Creating a climate change risk assessment procedure: Hydropower plant case, Finland

Riitta Molarius, Jaana Keränen, Jari Schabel and Nina Wessberg

ABSTRACT

This paper examines the risk assessment procedure for a Nordic hydropower production process while taking climate change into account. It is evident that climate change poses new risks and concerns for hydropower companies, especially with regards to the high uncertainty that results from the ignorance of relationships between climate change and hydropower production (descriptive uncertainty). However, climate change may also provide opportunities. This paper focuses on the development of a risk assessment procedure to support the risk identification process as a means of reducing the descriptive uncertainty. The intention of the study was to develop and test a procedure in which climate scenarios and traditional technical risk assessment have been integrated. This allows us to obtain a practical method as well as associated support tools for identifying and evaluating climate change-related risks and opportunities for hydropower plants. This new procedure is intended to help hydropower plants plan their future investments and strategies by identifying and prioritizing the risks caused and opportunities created by climate change. The study was conducted as a part of the Nordic Energy Research funded Climate and Energy Systems (CES) project and was coordinated by VTT Technical Research Centre of Finland.

Key words | climate change, climate scenarios, emerging risks, hydropower, risk assessment procedure, uncertainty

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INTRODUCTION

According to recent observations and studies, climate change will transform the environmental conditions associated with hydropower production in Finland (Tammelin *et al.* 2002; Kirkinen *et al.* 2005; Carter 2007). It has been assumed that the future will bring more rainy days, longer dry periods and fewer frosty nights, for instance. Snowfall patterns will also change in Finland, with more snow in certain regions and less in others. These changes may in some instances be beneficial; for instance, greater precipitation may increase hydropower capacity (Roos 1996). Although this will have a variety of impacts on local hydropower production, the entire energy sector must adapt to climate change. To support future investment decisions, it is essential for power companies to consider foreseen environmental changes and, in doing this, develop climate change strategies for each power plant.

The intention of this study was to integrate climate scenarios with technical risk assessment traditions in order to create a practical method for climate change risk assessment at hydropower plants. The study is part of the Climate and Energy Systems (CES) project funded by Nordic Energy Research (http://en.vedur.is/ces). The project follows the earlier Climate and Energy project (CE).

Risk assessment is a diverse field and a variety of qualitative, semi-quantitative and quantitative tools and approaches exist. The definition of risk and the procedures and methods used in the risk assessment process vary

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depending on the case and, more especially, the field of science. In engineering and technical risk assessment, risk is defined as a function of likelihood and the associated consequences. Risk assessment procedures focus on both practices and the functions of a technological system (Wessberg 2007; Wessberg *et al.* 2008).

In strategic risk management, risk is defined as a possible future event that, if it occurs, might impact on the ability of an organization to achieve its objectives (Hillson 2007). Rosa (2003) and Aven (2008) state that risk is a situation where human values are at stake and where the outcome is uncertain. These are probably the most useful definitions of risk for use in the context of climate change and efforts to adapt to the new circumstances, since it considers risks to be either negative or positive i.e. involving either profit or loss (Power 2004; Smith 2004). In the same way, risk can also be seen as an opportunity that might be lost if one does not have enough information to act. Because climate change may affect hydropower production either negatively or positively, this study also focuses on opportunities.

Risk identification has typically been approached with traditional qualitative methods, using brainstorming sessions and checklists. Most importantly, risk identification is based on the strict and known scope definition. However, because we cannot be certain about what is going to happen, the scope cannot be strictly defined when attempting to address climate change. Accordingly, when seeking to identify future risks, new methods based on future studies are also needed. Future-oriented approaches attempt to illustrate and manage the future in an explicit and systematic way by identifying, assessing, analyzing, combining and interpreting existing data, information and expert opinions (Koivisto *et al.* 2008).

By integrating the methods traditionally used in future-oriented technology studies with technical risk analysis practices, tools for supporting decision-making and material for generating adaptation strategies can be realized to address the new risks associated, for instance, with climate change in relation to the energy production and distribution sector. In this study, we combined future climate scenarios with the risk assessment procedure outlined in standard IEC 60300-3-9 (2000) (safety standard of risk analysis for technological systems).

Climate change could involve new, emerging risks that are either previously unknown or have not yet been observed (Rowe 1977; van Asselt 2000). No statistics or experiences of managing these kinds of risks exist; one of the most challenging aspects associated with future risks therefore concerns risk and opportunity identification and specifying their probability. Rowe (1977) has stated that risk identification always involves some descriptive uncertainty in addition to measurement uncertainty which can be calculated from statistics. Descriptive uncertainty in this context arises from the absence of information relating to the identification of the variables that explicitly define the relationships between climate change and hydropower plants. For example, the environmental impacts of climate change and the societal transformations occurring on the heels of behavioural or economic transition involve descriptive uncertainty. There are great difficulties (it could even be impossible) in determining the uncertainty by calculating the probability of risks that are rare or have never occurred and which, most significantly, are part of a system that cannot be explicitly defined. There is therefore an absence of information relating to the variables that define the system.

