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Article

Prioritizing Climate Change Adaptations in Canadian Arctic Communities

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Abstract: Arctic regions are experiencing the most rapid climate change globally and adaptation has been identified as a priority across scales. Anticipatory planning to adapt to the impacts of climate change usually follows a number of steps: assess current and future vulnerability, identify potential adaptations, prioritize options, implement prioritized options, and monitor and evaluate implementation. While most of these steps are well documented, there has been limited examination of the process of adaptation prioritization in Arctic communities. In this paper, we build upon existing tools and propose a framework for prioritizing adaptation options and guiding decision-making for implementation in Arctic regions. Using four adaptation performance criteria (timescale, equity, sustainability and total costs) to evaluate options through a multi-criteria decision analysis coupled with a network centric approach, our Adaptation Prioritization Framework promotes a participatory approach for adaptation prioritization and planning. We illustrate application of the framework using a hypothetical example from the territory of Nunavut in the Canadian Arctic.

Keywords: adaptation; climate change; prioritization framework; multi-criteria decision analysis; network-centric approach; adaptation planning; Arctic; food security

1. Introduction

It is widely acknowledged that the Arctic is undergoing transformative change in climatic conditions, with wide-ranging implications for human and natural systems already documented, and significant

warming projected for the future [1]. Across the Canadian North, Indigenous populations, who live in small isolated communities and depend to some degree on subsistence hunting and trapping, are believed to be particularly sensitive to these changes, with constrained access to hunting areas and enhanced danger widely documented, with implications for food security, health, and community well-being [2–4]. Landscape hazards associated with rising sea levels, coastal erosion and flooding, and permafrost thaw are also threatening the viability of buildings and affecting the integrity of infrastructure (e.g., roads, sewage lagoons, pipelines, tailings ponds, *etc.*), with potential benefits of climate change expected to accrue from enhanced shipping access to the region [1,5–9].

Reflecting the visibility and risks posed by climate change, the last decade has experienced a rapid increase in Arctic research on impacts, adaptation, and vulnerability [10–13]. While much of this work has focused on developing a baseline understanding on the pathways through which climate change affects northern communities, projects are increasingly working with decision makers to support the development of adaptation plans and strategies [3,14–16]. In Canada, this has been spurred by the creation of a number of northern-focused federal programs for creating adaptation plans, along with programs designed to explicitly engage northerners in assessing the risks posed by climate change and identify adaptation options [17–20]. Interest in adaptation at a territorial and regional level has also increased in Canada, emerging as an important focus of territorial climate change plans (e.g., [21,22]), and a feature of research and lobbying by organizations representing northern Indigenous populations.

Anticipatory adaptation planning projects in northern Canada have been undertaken by a variety of actors, ranging from communities, to university researchers, scientists, consultants, government departments, industries, northern science bodies, and civic society organizations (e.g., Canadian Institute of Planners) [14]. Different tools and frameworks from the general adaptation literature have guided this work, and while there are differences between them, five steps are commonly evident (see Figure 1): assess current and future vulnerability, identify potential adaptations, prioritize options, implement selected options, and monitor and evaluate their performance [14,23–25] (Step 1 identifies climate-related risks and assesses a system's vulnerability to these risks, as well as identifying key actors and stakeholders. Step 2 involves three tasks: (1) identifying on-going coping and reactive adaptations as well as proactive adaptation options; (2) assessing the system's adaptation readiness by identifying barriers and limits to the implementation of each option; and (3) determining the roles of previously identified key actors and stakeholders in the implementation. Step 3 includes prioritization of adaptation options, which is described in this article. Step 4 comprises the implementation phase of the previously prioritized adaptation options, while Step 5 involves monitoring and evaluating the adaptation option's performance).

Substantial knowledge has been created for the first two steps, varying by sector and region, yet in the Canadian Arctic there is limited evidence of specific adaptations being implemented or changes being made to existing policies in response to adaptation projects [3,26–28]. One challenge is that adaptation assessments frequently produce a portfolio or "wishlist" of potential response options, but provide limited guidance for end users on which to prioritize (*i.e.*, step 3) [14,29]. A similar problem has been identified in the general adaptation scholarship, highlighting the importance of systematically evaluating and prioritizing adaptation options if they are to guide decision-making [30].

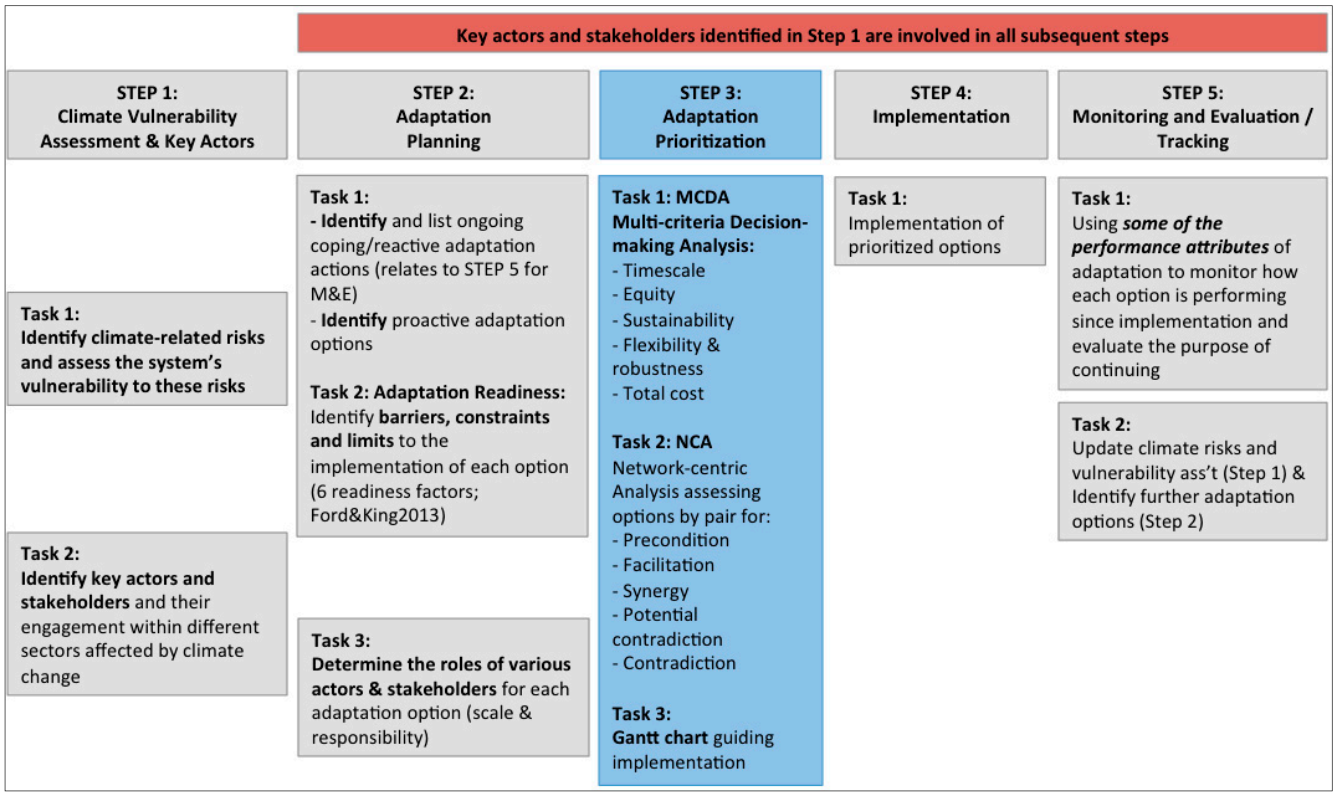

Figure 1. Anticipatory adaptation process to climate change—A five-step approach.

