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Test and evaluation of a climate risk assessment procedure

Case study: The Norwegian hydro power company SFE

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Sammendrag:.	**Abstract:** VTT Technical Research Centre of Finland has developed a climate risk assessment procedure based upon a pilot case study at and with the Finnish power company Kemijoki Ltd. I test this procedure on two hydro power plants owned by the Norwegian hydro power company SFE. Based on this experience, I suggest some concrete changes in the major tool, the risk/opportunity table. Also, I reflect upon the use of the concept risk in the risk assessment procedure and compare it with the definition of risk according to the Capital Asset Pricing Model in Finance. Both this study and the climate risk assessment procedure which this study refers to were conducted as parts of the Nordic Energy Research funded Climate and Energy Systems (CES) project
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1 Introduction

VTT Technical Research Centre of Finland has developed a climate risk assessment procedure based upon a pilot case study at and with the Finnish power company Kemijoki Ltd. I test this procedure on two hydro power plants owned by the Norwegian hydro power company SFE. Based on this experience, I suggest some concrete changes in the major tool, the risk/opportunity table. Also, I reflect upon the use of the concept risk in the risk assessment procedure and compare it with the definition of risk according to the Capital Asset Pricing Model in Finance.

This report is devided in two sections. The first section presents my result from the test of the procedure. This part is devided into five subsections following the five steps in the VTT procedure. In the second section I give my evaluation of the procedure.

In the Appendices I have included information about the VTT climate risk assessment procedure, information about the Norwegian case study and suggested revision of the VTT risk/opportunity table.

2 The case study: SFE

2.1 Step 1: Scope definition and targets

Norway's electricity production is approximately 120 TWh and is based 99 percent on hydropower. Hydropower is supplied by over 600 plants. 90 percent of the production capacity is publicly owned (35 percent state and 55 percent municipal ownership). The deregulation of the electricity market in the 1990s resulted in unbundling of the vertically integrated hydropower companies into a competitive part (production and sale) and a monopolistic part (transmission/ distribution)[i].

2.1.1 Case description

For the purpose of this paper, I have selected the following vertically integrated hydro company: [ii] [iii]

Name:	SFE
Address:	Bukta, 6823 Sandane, Norway
Turnover:	90 MEUR
Equity:	135 MEUR
Number of employees:	197
Yearly electricity production:	1300 GWh
Electricity grid:	3500 km serving 22.300 customers

SFE is located in the county Sogn and Fjordane in the Western part of Norway. Its main activitities are production, distribution and sale of hydropower[iv] which are controlled by the separate subsidiaries SFE Produksjon, SFE Nett and SFE Kraft, respectively. The region is mountainous and sparsely populated. There is more rain in this part of Norway, than in the South and the East. And, downscaled climate scenarios predict higher increases in precipitation and wind here than in other parts of Norway.

2.1.2 Scope definition

I have identified two hydro power plants (see Appendix IV and V):

Mel

Åskåra I

Both draw water from reservoirs and have a drainage basin which includes glaciers.

Both plants have installed Pelton wheels[1] which are well suited for high head, low flow applications[v] . Water is piped down a hillside so that at the lower end of the pipe it emerges from a narrow nozzle as a jet with very high velocity. Nozzles direct forceful streams of water against a series of spoon-shaped buckets mounted around the edge of a wheel. To achieve maximum power and efficiency, a very small percentage of the water's original kinetic energy should remain in the tail water.

Mel uses water from four reservoirs in Vetlefjordvassdraget. The drainage basin includes part of the glacier Jostedalsbreen. Water from three smaller magazines is transported in tunnels to Nedre Svartevassvatn reservoir which is regulated between 815 and 883 meter above sea level. When there is overflow, the excess water may cause flooding of farm land down in the valley. The power plant has an installed effect of 52 MW and an average yearly production of 212 GWh.

Åskåra I uses water from the reservoir Store Åsgårdsvatn which is regulated between 614 and 697 meter above sea level. The drainage basin includes the glacier Ålfotbreen. The drainage basin is characterized by gravels and smooth rock slopes which quickly leads the water to Store Åsgårdsvatn; thus, compared with Mel, the reservoir filling will vary more directly with the amount of rain. The plant has an installed effect of 116 MW and an average yearly production of 535 GWh.

SFE Nett, the grid subsidiary, is allowed to operate as a monopolist in its region. However, its revenue is regulated by Norwegian Water Resources and Energy Directorate (NVE). The revenue cap reflects factors which influence costs in the area served by the net company, such as climate, topography and settlement patterns. On one side the revenue cap regulation gives incentives to cut operating costs, which is good. On the other, this incentive may result in reduced delivery quality. Thus, NVE has introduced a mechanism whereby a cessation in delivery of electricity results in reductions in the revenue cap. However, it has been argued, that the revenue cap system still gives too low incentives to develop and maintain the electricity grid.