As a consequence, traditional statistics- or experience-oriented risk identification processes are not sufficient; new future-oriented and uncertainty-tolerant risk identification approaches are needed. Rowe (1977) indicates that new risks can be mitigated only by decreasing descriptive uncertainty. We state that descriptive uncertainty mainly concerns the consequences of climate change. Accordingly, one focus of this study is to visualize the descriptive uncertainty with two dimensions in the context of climate change and hydropower production. This will also be the main difference of this study compared to traditional risk assessment procedures which only elicit one dimension of uncertainty for risk evaluation.

OBJECTIVES AND METHODS

The main goal of this study was to develop a risk/opportunity analysis procedure for use at a single hydropower plant. We sought to make the procedure practical, understandable, logical and simple to use. The risk assessment procedure should also improve users' knowledge of the impacts and risks of climate change at hydropower plants, thus supporting the power plant's decision makers in defining suitable adaptation strategies and control actions. Furthermore, the procedure could help them to determine future production potential and investments. The procedure is therefore meant to help hydropower plants to plan their future by identifying and prioritizing the risks and opportunities caused by climate change. The risk/opportunity analysis could therefore result in concrete proposals for the improvement of the technical or operational performance of power plants.

To effectively convey information about climate change-related risks and opportunities into corporate decision-making in practice, several key issues needed to be addressed first: (1) how to analyze the future risks associated with climate change; (2) how to integrate the regional climate scenarios into a risk assessment procedure; and (3) how to visualize and document the risks, opportunities and uncertainties.

Because the aim is to identify and evaluate the risks associated with climate change in a technological system, a technical risk analysis in line with the industrial safety standard of risk analysis for technological systems (IEC 60300-3-9 2000) was utilized. This standard provides a structure for risk analysis processes conducted at companies, for instance in the process industry. The climate change risk assessment guide of the Australian Greenhouse Office (2006) also provided useful guidance.

In the context of the possibilities and frequencies of climate phenomena, the classification described in the reports of the Intergovernmental Panel on Climate Change (IPCC 2007) was adopted (Table 1).

Table 1 | Description of likelihood according to the IPCC (2007). Likelihood refers to a probabilistic assessment of some well-defined outcome having occurred or occurring in the future, and may be based on quantitative analysis or an elicitation of expert views

Terminology	Likelihood of the occurrence/outcome
Virtually certain	>99% probability of occurrence
Very likely	90–99% probability
Likely	66–90% probability
About as likely as not	33–66% probability
Unlikely	10–33% probability
Very unlikely	1–10% probability
Exceptionally unlikely	1% probability

Since creating shared understandings about possible future developments among stakeholders plays an important role in risk management (Koivisto *et al.* 2008), qualitative brainstorming-based risk identification methods such as what-if analysis and focused group interviews were chosen as the basic building blocks of the method and its development. Functional modelling (Suokas *et al.* 1992; Suokas 1995; Koivisto *et al.* 1999; Rasmussen *et al.* 2001) has shown itself to be effective in many risk assessment applications by helping to define the scope and systematically structuring the risk identification process in brainstorming sessions.

The functional modelling method was used to support hazard identification at the plant level. The plant was divided according to its different functions into the energy resource area, hydropower plant area and distribution area. All the inputs of the environmental factors as well as the inputs and outputs from the previous functional area to the next functional area were identified. The functions were described using a box with incoming and outgoing arrows. The functional model is therefore a simple flow diagram of the plant (Koivisto *et al.* 1999).

In addition to risk analysis and other relevant standards, the study comprised a literature study, interviews, brainstorming sessions and desk work in order to design a new risk analysis method procedure. All these research methods were used iteratively; after each step, the developed risk analysis procedure was re-examined and improved as deemed necessary.

The whole concept development process is illustrated in Figure 1.

The literature study also involved gathering information about the essential technical and environmental data that are used for risk identification and evaluation in hydropower production. The main questions concerned: (1) the environmental factors that significantly impact hydropower production in Finland; and (2) how climate change will affect these environmental issues.

The results of the literature study were subsequently analyzed and the first configuration of the procedure was drafted. The results of the preliminary desktop investigations were used as the basis for the material used during group interview sessions at the Finnish Meteorological