In response to this challenge, a number of tools have been developed in the general adaptation scholarship to assist adaptation practitioners in prioritizing adaptation options at a community level, and have been developed mostly for low- and middle-income nations (see Section 2.1.1). These tools range from those that are solely devoted to the prioritization of adaptation options (e.g., [23,31–38]), to decision support methods embedded within overall anticipatory adaptation processes and development frameworks aimed at mainstreaming adaptation into development [24,25,39–46] (see Section 2.1.2). Most tools use multi-criteria analysis (MCA) to evaluate the potential performance of adaptation options, although cost-benefit analysis (CBA) and cost-effectiveness analysis (CEA) have also been proposed as well as analytic hierarchy process (AHP). A number of shortcomings have been identified in the existing toolkits however, including: (1) limited stakeholder engagement in identifying and prioritizing adaptation options; (2) reliance on a limited number of methods which reduces the inclusion of different points of view and increases subjectivity; (3) limited consideration of how different options interact and influence simultaneous implementations; (4) an absence of studies combining both qualitative and quantitative insights; and (5) there are few examples where existing toolkits have been designed to prioritize adaptations in small remote communities in high-income nations, including the Arctic [14,31,36,47,48].

Reflecting these challenges and gaps, in this paper we review the literature on adaptation prioritization tools and framework and develop an adaptation prioritization framework to engage stakeholders in the prioritization of adaptation options at the community level in the Canadian Arctic, using a hypothetical case study to illustrate its application. The framework incorporates both qualitative and quantitative methods, and is designed to assist community representatives, local government, NGOs, researchers, decision-makers and other stakeholders in the prioritization of adaptation options identified in vulnerability

and impact assessments. While designed for use in an Arctic context, the framework has potential for broad application, particularly in the context of remote, resource dependent communities.

2. A framework for Prioritizing Adaptation Options

2.1. Review of the Literature on Adaptation Prioritization Tools and Frameworks

Among the prioritization tools and frameworks reviewed, we distinguish between two main categories: the first includes tools that exclusively detail the prioritization of adaptation options, and the second refers to detailed adaptation decision support methods embedded within overall vulnerability and adaptation assessment frameworks. Between these two categories, some tools overlap in terms of method and criteria used. In this section, we briefly describe the key tools (see complete review in Table S1).

2.1.1. Review of Adaptation Prioritization Tools

Within reviewed frameworks and tools exclusively detailing the prioritization of adaptation options, policy makers usually first assess the short-list of adaptation options according to the costs and related benefits of the option for the target population in a cost-benefit analysis (CBA). However, CBA is difficult to use for many adaptation options because it requires a common metric for benefits and costs in order to estimate if the benefits exceed the costs. Furthermore, not all benefits have a monetary value. In addition, the CBA alone would not be sufficient to prioritize and implement successful adaptation. As Taylor (2014: online) states when introducing the Adaptation Decision-making eXplorer (ADx): "there is no cure-all method to analyze everything: do not rely on only one approach" [38]. The ADx is an interactive tool that combines the results of several analyses using different methods (e.g., MCA, CBA or AHP) in order to compare them and prioritize the option with the best results in all methods. For instance, while Qin *et al.* (2008) use several multi-criteria decision-making tools to enhance the robustness of decision-making in their case study on water resources in Georgia Basin, Canada, Taeihagh *et al.* (2013) combine an MCDA composed of several performance and implementation attributes used to rank each measure, with a network-centric approach examining five types of relations between each pair of measures [33,48]. In their example, Ebi and Burton use MCA because it allows for different metrics to be measured within one approach and assigning different weights to the criterion can help reflect each criterion's relative importance for a particular community or context [23]. Debels *et al.* (2009) stress the need to recognize that adaptation options are context specific, as one option may be considered useful and successful for target populations over different time periods [31]. Therefore the criteria used to assess adaptation options and their relative importance depends on the spatial, temporal and social context of adaptation, as well as expert judgment [31]. Among the tools reviewed that focus only on prioritizing adaptation options, only two refer to the importance of local and traditional knowledge in the set of criteria they put forward to prioritize adaptation option, and none mentions indigenous knowledge [31,32].

2.1.2. Review of Adaptation Decision Support Methods Embedded within Adaptation Assessment Frameworks

Adaptation decision support methods embedded within overall vulnerability and adaptation assessment frameworks can be divided in two sub-categories. The first sub-category includes decision support tools embedded within development policies and assistance initiatives in developing countries and usually represent one step within an overall vulnerability and adaptation assessment [39–43,49]. While some of these tools focus on community scale and are driven by participatory approaches (CRiSTAL, ORCHID, Nunavut toolkit), others engage stakeholders in certain sectors at the national or regional scale (Tearfund, CEDRA, NAPAs). The second sub-category includes tools used at the organizational level to adapt assets, customers, finance, logistics, reputation and staff, mostly used in developed countries to decide on adaptation within organizations [24,45]. For instance, the UKCIP decision support tool is integrated in a larger framework starting with current and future climate change vulnerability assessments, adaptation options assessments and implementation, and finally monitoring, review and evaluation. The UKCIP wizard leads the user to use cost-benefit analysis and/or multi-criteria analysis, with criteria such as effectiveness, efficiency, equity, flexibility, sustainability, practicality, legitimacy, urgency, costs (economic, social and environmental), robustness, synergies/coherence with other strategic objectives, as well as other factors, specific to the context [24].

2.1.3. Overview of Adaptation Prioritization Framework

In this article, we focus on the third step in the process of anticipatory adaptation planning, namely the prioritization of adaptation options. We propose a multi-method framework for prioritizing adaptation options, and hence build on the second category of tools reviewed focusing on adaptation prioritization embedded in our overall adaptation framework (see pp. S10–S11 and Table S2). The framework builds upon existing scholarship on adaptation assessment and prioritization, taking into account the strengths and weaknesses found in the reviewed literature. Therefore, it is developed specifically for an Arctic context, and is designed to be participatory and community-based to ensure local and traditional knowledge, culture, and local perspectives are fully engaged in the process. The proposed framework is contingent upon the completion of assessments identifying potential adaptation options and their adaptation readiness (Steps 1 and 2 of Figure 1), and begins by using a multi-criteria decision analysis (MCDA) to examine adaptation performance according to four criteria chosen among the reviewed literature for their complementarity in prioritizing options in remote community contexts (Figure 2) (The adaptation readiness assessment uses 6 readiness factors (political leadership, institutional organization, adaptation decision making and stakeholder engagement, availability of usable science to inform decision making, funding for adaptation planning, implementation and evaluation, and public support for adaptation) (Ford and King, 2013 [30]). This adaptation readiness assessment is part of Step 2 of the anticipatory process of climate change adaptation described in Figure 1 above, and reduces the number of identified options that reach Step 3 (Prioritization), which is described in this paper.).