2.1.3 Targets of the analysis

The target of the analysis is to test the RA framework; that is, to detect problems in carrying out such an analysis and to discuss improvements.

SFE do conduct risk assessment analysis, but not with a specific focus on climate change. On demand, they have also written one climate change impact analysis for Sogn and Fjordane County Administration. If they were to start assessing their climate risk on a regular basis, the target would be to identify upcoming investments. However, in discussing these issues with SFE, I got the impression that they thought possible climate changes were far into the future and that the company would have time to adjust gradually as the changes occur.

2.2 Step 2: Data collection/organizing the meeting

2.2.1 Data collection

Ahead of the meeting with SFE, I identified a regional climate scenario for Western Norway along 5 dimensions:

[1] For more information on Pelton wheels see http://en.wikipedia.org/wiki/Pelton_wheel

Temperature: higher

Precipitation: more, and more intense

Wind: more, and more intense

Snow & glaciers: less

Sea and rivers: more autumn and winter flooding, changes in seasonal patterns

The detailed climate scenario is included in column 1 of the Risk/Opportunity table (see Appendix III). The information reflects the results from the research program REGCLIM (2003-2006) [vi] which focused on climate changes in the Nordic countries. Thus, the information I used is based on specific contributions[vii] on each of these weather characteristics, and as such, does not constitute one scenario. For example, the time horizon may differ. Also, the different contributions may reflect different emission scenarios and global climate models. However, all are results presented in REGCLIM and does therefore adhere to some common assumptions.

2.2.2 Brainstorming session

I asked the CEO of SFE to invite a working group for the brainstorming session. It should preferably cover the whole value chain consisting of production, transmission and sale. It was arranged that I should meet the following employees in SFE on September 4, 2008:

Tormunn Skarstad (SFE Prod.): responsible for water resources/security issues

Per Eirik Eimhjellen(SFE Prod.): responsible for production planning

Rune Haukebø (SFE Prod.): responsible for carrying out the yearly risk assessment reports. Has for many years been working on maintenance of electricity grid.

Ahead of the meeting I sent the participants (see Appendix I , II and III):

Molarius et al (2008): "Creating a climate change risk assessment procedure-Hydropower plant case, Finland

Accompanying slides dated 2008-04-27

Risk/Opportunity table including the Western Norway climate scenario in column 1 and 2

The meeting lasted for three hours. Tormunn Skarstad was unfortunately prevented from meeting, but gave complementary information on phone and email in the following week.

2.2.3 Risk/opportunity table

In the meeting our focus was on the Risk/Opportunity table. Based on the Western Norway climate scenario, SFE should answer:

<u>Column 3-5</u>: What are the impacts (positive/negative) on different part of the value chain

<u>Column 6</u>: What can be done to change (increase / reduce) the impacts on the company?

<u>Column 7</u>: Taking your answer on the latter question into account, what is the probability that the climate change may impact on SFE?

<u>Column 8</u>: If SFE is affected by the climate change, what is the consequence? Positive consequences are rated from +1 to +3 where +3 means a major positive impact. Negative consequences are rated from -1 to -3.

2.2.4 Seasonal plan/Value chain

I used the Seasonal plan to check if I had covered the likely climate changes throughout the year in the regional climate scenario above. The two illustrations, seasonal plan and value chain, was also presented in the meeting to stress that the Risk Assessment procedure should focus on climate impacts over time and across the organization.

2.3 Step 3: Risk/Opportunity identification

Here we focused on column 3-5 in the Risk/Opportunity table identifying positive and negative impacts of climate change on the different parts of the value chain:

Energy source (column 3)

Power plant (column 4)

Distribution network (column 5)

After we have finished, I referred to issues identified in the Finnish case study which had been ignored in SFE's answers. Some were included, others were not relevant.

Some risk aspects which are specific to the Norwegian study as compared with the Finnish study are:

Reservoir: more volatile weather conditions may increase risk of overflow

Glacier: If glaciers disappear/are reduced, the plant looses an extra reservoir.

Pelton turbine: Increased sea level may reduce the efficiency of Pelton turbines

2.4 Step 4: Risk/Opportunity estimation

2.4.1 Define risk reduction/control potential

Next we focused on column 6 in the Risk/opportunity table which I had interpreted as: What can be done to change (increase / reduce) the impacts on the company? Here SFE suggested investments or changes in behavior that it deemed profitable or otherwise feasible. For example, we discussed that it might not be political feasible to invest in increased water reservoir as the amount of precipitation increases. Or, if the weather becomes more volatile, it may be profitable to allow for increased overflow compared with the situation today.

One important issue was the use of Pelton turbines. To achieve maximum efficiency, there should be a sufficient vertical distance between the lowest parts of the turbine and the tail water. If the sea level increases with one meter or more, this might result in major rebuilding of the plant site. We did not reach a major conclusion on this issue, but it seems to me that this should be an important consideration when planning new hydro power plants.

