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Article

Combining Climate Scenarios and Risk Management Approach—A Finnish Case Study

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Abstract: Climate change impacts on nature and the environment have been widely discussed and studied. Traditionally, a company's continuity management is based on risk analysis. There are also attempts to implement scenario-based methods in the risk management procedures of companies. For industrial decision makers, it is vital to acknowledge the impacts of climate change with regards to their adaptation strategies. However, a scenario-based approach is not always the most effective way to analyze these risks. This paper investigates the integration of scenario and risk-based methods for a company's adaptation planning. It considers the uncertainties of the climate change scenarios and the recognized risks as well as suitable adaptation strategies. The paper presents the results of climate risk analysis prepared for two Finnish hydropower plants. The introduced method was first piloted in 2008 and then again in 2015. The update of the analysis pointed out that at the company level, the climate risks and other risks originating from governmental or political decisions form an intertwined wholeness where the origin of the risk is difficult to outline. It seems that, from the business point of view, the main adaptation strategies suggested by the integrated risk and scenarios approach are those that support buying "safety margins" in new investments and reducing decision time horizons. Both of these adaptation strategies provide an advantage in the circumstances where also political decisions and societal changes have a great effect on decision making.

Keywords: climate change; risk analysis; climate scenarios; hydropower plant

1. Introduction

Climate change creates a complicated challenge to companies due to the differing, and even contradictory, views of researchers and stakeholders on how they should be prepared for climate change. The main argument to adapt for climate change is usually that climate change has already heightened the frequency and intensity of extreme weather related risks and hazards, and that these will grow even more extreme in future [1–4]. However, this is not unambiguously clear. It has been pointed out that extreme weather events do not seem to emerge in line with basic climate events [5], and when compared to a base-line the trend of extreme weather might be higher, or even lower [6]. This suggests that the increase in mean precipitation does not self-evidently forecast the increase of extreme rainfall. Easterling *et al.* [7] studied the societal impacts of extreme weather in the United States and discovered that most of the increase in costs associated with such events was due to societal shifts and not to increases on weather extremes. Research of Bouwer [8] resulted in the same conclusion when he analyzed 22 disaster loss studies, which claimed that economic losses from weather-related natural hazards (storms, tropical cyclones, floods, wildfires, and hailstorms) have increased around the globe. When these studies were corrected for changes in population and capital at risk, no increase in costs resulting from the disasters was evident. The United Nations' International Strategy for Disaster Reduction also emphasizes that extreme weather events are not the main drivers for disaster risks, but they are increasing due to development processes that exposes more people and assets to hazards [9]. One of the confusing and even misleading factors is that there is no agreement on the definition of "extreme event" that can be understood as severe event, adverse event, rare event, or high-impact event [10]. However, in addition to old ones, newer and more serious "extremes" may emerge and pose new threats to society. Therefore, past climate conditions are not useful guides for future conditions [2].

Although we cannot be certain what natural phenomena may cause damages in the future, extreme weather can bring costly and harmful events for society and companies. Hence, there is a need to prepare for them to ensure business continuity and the normal operation of society. Climate change forms a strategic risk for a company, and to tackle it there is a need for new policies, strategies, plans and projects through which climate change can be handled. There is also the possibility that climate change creates new business opportunities for companies and these possibilities should also be taken into account. This can be a motivation for adaptation [11].

There are two main lines for climate change preparation: the risk assessment-based approach, and the scenario-based approach. Risk assessment is a conventional way for companies to tackle all kind of risks, including for example, technical, environmental, occupational, economic, and image risks. The main risk management strategies consist of prevention strategies, mitigation strategies or coping strategies [12]. Prevention strategies include the actions made before the risk occurs and their aim is to reduce the likelihood or probability of the risk. The mitigation strategies decrease the impacts of the risk. These actions can be made before the risk occurs (insurances, preparedness actions) or as responding to the risk after it takes place (response actions).

Just like risk assessment, adaptation is not only a once-in-a-lifetime operation but rather a continuous stream of several activities involving analysis, decision making, and taking appropriate measures. Adaption planning has many common features with risk management [13] but the methodology used in adaptation planning is more challenging. For businesses, adaptation decisions are a part of other decisions and hence, it is difficult to separate decisions pertaining to climate change adaptation from normal economic or social actions [11]. Private-sector decisions, including those around adaptation to climate change, are quite often focused on economic efficiency. There are several ways to classify the adaptation strategies and some of them are quite similar to risk management strategies. For example, Burton *et al.* [14] classified the adaptation strategies in six classes: (1) share the loss, (2) bear the loss, (3) modify the event, (4) prevent effects, (5) change use, and (6) change location. All these strategies are usable also in general risk management.

The UK Climate Impacts Programme [15] presents four main approaches to handle climate change which can also be strategies to handle risks; (1) high-risk strategy, (2) strategy to avoid under-adaptation, (3) strategy to avoid over-adaptation, and (4) regret-based strategy. The high-risk strategy is based on determining and implanting options that provide best outcomes, *i.e.*, the selection of the highest possible overall pay-off. The strategy to avoid under-adaptation bases on the idea to weight the decisions towards the presumed climate change and its impacts; the idea is to find the options that result in the lowest value of the maximum pay-offs. The strategy to avoid over-adaptation instead tries to find the options that result in the highest value of the minimum pay-offs. Regret-based strategy, in turn, focuses on the opportunities that benefit the company in all possible future climate circumstances.

