to inhabitants, local politicians, and central authorities. They ensure continuity despite changing responsibilities and make it easier for new employees to understand past work. This is crucial for Longyearbyen, given its high turnover of inhabitants and employees. Establishing a monitoring system is demanding, but not knowing the status of climate adaptation work could be far more costly.

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[b] Section 3-1 of the Planning and Building Act requires municipalities to adapt infrastructure to expected climate change, as well as prevent damage. §11-8 and §12-7 set requirements for security and monitoring.

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