2.4.2 Define probability of the consequences

Here we focused on column 7 in the Risk/opportunity table which according to my interpretation could be formulated as: Taking your answer on the latter question into account, what is the probability that the climate change may impact on the power company?

According to Molarius et al (2008) "The likelihood of the consequences should be ranked according to the power plants' own ranking system (..)." SFE's ranking system, which they use in their yearly risk assessment procedure, is as follows:

Probability:	Level:	Incidence frequency:
Very likely	5	1 time in a year or more often

Likely	4	1 time in 10 years or more often
Less likely	3	1 time in 50 years or more often
Not very likely	2	1 time in 100 years or more often
Not likely at all	1	More seldom than 1 time in 100 years

We tried to use this ranking. However, the focus on incidence didn't seem to suit our problem with climate changes.

At this stage the information was difficult to present in the table in a structured way. The reason was: For a given climate change in column 1, there may be several impacts on different parts of the value chain; and, each impact may have a separate probability of occurring.

2.4.3 Define consequence category

Finally we tried to assess the impact on the company in column 8; or in my words: If SFE is affected by the climate change, what is the consequence? Instead of using the suggested color codes[viii], I suggested that positive consequences are rated from +1 to +3 where +3 means a major positive impact. Negative consequences are rated from -1 to -3.

One example of a major positive impact (+3) is: increased production due to more rainfalls. Examples of major/medium negative impacts (-2/-3) are: extreme wind and extreme rainfalls will reduce access to reservoirs (need helicopters) and networks more difficult and damage installations.

2.5 Step 5: Risk/opportunity evaluation

2.6 Risk/opportunity fourfold table

The fourfold table was not completed, but this could be done using the information in column 6 to 8 in the Risk/opportunity table.

3 Evolution of the risk assessment procedure

The risk assessment procedure uses a regional climate scenario as a starting point. For each climate change aspect it details the impacts on different parts of the value chain. Then we investigate whether anything can be done to increase/reduce the impact, whether the impact is major or minor and finally the probability that it will occur.

It is my impression that the risk assessment procedure is an easy to use procedure which covers the main characteristics of the power sector and applies a measure of risk (probability x impact) which is widely used and understood by the power sector. However, the procedure can be improved and I will in the next two subsections suggest some amendments. First, the main tool, the risk/opportunity table, could be improved to avoid misinterpretation and to make the results easier to understand. Second, there is a need of a more thorough discussion of the concept of risk using the finance literature as a starting point.

3.1 The risk/opportunity table

Based on problems encountered using the risk/opportunity table, I recommend the following changes:

Use one scenario: Molarius et al (2008) refers to scenarios (in plural) in column 1 and 2 of the risk/opportunity table. But are there several scenarios? Shouldn't the information in these columns optimally refer to a common set of assumptions (for instance, one global emission scenario, one global climate model, one regional downscaling method, one time frame etc)?

To illustrate the big uncertainty with respect to how the global climate will change, it could perhaps make sense to present two alternative scenarios. However, this would mean that the company would have to fill in two risk/opportunity tables.

Use clear and concise questions: It was not always clear to me what information VTT was actually seeking in each column of the risk/opportunity table. The formulated question in subsection 2.3 above, was my attempt to create some clarity before the meeting with SFE. To be specific:

Column 6: Should we include only politically feasible and profitable activities? Or, should all possible activities be included resulting in a list of possible actions. The first alternative would be preferable.

Column 7: Again, several interpretations are possible. Is it the probability of the company being affected given that the climate change occurs (column 2) and given that it has undertaken the control activities (column 6)?

Change the codes in use: In column 7 and 8 the information is coded using numbers (levels) and colors. I would suggest that probability was expressed as a percentage (like in column 2) and impact was expressed as a value. In this case it would be possible to calculate expected impact[ix] as column 7 times column 8. Also, it would illustrate the importance of taking into consideration impacts that are unlikely but with huge consequences! The value should reflect net present value taking into consideration all future cash flows caused by the impact; or, the net increase/decrease in equity value. To avoid focus on details, the value ranges should be broad. To make these risk assessments comparable, I would suggest not to use company specific ranking levels.

Use one table for each part of the value chain. For each climate change (column 1), there may be many impacts relating to different parts of the value chain (column 3-5); each with different probability of occurring and consequence for the company. Thus, I think it might be more systematic to take one part of the value chain at the time. This also means that part of the brainstorming session could be conducted in separate groups specializing on the different parts of the value chain.

An example of a revised risk/opportunity table is given in Appendix VI.

3.2 The concept of risk

Finally, the concept of risk should be clearly defined. Risk is often defined in a pseudo-formal where the components of the definition is vague and the theoretical basis weak. In *engineering*, the definition is simply this[x]:

(1) Risk=(probability of event occurring) x (impact of event occurring)

This is the measure of risk applied by Molarius et al (2008).