However, there are also different types of adaptation strategies that focus more on climate change itself. For example, Miller *et al.* [5] presented three main strategies to adapt climate change: (1) reduce the sensitivity of the system to climate change, (2) alter the exposure of the system or (3) increase the resilience of the system to cope with changes.

Hallegatte [16] focuses on companies and presented them with five strategies to adapt to climate change: (1) selecting "no-regret" strategies that yield benefits even in absence of climate change; (2) favoring reversible and flexible options; (3) buying "safety margins" in new investments; (4) promoting soft adaptation strategies, including the long-term perspective; and (5) reducing decision time horizons. For example, new building insulation norms and climate-proof buildings can be regarded as examples of a "no-regret" strategy [16]. When using the reversible and flexible options, one tries to keep the costs of bad or false decisions as low as possible. For example, early warning systems represent this kind of strategy as it is easy to adjust to varying circumstances. Furthermore, a slow urbanization process with adaptive land-use planning over a longer time span is also an example of flexible adaptation strategy. The aim of safety margin strategies can be, for example, to improve city resilience and reduce vulnerability by improving drainage systems, sea walls, culverts *etc.* Soft strategies include institutional and financial tools to minimize the impacts of climate change, for example the use of insurances. The last strategy, reducing decision time horizon, can include new technical solutions that could be planned to sustain shorter time than the older ones but which could be replaced with other solutions whenever needed [16].

To prepare for the future, companies need long term vision and new policies dealing with how they will meet and solve the problem. The core challenge for a company' commitment to climate change adaptation is the time frame. When comparing large and small electricity distribution companies, the large ones tend to prepare more systematically for climate change [17]. In addition, there are some studies [18,19] showing that companies will adapt to climate change if they achieve competitive benefits from it in the future. Possibly, companies which own major infrastructure assets like hydropower plants might see the adaptation question somehow relevant. Smaller companies owning only small or no infrastructure-related commitments—for example, service companies—usually have a shorter strategic planning period, and they might rather concentrate on their continuity from year to year.

Before the company can make decisions on how to adapt, they need to know to what they should adapt—that is, what are the most harmful phenomena and what are the most profitable opportunities of climate change? It seems that there is no evidence that there will be sudden changes with extreme weather due to climate change [20]. Therefore the improvements of infrastructures and continuous maintenance are the best ways to reduce vulnerability. To identify harmful weather events and to evaluate their significance the company should produce a systematic and broad weather risk analysis on what can happen, and how that will affect the company and its business. All climate-induced disasters and crises are inherently complex and multidisciplinary. This means that they can have consequences in many areas, and the complexity must be monitored with an analytical approach to vulnerability, risks and opportunities. It is essential that the entire risk cycle should be taken into account in both the short-term and long-term perspective of investments with long repayment periods [21]. According to Solecki *et al.* [2] climate change adaptation and disaster risk reduction have three overlapping areas: (1) event likelihood, (2) impact parameters and (3) societal responses, or risk management. For companies, the vital question is how the weather risks can be identified and analyzed to allocate the needed risk management—or adaptation—measures effectively.

In this paper, the term "climate risk" stands for the selection of various climate and weather related risks that induce threat to society, the environment and the economy. This risk mainly arises from adverse weather events but also from the gradual change in mean temperatures which affect the environment.

2. Selection of Risk Analysis Approach

To fully understand the threat of climate risks on a company level, it is important to identify what kind of weather phenomena should be analyzed; is the question one of precipitation, snow fall, wind gusts, or even blizzards or thunderstorms? In addition, extremes of heat and cold might need to be considered. When the phenomena have been decided, the frequency and impacts they have should be analyzed. There are two main approaches to study the risk of weather phenomenon to companies: the scenario-based approach or classical risk-analysis-based methods (Figure 1 below). By scenario-based approach, we mean here vulnerability analyses that are based on expected future climate conditions, how the climate may be in the future and how to adapt to it. The risk analysis-based approach takes into account both the probability and the consequences of hazardous events. In a risk-analysis based approach the probability of risk can be assessed through historical data, while a scenario-based approach has uncertainty built into the process, which is not visible for decision makers. The decision whether to use the scenario-based method or risk-analysis-based method depends on the planning period and repayment period. The scenario-based methods are more suitable when there is a long planning and construction period (*i.e.*, over 70 years). The risk-analysis-based approach is more suitable if the focus is shorter investment periods and operative level planning.