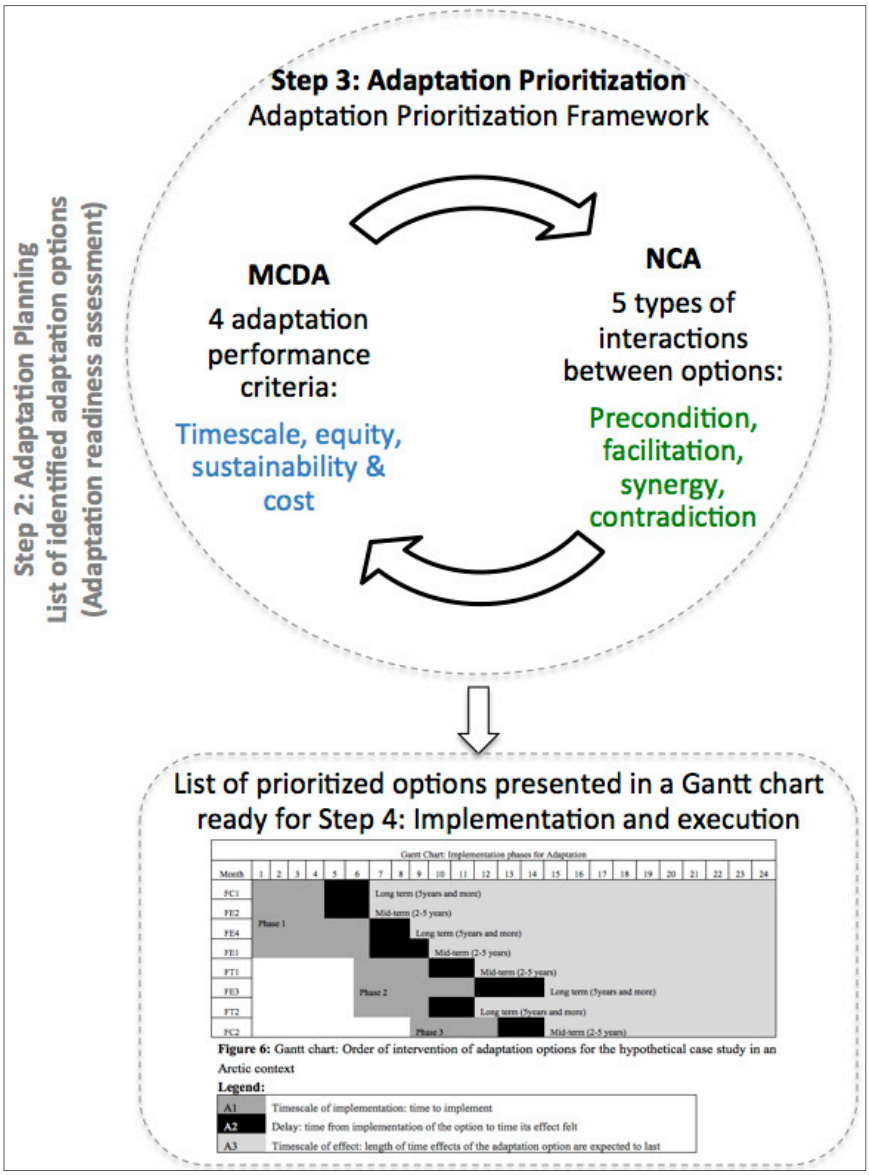

Figure 2. Climate change adaptation prioritization framework.

Because the MCDA assesses each option independently, we build upon Taeihagh *et al.* (2013) and add to our proposed framework a network-centric approach (NCA) to ensure each option is selected for implementation in a timely manner that respects the interactions between all options. The network analysis is used to articulate all possible interactions within an adaptation intervention, such as synergies, contradictions and facilitations that might occur between and among adaptation options (Figure 2) [48]. Using MCDA and NCA allows us to capture cultural, political, social and economic factors as well as to assess the adaptation options in a network visualization to determine successful interactions within the adaptation planning and implementation process. Furthermore, in order to test the robustness of the MCDA's results, the re-assessment of the MCDA acts as a sensitivity analysis by changing the weights applied on the four criteria. Next, we begin by presenting strengths and weaknesses of both methods; we then describe MCDA and NCA including their respective criteria and types of relations. These two methods (MCDA and NCA) both present strengths and weaknesses, displayed in Table 1. We then illustrate the framework with a hypothetical case study and conclude with a discussion of future applications of this work.

Table 1. Strengths and weaknesses of the multi-criteria decision analysis (MCDA) and neetwork-centric approach (NCA).

Method	Strengths	Weaknesses
Multi-Criteria decision Analysis	Combination of quantitative data (ranking and weighting each criterion and qualitative data (comments on quantitative results of MCDA).	Subjective as every expert and stakeholder will not have the same opinion on ranking and weighting each criterion.
	Low cost and low time needed to conduct MCDA; simple and transparent	Qualitative analysis of uncertainty may be too subjective
	Combination of experts' judgment with stakeholders' who can associate each attribute with certain weights according to their importance in the community	
	Use of local knowledge	
Network-centric approach	Promotes participation of several actors and viewpoints. Use of local knowledge Combination of experts' and stakeholders' perspectives	Subjective bias Time-consuming

2.2. Multi-Criteria Decision Analysis (MCDA)

Multi-criteria decision analysis (MCDA) is a form of multi-criteria analysis (MCA), using both quantitative and qualitative forms of assessment to prioritize a series of options in order to help decision-making [50]. Furthermore, MCDA provides a basis for systematically assessing adaptation options according to a set of criteria that can be defined further and weighted according to the context, in collaboration with researchers, practitioners, decision makers, and community members, and has been widely promoted in the adaptation planning scholarship [31,50]. The MCDA model developed here consists of four adaptation performance criteria and builds upon existing tools in the literature (see pp. S10–S11 and Table S2). These four adaptation performance criteria were selected from the reviewed literature since they have been identified as essential in the prioritization of adaptation options, and they cover various aspects of the adaptation option, including temporal, spatial, social, political characteristics, and financial aspects of adaptation planning and implementation.

2.2.1. Timescale: How Long Does the Adaptation Option Take to Implement, How Soon Will the Effect be Felt and How Long will the Effects Last for?

