Chapter 3

Tools and Methods for Supporting Regional Decision-Making in Relation to Climate Risks

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Additional information is available at the end of the chapter

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Abstract

Climate change has had a major impact on the Nordic region. For example, the mean temperature rise is expected to be 4–6°C by 2080. In Finland, the regional authorities are responsible for climate change adaptation. Some of the most vulnerable sectors include energy, tourism, transport and water supply. Currently, it appears that the authorities are not familiar with the tools for assessing climate risks and lack knowledge about the impact of climate change. In this paper, we provide a review of risk assessment methods and decision-making tools, focusing on adapting to climate change in a Finnish context. Our research method comprises a systematic qualitative literature review dealing with relevant journals, dissertations and deliverables of relevant EU projects since 2005.

Keywords: climate change, climate change adaptation, decision-making, land-use planning, literature review, local authority, Nordic, risk assessment, risk assessment tools

1. Introduction

Finland is located north of the 60th parallel, making it one of the northernmost countries in the world. It has been predicted that the increase in temperature in the northern hemisphere as a result of climate change will be faster and higher than average, and winter temperatures in particular will rise with increasing precipitation. This means milder winters with less sun, less snow but more rain [1]. The mean temperature rise is expected to be 4–6°C by 2080. Even though Finland will probably not be affected by major floods or long-term heat waves, there are still many climate change impacts which need to be adapted. The change from frozen land to unfrozen land during the winter will be particularly challenging for many sectors. For example, the increased presence of unfrozen ground requires plant breeding to develop grain varieties that can withstand shorter winter precipitation and longer, perhaps drier summers [2]. In the forestry sector, winter storms and unfrozen land expose spruce forests to storm damage as the spruces' roots are torn from the ground [3]. Fallen trees may also sever power lines or railway catenary causing disruptions in the electricity supply [4, 5]. A rainy winter with no deep-rooted vegetation exposes roads and railways to erosion faster than ever before [6]. Tourism in Lapland may also suffer from an earlier spring season and warmer winters with less snow [7]. Finnish water utilities distribute 60% of their groundwater volume, which is mainly potable without any need for purification [8]. However, increasing precipitation may dilute the quality of groundwater and increase the cost of purification.

In Finland, primary responsibility for improving adaptation to climate change lies with the Ministry of Agriculture and Forestry, which published the National Adaptation Plan for Climate Change 2022 in 2014. This paper details the goals and objectives of adaptation activities, as well as the main measures and players. Usually, in the real world, the authorities are the main stakeholders for responding to adaptation for climate change. Thus, the national research institutes have been tasked with studying the effects of climate change and developing new means of adaptation. For example, the Finnish Environmental Centre is studying environmental tolerance, the Natural Resources Institute is studying forest and plantation areas, the Geological Survey is studying groundwater and the Finnish Meteorological Institute's (FMI) role is to predict the future climate. All these institutes provide up-to-date information to municipal, regional and state authorities in order to adapt to climate change. Indeed, the FMI has created websites that provide information on a regional level for decision-makers and the general public about the effects of climate change in different parts of Finland (see [1]).

Municipalities have a main role in adapting to climate change as they are able—through land-use planning and building regulations—to decide on where to build, how to build, what kind of response needs to be arranged, what kind of transport network to use, etc. [9]. However, adaptation to climate change also requires co-operation between various sectors and levels of administration. In Finland, it has been stated that the adaptation policy should be mainstreamed and integrated to fully cover public administration, and co-operation with the private sector and the third sector players should also be developed [10]. Land use in particular needs to be reviewed as a cross-sectoral issue.

Adapting to climate change involves multiple strategies, for example, reducing the sensitivity of the system by increasing the safety margin of new investments or using reversible options by trying to keep cost as low as possible (see [11, 12]). Whatever strategy is used, it is important to select case-specific risk assessment approaches to ensure adequate risk management measures [13].

Several methods have been developed over the last decade for supporting decision-making in relation to climate change. In this paper, we assess the latest methods that could be used to support regional or municipal decision-making, especially in Finland. This paper studies these methods and classifies them to help decision-makers select adequate methods for their purposes.