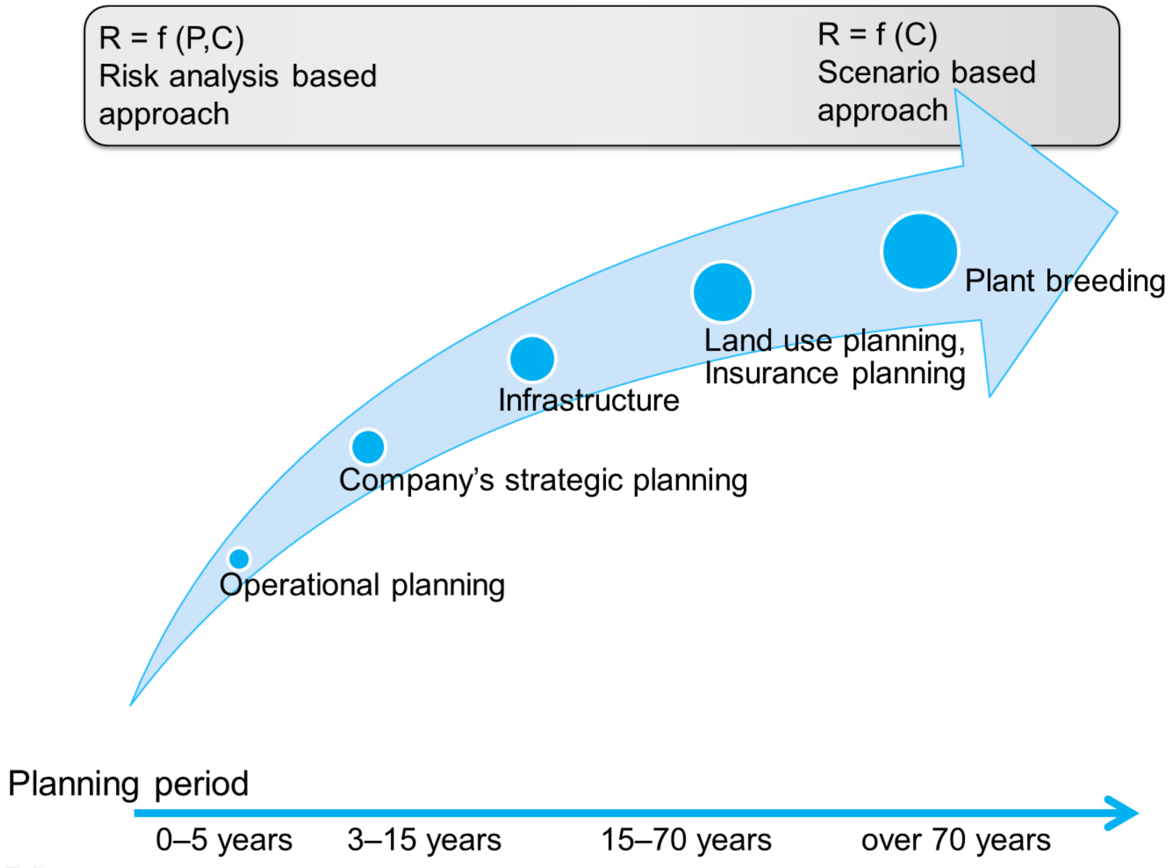

Figure 1. The suitability of risk-analysis-based and scenario-based approaches for analyzing climate change adaptation based on the planning period.

The scenario-based approach requires a lot of information on future climate and extreme weather events. Sousa [22] pointed out already 30 years ago that it is difficult to objectively determine the thresholds between extreme and normal climate phenomena. Hence, organizations are obliged to prepare for different periodic fluctuations in climate events. The scenario-based approach has also met some criticism. Smit *et al.* [23] argue that the scenarios include a simplified version of the local climate and usually only give information in regards to changes of mean temperatures, rainfall, and sea level. It is also important to note that it is risky to rely on a single climate scenario alone as, depending on the scenario, their dispersion is wide. Tompkins *et al.* [24] in turn, noted that in the private sector especially, it is not wise to rely on climate change impacts alone, as it may delay preparedness for extreme weather events. In addition, van Aalst *et al.* [25] state that the scenario approach does not highlight that the impacts of climate change are uncertain, and that they could be reduced under potential future socioeconomic circumstances, including technological change, and social and economic circumstances. Hence, we make future decisions relaying on today's knowledge. Due to uncertainty in assessing the impacts of climate change, any adaptation measures have to cope with a large range of climate conditions, which in turn demand high-cost solutions [16]. Adaptation to climate change depends not only on the climatic changes but also on changes in environment, society, and politics [10]. It seems that climate scenarios do not provide enough information of future extreme weather patterns that are more important from a company's perspective.

One suitable solution to answer the needs of companies is to use a combination of risk-analysis-based and scenario-based methods in the analysis process. Van Aalst *et al.* [25] suggests a bottom-up process that is based on vulnerability to current climate variability and extremes, and current adaptation strategies, policies and measures as a starting point. Hence, risks related to the current climate already exist and any adaptation process should be based on these factors. Risk-analysis-based methods rely on risk-management process [26] whereby the risks need to be identified, analyzed and evaluated in order to select the suitable management—or adaptation—measures. These kinds of methods can take advantage of climate scenarios, extreme weather events in the current climate, seasonal calendars, and historical data of past weather events and so forth. This was the starting point for the climate risk analysis for the hydro power plant case studies presented here.

3. Performing the Risk Analysis

This study presents a "climate-risk" analysis performed in Kemijoki Ltd Hydropower Company in Finnish Lapland in 2008 and 2015. The utilised method advances from hydraulic modelling based on global and regional climate models (scenario based approach). It also employs the historical and current data of hydrology of the river Kemijoki and environmental circumstances of the area (risk-analysis-based approach).