Debels *et al.* [31] argue that in planning adaptation options, it is crucial to consider time horizons for project implementation, monitoring and evaluation, and also to ensure adaptations can be incorporated into existing planning processes. To assess the timescale of adaptation options, we build upon Taeihagh *et al.* [48] and argue that the three following elements are important to include in the prioritization of options for thorough implementation: (i) timescale of the implementation: how long it takes to implement an option; (ii) time from end of implementation to effect being felt (delay); and (iii) timescale of effect: time during which the option's effect will be felt after implementation. In a best-case scenario, an adaptation option should have a short timescale of implementation, the population should feel the effects immediately after implementation, and the effects should be long lasting. These criteria are particularly pertinent in the context of northern Canada where urgent and immediate non-climatic policy priorities (e.g., poverty alleviation, housing, health disparities, cultural preservation, *etc.*) have limited interest in adaptation actions which have long lead times to have an impact [3,51], with the general literature also indicating that community-based adaptations often require short-term impacts to develop community buy-in [52,53].

Although we define different timescale elements in terms of duration (see pp. S10–S11 and Table S2), these definitions are context dependent and may be adjusted accordingly. Definitions of short-, mid- and long-term will vary amongst communities, decision makers, and community representatives, and need to be defined in partnership before conducting MCDA. Further, clear communication with knowledge users regarding the expected timescale of the adaptation option is important in order to manage expectations and maintain the legitimacy of the adaptation intervention [54].

2.2.2. Equity: Is the Adaptation Option Equitable to All?

Equity of an option refers to the fact that adaptation options should not adversely affect vulnerable groups or other areas (*i.e.*, downstream effects), and/or should not exclude or marginalize certain groups of the population [55]. As argued by Keskitalo [56], equity is important in the assessment of adaptation options, as different social groups are affected differently by climate change impacts and associated adaptations, reflecting livelihood and habitation characteristics and socio-economic processes and conditions. Evaluating equity in adaptation options is therefore subjective to the local context [57,58]. For this proposed framework, we use equity as an important criterion to consider at different spatial scales. We do not include intergenerational equity here as it is covered in the sustainability criterion. In our Arctic context, the community scale is especially relevant where households with limited sources of income or food may be more vulnerable than households with multiple sources of income or food.

Two approaches exist in considering equity in policy: the egalitarian approach is targeted at the population and/or region most in need, which results in a smaller number of people benefiting from adaptation [59]; and the utilitarian approach in which policies are designed for maximum efficiency for large populations or regions, but may neglect other smaller populations or regions facing real needs for adaptation [59]. In practice, these two approaches are often combined. Because inequitable adaptation options may undermine both sustainable development and adaptation, this criterion needs to be closely evaluated and monitored during and after the implementation of a given adaptation option [60,61]. Examining an option's direct effects as well as externalities (identified in Step 2 when designing options and assessing adaptation readiness) may contribute to the understanding of the equity of an option.

2.2.3. Sustainability: Is the Adaptation Option Sustainable?

Sustainability of an option refers to the viability and effectiveness of the option in the long-term within the context of uncertain future socioeconomic, environmental and climatic conditions. In this framework, we consider that the sustainability of an adaptation option can be improved if it maintains a level of mainstreaming with other national and sub-national strategies and development programs, if it is compatible with other sectoral policies (e.g., health care) and mitigation strategies, if it is consistent with cultural and social values of the given population, and if it is sufficiently flexible and robust to incorporate climate uncertainty [3,23,25,31,38,48,59,62,63]. Brooks *et al.* [59] argue that an option is sustainable when the benefits of adaptation are felt during, after and/or at the end of implementation. In order to be sustainable, it is important that an option take into account the determinants of vulnerability, learn from past and existing coping and adaptation mechanisms, and continually adjust to fit existing and emerging conditions, especially in indigenous contexts where, for instance, strategies are often specific to local context and culturally attached to the land. Externalities or negative effects of adaptation options should also be accounted for to prevent maladaptation. It is worth noting that this criterion is

closely related to the timescale of effect; however, whereas the timescale of effect describes the length of time in which the option's benefits will be felt, the sustainability criterion refers to the ability to learn from and adapt the option to emerging conditions without resulting in unintended externalities. A sustainable adaptation option thus ensures that social and environmental welfare are not adversely affected by any unintended consequences of the option. A sustainable option then is one that is effective, flexible and robust in the long-term, as well as compatible with other sectoral policies and development programs.

2.2.4. Cost: How Much Does the Adaptation Option Cost?

The total cost of an adaptation option captures the economic value of the design, implementation, execution and monitoring and evaluation of the option [31,48]. With financial feasibility assessed in Step 2 as part of the adaptation readiness assessment, the selected adaptation options are already considered cost-effective once prioritization starts. Hence, as it is financially feasible and qualifies for Step 3, here we use the total cost of an option as a criterion can help decide the order in which to implement each option so as to optimize and potentially change the overall intervention costs. Indeed, understanding the different costs components of each adaptation options may contribute to an optimized order for adaptation implementation. A *high cost* in this framework signifies, for instance, that the option requires financial support that has not been already invested in other policies. A *medium cost* means that the option can be mainstreamed to a certain extent into existing development policies with some additional expenses potentially required, while a *low cost* option means that the option can be largely absorbed and mainstreamed into existing development policies with minimal additional costs.

2.3. Network-Centric Approach

While the MCDA allows for a comprehensive evaluation of each potential adaptation option independently, it does not articulate relations such as synergies and/or contradictions that might occur between and among adaptation options. According to Saaty and Vargas [64], decision-making cannot only rely on hierarchically structured analyses, but should also involve a network analysis to consider the interactions and dependencies that might exist between options. As part of their policy measures ranking methodology (PMARM) for promoting walking and cycling in cities, Taeihagh *et al.* [48,65] complement their MCDA with a network analysis of the relations between different policy measures. Givoni *et al.* (2010) also refer to Taeihagh *et al.*'s network approach among complementary measures on the European transport systems to analyze their synergies [66]. Each option's relations are examined in pairs and independently of the rest of the options, using a multi-relational matrix to inventory all relations (Table 2). We use the five types of relations possible among policy options identified by Taeihagh *et al.* [48,65,67]:

- Precondition (P): the successful implementation of option "A" can only happen if option "B" is implemented first, option "B" is therefore a prerequisite to option "A".
- Facilitation (F): implementation of option "A" facilitates the implementation of option "B"; therefore the implementation of option "B" will work better after option "A" is implemented.
- Synergy (S): two-way facilitation, implementation of option "A" works better after option "B" has been implemented or if it is being implemented at the same time as option "B" and implementation of option "B" works better after option "A" has been implemented or if it is being implemented at

the same time as option "A", therefore they can be implemented simultaneously and may result in even greater benefits than if "A" or "B" is implemented alone.

- Potential contradiction (PC): the implementation of option "A" may potentially contradict the implementation of option "B"; therefore caution should be used when deciding on the implementation timing of these two options.
- Contradiction (C): the implementation of option "A" contradicts the implementation of option "B"; therefore these two options should not be part of the same intervention.
- No relation: "A" is not related to any option within the intervention.

Table 2 is an example of a multi-relational matrix showing different types of relations and interactions between five options, which are then visualized in a network in Figure 3.

Table 2. Example of a multi-relational matrix (Precondition (P); Facilitation (F); Synergy (S); Potential Contradiction (PC); Contradiction (C)).