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2. Methodology

This paper utilises a comparative analysis of climate risk assessment methods and frameworks based on a systematic literature review. A systematic review provides an audit trail of the reviewers' decisions, procedures and conclusions [14, 15]. It adopts a replicable, scientific and transparent process that aims to minimise bias through an exhaustive literature search. In this paper, an iterative process that has been modified from methods presented in [14, 16] has been utilised: (1) data collection and (2) descriptive analysis and data evaluation.

In this paper, climate risks are considered as being risks that result from climate change and that affect natural and human systems and regions. The risk assessment tool is a tool for assessing risks, that is, to determine a quantitative or qualitative estimate of risk related to a well-defined situation and a recognised threat.

2.1. Data collection

In this phase, the data to be collected were defined and delimited. The systematic literature review was conducted using the eKnowledge database, which enables access to a large number of scientific databases such as Scopus, Web of Science, ScienceDirect, and open access databases. Keywords for the search comprised a combination of "blizzard," "climate," "climate change," "climate risk," "climate risk assessment," "cold spell," "decision," "decision support," "extreme event," "extreme weather," "heat wave," "heavy precipitation," "heavy rain," "Nordic," "risk assessment," "risk assessment method," "storm," "tourism" and "wind gust." The literature review was complemented by methods and frameworks with which the authors are already familiar (**Figure 1**).

The preliminary screening was conducted based on the titles and abstracts of the papers. Journal-specific screening was also simultaneously performed including journals such as

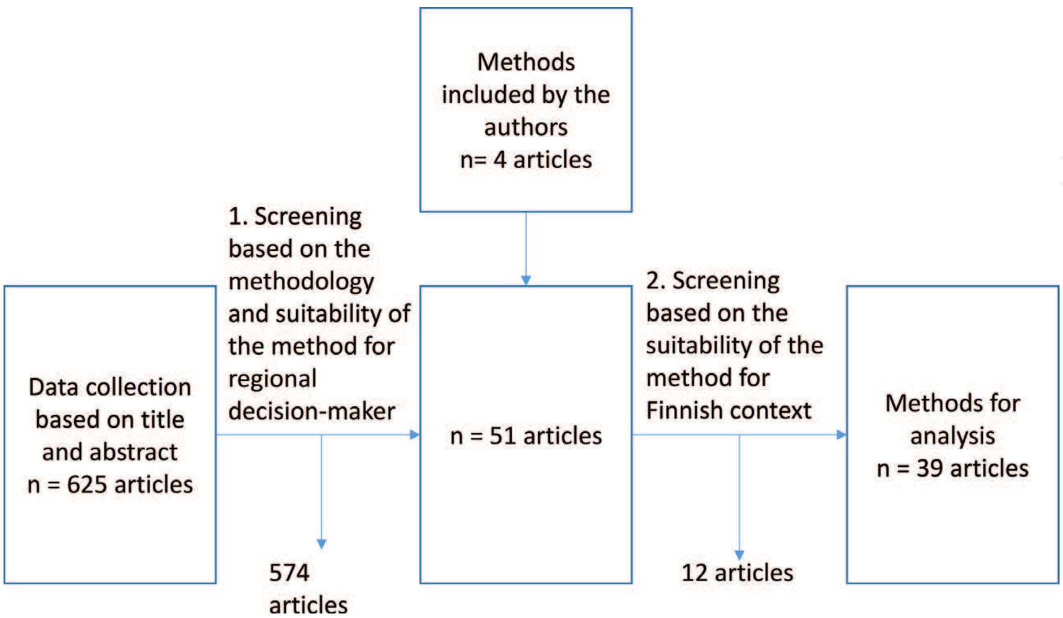

Figure 1. The data collection process.