3.1. Flood Assessment in Finland

This chapter presents the hydrological model and simulated environmental future circumstances used as the background information for climate risk analysis. In Finland, the Finnish Environmental Institute conducts most flood assessments. Figure 2 presents the schematic figure of the method used for assessing floods by taking into account the climate scenarios. For this case study, the hydrological models were simulated using two regional climate model scenarios (HadCM3 global model & A1B emission scenario, and ECHAM5 global model & A1B and A2 emission scenario) [27,28].

In Nordic climatic conditions, snow plays an important role in hydrology. In most parts of Finland, snowmelt accounts for a major contribution to seasonal largest floods. Climate change has contradictory effects in flooding as annual precipitation is expected to increase in Finland by 13%–26% by the 2080s [29], but, at the same time, temperature is expected to increase by 2–6 °C which could decrease the snow accumulation by 40%–70% [29–32].

In order to better understand the impacts of climate change on the hydropower operational environment, the hydrological scenarios of the river Kemijoki catchment area were utilised. The same scenarios were used both in year 2008 analysis and re-analysis in year 2015. The simulations were performed by the Finnish Environmental Institute's Watershed Simulation and Forecasting System (WSFS). The model is based on the HBV-model (Hydrologiska Byråns Vattenbalansavdelning), which is developed for Scandinavian circumstances [33,34]. The WSFS is a conceptual hydrological model (Figure 3), used for operational flood forecasting and for research studies [30]. The main components of the model are precipitation, snow, soil moisture, and subsurface and ground water models. Important parameters in the snowmelt model are liquid water retention in snowpack (snow load), refreezing of melted water, and simulation of snow-covered area and temporary surface storage during snow cover (soil moisture). Temporary storage causes delay in water outflow from the sub-basin due to snowdrifts and snowpack restricting water-flow through the terrain [33].

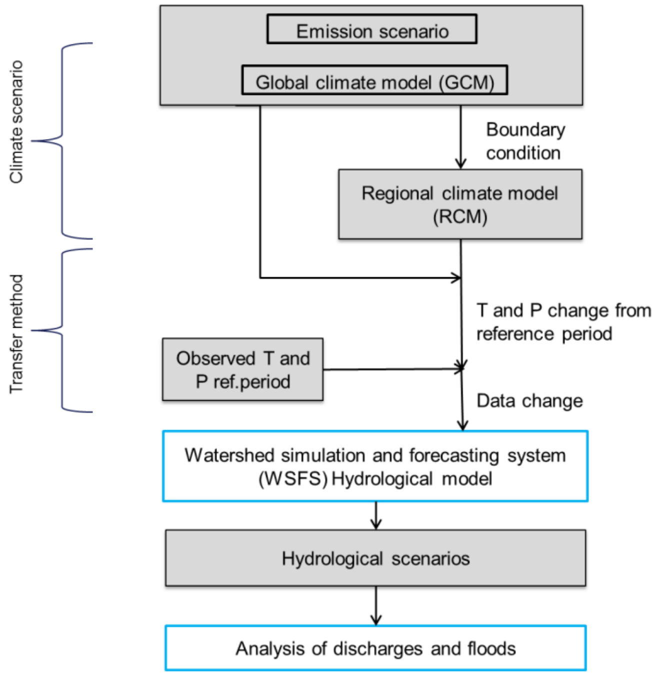

Figure 2. Schematic figure of the method used in flood assessment in Finland based on the data presented in Figure 11 originally published in Veijalainen *et al.* [28]. Grey boxes indicate input/output data and white boxes research methods.

Table 1 presents the updated environmental parameters conducted from the mean climate scenarios [34]. In Finland the estimated changes in precipitation is +7% and in temperature +1.7 ℃ (B2 emission scenario, HadCM3 and timescale 2010–2039) [35]. The years of comparison are 1961–1990.

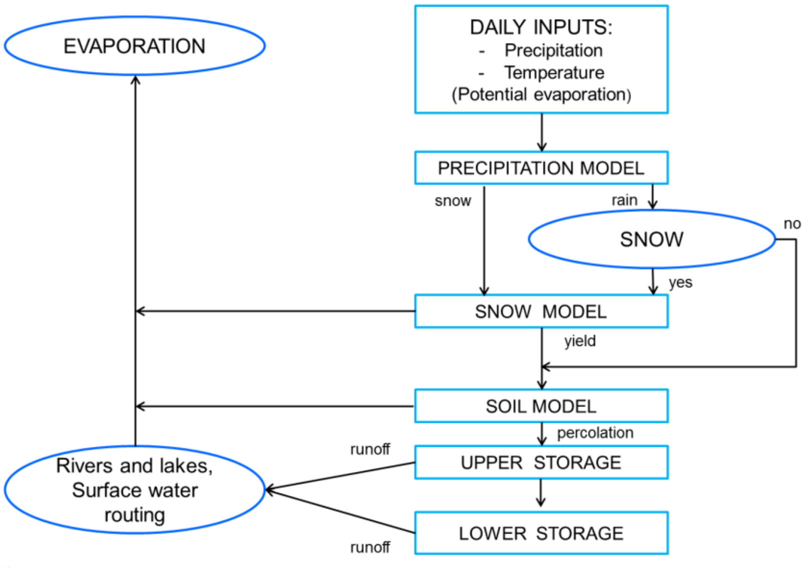

Figure 3. The schematic figure of the hydrological model used in Finland based on the data presented in Figure 6 originally published in Vehviläinen & Huttunen [33].