Option #	#1	#2	#3	#4	#5
#1		PC	F	P	0
#2	PC		0	S	0
#3	0	P		C	S
#4	0	S	C		S
#5	F	F	S	S	

Option #1 is in potential contradiction with Option #2, facilitates Option #3 and is a precondition to Option #4. Option #2 is in potential contradiction with Option #1 and is in synergy with Option #4. Option #3 is a precondition to Option #2, contradictory with Option #4 and in synergy with Option #5. Option #4 is in synergy with Option #2, contradictory to Option #3, and in synergy with Option #5. Option #5 facilitates Option #1 and Option #2 and is in synergy with Options #3 and #4.

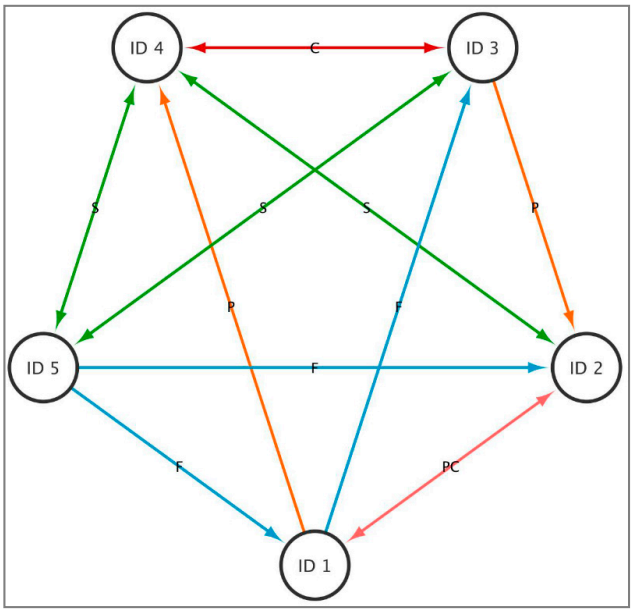

Figure 3. Example of a network visualization linked to data from Table 2 (using Cytoscape Open Source Platform for complex network visualization). (Key: Orange arrow = Precondition (P); Blue arrow = Facilitation (F); Green double arrow = Synergy (S); Pink arrow = Potential Contradiction (PC); Red arrow = Contradiction (C).)

Based on the relations of these options, the order of implementation for this example would be to start with option number #1, #3, #5, #2 and finish with #4.

2.4. Application of the Adaptation Prioritization Framework

While both methods used in our framework are part of an iterative and participatory process, conducting the MCDA first will give important insights on the content of each option and may facilitate the completion of NCA later on. Our adaptation prioritization framework is designed to be participatory and therefore to engage different stakeholders, such as community members, researchers, and experts in its application in order to obtain the most comprehensive results and avoid personal or institutional bias. We suggest that each stakeholder conduct both analyses individually first and then gather together in multidisciplinary focus group discussions, mediated by volunteer stakeholders, joining experts, researchers and community members to combine results, discuss outcomes, and allow for different perspectives to be heard (see Figure 4). Acting as mediators of the focus group discussions, volunteer stakeholders would be randomly selected to avoid bias and trained to conduct focus group discussions. Once each group has finished discussing each adaptation option, each mediator would then share the results of his/her group to the rest of the audience and the focus group discussion would continue in a plenary session until a consensus is reached on the results [37]. It is important to note that building consensus may be difficult if stakeholders have different political interests and internal power dynamics; therefore, we stress the need for a sensitivity analysis and that more time is spent on training volunteer stakeholders in order for them to anticipate the complexities of participatory processes [54,68]. Next, we detail the application of each method of the framework as well as the sensitivity analysis.

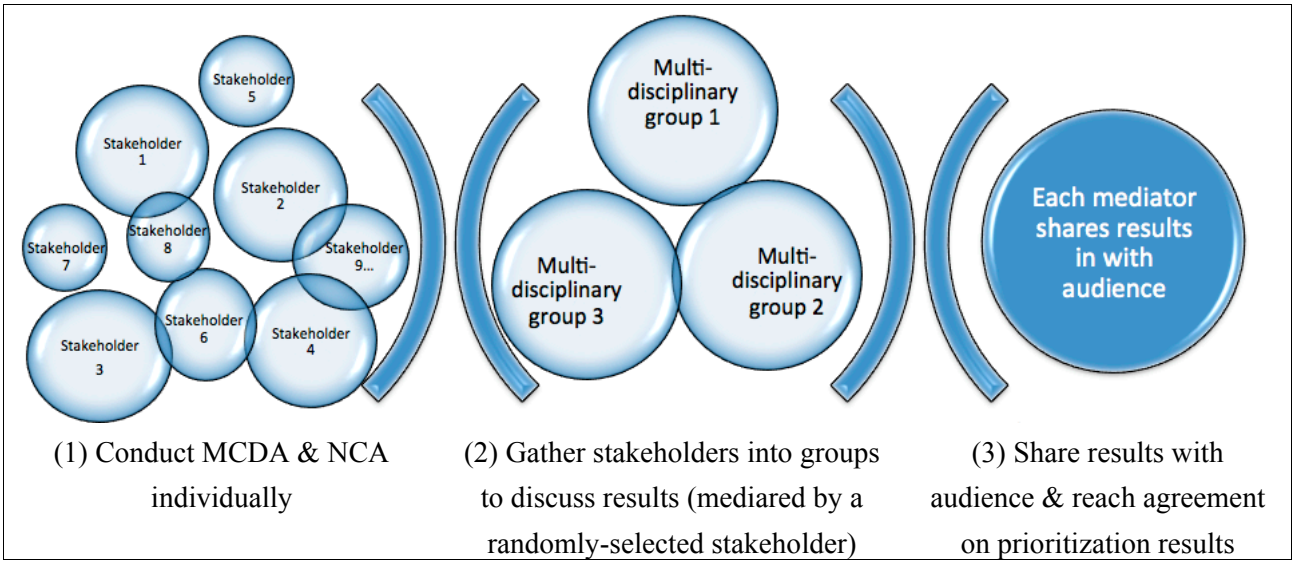

Figure 4. Application of the adaptation prioritization framework.

2.4.1. MCDA Application

The MCDA component of the framework is used to enable adaptation prioritization in a systematic and transparent manner. Data on each option is provided from Step 2 and stakeholders assess each MCDA criterion against each identified adaptation option. Each criterion is ranked (e.g., low, medium, high) and subsequently transformed into scores from 1 (low) to 5 (high) (see pp. S10–S11 and Table S2).

The ranking is used to rate the potential performance of an option, and each criterion may receive different weights to define their importance for a specific context (from 1 for normal criterion to 5 for a highly important criterion). We build upon Haque *et al.* [37] who promote a participatory approach in which weights can be added to each criterion by stakeholders to capture local perceptions of what is important in adaptation options in the context of flood protection measures. Scores for each of the four criteria are then summed to provide a total score for each adaptation option. One of the strengths of MCDA is to combine quantitative and qualitative data (Table 1), therefore, in addition to using criteria and scores to prioritize adaptation options, the MCDA can be complemented by qualitative comments on the overall score of each option to explain the rationale behind the score given to each option, as only relying on quantitative analysis may not reflect the nuances involved.