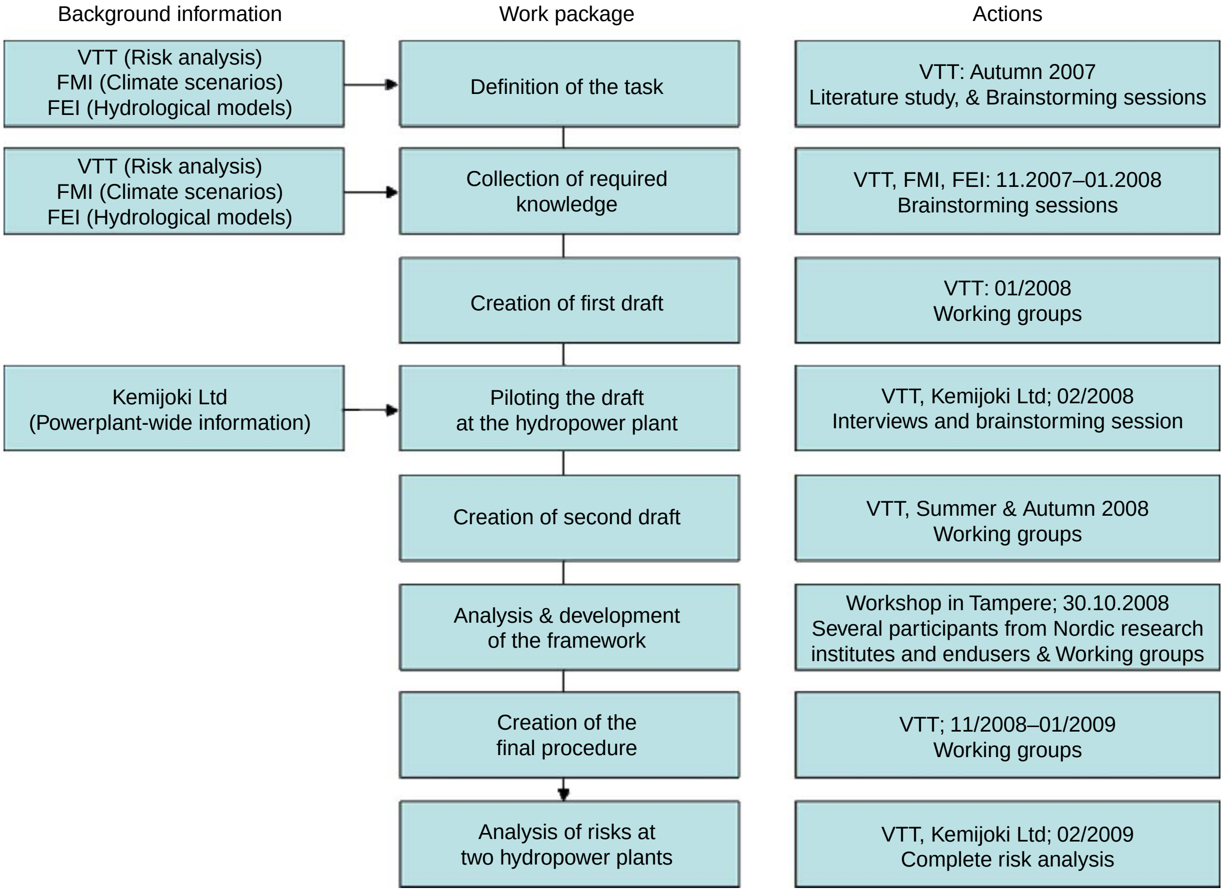

Figure 1 | The process of the development of the risk assessment procedure for hydropower plants.

Institute (FMI) and the Finnish Environment Institute (FEI). Future climate scenarios were created for the Kemijoki River and catchment area in the year 2030.

Regarding background information, one of the most challenging issues is to ensure that the information provided by climate scenarios and hydrological models is readily comprehensible. The FMI has an expertise on climate scenarios and, in collaboration with their experts, the scenarios were reworked to make them understandable to hydropower plant personnel. The climate scenarios used were produced for the Climate and Energy project (CE) and are based on two global climate models: ECHAM4/OPYC3 (European Centre Hamburg model 4/Ocean and isoPYCnal coordinates model 3) and HAdAm3H (the Hadley Centre global Atmospheric model 3H). The CE project follows the SRES emission scenarios A2 and B2 (Rummukainen *et al.* 2007).

The first co-operation occasion was a brainstorming session between VTT Technical Research Centre of Finland and FMI. VTT developed the first draft of the risk/opportunity table for this session (R/O table, see Table 2). The table was intended to serve as the main document in which all the necessary data would be collected. During the session, the information from regional and global climate scenarios was simplified and recorded in the R/O table. The table was developed to suit this purpose better. Three meteorologists from FMI and two researchers from VTT participated in this session.