In Table 1, below the snow cover provides the average annual maximum daily-accumulated amount of snow (kg/m^2) (30-year period). The amount of snow is the weight of water contained in the snow per unit area. Soil moisture presents the average annual maximum of daily soil moisture deficit (30-year period). Soil moisture deficit is defined as the amount of precipitation required to bring the soil to a saturated state. Annual evapotranspiration is the average annual evaporation from the land surface (30-year period). It presents the quantity of water transferred from the soil to the atmosphere by evaporation and plant transpiration. Finally, the average annual maximum daily runoff (30-year period) presents the part of precipitation that flows towards the stream on ground surface or within the soil [35].

Table 1. Expected changes in hydropower-specific environmental parameters in future climate compared to the years 1961–1990. The data is collected from the climate statistics produced by Finnish Meteorological Institute [35].

Environmental Parameter		**1961–1990**	**2010–2039**	**2040–2069**
Snow cover	days	180–240	150–210	150–180
Amount of snow, max	kg/m^2	130–180	80–180	80–130
Soil moisture deficit, annual	mm	30–90	30–90	30–90
Annual evapotranspiration	mm	100–200	100–250	100–250
Runoff, daily, max	mm	5–15	5–10	5–10
Runoff, total/year	mm	300–400	300–400	300–400

The hydrological scenarios in this case study represented flow changes during two 40 year-periods: the reference period 1961–2000 and the studied future period 2010–2049. The hydrological scenarios included the annual average, and the maximum and the minimum of incoming flows (m^3/s) for the studied hydropower plants. The scenarios also contained the annual average, the maximum and the minimum water level for the regulated reservoir—Lake Kemijärvi—located in the catchment area. Six individual great flood years or extremely dry years were also represented.

3.2. Description of the Risk Analysis Method Utilized

It has been argued that climate models are the only usable tools to enable understanding of future climate, even if they provide only an approximation of the future climate. As hydropower plants are planned for long operating periods (for as long as a hundred years) the future climate patterns need to be taken into account when analyzing the future risks [36]. This was the leading idea when analyzing the future risks for the Kemijoki hydropower company. The main questions discussed the environmental factors that significantly impact hydropower production in Finnish Lapland and how climate change will affect these factors [37].

The climate risk assessment study was made in the Kemijoki Ltd Hydropower Company in Finland. Kemijoki Ltd is located in Lapland, in the north part of Finland where the impacts of climate change are expected to be stronger than in the southern part of the country. From a hydropower company point of view, this scenario seems both harmful and promising. It seems that climate change strengthens global warming, which will also shorten the winter in Lapland and make weather patterns less stable [38]. However, it evens out the river flow from today's huge spring floods to more stable flow rate around the whole year. This is a profitable situation for hydropower plants [38].

The first climate change risk assessment for Kemijoki Hydropower Company was performed in spring 2008, and the assessment was further updated in 2015. The second assessment was performed to find out if any of the climate induced risks analyzed in 2008 had already emerged or showed any signs of change. The motivation to update the risk assessment arose from a research point of view when it was noticed that, since the first risk assessment (only 7 years ago), the yearly mean temperature has risen compared to the last three decades [39]. Another driver was that the persons who participated in the first risk assessment were about to retire, and there was a desire to utilize their vast and long-term experience of river behavior and risk management.

The risk assessment was performed in Kemijoki Ltd with the method presented by Molarius *et al.* [37]. The risk assessment process (Figure 4) is based on the standard IEC 60800-3-9 (2000) with a strong emphasis on data collection in the beginning of the process. The process includes the following steps: scope definition, data collection, risk/opportunity identification and risk/opportunity estimation. Risk/opportunity evaluation is a part of decision-making in which decision makers judge the tolerability of risks and select between potential risk avoidance and reduction actions.