In *finance* a more thorough and theoretically based concept of risk is developed in the Modern Portefolio theory and the Capital Asset Pricing Model. The main assumptions underpinning this model are:

Only risk which affects the investor is considered

Risk means that the value of an asset may be higher or lower than expected (can be measured by the standard deviation of returns on an asset).

Total risk = systematic risk + unsystematic risk. Unsystematic risk can be eliminated by investing in a diversified portfolio of assets. Systematic risk cannot.

Thus, we should only concentrate on systematic risk as measured by the investment j's β:

a)$\beta_j = \frac{cov(r_j,r_m)}{var(r_m)}$ where r_j refers to the return on investment j, r_m refers to the return on a diversified market portefolio, $cov(r_j, r_m)$ is the covariance between the return on investment j and market portefolio m and $var(r_m)$ is the variance of the return on market portefolio m.

b)The investment j's β says to what extent the value of the investment j will fluctuate with changes in the economy. A β above 1 means that the investment is pro-cyclical and thus risky – and vice versa.

According to the Capital Asset Pricing Model theory, the risk of an investment (for example in shares in SFE) is measured as the investment's contribution to the standard deviation of a well diversified portfolio. Thus, investments which tend to be strongly pro-cyclical are seen as risky, while investments which tends to be weakly related to the changes in the rest of the economy are seen as less risky. Since hydro companies may be positively affected by the climate change, while the economy as a whole may loose, the risk of investing in the power sector may be seen as small or even negative! On this basis, it can be argued that investments in emission-reducing technology should be discounted using a very low interest rate (reflecting their low systematic risk).

This way of measuring risk deviates from the one used by Molarius et al (2008) in important ways. Even if Molarius et al (2008) include both positive and negative impacts in their procedure, they focus on negative impacts when using the word risk (for example "risk/opportunity table"). Furthermore, Molarius et al (2008) do not treat deviations from the expected values as risk. Rather it is the revised expectations for the firm based on the most likely climate scenario which is seen as a risk as compared with earlier forecasts. Thus, one important risky issue is not addressed: What if the global climate change turns out to be much more severe or much less severe than foreseen in the chosen scenario?

Based on this discussion the risk assessment procedure could be improved in two alternative ways:

Use the procedure as it is, only be careful with how the concept risk is used. For example, rename the procedure to: Climate Impact Assessment Procedure. What you are measuring is not risk, rather the expected gains and losses from a most likely climate scenario. Likewise, rename risk/opportunity table to climate impact assessment table, or gains/losses table.

Alternatively, do as suggested above but include also a separate section on risk assessment. In this section the risk measure β is used, and through a thorough evaluation of each part of the value chain you seek to establish the β values for the energy source, production and distribution. The revised betas would then result in revised expected returns according to the CAPM:

$$r_j = r_f + \beta_j(r_m - r_f)$$

where r_f is the return on risk free asset.

i See Førsund, F.R. (2007): Hydropower Economics, International Series in Operations Research & Management Science, Springer.

ii For your information: I have been a board member in SFE since 2002.

iii See http://www.sfe.no/ for company information in Norwegian. The facts are based on the 2007 Annual Report. I have used the central bank's excange rate, average for 2007 equal to 8,0153 NOK/EUR.

iv SFE has also invested in broadband infrastructure and distribution and sale of LNG.

v See Wikipedia at http://en.wikipedia.org/wiki/Pelton_wheel.

vi RegClim (phase III: 2003-2006) is a coordinated research project with the overall aim to produce scenarios for regional climate change in Northern Europe, bordering sea areas and major parts of the Arctic, given a global climate change. Financed by The Research Council of Norway. See http://regclim.met.no/ for more information and references to literature.

vii The following REGCLIM publications are explicitly used:

Haugen, J. E. and T. Iversen (2008). "Responses in extremes of daily precipitation and wind from a downscaled multi-model ensemble of anthropogenic global climate change scenarios." Tellus, 60 A.

Roald, L. A., S. Beldring, T. Engen-Skauen and Eirik J. Førland (2008). "Flere vinterflommer." Klima 2/2008.

Røed, L. P. And J. B. Debernard (2008) . "Små endringer i bølger og stormflo." Klima 2/2008.

viii This was partly a pragmatic decision since I did not have easy access to a color printer.

ix If the probability in column 7 is conditional on climate change occurring the expected impact will be equal to column 2*column7*column 8.

xx See http://en.wikipedia.org/wiki/Risk

Appendix I: Molarius et al (2008). Paper

XXV Nordic Hydrological Conference – Northern Hydrology and its Global Role (NHC-2008)

Reykjavík, Iceland. 11-13 August, 2008.