The FEI develops hydrological models in every part of Finland, also for future circumstances. Experts at hydropower plants are familiar with today's hydrological models, and it was therefore easy to introduce these new models to them. Assessment of the future hydrological regime is a production chain where changes in external forcing caused

Table 2 | An example of the final R/O table which includes all the collected information about the identified risks

Scenarios and phenomena	**Likelihood of the phenomena**	**Energy source, (e.g. catchment area, peat or biomass production area)**	**Power plant**	**Distribution network**	**Risk reduction/ control/potential**	**Likelihood of consequences to energy production**	**Consequence category**
Phenomena according to regional scenario of future climate, hydrological model or wind model	Likelihood according to IPCC 2007	The consequences of the phenomena to the energy source and its usability	The consequences of the phenomena to the power plant	The consequences of the phenomena to the distribution network	Actions that will be taken to protect against the phenomena and their consequences	Likelihood according to own ranking (Table 3)	Consequence category according to Figure 5 (legend)
Scenario							
1. Warmer climate							
Phenomena 1.1–higher temperatures, especially during winter	Very likely; the probability that the next decade will be warmer is 90%	Increasing water capacity	Hot weather decreases the lifetime of transformers	Increased electrical resistance energy losses	Increased turbine capacity	Very likely	
1.2–…							
2. Increased precipitation							
2.1–More rainfall:annual runoff will increase by 0–8%	Very likely						

by greenhouse gas emissions are introduced into atmosphere–ocean general circulation models (AOGCMs) and regional climate models (RCMs). The climate model results are used for driving hydrological models (Beldring *et al.* 2006).

FEI uses the ECHAM4/OPYC3 and HadAm3H models to assess the impacts of climate change on water resources in all of the Nordic countries. Hydrological simulations are performed with the conceptual HBV model (Beldring *et al.* 2006). This conceptual model is based on physical arguments and it is developed by Bergstrom (1976) at the Swedish Meteorological and Hydrological Institution (SMHI). The HBV-model has been shown to give good estimates of the runoff from several Scandinavian catchments. In Finland, the simulations are carried out with the Watershed Simulation and Forecasting System (WSFS), developed by FEI on the basis of the HBV model (Veijalainen & Vehviläinen 2006).

The second co-operation occasion was a brainstorming session between VTT and FEI. The second draft of the R/O table was used. The purpose of the session was again to simplify the hydrological model data and record it in the table. Two hydrological modellers from FEI and two researchers from VTT participated in this session.

A case study was devised for hydropower plants, and the personnel of the Finnish hydropower company Kemijoki Ltd actively participated in the development study. Seven key employees of the company were involved in the third development session, during which the overall draft of the procedure was discussed. The participants in this session were the production manager, production director, energy economics manager, line manager, environment director, real estate director and development manager.

The overall draft was presented to the participants from Kemijoki Ltd and they were asked to analyze it step by step. The analysis focused on these questions:

1. Are the descriptions of scenarios and models and their consequences clear enough?
2. Is the R/O table clear to use or does it need some reworking?
3. Is the fourfold table understandable?
4. What other types of supporting tools could be helpful?

A new tool called the Seasonal Plan was developed during this session. It is a checklist that will help power plant personnel to connect the outputs and inputs in the right season and also in the future.

Next, the draft method was proposed to Nordic researchers and an expert group at a seminar in Tampere in October 2008. The group consisted of 19 researchers and experts from CICERO (Center for International Climate and Environmental Research, Oslo), IVL (Swedish Environmental Research Institute), Risø DTU (National Laboratory for Sustainable Energy, Denmark), University of Helsinki (Finland), University of Joensuu (Finland), Sintef (Stiftelsen for industriell og teknisk forskning, Norway), EaEA (Ea Energy Analyses, Denmark), FEI (Finland), FMI (Finland), Kemijoki Ltd (Finland) and NEA (the National Energy Authority of Iceland). The procedure was presented to the group, which then analyzed its strengths and weaknesses part by part. The computer-aided ThinkTank GroupSystem Method was used in the analysis. All the results and discussions of the seminar are documented in the unpublished working paper on the CES Risk Assessment Workshop (available from the authors on request). The seminar resulted in improvements and clarifications to the guidelines of the whole risk assessment procedure.

Finally, the procedure was tested at two hydropower plants in the Kemijoki area in Finland during February 2009. The Kemijoki hydropower company's plants are located along the Kemijoki River, the largest river in Finland. Kemijoki Ltd was chosen to test the risk assessment procedure as it is a significant hydropower producer in the north of Finland; its 20 hydropower plants produce about 1000 MW–about 10% of Finland's energy needs. The Kemijoki River is 550 km long and has a catchment area of about 51,000 km^2 and average flow of about 500 $\mathrm{m}^3\,\mathrm{s}^{-1}$.

The risk analysis at Kemijoki Ltd was performed according to established procedures by using the structured What-If technique. The analysis team included experts in the various areas involved. The participants from the company were the production manager, the energy economics manager, the environment director, the real estate director, the power station director, the modeller and the development manager. The final results of the risk identification and evaluation were delivered to the company as a confidential report.

RESULTS

The general risk assessment procedure as shown in Figure 2 was developed during the preliminary stage of the study. The main parts, which are the scope definition, the data collection, the risk identification, the risk estimation and the risk evaluation, form the body of the risk assessment procedure which follows the traditional risk assessment approach (IEC 60300-3-9 2000).