2.4.2. NCA Application

Once the MCDA is complete, stakeholders can move on to examine the interactions between adaptation options: the network-centric approach (NCA). Options are assessed in pairs independently and against one another to identify the following potential interactions: precondition, facilitation, synergy, potential contradiction, contradiction or no relation. This analysis can be conducted using data from Step 2 and from the results of the MCDA and recorded in a multi-relational matrix in which each option is assessed against all other options one at a time (see Table S5). The results of these interactions recorded in a multi-relational matrix are then translated into network visualization with one node per adaptation option linked to all other options by different colored arrows, each representing a type of interaction (see Figure 3). The results of both MCDA and NCA are finally transferred into a Gantt Chart, used to show the intervention schedule broken down over the three timescales criteria for each adaptation option.

2.4.3. Sensitivity Analysis

In order to reinforce the robustness of the results and to assist in building a consensus in the participatory process, we suggest a sensitivity analysis to these two methods, consisting of the re-assessment of the MCDA by changing the weights of one of the four criteria according to the local context in order to understand the differences in the total score of each option [37]. As we promote a participatory framework, weights may be changed according to the preferences of the stakeholders engaged in the adaptation prioritization process. Stakeholders may decide as a group on changing the weights as they see fit and conduct the sensitivity analysis at least twice with different weights. To simplify the process of the sensitivity analysis, end users can use the same multi-relational matrix (as in Table S5) used at first, change the given weights of criteria and examine how MCDA scores change and how the interactions are affected by the modified-MCDA, to finally result in a Gantt Chart for Step 4, namely the implementation of adaptation options.

3. Pilot Application

3.1. Hypothetical Case Study

In order to illustrate the use of this framework, we present a hypothetical study, inspired by Markandya and Chiabai [69,70], and draw upon ongoing work on adaptation with Inuit communities in the Canadian Arctic. In this hypothetical case study, the objective is to assist communities prioritize their adaptation options to food insecurity, a key climate-related health risk already being compromised by observed climate change impacts, and projected to become more problematic in-light of future change [1,71–74]. Inuit food systems are closely linked to subsistence harvesting practices, where locally harvested traditional foods (e.g., caribou, seal, arctic char) form an important part of diet. The dependence on land-based harvesting creates significant sensitivity to changes in sea ice conditions, weather, and animal health and behavior, with several studies documenting reduced food access, availability and quality with climate change [15,75–77]. For this hypothetical case study, we assume that Step 2 of the anticipatory adaptation process (see Section 1) has already been conducted (including a climate readiness assessment of the community and the determination of the roles of stakeholders for each adaptation option). Adaptation options have therefore been selected based on their potential adaptation performance, and there is a present need to prioritize (Step 3) the implementation (Step 4) of these adaptation options, as these are too often provided as "wishlists" without guidelines on when and with which option to start the implementation. Table 3 identifies selected adaptation measures designed to reduce vulnerability to these climate change impacts based on potential adaptations identified in the literature, and includes three different types of adaptation measures (see Table S3 for a description of these adaptation options):

- Technical measures are the hard or structural adaptation options, such as investing in community freezers in the Arctic context to improve conservation of food bought or locally harvested and enhance food security.
- Educational and advisory measures are soft adaptation options pertaining to raising awareness about climate change risks and outcomes in the community. These options require the involvement of the community's traditional and indigenous knowledge in order to successfully be implemented.
- Cultural and behavior measures are also soft adaptation options related to behavioral and cultural changes within a community. These options require the involvement of the community's traditional and indigenous knowledge in order to successfully be implemented.

In this hypothetical case study, it is assumed that all selected adaptation options are to be financially supported by local governments, indigenous organizations, and/or NGOs. This assumption is supported by the adaptation readiness assessment since Step 2 screens out other adaptation options that are not considered to be financially feasible. We also assume that researchers and local NGOs would collaborate with community representatives and local officials, identified in Steps 1 and 2, in the prioritization of these measures within multidisciplinary groups mediated by volunteer stakeholders, as well as in the assessment of risks and impacts of climate change on food security. Please note that because this is a hypothetical study only to illustrate the framework, we did not assign weights to the four adaptation criteria of the MCDA and did not conduct the sensitivity analysis.

3.2. Results from the Hypothetical Case Study

The detailed results of the MCDA for each adaptation option are presented in Table 3, with additional detail provided in supplementary materials.

In our network centric approach, we found that soft measures, concerned with educational and advisory activities as well as cultural and behavioral ones tend to facilitate the implementation of hard and technical measures, which shows that, in our hypothetical case study, they should be implemented first to lead the way for a successful intervention. Indeed, the enhancement of traditional knowledge and land-skills training (FC1) for instance, are essential to the overall intervention, as they are a precondition to FT1 (collaboration on weather and hazard forecasting between meteorologists and Inuit communities) and facilitate the implementation of FT2 (investment in community freezers). (Legend for the codes: F for Food; T for Technical options; E for Education and advisory options; C for Cultural and behavior options. (Adapted from Markandya and Chiabai, 2009 [71] and the WHO website [72])). Land-skills training is also needed for FT1 for harvesters to know how to recognize weather patterns and to learn about modern technologies, such as GPS tracking. FC1 also facilitates the implementation of the promotion of community food programs (FC2) as it promotes cultural preservation and traditional practices of food sharing among communities. FC1 is in synergy with the food safety education campaign (FE2). While FC1 works to preserve food traditions and traditional knowledge of food preparation and storage, the promotion of safe food practices (FE2) ensures that the traditional food preparation and storage does not lead to the contamination of food. Similarly, the implementation of FE2 in conjunction with FC1 helps to further promote traditional food practices, which might lead to stronger overall food security, particular amidst changing conditions.

Strengthening institutional services for communities (FE1) is another soft measure playing an important role in the overall intervention in this hypothetical case study, as it facilitates the implementation of FT1 and FT2, which both need strong community targeted institutional support. FE1 is also in synergy with FE4, since community harvesters and traditional livelihoods will likely experience greater benefits from the implementation of both options. For example, raising awareness of community conditions and needs under FE1 will likely lead to stronger programming in the Harvester Support Program, which is also an objective of FE4. Similarly, the improved communication of the program to hunters under FE4 has the potential to further FE1's goals of facilitating cross-cultural communication.

As observed in this hypothetical case study, "soft" measures often act as facilitators to the "hard" measures, meaning that in order to be successful, this intervention must first raise awareness and adapt behaviors via soft measures, in order to set the background and then implement the hard adaptation options. These two different analyses (MCDA and NCA) allow us to prioritize adaptation measures first in terms of four adaptation performance criteria, and second in terms of their interactions and dependency (Table 4 and Figure 5).

Table 3. Results of the multi-criteria decision analysis for 8 adaptation options in an Arctic community.