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

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ABSTRACT

This paper examines the risk assessment procedure for a Nordic hydropower production process in the light of climate change. The case study research focused on hydropower plants in the Kemijoki region of northern Finland. This paper describes the development of the risk assessment framework and presents the tools developed during this process: the general risk assessment procedure, guidelines for gathering the background information, the seasonal plan, risk identification model and risk/opportunity table, and a method for risk estimation and evaluation. A generic model of the risk assessment procedure will initially be sought, for application within the Nordic countries. The study is a part of the Nordic Energy Research funded Climate and Energy Systems (CES) project.

Introduction

This paper examines the risk assessment procedure for Nordic hydropower production in the light of risks and opportunities raised in association with recent observations on climate change. The case study focuses on hydropower plants in the Kemijoki region of northern Finland. A generic model of the risk assessment procedure will initially be sought, for application within the Nordic countries. The study is a part of Nordic Energy Research funded Climate and Energy Systems (CES) project. A description of the information gathering and risk assessment procedure design based on functional modelling is included in this paper.

VTT has developed risk assessment methods since the 1970s. An overall knowledge-based methodology for hazard identification, so-called *functional modelling* (Suokas 1995), has been a favoured approach in VTT's method development for process industrial risk management. Functional modelling has also been applied in the field of food safety (Rasmussen *et al.* 2001). Other recent relevant work at VTT includes, for instance, environmental risk analysis methods for industrial accidental emissions (Wessberg *et al.* 2008). Climate change risk assessment methods are not only being developed in the CES project, but also in the Finnish national TOLERATE (2007) project, where the special focus is on flooding and severe droughts that are associated with climate change. In general, the area of study is developing and is not especially mature; and few references dealing specifically with risk assessment exist.

Risk assessment framework

The general risk assessment framework follows the industrial safety standard of risk analysis for technological systems (IEC 60300-3-9 2000). Other references, especially the climate change risk assessment guide made by the Australian Greenhouse Office (2006), and Kirkinen *et al.* (2005) describing the potential consequences of climate change in Finland, are also used to guide this work. In the context of possibilities and frequencies, we have adopted the same system that is used in the reports of Intergovernmental Panel on Climate Change (IPCC, 2007).

The draft version of the risk assessment procedure includes a general framework of the entire procedure (Figure 1), guidelines for gathering the background information, a seasonal plan, risk identification model, risk/opportunity table, and tools to estimate and evaluate the identified risks. These tools are shown in italics in Figure 1 (Risk assessment framework). The key aspect involves conducting the risk identification and assessment process within brainstorming sessions involving the hydropower and power plant specialists.

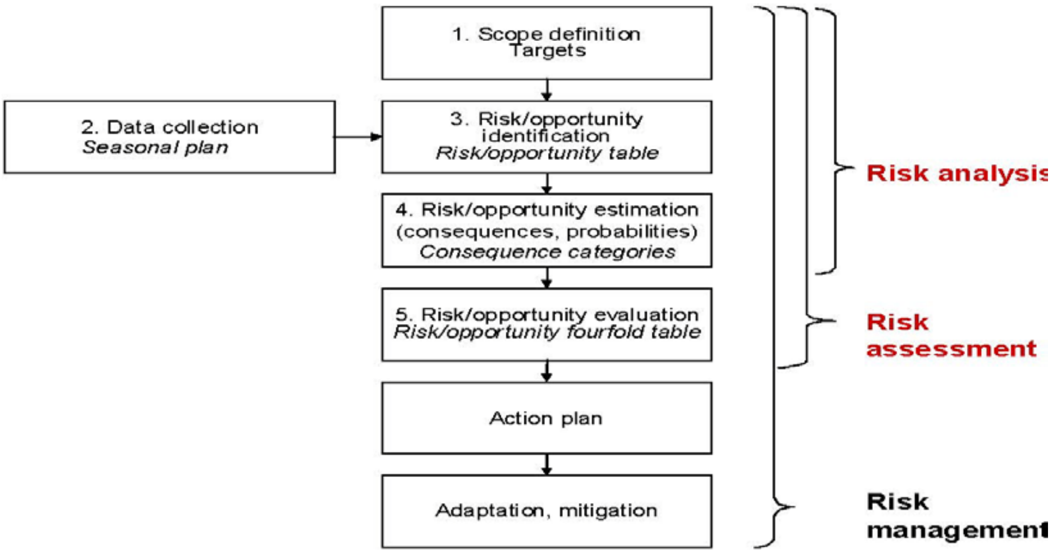

Figure 1. Risk assessment framework

CASE STUDY

The case study centres on the catchment area of Kemijoki – the largest river in Finland. The catchment area of this 550 km long river is about 51 000 km^2. Although the greatest flood flow was about 5000 m^3/s (in 1973), the average flow is about 500 m^3/s. The twenty hydropower plants along the river produce about 1000 MW – about one tenth of Finland's energy needs. According to spatial climate models and hydrological models in the Kemijoki area, future winters might be milder than those of today. However, increased precipitation might mean more water in the river during winter – or if the temperature is below zero, more snow cover and potentially more floods in the spring. At the same time, the summers might be drier.