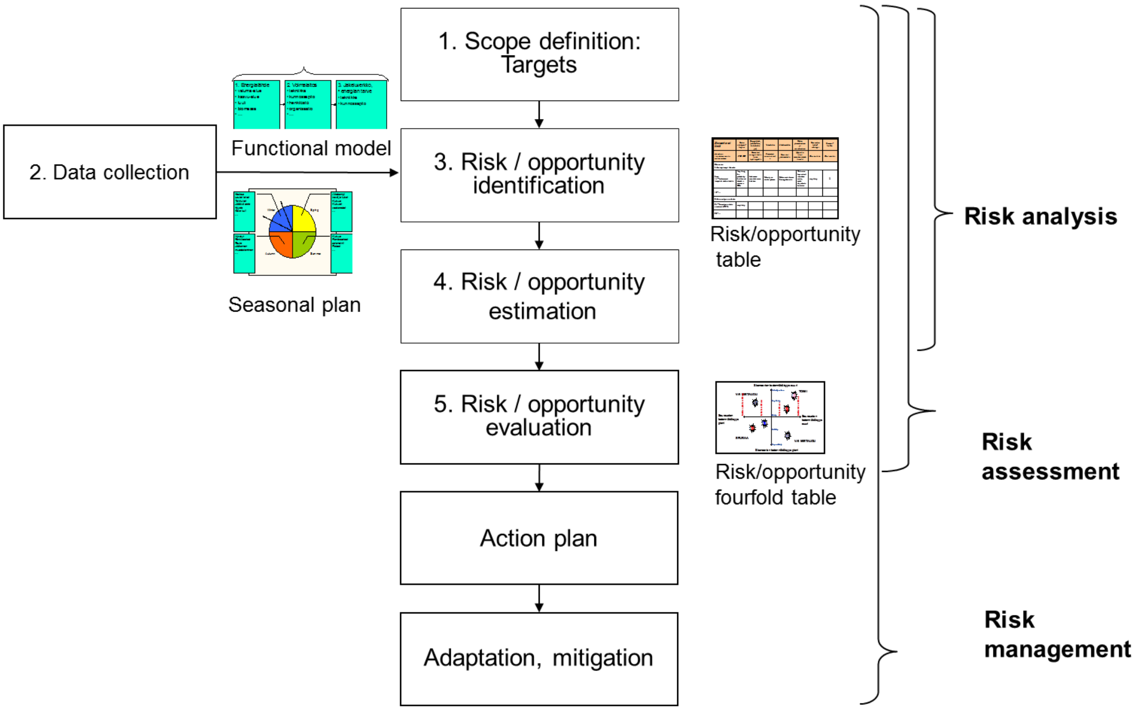

Figure 4. Risk assessment method for assessing future risks derived from climate change [37] (Reprinted from Hydrology Research, volume 41, issue number 3–4, pages 282–294, with permission from the copyright holders, IWA Publishing).

Two tools to help risk/opportunity identification were utilized. The functional model divided the power production and distributional process into three parts: energy source (*i.e.*, the catchment area in the case study), power plant and distribution. Each part can be affected in a specific way due to the changing climate and therefore it was meaningful to examine the parts one by one. Firstly, the catchment area of two hydropower plants including regulated reservoir were studied. In this stage the changes in the natural environment during the seasons were mainly pointed out. Secondly, the power-plant operational environment was studied. In this stage, the technology in use, maintenance, personnel and organizational point of views were especially discussed. Finally, the changes in distributional network during the seasons were studied. According to this, the effects on power production was studied. Another tool, seasonal plan, helped to generate an overview of the seasonal issues by incorporating climate scenario data and information on typical seasonal actions of the power plant energy production.

With the help of these two tools, the brainstorming-based risk/opportunity identification method “What-if?” was utilized. Both future climate scenario data and historical hydrological data were studied to create a shared understanding about the possible future events.

The risk/opportunity estimation focused on two kinds of likelihoods: the likelihood of the climate scenario and the likelihood of the identified risks. The likelihood of the climate scenario was estimated by the principles of scenario designers. The regulation guideline and its suitability for different simulation cases were main factors for result reliability. The summary scenarios for years 2010–2049 were estimated to be very likely and scenarios for single great flood year or extremely dry year were estimated to be likely. The participants of the risk analysis performed the estimation of likelihoods.

The results of the analysis were presented in risk/opportunity table. The table is an overview of all information that arose during the risk assessment process.

The update of the risk assessment was done in two steps in 2015; (1) Analysis on changes in environmental parameters conducted from climate scenarios and (2) risk analysis workshop based on the risks identified in 2008 in two hydropower plants.

3.3. Risk Assessment Workshop in Kemijoki Ltd

The risk assessment workshop was held in the city of Rovaniemi in May 2015. The aim of the workshop was to examine changes compared to the risk assessment performed in 2008, and to identify the changes in operating environment, nature *etc.*, and to highlight the realized risks over the last seven years. The risks and also potential benefits were identified based on the incoming runoff values for the hydropower plants or water level values for regulated reservoir according to the hydrological scenarios. The main questions during the workshop discussion were: What kind of changes, risks and benefits the climate change induces? Have the effects been already seen and if yes, how they have been taken into account?

The risk assessment workshop was carried out by researches from VTT and experts from the Kemijoki Ltd. The wide range of knowledge about the hydropower plants made it possible to identify various situations where risks might occur and therefore obtain a comprehensive view of future risks. The especially valuable factor for the fluency risk assessment workshop was the availability of wide historical knowledge of hydropower plant operations in various seasonal conditions. In addition, the availability of collected data of peak weather parameters during the last decades made it possible to achieve good risk assessment results. It was also important to have background knowledge to estimate the usability and usefulness of the risk assessment method and hydrological scenarios.

In the latter risk assessment workshop in 2015, the results of the previous risk analysis was scrutinized and estimated again. The accuracy of hydrological scenarios from the time period 2008–2015 perspective was also estimated. The main issue was to clarify if the measured hydrological values, like incoming flows for hydropower plants and water level values for reservoirs, in years 2008–2015 have been in accordance with the simulated values. The other key issue was to examine if there were changes in the operational environment which were significant enough to be taken into consideration.

4. Results

The results of the risk assessment workshop in 2015 pointed out that the major changes due to climate changes have not yet taken place in the operational environment of the hydropower plant. Some small-scale changes have already occurred but according to the companies' experts, it is too early to say if these changes are the results of climate change.