Climate, Climate Services, Coastal Engineering, Geographia Napocensis, Natural Hazards, Ocean and Coastal Management, Science of the Total Environment, Transportation Research Procedia and Water Resources Management. Papers published between 2005 and 2018 were included in the review and only included the most recent papers. We focused on papers that described climate risks that were considered important in a Finnish context. Additionally, we concentrated on the sectors and industries that are important to the Finnish economy and most affected by climate change. Peer-reviewed articles, conference papers and book chapters were included to provide rich material for analysis. At this point, we focused on methods that could be easily used by regional decision-makers. Thus, methods that require expertise in order to use complex models were not included. Additionally, portfolio theory, real options and methods utilising future study methods were excluded (pure scenario methods, some methods with scenario components were included). After the first screening, 51 different papers were selected for the next stage.

In the second stage, the criteria that took into account the Finnish context were used. These included the next issues:

- The development of flood risk maps has not been included in the research as these kinds of maps are already available in Finland from the authorities. However, if there were ways of upgrading these kinds of maps, they were included in the further analysis.
- Methods that study the rise in sea level have not been taken into account because, in Finland, it is believed that the rise in ground level since the last Ice Age is still higher than the rise in sea level in most part of the country [1]. However, the methods that address storm floods and the methods that integrate the rise in sea level into more extensive methods have been taken into account.
- The methods planned for areas with scarce data have not been taken into account because the whole of Finland has been covered by an effective weather monitoring network since 1880.
- Articles that only deal with aspects of resilience have been excluded.
- Methods that can be performed with minor assistance from consultancy services have been taken into consideration. For example, climate change projections, flooding predictions, or groundwater level variations are examples of data in which an expert may be required to facilitate the interpretation. These, in turn, are often the starting point for the many existing methods such as risk maps.

After the second screening, 39 papers were selected for further analysis. The papers included in the literature review are presented in Notes.

2.2. Descriptive analysis and data evaluation

The formal aspects of the data were assessed and categories were selected and applied to the collected data during the descriptive analysis and category selection. Eight categories of climate risk assessment and decision support methods were identified. Additionally, information on the basic characteristics of the method, such as location, phenomenon or risk, application and time frame for analysis, was classified. These categories were used in the subsequent evaluation.

During the data evaluation phase, the material was thematically analysed according to the selected categories. The validity and reliability of the results were increased by using an iterative process. When analysing the data, the authors looked for emerging classifications and patterns. The classifications were created based on the classifications used in the literature and findings from the data.

3. Decision-making in the context of climate risks

There is a myriad of methods available for supporting climate risk assessment and decision-making. The nature of methods can vary greatly regarding data requirements, time frame and purpose [17]. UNFCCC [18] has identified the following approaches and methods: cost-benefit analysis (CBA), cost-effectiveness analysis (CEA), multi-criteria decision analysis (MCDA), portfolio theory and real options, pathway analysis, adaptive capacity assessment, risk management methods, scenario-based approaches, technological assessments, normative policy assessments, identifying learning in individuals/organisations, participatory methods and social learning.

These methods are mostly complementary in nature and can be used to support a variety of different climate change-related decision-making situations. In this paper, we introduce a group of climate risk assessment and decision support methods that we consider suitable for a regional decision-maker.

3.1. Cost-benefit analysis

Cost-benefit analysis (CBA) can be defined as a comparison of the marginal costs of policies with the marginal benefits associated with the climate change effects that are prevented in order to identify the most economically efficient policy response [19]. It provides monetary valuations for every kind of impact involved and is particularly suited to supporting decisions related to the feasibility of investment projects, in which the future financial effects can be identified and predicted [20]. It is considered a more objective method compared to its main competitors, MCDA and CEA [21]. However, there are issues in using CBA for climate risk assessment. Multiple externalities are difficult to value and do not figure in the evaluation of costs and benefits [20], and the inclusion of complex features such as future time, doubt, irreversibility and indirect benefits is difficult [22, 23].

3.2. Cost-effectiveness analysis

Scrieciu et al. [20] defined cost-effectiveness analysis (CEA) as an identification of least-cost options to meet a certain target or policy objective. The rationale behind CEA is that there is a single indicator of effectiveness. Cost curves are a classic application area of CEA. CEA has been criticised for the difficulties it has in identifying consistent metrics for adaptation and the local- and sector-specific nature of climate impacts [23].