VTT's researchers visited the power production company Kemijoki Ltd at the end of January 2008. After a long brainstorming session with the personnel, the risk/opportunity table was completed together with other parts of the draft risk assessment procedure. During the process the most critical risks of power plant were roughly identified and, together with the company representatives, the more significant were selected for further investigation. Useful knowledge was gained through the discussions even though a detailed risk assessment could not be done at this stage, (especially areas of the risk estimation and evaluation parts were unclear) because we lacked detailed data concerning the hydrological models of Kemijoki region.

Applying this approach roughly in the case study area identified some risks and opportunities that are common to all of northern Finland. Fortunately, due to increasing precipitation there is an opportunity for additional water power in the future. On the other hand, factors which counter this opportunity also exist. Foremost, due to the milder winters and increased water flow, the ice covers on the rivers will freeze more slowly. In such conditions, ice dams and frazil ice can form, which can lead to flooding, and in the worst case, result in a dam break or damage to turbine equipment. The other surprising 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 frozen rivers will not be able to handle the extra water flow. In such a situation the northern area will flood and that water will typically not reach the power plants.

RISK/OPPORTUNITY IDENTIFICATION

A simple functional model for hydropower production is shown in Figure 2 – including the energy source, power plant, and distribution network. These three elements help to structure the risk identification process into different phases for the risk assessment process.

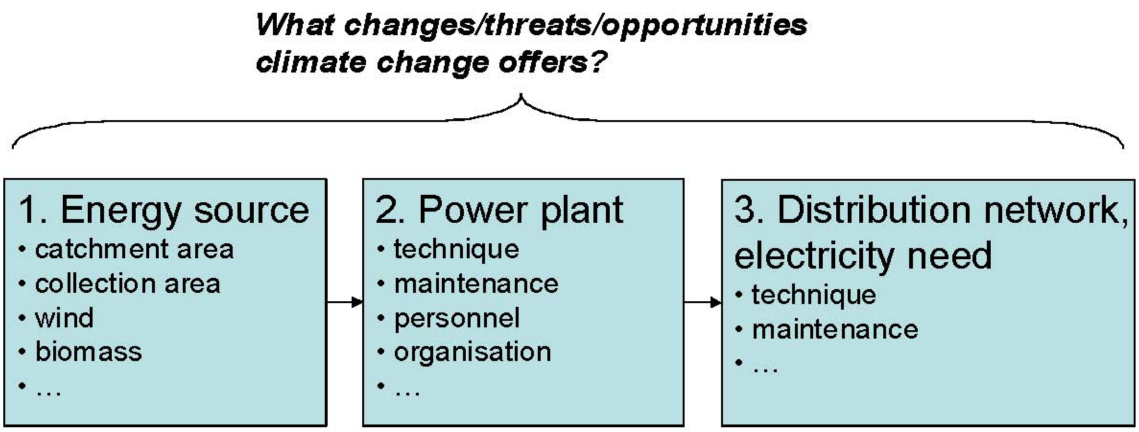

Figure 2. An example of input for the three dimensions of risk/ opportunity identification and assessment.

The main tool for identifying risks is the Risk/Opportunity table (Figure 3), which includes all the necessary information for guiding and documenting a risk analysis session. Some parts of the forms can already be completed prior to the brainstorming session.

To create the Risk/opportunity table, data about the basic information concerning the possible future climate (regional scenarios) and flood situation (hydrological models) in the study area was collected. Information about the changes in climate was obtained from the Finnish Meteorological Institute (FMI), and information about the hydrological changes in the Kemijoki region from the Finnish Environment Institute (FEI). In addition, the information about the power production was collected from Kemijoki Ltd

Scenarios and Phenomena	**Probability of the phenomena**	**Energy source,(e.g. catchment area, peat or biomass production area)**	**Power plant**	**Distribution network**	**Risk reduction / control / potential**	**Probability of the consequences to the energy production**	**Consequence category**
Phenomena according to regional scenario of future climate, hydrological model or wind model	*Probability according to IPCC 2007*	*The consequences of the phenomena to energy source and its usability*	*The consequences of the phenomena to the power plant*	*The consequences of the phenomena to the distribution network*	*The operations which will be done to protect against the phenomena and its consequences*	*Probability according to own ranking (Table 2)*	*Consequence category according to Figure 6*
Scenario 1. warmer climate							
Phenomena 1.1 - higher temperatures, especially during winter	Very likely, the probability that the next decade is warmer is 90%.	increasing water capacity	hot weather decreases the lifetime of transformers	increased electrical resistance ◊ energy losses	increase turbine capacity	very likely	3
1.2 - …							
2. increased precipitation							
2.1 - More rainfall: annual runoff will increase 0-8 %	very likely						
2.2 - …							

Figure 3. Sample risk/opportunity table.