Based on the outcome of Step 5 (Figure 2), during which the key actions would typically be identified and summarized, the action plan for the management of risks (and opportunities) would be created. An adaptation strategy would be developed in conjunction with any necessary mitigating actions. The entire process constitutes a risk management system. Also in Figure 2, the thumbnail pictures associated with Steps 2–5 depict the four main tools that were developed to assist the risk analysis process.

Tools for data collection

Two tools to aid data collection and data structuring were developed during the study: a functional model encompassing the scope and a seasonal plan. Both tools were applied in the pilot case in order to document the data related to the climate scenarios and the power plant.

The functional model provides an overview of the functional parts of the power plant that are to be taken into account in the risk analysis process. It represents the issues currently affecting the functionality of the hydropower plant.

Figure 3 presents a hydropower plant that has been divided into three parts, each of which could be analyzed in a different way. The boxes list the issues that should be considered at each stage of the risk analysis process, ideally by investigating the effects of and risks or opportunities created by various climate change scenarios. Researchers and hydropower plant staff co-operate to divide the scope into the main areas and fill out the boxes for each heading with the targeted characteristics. In Figure 3, the boxes list aspects associated with the given headings; these are typically areas of concern that are to be specifically addressed in the subsequent stages.

The seasonal plan (Figure 4) was developed to assist in the visualization of how the seasons will change in the future–whether they will be warmer or colder, more humid or drier, longer or shorter, etc. This tool can be regarded as one of the future-oriented tools, as it converts the climate

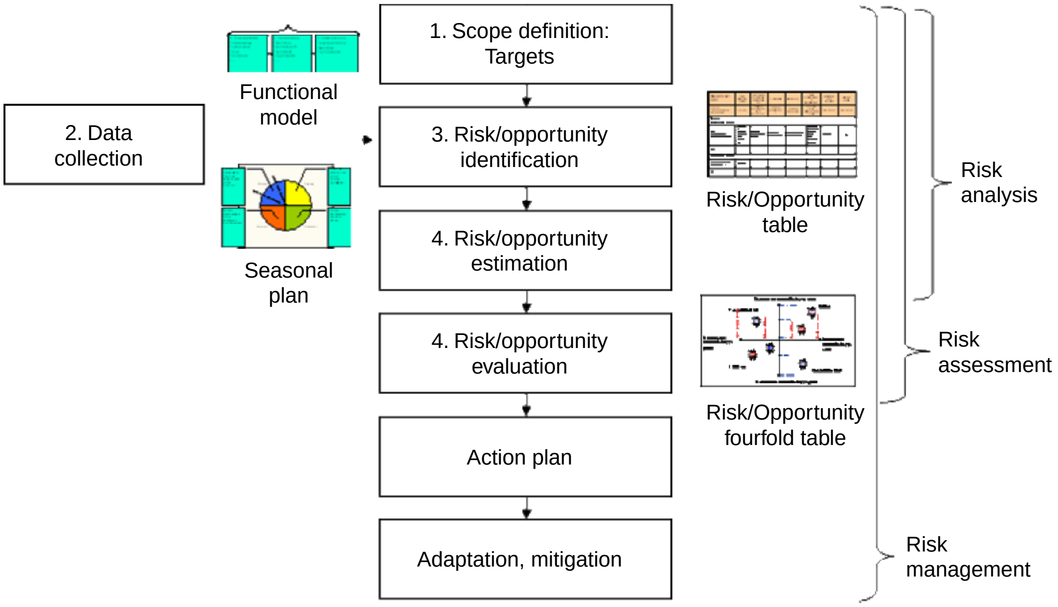

Figure 2 | Risk assessment method for assessing future risks derived from climate change (modified from IEC 60300-3-9 2000).

Figure 3 | An example of the functional model: the functions of the hydropower plant are divided into three functional parts.

scenario information into key words that can be used in the identification of future seasonal risks.

This knowledge of regional climate scenarios and hydrological modelling were acquired from the literature and expert interviews conducted at FMI and FEI. The main factors are collected from regional climate scenarios and, whenever possible, from different kinds of natural environment models (e.g. hydrological models, snow and ice cover models, etc.). The timeframe of the seasons is visualized by enhancing or narrowing the appropriate sectors.

Tools for risk/opportunity identification

The R/O table is the main documentation tool. It was developed for documenting all the necessary risk information from different sources such as knowledge from climate scenarios and hydrological models and brainstorming sessions at the hydropower plant. The risks and opportunities could be evaluated on the basis of all this information.

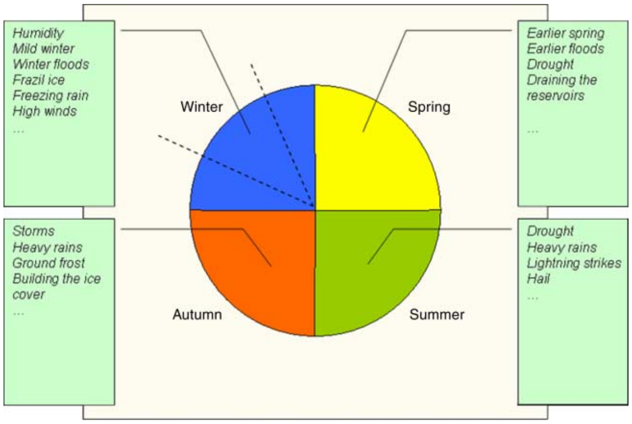

Figure 4 | An example of the seasonal plan tool: the variable seasonal events are listed and it can be used as a check list in risk assessment session.