4.1. Technical and Societal Risks Due to Environmental Circumstances

The most significant risk identified was related to hydropower plant operations. The pack ice that forms when the river pushes ice floes towards the dam causes increasing pressure against the power plant structures. There have already been some difficult ice conditions in early winter time during the last years. If the autumnal flow increases in the long term, as scenarios partly estimates, the risk of pack ice may come greater. The major concern of large scale pack ice is the breakdown of dam structures. The worst-case scenario is a large failure of dam infrastructures, which both interrupt the power energy production and causes major safety risks for workers as well as the nearby environment.

Another adverse ice condition results from sub-cooled water which takes place when cold running river water cools below 0 ℃ and rapidly freezes when touching solid structures. This can occur in shallow water (under two meters approximately) at the bottom of the waterway channel or in the structures of the hydropower plant when there is not yet ice-cover on the river. When frazil ice begins to form on a solid surface, and if the frazil ice layer continues thickening and become heavy enough, it can break structures. For instance, turbines and gates of power plants can be damaged during frazil ice formation.

The flood peaks in late autumn and in early wintertime can prevent ice cover build-up. Rapidly changing temperature also makes it challenging for good ice cover to form. By regulating the incoming water flow, the power plant is striving for the river conditions that enable ice formation on the surface of the river. Ice-covered river flow assures more constant incoming flow for the power plant and prevents many problems caused by ice and open water. The hydrological scenarios forecast some increased autumnal flow peaks and floods and thus more frazil ice problems and freezing of structures might happen in future.

The Kemijoki River is also gradually eroding river banks and this is especially forceful if the floods take place in early summers or autumns when the banks are not frozen and there is only weak vegetation protecting them. According to the watercourse regulation permit, the hydropower producer is to some extent responsible for the environmental damage that occurs in these circumstances. In exceptional circumstances, when large, controlled-release actions are necessary to protect more densely populated areas, the hydropower company must pay compensation for any flood damage to public infrastructure, river banks, farmland and other privately owned structures such as houses and cottages. This risk is expected to become more frequent in the future.

4.2. Observable Changes in Weather Conditions and Environment

The hydrological parameters in the river Kemijoki catchment area vary from year to year and even large-scale variation is a normal phenomenon. However, it is important to examine the most significant risks that have been identified to be better prepared for possible future incidents and changes.

In the analysis it was discovered that company experts had historical data about mean runoff from years 1991–2014. According to this data, the runoff has already risen about 10% compared to time period 1961–1990. In general, the impact of climate change remains moderate in the hydrological scenarios and flow parameters. The scenarios indicate that springtime floods will begin, on average, 10 days earlier than the reference period. However, the scenarios do not identify the major flood peak for which the preparedness should be proportioned. If the extreme hydrological conditions are undervalued, the preparedness may not be on the right level. In the case study the hydrological scenarios were also made based on two extreme springtime floods. Nevertheless, already in 2000s there has been one springtime flow peak higher than the hydrological scenarios indicated. It is also known that in the 1930s in Kemijoki catchment area there have been larger springtime flows than the hydrological scenarios were based on.

The changing weather conditions bring about many indirect impacts for the companies. The environmental permits, the watercourse regulation permits and other permits or guidance may need reassessment. With the help of watercourse regulation the watercourses over large areas are controlled. However, if the seasonal changes of water flows and environmental conditions are broad enough, the appropriate water area usage also needs to be adapted. For instance, in the catchment area of river Kemijoki, a new endangered butterfly species was discovered that now needs to be protected, and this will change the environmental responsibilities for the hydropower company. Wading birds are also a concern for the company, as they flock to the seasonal floodplain areas for food supply during the springtime, and therefore the hydropower company's requested to water course regulation permits in regards of flood-peak timing were not accepted by the environmental authority. The more difficult challenge originates also from the watercourse permit that was given about 50 ago: the hydropower producer has a commitment to build three ice-roads across the river during the wintertime. This has proved to be very demanding as winter temperatures nowadays are not only warmer, they vary continuously and they cause winter ice formation to occur later in autumn. If the ice-road building commitment is strictly enforced, the flow for the hydropower plant has to be restricted so that the water flow is slowed to encourage surface-ice formation, and that, in turn, will have a negative influence on power production.

4.3. Non-Climate-Induced Risk Factors

The risk analysis process highlighted that there are several other factors in addition to climate change that have effect on hydropower plant's future. Hence, it was not possible to delimit the analysis only in impacts of climate change. The long time-span makes all kinds of changes possible: there were changes in business itself, in energy politics both in Finland and internationally, there were changes in other businesses that use energy and there were changes in the use of electricity *etc.*

In Finland there has been a huge change from coal-fired power plants to wind and sun power, and also to nuclear power. Previously, nuclear power was the main provider of base load capacity—with contributions from wind and solar power—while coal-fired plants and hydropower provided peaking power. Nowadays, when the amount of coal-fired power has decreased and the amount of wind power generation has increased, hydropower alone bears the main responsibility of the peaking power generation. Neither is the Nordic hydropower produced in Sweden or Norway, in use for Finland, as today it provides European wind power as peak power.