Much general knowledge about the expected changes in Finnish weather conditions, especially in the northern parts of Finland, was identified in the discussions with FMI and FEI. However, not all of this knowledge was exclusively attributable to the Kemijoki region.

All the basic information was then used to develop the rough scenarios for the Risk/opportunity tables. The data collected in the case study was then assigned to the five scenarios: warming climate, increased precipitation, drought, shortened and warmer winter, and exceptional weather conditions. Each scenario was then assigned a probability, in accordance with the associated data. The data related to the frequency of the scenarios and phemonema was recorded, i.e. is the phenomena very likely, likely or unlikely. In this phase, the terminology and classification from IPCC can be useful (Table 1).

Table 1. The Frequency of scenarios and phenomena. (IPCC, 2007)

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

The final Risk/opportunity table was then created from the data by associating it with the three elements of hydropower production and the five scenarios (Figure 3). In this phase the most important questions are related to what kind of effects the realizations of the scenarios or phenomena have to the energy source, power plant or distribution systems. Also columns for the information concerning the consequences and risk reduction are included in the table. The likelihood of the consequences should be ranked according to power plants' own ranking systems (see an example in Table 2).

Table 2. An example how to rank the frequency of the harmful consequences.

Terminology	Explanation of the term
	If the phenomena happens there is/are:
Very likely	- only a one in a million chance to prevent the consequences
Likely	- some possibilities to prevent the consequences
Unlikely	- a lot of possibilities to prevent the consequences
Very unlikely	- no difficulties to prevent the consequences

To enhance the discussion within brainstorming sessions, an extra tool, Seasonal plan tool (Figure 4) was developed. With this tool, the year's activities can be collected for discussion. The tool aids the visualisation of the seasonal changes: the autumn changes to winter and again to spring smoothly. The Seasonal Plan provides the possibility to imagine what happens in the power plant, for example, if the winter comes later than normally. The idea is to depict the risk/opportunity relevant knowledge in order to easily link the main conditions, tasks, etc. during the year in order to guide the risk identification process and assessment.

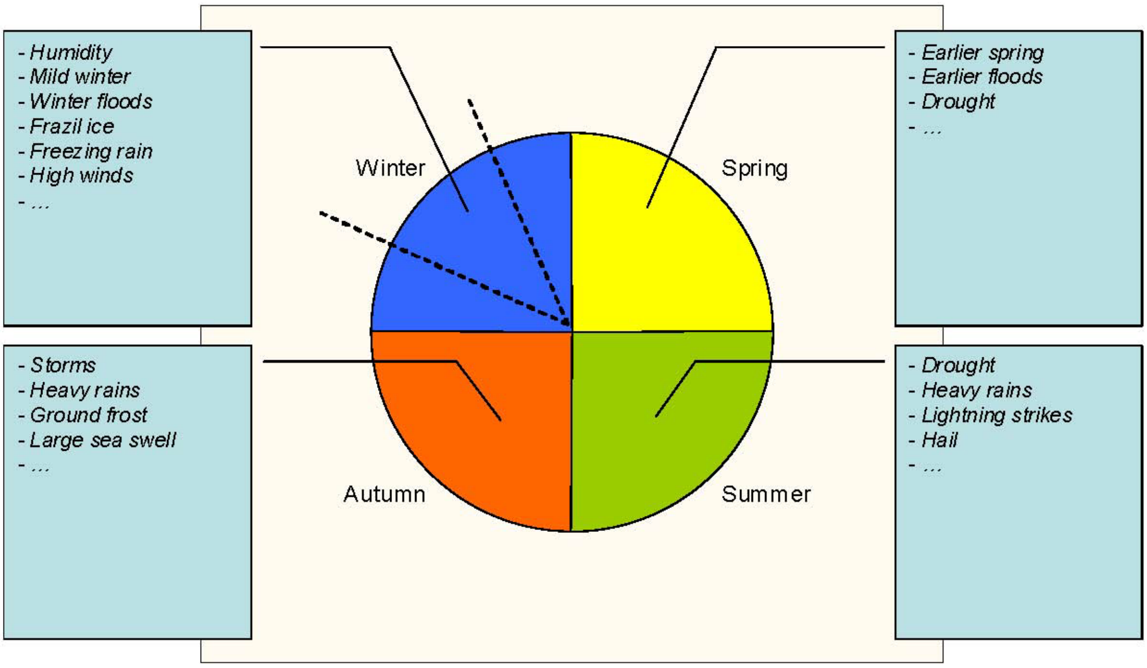

Figure 4. Example of the Seasonal plan.

Risk/opportunity identification was carried out in a brainstorming session, with the aid of the Risk/opportunity table and Seasonal plan, by discussing the scenarios and completing the risk/opportunity table.

RISK ESTIMATION AND EVALUATION

The risk/opportunity fourfold (R/O Fourfold) table (Figure 5) has been developed as a tool for guiding the risk estimation and risk evaluation during the risk analysis process. Further clarification is provided by the consequence categories (ConseMatrix, Figure 6) – two tools are designed to be used in conjunction with each other.