3.3. Multi-criteria decision analysis

In a complex decision-making situation involving multiple stakeholders (i.e. climate risk-related decisions), a decision-maker may have several conflicting objectives. Multi-criteria decision analysis (MCDA) permits the consideration of quantitative and qualitative data together using multiple decision criteria [18]. With MCDA, the benefits and costs are measured on a value scale that reflects the desirability of the options from the perspective of the decision-maker [24]. The decision criteria should reflect which features decision-makers find important in decision-making [25]. Weights are given to each criterion, and the weighted sum of the different criteria is taken in order to gain an overall score for option, which, in turn, can be used to rank options [23]. The use of MCDA is appropriate when it is difficult to assign monetary value to the decision criteria. However, some of the same critique applies to MCDA as CBA and CEA [23].

3.4. Robust decision-making

In robust decision-making (RDM), the goal is to identify the full range of plausible future states and make decisions that are robust across a wide range of such future states as possible [20]. It starts with selecting decision options and then estimates utilities of options to identify the potential vulnerabilities of strategies [23]. RDM provides an analytical decision support framework for situations characterised by high uncertainty. Four key elements of RDM include: (1) assembling a high number of scenarios, (2) seeking robust strategies that perform sufficiently well across a broad range of futures, (3) employing adaptive strategies to achieve robustness and (4) designing an analysis for interactive exploration of the plausible futures [23]. Issues related to RDM include the complexity of the method and the need for advanced statistical and mathematical methods [20].

3.5. Participatory methods

Assessing climate risks often requires an approach that incorporates the perspectives of stakeholders in the problem and solution definition. Participatory methods cover a variety of approaches that support the inclusion of experts and users in the decision-making and assessment process (see e.g. [23]). Participatory methods are often utilised in methods such as MCDA to provide weights and valuations for criteria that are difficult to otherwise quantify. As standalone methods, they are utilised, for example, in understanding complexity, participatory analysis and stakeholder engagement and mapping. It is argued that participatory methods based on the joint work of scientists, experts and stakeholders lead to better assessments because they combine the latest expert information with first-hand policy experience in the affected society [26].

3.6. Risk analysis methods

The risk analysis process is presented in the risk management standard [27]. According to this standard, risk analysis forms part of a broader risk assessment process focusing on the nature of risk and its characteristics. Risk analysis involves a detailed consideration of uncertainties, risk sources, consequences, likelihoods, events, scenarios, controls and their effectiveness. In practice, detailed and diverse information is not always available. Even so, one main principle of risk analysis is to use the best available information, which is supplemented during the process.

Highly uncertain events can be difficult to quantify. This can be a disadvantage if, for example, low probability but high cost events are analysed. In such cases, a combination of methods may result in a better understanding.

3.7. Event tree analysis

The aim of Event tree analysis is to identify the undesirable consequences of an initial harmful event. ETA focuses on identifying the failure combinations that could lead to undesirable outcomes [28]. Because of the tree structure, it is possible to assign probabilities to these outcomes. This method has been used to model weather-induced event chains [28–30].

3.8. Risk index methods

Risk index methods stipulate methods that provide a numeric value (index) for the identified risks. The calculations are based on several factors that impact the risk, which are often categorised in order to obtain comparable values. The equations for calculation may include long impact chains, as in the case of the EWRI index [13]: R = f(H,V); H = f(P); V = f((ExS)/CC). In this chain, R = risk, H = hazard, V = vulnerability, P = probability, E = exposure, S = susceptibility and CC = coping capacity.

4. Results

The analysed methods suitable for a Finnish context were categorised into different classes. One classification was based on the climate risk to which the method was applied (see **Figure** 2). The most common climate phenomenon was flood. Other climate risks such as storms or extreme weather events were also included in the flood risk examination. Two methods were applied to winter storm hazards. Heat wave or drought risks were examined using two methods. Eight methods were applied to multivariable risks such as landslide, drought, flood, sea level rise and erosion. In connection with seven methods, the applicable climate risks were not specified.