As presented in Table 2, the table also aims to record basic information concerning the possible future climate (regional scenarios) together with other relevant data (e.g. flood forecasts based on hydrological models, etc.). Moreover, it is also used to collect likelihood data that expresses the uncertainty of the scenario or phenomena.

Knowledge concerning climate scenario likelihood was also collected from the climate change experts at FMI and FEI. The classification of scenario likelihoods is adopted from the IPCC (2007). The data from FMI and FEI is entered in the first two columns of the R/O table (i.e. 'Scenarios and phenomena' and 'Likelihood of the phenomena').

Risk and opportunity identification is carried out with the aid of the data collection tools (seasonal plan and functional model) and using the R/O table in brainstorming sessions with the hydropower specialists, namely the power company personnel. The idea was to determine what kinds of effects the changed climate circumstances and phenomena might have on different parts of the hydropower process in practice, and not only in the everyday routines of hydropower production. In addition, all the means and possibilities to control or reduce the risks and to benefit from opportunities should be discussed and documented.

The seasonal plan is used to envision the seasonal changes and is geared towards stimulating discussion on how climate change could affect the typical seasonal routines and practices at the power plant. Again, not only risks should be sought; opportunities for hydropower production should also be identified.

The functional model is used to structure the risk and opportunity identification brainstorming session, with a view to ensuring that everything that needs to be taken into account is discussed. It forms a unified picture of the scope under scrutiny.

After identifying the consequences and the actions taken to prevent risks or enhance opportunities, the uncertainty must also be discussed. Uncertainty in this context pertains to the likelihood of the risk or opportunity materializing after the planned actions for risk prevention or opportunity enhancement have been implemented. This likelihood can be classified in various ways and even using the power plant's own terminology, if available. The classification used for the pilot case is shown in Table 3.

Table 3 | An example of how to rank the frequency of the risk (or opportunity)

Terminology	Explanation of the term
Very likely	There is only a one in a million chance to prevent the risk; the opportunity is almost certain to occur
Likely	There are some possibilities to prevent the risk; some factors may reduce the opportunity's occurrence
Unlikely	There are many possibilities to prevent the risk; many factors may reduce the opportunity's occurrence
Very unlikely	There are no difficulties in preventing the consequences; the opportunity is precluded

Tools for evaluating the risks and opportunities

The fourfold table was developed to visualize the risk and opportunity evaluation. Together with the subsequent key action and summary follow-up listing, it is the final outcome of this risk identification and evaluation process (Figure 5). The main idea of the fourfold table is to provide a readily interpretable overview of the highlighted risks and opportunities in relation to the likelihood of the scenarios and of the risk or opportunity occurring. These two kinds of likelihoods form the axes of the fourfold table. In other words, the risks and opportunities are mapped into the chart on these two axes: climate scenario likelihood and risk/opportunity phenomena likelihood. The risks are presented as circles and the opportunities as squares. The sizes of the shapes can be used to express the quantified costs of the risks or the benefits of the opportunities.

The analyzed risks and the opportunities are measured by using three different variables: likelihood of the future scenario, likelihood of the realization of the risk or opportunity and the loss or growth of production caused by the risk or opportunity. Disadvantages or benefits are quantified on the basis of the loss or growth of production following from risks or opportunities. These can be divided into three classes (e.g. less than 10 MWh, 10–100 MWh and >100 MWh or any other reasonable way). These three classes correspond to three different magnitudes of risks or