Type of Option	Code	Adaptation Measures	Total (max = 30 min = 6)	Comments (for More Details about Scores for Each Criteria, Please See Table S4)
Technical	FT1	Collaboration on weather and hazard forecasting between meteorologists and Inuit communities Level of action: local and territorial government	19	This measure scores the lowest among all adaptation options (19). We argue that this score reflects the challenging nature of implementing and sustaining in the long term an exchange platform with meteorologists, whether it be based in the North or in the South. Although the cost of implementation is estimated high, this option has the potential to help hunters better understand climate change and hazard in order to pursue their traditional livelihoods and provide traditional foods for their family/community and revenue to buy store foods.
Technical	FT2	Investment in community freezers Level of action: local and territorial governments	22.5	This measure scores high in all attributes, except for equity because remote indigenous communities may be involuntary excluded. Although its cost estimate is medium, we argue nonetheless that this is an option that proves to be efficient to increase food security by securing and stabilizing food quality once accessed.
Education and advisory	FE1	Strengthening institutional services for indigenous communities Level of action: community; local and territorial governments	19.5	This measure scores only 19.5, largely because of the time and the medium cost needed to implement and sustain institutional change in the long term. Once implemented, it will support programs dedicated to help indigenous improve their food security in the face of climate change.
Education and advisory	FE2	Food safety education campaign Level of action: community; local government	23	This measure scores 23, largely because of its low cost estimate. However, it not only may exclude marginalized population and therefore scores low on equity, but also the timescale of the effects will depend on the quality of the campaign and the level of awareness raised on food safety.

Table 3. *Cont.*

Type of Option	Code	Adaptation Measures	Total (max = 30 min = 6)	Comments (for More Details about Scores for Each Criteria, Please See Table S4)
Education and advisory	FE3	Promotion of livelihood diversification through capacity building programs. Level of action: community; local government	23	Because this measure is driven by the local government and promotes non-traditional livelihoods, it may not be seen as successful for indigenous communities. However, its low cost estimate and the potential benefits for the community, once implemented, are not only expected to last in the long term, but also to provide co-benefits to other sectors such as health, wellbeing, economy, and education.
Education and advisory	FE4	Foster community hunters through harvester support programs. Level of action: community; local and territorial governments	23.5	This measure scores the second highest among the 8 options (23.5). Although it may take 4 to 5 months to implement and it has a rather low stakeholder involvement, fostering community hunters through harvester support programs will show efficient outcomes in terms of acceptability and equity among communities and proves to be sustainable, flexible and well transferrable. Therefore we can argue that this measure increases access to traditional foods and increases food security at large, at a medium cost of implementation.
Cultural and behavior	FC1	Enhancement of traditional knowledge and land-skills training programs. Level of action: community; local government	26	This measure scores the highest among the 8 options presented in this intervention. We argue that its community driven approach ensures a high adaptation performance on all attributes as it aims at preserving traditional and indigenous knowledge and land-skills while also integrating modern techniques in a rather short timeframe with long-term effects and a low cost of implementation.
Cultural and behavior	FC2	Promotion of community food programs Level of action: individual and community; local government	21.5	We argue that its community driven approach ensures a high adaptation performance on all attributes as it aims at promoting collaboration on food production and distribution between and among communities while also promoting healthy food on a regular basis via community meetings in a rather short timeframe with long-term effects and a medium cost of implementation.

Each pair of options was assessed and evaluated for precondition, facilitation, synergy, potential contradiction and contradiction in order to fill a multi-relational matrix (see Table 4 and Figure 5 below). Legend for the codes: F for Food security; T for Technical options; E for Education and advisory options; C for Cultural and behavior options. (Adapted from Markandya and Chiabai, 2009 [71] and the WHO website [72]).

Table 4. Multi-relational matrix of adaptation measures to increase food security in a hypothetical case study in an Arctic context.

Type of Option	Code	Adaptation Measures	TOTAL (max = 30; min = 6)	Adaptation to Food Insecurity							
				FT1	FT2	FE1	FE2	FE3	FE4	FC1	FC2
Technical	FT1	Collaboration on weather and hazard forecasting between meteorologists and Inuit communities	19		–	0	–	–	0	0	–
	FT2	Investment in community freezers	22.5	–		0	S	–	0	0	S
Education and advisory	FE1	Strengthening institutional services for indigenous communities	19.5	F	F		–	F	S	–	F
	FE2	Food safety education campaign	23	–	S	–		–	–	S	S
	FE3	Promotion of livelihood diversification through capacity building programs	23	–	–	0	–		–	S	–
	FE4	Foster community hunters through harvester support programs	23.5	F	F	S	–	–		0	S
Cultural and behavior	FC1	Enhancement of traditional knowledge and land-skills training programs	26	P	F	–	S	S	S		F
	FC2	Promotion of community food programs	21.5	–	S	0	S	–	S	0	

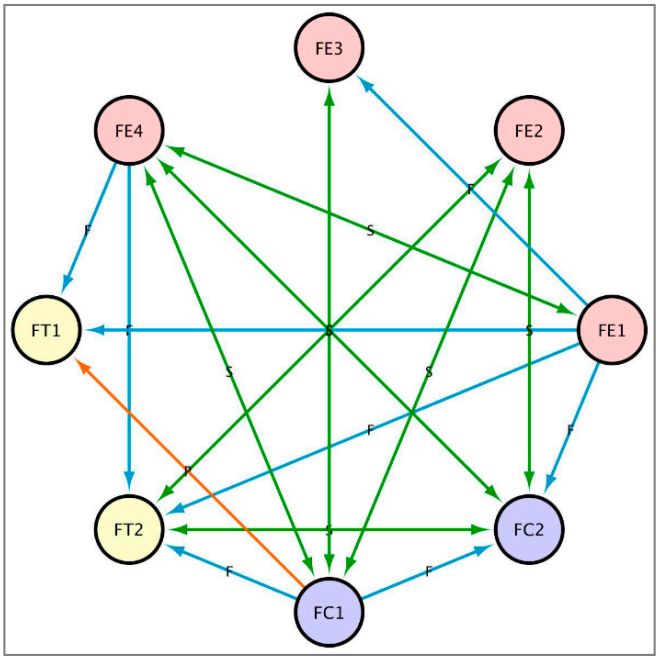

Figure 5. Network centric visualization for the hypothetical case study in an Arctic context. (Key: Orange arrow = Precondition; Blue arrow = Facilitation; Green double arrow = Synergy; Blue and red nodes: "soft" adaptation options; Yellow nodes: "hard" adaptation options).

The combination of these analyses improves our understanding in terms adaptation planning, as by prioritizing these measures, we rank them in the order these should be implemented and show the delay and timescale of each option's effects. The Gantt chart in Figure 6 below displays the order in which we suggest adaptation options should be conducted according to the two methods' results (MCDA and NCA).