Kemijoki Ltd has also outsourced its maintenance staff from a private service company. This means that the maintenance breaks which were once done in springtime (during the main flood period) now take place in autumn, as they are cheaper to perform at that time. However, this change created a knock on effect firstly on the water level in the dam area, then to the power production itself, and even further to possible flood formation. During the next few years, the control room of the power plants will also be removed from the river area and located to Southern Finland. This might also change the flood control as the know-how of “playing with several plants and dams” declines.

Furthermore, there have been big structural changes in Finnish industry during the last 15 years as the pulp and paper industry, which was the main energy user, has collapsed; resulting in a reduced demand for the consistent supply of energy.

Due to these societal changes, it is difficult, or even impossible to compare if there are climate change-induced variations in water levels or water discharge in hydropower plants as the use of hydropower has also changed.

4.4. Other Notifications from the Risk Analysis Workshop

The risk analysis concentrated on both risks and opportunities due to climate change. It seemed easier to identify the risks as only one business opportunity was identified. The scenarios showed that springtime flooding may also increase moderately, as the flood time lengthens and the flood peaks become lower. If this estimation comes true, the adjustment ability of hydropower production improves and less incoming flow passes the turbines. This opportunity accelerates the plans to renew the turbines to be more efficient.

One main character of the used risk analysis method was the future-oriented seasonal plan tool (presented in Figure 2). In Northern Finland seasonal variation in weather and hydrological conditions is wide, and it is vital to take it into account when planning the operations of a hydropower plant. For instance, the proactive maintenance actions should be planned according to the power plant’s annual operating plan. In future the seasonal variation is expected to change: autumns are longer and winters are shorter. This means that the season-specific maintenance operations have to be adjusted corresponding to the new seasons. The seasonal plan tool was developed in order to simplify operational planning. Therefore, the seasonal plan presents major seasonal weather conditions, seasonal events and the power plant’s operations divided into four seasons. It portrays, for instance, climate scenario information according to changing seasonal circumstances and makes it easier to include climate change information into risk analysis. This method was considered a helpful tool for the hydropower company risk assessment.

5. Conclusions

The updated risk analysis on Kemijoki hydropower plant pointed out that through climate change risk analysis, risks that might emerge in the near future and impact on hydropower production can be identified and dealt with. During the risk analysis process, it was seen very clearly how difficult, or sometimes even impossible, it is to analyze the risks due to climate change and their impacts on business. It is not that we have little information or data on climate change and its impacts on the discussed climatological area. The difficulties originate from the long planning time span. The risks that might happen in the far-away future are not easily identified or analysed as they can fluctuate in line with the other societal changes, such as the reduction of energy needs by the Finnish pulp industry mentioned above. This study supports remarks of [8] that it is very difficult to differentiate between the impacts of climate change and the impacts of other parallel societal development, as they are usually intertwined. Therefore, focus should not only be on the future climate, but also on the future society.

During the risk analysis process, we worked with experienced hydropower experts who had vast knowledge of hydropower production and weather conditions. Their skills were used to analyze the results of hydrological models and to compare them with past weather events. Even so, their decisions dealing with risks lean more on past events than on hydrological models. This was because the hydrological models did not adequately highlight the most extreme events that were experienced. This might be a consequence of the use of too narrow selection of global or regional climate models, as Veijalainen *et al.* [27] present or the use of insufficient methods to estimate the probability of extreme weather events [39]. Nevertheless, it seems that the main risks can be best recognized by analysing the extreme weather events of past decades and years, together with studying the possible climate change impacts on seasonal variations. Hence, the most suitable risk assessment methods are qualitative.

When planning new production or locating new buildings near river sides, it might be misleading to rely only on climate scenario-based hydrological models, and it can be misleading to use them as background information for risk analysis. It is essential for the companies as well as the producers of risk analysis to understand what kind of limitations the hydrological scenarios may include. All three factors, the high-quality hydrologic scenarios, the interpretation of scenarios and also the knowledge of historical weather data are essential information for supporting the decision making process.

The results of this study show that for companies, it is necessary to select suitable risk or adaptation management strategies to avoid gratuitous investments. According to this study, it seems that the main adaptation strategies can be found from the strategies presented by Hallegatte [16] as buying ‘‘safety margins’’ in new investments and reducing decision time horizons. Both of these strategies provide an advantage in the widely fluctuating circumstances where political decisions and societal changes have a greater effect on business than does climate change. When business prepares for extreme weather events at the same time as it prepares climate change, there can be smooth adaptation over a long time span. Both of these strategies can also be employed as risk management strategies.

The significance of hydroelectric power plants will remain, but their role in electricity production will gradually change. In Finland, hydroelectric power plants have the role of peak load power plants. Power production is therefore altering into becoming more diverse and decentralized. Wind power mills have been planned for and built in Northern Finland and coastal areas, and, in the future, this increased wind power generation will also require new peak power units. In future, consequently, more hydropower will be exploited to provide peaking capacity for the base load wind power.

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Author Contributions

Riitta Molarius and Jaana Keränen performed the main analysis and wrote the paper; Liisa Poussa contributed by completing the discussions and results.

Conflicts of Interest

The authors declare no conflict of interest.

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