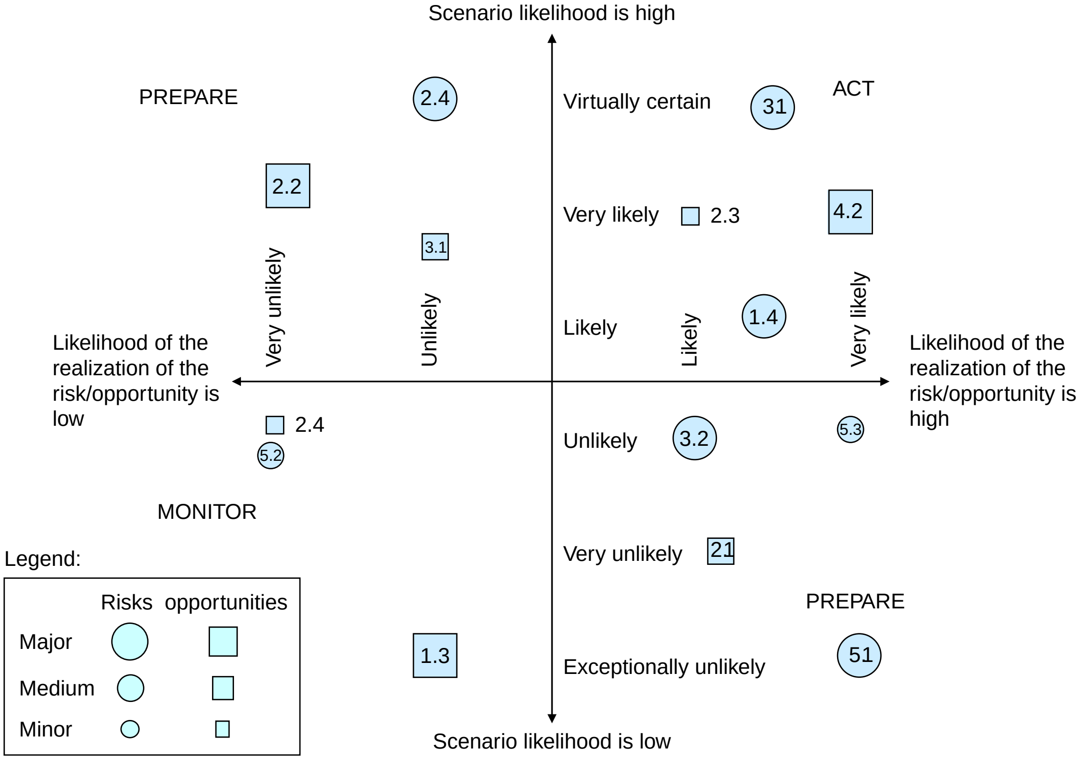

Figure 5 | The fourfold table which includes the identified risks (circles) and opportunities (squares) and illustrates the likelihood of the scenario and the likelihood of the realization of the risk or opportunity after the planned actions for risk prevention or opportunity enhancement have been implemented. The numbers within the shapes correspond to the risks and opportunities identified in the R/O table.

opportunities. These classes can then easily be visualized in the fourfold table using the three different circle or box sizes. In Figure 5, the consequences of risks or the benefits from opportunities are grouped into three classes: major, medium and minor.

Example results from risk identification and evaluation process in the pilot case

According to spatial climate and hydrological models of the Kemijoki area, future winters are expected to be milder. Due to increased precipitation, more water could be expected in the river during winter or, in sub-zero temperatures, more snow cover and a potential increase in springtime floods. At the same time, the summers might be drier.

Some risks and opportunities that are common to all of northern Finland were identified when applying this approach roughly to the case study area. The expected increase in precipitation presents an opportunity for additional water power in the future. In order to best utilize this increasing energy reserve, new turbines or water reservoirs would be needed. Above all, the milder winters and increased water flow will mean that the ice cover on the rivers will freeze more slowly. In such conditions, ice dams and frazil ice may form. This can lead to flooding and generally create difficulties in running the power plant. In the worst case, it can cause dam breaks or damage to turbine equipment.

One identified risk relates to extreme weather phenomena: if in a certain year the snow melts first in the more northern part of the catchment area, the still-frozen rivers in the more southern part of the catchment area will not be able to handle the extra water flow. This would mean that the northern area will flood and the water will typically not reach the power plants.

DISCUSSION

The purpose of this study was to find new methods to reduce the descriptive uncertainty of the risk analysis process while analyzing the risks associated with climate change in particular. Descriptive uncertainty typically hinders the identification and evaluation of new risks. By using a fourfold table which enables the visualization of two different kinds of likelihoods at the same time, descriptive uncertainty can be clarified, helping decision-makers to understand the uncertainty of an identified risk or opportunity. The fourfold table also provides a means of prioritizing risky scenarios and advising on corporate strategic planning concerning the risks or opportunities: act, prepare or monitor.

The new method was well received at the pilot hydropower plant. According to the trial participants, it helped them to better understand both the uncertainty of the phenomena or scenarios, and the likelihood of the realization of risks or opportunities. The tools also assisted in the visualization of the uncertainties by making the potential risks and opportunities more concrete than they had previously been.

The participants stated that their experiences of the entire testing process of the risk assessment method were positive. However, the fourfold table and the seasonal plan seemed to be particularly useful in actual decision-making as these tools present the relevant information in a concise form.

One clear observation was that local environmental knowledge is vital for interpreting the modelling results. In the Kemijoki case, the knowledge of the local company personnel concerning the Kemijoki River was seen as being relevant. The hydrological models gave a frame to the climate scenarios, but the knowledge of the local people was invaluable in translating what the modelling results mean in practice.