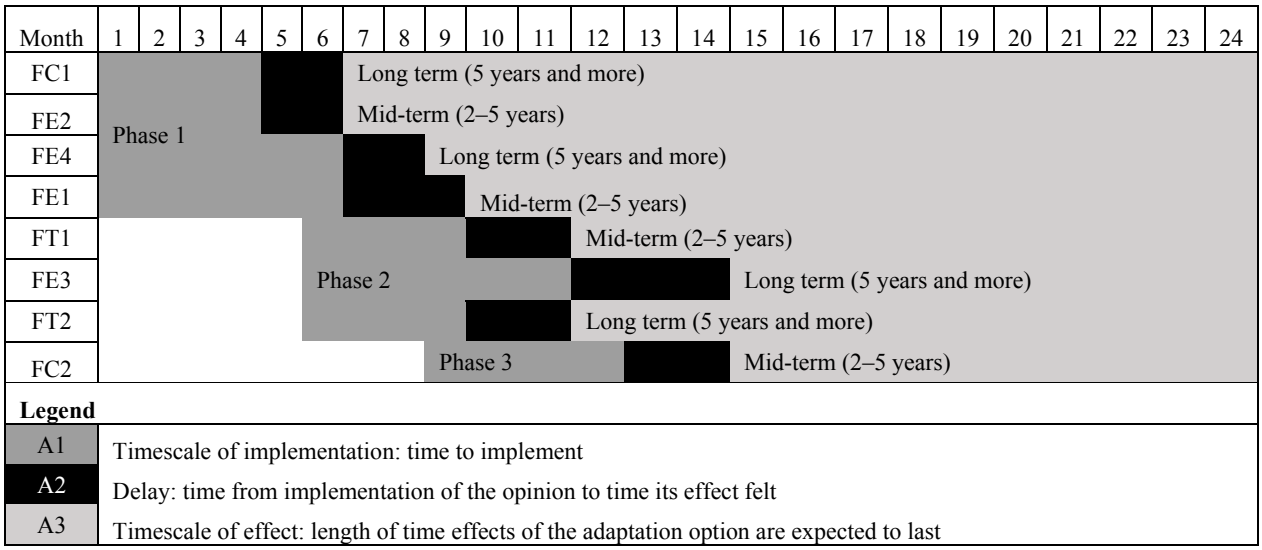

Figure 6. Gantt chart: order of intervention of adaption options for the hypothetical case study in an Arctic context.

Among the eight measures, we distinguish five different phases of implementation:

- **Phase 1: FC1, FE2, FE4 and FE1 simultaneously**
  - FC1: Enhancement of traditional knowledge and land-skills training programs
  - FE2: Food safety education campaign
  - FE4: Foster community hunters through harvester support programs
  - FE1: Strengthening institutional services for indigenous communities
- **Phase 2: FT1, FE3 and FT2 in sequence**
  - FT1: Collaboration on weather and hazard forecasting between meteorologists and Inuit communities
  - FE3: Promotion of livelihood diversification through capacity building programs
  - FT2: Investment in community freezers
- **Phase 3: FC2**
  - FC2: Promotion of community food programs

Enhancing traditional knowledge and land-skills training programs (FC1), promoting a food safety education campaign (FE2), fostering community harvesters through harvester support programs (FE4) as well as strengthening institutional services for communities (FE1) all score high in the MCDA and influence all other four measures in the intervention; therefore the analysis indicates these four options should be prioritized, simultaneously implemented and managed during the duration of the intervention. The second phase of the intervention groups the technical (hard) adaptation measures that should be implemented progressively. While adaptation is usually seen as more efficient when conducting hard and structural interventions, this analysis, shows that between the two technical measures (hard/structural) of our hypothetical case study, FT1 could not have been acted upon without the soft intervention of FC1, aimed at enhancing traditional knowledge and land-skills training programs, while the other technical measure's implementation (FT2) was facilitated and improved by three soft measures.

FC1 obtains the highest score (26) in the MCDA, has a low cost of implementation, is a precondition to one option, contributes to the facilitation of two other options and is in synergy with three other

options. This emphasizes that the implementation of this particular option should be prioritized due to its important contribution to other options and to the community. Following this prioritization (Step 3) that we have outlined in the case study, implementation of options as Step 4 would occur and be followed by monitoring and evaluation of the implementation as Step 5.

4. Discussion and Conclusions

In this paper, we propose a framework for prioritizing adaptation options using a participatory approach. The results of the hypothetical study demonstrate that in order to plan for adaptation interventions, the potential adaptation performance of each adaptation option needs to be examined alongside the multiple interactions between and among options. Had the NCA not been included, the MCDA would only provide a rating of each independent adaptation option according to the four criteria, but no order in which options should be implemented. Although this framework demonstrates its value in this hypothetical study, it is important to mention that this hypothetical case study represents a first approximation of the Adaptation Prioritization Framework application and should be examined with caution. However, on the ground application of the framework was outside the scope of this project, therefore further empirical research is necessary to verify the framework's efficiency in prioritizing and planning adaptation options.

In addition to prioritizing adaptation options, the Adaptation Prioritization Framework may address gaps in the literature, as well as inform research and policymaking in several areas:

- Utilization of both MCDA and NCA: By using MCDA and NCA as well as a modified MCDA as a sensitivity analysis, our proposed framework addresses some of the limitations identified in the reviewed literature. For example, this framework seeks to improve its robustness and objectivity by relying on multiple methods to prioritize adaptation options. Additionally, the framework combines both qualitative and quantitative data by analyzing the interactions between and among options in the NCA and scoring adaptation options according to four adaptation performance criteria within the MCDA.
- Context-specificity of the framework: By providing the opportunity to alter the weights assigned to each MCDA criterion according to their importance within the local context, the framework promotes a participatory process and minimizes subjectivity by engaging different stakeholders and considering their different perspectives on each adaptation options. This participatory approach is reinforced by a sensitivity analysis to assist in an unbiased consensus building among stakeholders.
- Potential to assess the performance of adaptation options during implementation: The framework can also be used to assess the adaptation success of implementation as different options are being implemented. The framework can also potentially be used to monitor the interactions between adaptation options to ensure that synergies are maximized and contradictions are minimized. In this sense, the prioritization framework may also provide useful insight on improvements for on-going and future implementation.
- Potential application in monitoring and evaluating: Once adaptation options are implemented, monitoring and evaluation of the outcomes of each adaptation option will be facilitated as a result

of the skills and experiences that stakeholders gain through the use of this framework, potentially fostering a participatory monitoring and evaluation process.

- Potential application as a knowledge exchange platform: As a participatory approach, the framework can also serve as a knowledge exchange platform for community representatives and community members to make decisions regarding the prioritization of adaptation options during workshops and community meetings. This knowledge exchange platform may also work at the local government level exchanging with community representatives, NGOs or researchers conducting research at the community level and relaying information to the local and regional governments.

The adaptation prioritization framework developed here has the potential to address some of the existing gaps in the literature. However, the application of this proposed framework in an empirical case study will be an important next step to ensure that adaptation options move from "wishlists" of adaptation options to adaptation action that is implemented in a participatory and timely manner.

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Author Contributions

Clara Champalle and James Ford conceived and designed the research framework; Clara Champalle performed the review of the literature and established the framework; Clara Champalle and James Ford analyzed the data; Mya Sherman provided analysis tools; Clara Champalle, James Ford and Mya Sherman wrote the paper.

Conflicts of Interest

The authors declare no conflict of interest.

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