Another classification was the application area in which the method in question was field tested (see **Figure 3**). The most common application area comprised infrastructure in which planning applications in general and the identification of vulnerable and valuable assets not specified in more detail was also classified. Five methods were tested in the energy sector. In addition, water supply or water management comprised the application areas for eight methods and transportation comprised the application area for four methods. Only two methods focused on the tourism sector. Five methods were described without mentioning a specific application area.

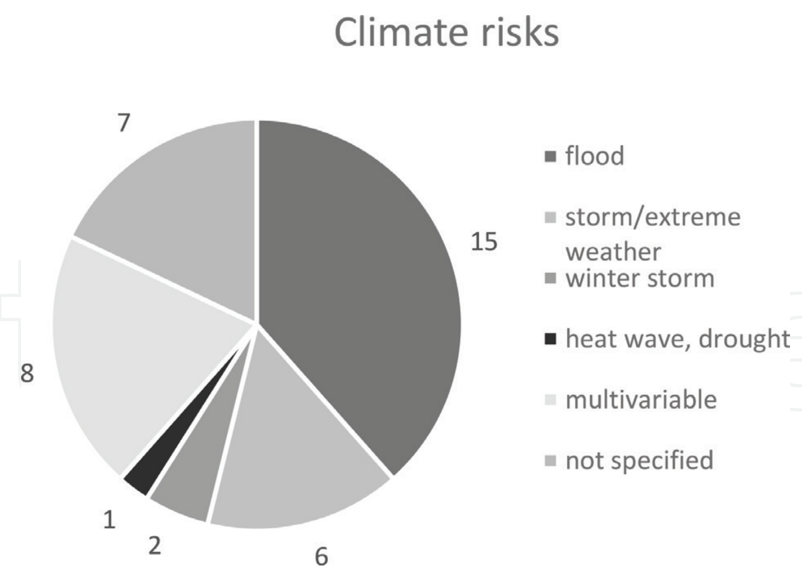

Figure 2. Classification of methods according to the climate risks concerned.

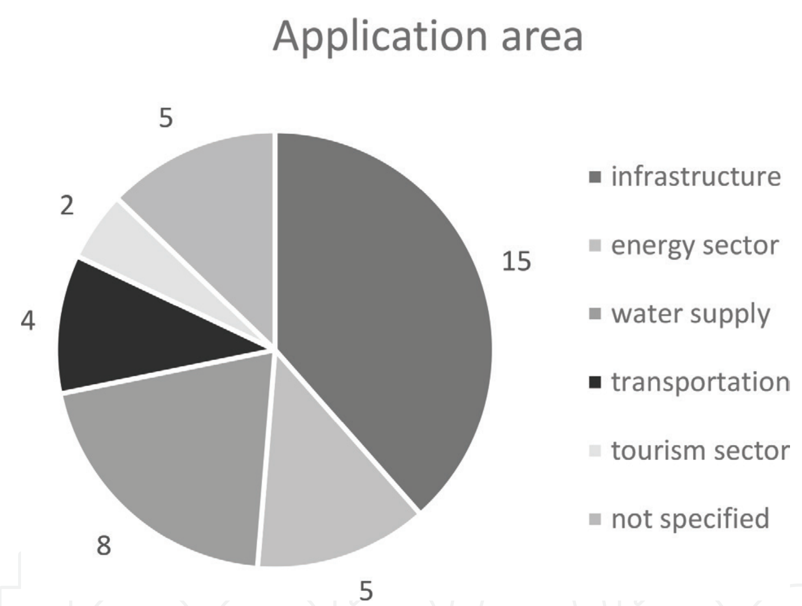

Figure 3. Classification of methods according to application areas.

Most of the methods applied to medium- or long-term planning assisting strategic (5–15 years), infrastructure (15–70 years) or land-use planning (over 50 years). One third of the analysed methods were suitable for short-term operational planning (0–5 years), while only four methods were regarded as being suitable for analysing risks 70 years into the future.