The main development suggestion concerned the actual risk evaluation; it was suggested that the ability to express the magnitude of the risk as an economic value would be beneficial. This knowledge would be especially important for decision-making regarding future investments. Although it may be very challenging to rank the risks according to their associated economic impact, determining their value would directly link them to the actual corporate decision-making process. Amending the risk assessment procedure in such a way may also more effectively reveal weaknesses in a company's climate strategy. The core question is whether a company's success is strongly or weakly dependent on direct environmental changes and indirect changes in the rest of the economy. The future development of the concept may focus on clarifying the related financial and economic issues.

Another aspect that may be worth developing further concerns the procedures for most effectively obtaining the required climate scenarios and necessary models. In the pilot case, both the climate change and hydrological modelling experts were asked to collect the most important data for risk and opportunity identification. However, these kinds of specialists are not typically available for consultative risk analysis. Reading reports and books and interviewing experts is quite time consuming and costly. Therefore, such a risk assessment procedure might be very difficult to implement without adequate expertise and both resource and support networks.

One challenge was how to simplify the knowledge from climate scenarios and hydrological models. We noticed that meteorologists and hydrological modellers are not always willing to translate this information into layman's terms due to the great uncertainty of the results. However, this work must be done by scientists because the personnel of the hydropower plant are not able to understand the scientific data.

To circumvent the associated obstacles, it may be necessary for the energy alliances to maintain their own portfolio of regionally tailored climate scenarios and any necessary hydrological models, etc. Obviously this would require ongoing close co-operation with climate change experts and hydrological modelling experts. The knowledge from the regional climate scenarios and hydrological models would also have to be available to the companies at a reasonable cost, and within a realistic amount of time.

Because risk is now more often seen as a missed opportunity, it is essential for any new methods to be able to account for future potential. The risk assessment procedure that has been developed allows for opportunities and their identification and, subsequently, their consideration by decision-makers.

The initial stage of the method development has recently been completed. The next stage will involve its overall refinement. Other improvements will be explicitly directed at the ongoing risk analyses and testing in the case study; for example, detailed hydrological models for the Kemijoki region will be prepared by FEI. A return visit to Kemijoki Ltd is being arranged and a more detailed risk identification and evaluation will be performed for a selected hydropower plant in association with the company's experts.

It is anticipated that the approach will also be tested with biomass power production in Finland. Selected CES consortium partners will also apply the method using the associated guide and supporting material, with energy providers (especially hydro, wind and bio) in their respective countries in order to generate a collection of case studies. The resulting feedback on the procedure will be discussed and it is expected that appropriate amendments will be made to the risk assessment procedure. After the experiences have been collected, the project will subject the procedure to a further round of testing during 2009.

The risk assessment procedure is currently only paper-based. Considering the large amount of information that is associated with the procedure, and especially the nature of the data and related material, the procedure would lend itself to electronic or even online development. Not only would the documentation be enhanced, but the visualization functionalities would particularly benefit from this.

SUMMARY AND CONCLUSIONS

In this paper we have described the development and application of a risk assessment procedure and the supporting tools developed during the CES project. Specifically in the pilot case study, we have described the general risk assessment procedure, guidelines for gathering the background information (the seasonal plan, functional modelling), risk identification model (R/O table) and a method for risk estimation and evaluation (fourfold table). The method is intended for identifying and evaluating the risks posed by climate change. The procedure should therefore be only used to identify the main climate change risks arising after about 15 years or more. The procedure was created for hydropower plants but is also suitable for different branches of industry that might suffer from climate change in future, such as peat production and the food industry. The procedure includes some tools that are useful for identifying current risks, such as the fourfold table and the documentation sheet.

This risk assessment process specifically aims to support the risk identification and evaluation process as a means of reducing the uncertainty that results from the ignorance of relationships between climate change and hydropower production. The results could also be used to support decision-makers at hydropower companies in their efforts to define suitable adaptation strategies and determine future investments.

The pilot case at the Kemijoki River in Finland confirmed that the risk assessment procedure and its tools can support corporate decision-making processes in relation to the potential risks and opportunities concerning hydropower production practices in the context of climate change. The seasonal plan and fourfold table were seen to be of particular assistance. Using the tools decreases the descriptive uncertainty related to risks and opportunities associated with climate change. Although uncertainty is still involved, the tools aid the visualization and documentation of the identified aspects, allowing them to be prioritized and action plans to be devised.

It is expected that the tools themselves will be refined further. Considering the nature of the data and related material, the documentation, data management and integration aspects of the current risk assessment procedure would benefit from being developed electronically. This would enhance the visualization functionalities in particular.

Supplementary development for supporting the method should focus on improving the availability of regional climate scenarios and any essential models. The companies would need the plant-specific scenarios and models to be available within a reasonable timeframe and at a reasonable price.

The ability to express the magnitude of the risk or opportunity as an economic value would be beneficial, especially for decision-making regarding future investments. Although it may be very challenging to rank the risks according to the associated economic impact, determining their value would directly link them to the actual corporate decision-making process.

Further support material and guidance will also have to be developed if the tool is to be widely adopted. Additional test cases will nevertheless need to be identified and further studies conducted.

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