Almost all methods that were hypothesised beforehand were evaluated suitable for regional decision-makers' use. Only methods in which cost-effectiveness analysis (CEA) was applied in a suitable way compared to Finnish content criteria were not found. Various visual risk assessment tools, for example, risk or vulnerability maps, were identified. Visual tools were not previously described as a method for carrying out a climate risk assessment. Thus, to highlight their relevance and abundance, these tools are presented as a separate group.

4.1. Cost-benefit analysis (CBA)

Five articles contained CBA approaches. Three articles discussed flood risk assessment [31–33] and two discussed the adaptation of the electricity sector to climate change and extreme weather events [34, 35]. The methods supported infrastructure (public infrastructure, electricity and the transport sector) adaptation. The methods supported a variety of decision-making situations and time frames from strategic planning (5–15 years) to infrastructure and land use (15–70+ years).

4.2. Multi-criteria decision analysis (MCDA)

MCDA was used in nine articles. Eight of the articles dealt with flooding and coastal risks (e.g. flooding, storms and erosion) and their effect on infrastructure and land use [24, 36–42]. Two of the articles also considered other events such as heat wave, drought, wildfire and windstorm. One article focused on energy sector adaptation [43]. All of the methods supported strategic, infrastructure or land use decision-making. However, three of the articles were also intended for operational decision-making support (0–5 years) [38, 39, 43].

4.3. Robust decision-making (RDM)

Three articles utilised the RDM approach. All of the articles considered the adaptation of the infrastructure sector, specifically water sector adaptation [44–46]. Factors considered in the papers included, for example, climate conditions, water demand, systems operation and cost-related uncertainties.

4.4. Participatory methods

Five articles included a participatory method approach. Three of the articles focused on specific climate impacts such as flood, storm and landslide [47–49], while two of the articles were more general approaches to climate risk assessment [50, 51]. The time frame of the presented methods varied from covering tools to obtaining information for operational planning to supporting long-term infrastructure planning. Diverse methods were introduced in the papers to collect bottom-up information, for example, a gamified assessment method, web-based participatory methods and more traditional focus group meeting methods.

4.5. Vulnerability or risk assessment

Six articles were established based on vulnerability or risk assessment methods. The vulnerability assessment method focused on the tourism sector and studied the vulnerability of cross-country skiing to climate change impacts [52]. Two risk assessment methods examined storm risks in coastal areas [53, 54]: one studied risks to groundwater and related ecosystems [24] and one studied risk assessment methods for the road infrastructure and transport [55]. One method analysed future risks to hydropower plants based on climate scenarios [18]. The methods also utilised visual tools such as exposure [54], vulnerability [52] or hazard maps [53].

4.6. Event tree analysis

ETA appears to be a straightforward method for modelling the direct consequences of the impact chains of weather events. It is recommended that the method is used in two stages: firstly, the risk analysis team specifies the generic event tree model including its main branches, and secondly, sector-specific experts are asked to complete it by providing probabilities for each alternative branch [30]. ETA was utilised for flood risk management [30] and electricity infrastructure adaptation to snow storm effects [56].

4.7. Risk index methods

The group of risk index methods includes both index calculations and key performance indicators (KPI) of harmful weather events. For example, EWRI (extreme weather risk index) is based on the probability of a weather event and the vulnerability of transport routes [57]. Also, the method that deals with KPIs assesses the risk of climate change and presents the results in a visual format [43]. These methods are based on mathematical risk functions.

4.8. Maps or other visual tools

Seven articles represented maps or other visual tools [13, 58–63]. Most of the methods in this category related to expected future changes in water resources, such as rising seawater, groundwater level variation, flooding or other extreme water flow events in a map format. Some of the maps primarily projected hydrology changes in hydrological cycle-like flood maps [61], and some were combinations integrating both water supply and demand scenarios [59]. A number of the maps were made to cover a wide area such as national-level representations, while parts of the maps were considerably more high resolution with regard to a particular river basin or district [63]. There was some variation in time frames but most of the methods focused on strategic planning or planning of infrastructure or land use. It is also noticeable that methods classified in other decision-making support groups sometimes included visual tools. For example, flood maps were utilised as part of the process.

5. Discussion

Many different methods were identified that were suitable for regional decision-making related to climate change adaptation and climate risk management. Apart from cost-effectiveness analysis (CEA), all other methods, which were previously hypothesised as being applicable to decision-making, came up during the literature review. Articles concerning CEA were also identified, but the presented methods did not fit the inclusion criteria. With regard to risk assessment methods, it appears that the main focus of recent research has been on studying the environmental impacts of climate change. These studies provide impact models that primarily concern water levels, drought, precipitation, wind gusts, etc.

Veijalainen [64] has described the chain from a global climate scenario to its environmental impacts as demonstrating that information from the climate scenario must be converted into

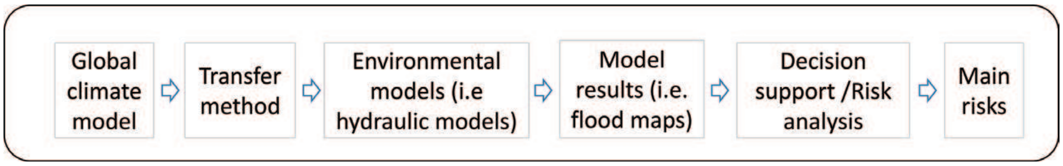

Figure 4. Converting global climate model information into regional or municipal decision-making.

information on hydraulic models. These models can be used for evaluating, for example, the return period of floods. Only then will municipal or regional authorities be able to carry out a risk assessment to determine what kind of adaptation methods they can select (**Figure 4**).

It appears that most of the studied articles use the term "risk assessment" to describe the analysis and methods of converting information from a global climate scenario for environmental models, such as flood models, evaporation models, etc. These models are suitable for a scenario analysis and are used for adapting to climate change from a long-term perspective in which the planning period is more than 30–50 years. The results of these methods require more specific risk assessment to support municipal or regional decision-making in a shorter time frame.

In addition to expertise on climate change, there is a need for further information on local or regional vulnerability. For example, the vulnerability of infrastructure, sensitive assets or socio-technical systems generally has to be taken into account in some way when analysing regional or local level climate risks and potential impacts.

The categorisation of methods was sometimes challenging. Some of the methods could have been categorised into several different classes. For example, the differences between risk analysis and multi-criteria decision analysis methods were not always obvious. In addition, the applicability of the method for a specific temporal extent (operational, strategic or land-use planning) was not obvious every time if it was not specified.

In order to find out the suitability of the methods in a Finnish context, a more detailed analysis should be performed. For example, the applied climate and hydrology models may be suitable for Finnish context, but only under case-specific circumstances. Also, the Baltic Sea is not included in most global climate models, even though it significantly influences the Finnish climate. Applications should be taken into account when adapting methods in new types of geographical or case areas. In Europe, climate risks, application areas and infrastructure are quite similar or, at least, consistent characteristics exist, and knowledge of climate and hydrology models, historical data, hazard events, infrastructure and current socio-technical systems also exist. On a general level, methods are applicable to various geographical areas and decision contexts.

6. Conclusions

The importance of climate change adaptation has been identified on a regional level in Finland. This chapter focused on methods of climate risk assessment that are suitable for regional decision-makers. Using a systematic literature review, 39 methods were identified that could support regional decision-makers. A wide range of methods were identified including multi-criteria methods, methods of analysing costs, the benefits of different options, risk assessment methods and the methods that utilise visual tools. The methods highlighted climate risks linked to hydrological cycles such as storm-induced risks and flood risks. However, the majority of the identified methods require consultancy assistance. Most of the methods include, for example, climate change projections or hydrology models that are quite complex and require specific knowhow in order to be applied in a case-specific manner.

Conflict of interest

The authors certify that they have no affiliations with or involvement in any organisation or entity with any financial interest (e.g. honoraria; educational grants; participation in speakers' bureaux; membership, employment, consultancies, stock ownership, or other equity interest; and expert testimony or patent-licensing arrangements) or non-financial interest (such as personal or professional relationships, affiliations, knowledge or beliefs) in the subject matter or materials discussed in this manuscript.

Notes

Papers included in the systematic literature review: Refs. [13, 24, 30–67].

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