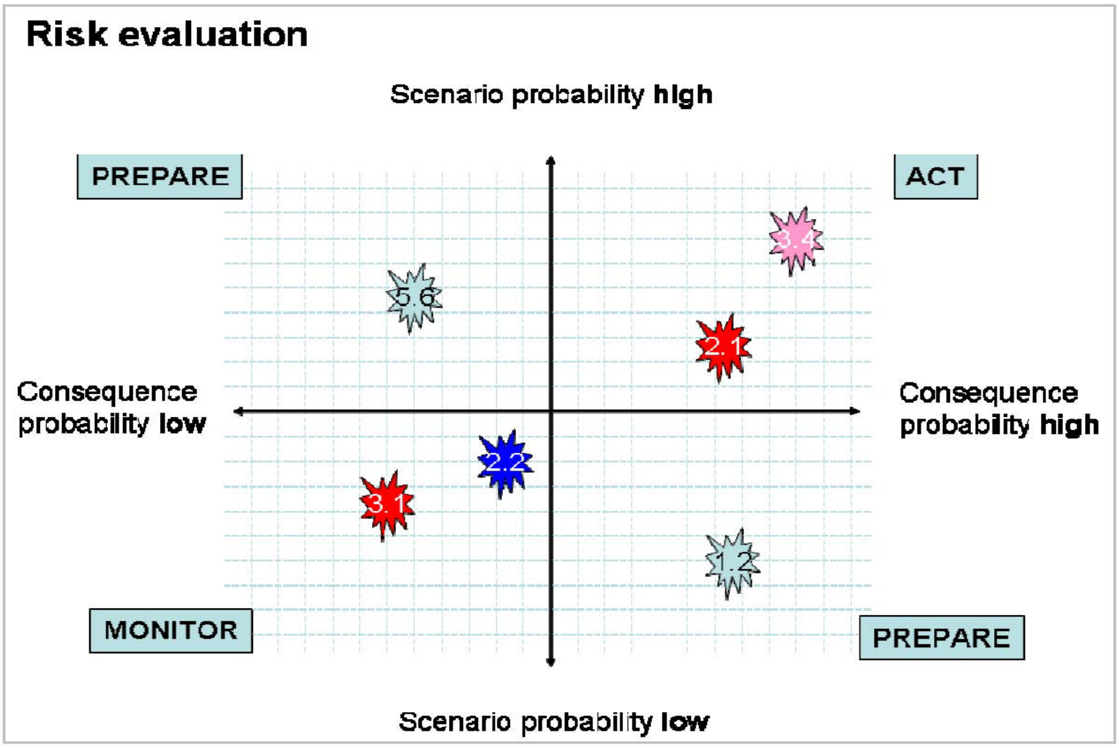

Figure 5. A sample "risk/opportunity fourfold table", mapping various scenario aspects according to the scenario and consequence probabilities. (R/O Fourfold)

	Consequence	Risk colour	Opportunity colour
1	Minor		
2	Moderate		
3	Major		

Figure 6. Consequence categories. (ConseMatrix)

All the identified risks and opportunities are mapped to the fourfold table (as a spot or star), and these then guide the company on how to deal with the topic: act, prepare or monitor. The colour of the designated marking originates from the ConseMatrix (Figure 6), while the identifying number stems from the Risk/Opportunity table (serial number of the identified risk/opportunity). ConseMatrix categories indicate the magnitude of the identified risk or opportunity in the fourfold table.

The fourfold table is used in place of the traditional risk matrix, and includes the associated probabilities and consequences. The tool is useful and provides a means to represent the scenarios relative to each other, even though the existing knowledge on these kinds of future risk assessments is very uncertain.

FUTURE EXPECTATIONS

The initial stage of the method development has recently been completed. The subsequent stage will involve refining it into a new, more specific risk analyses for further testing in the case plant. Prior to this, detailed hydrological models for the Kemijoki region will be prepared by SYKE. These models are expected to be ready in later in 2008. A return visit to Kemijoki Ltd will then be arranged and a detailed risk assessment for a selected hydropower plant will be performed together with the company's experts. It is anticipated that the method will also be tested with biomass power production in Finland.

Selected CES consortium partners will also apply the method, using the associated guide, with (especially hydro-, wind-, and bio-) energy providers in their respective countries so as to generate a collection of case studies. The associated feedback on the procedure will be discussed and appropriate amendments will then be made to the risk assessment framework. After all the experiences have been incorporated, the procedure will be subjected to a further round of testing in the project during 2009.

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Appendix II: Molarius et al (2008). Slides

CES Project – Risk Assessment Framework

CES Project – Risk Assessment Framework

CES (Riitta Molarius, Jaana Keränen, Jari Schabel, Nina Wessberg)

2008-04-27

The procedure follows the risk assessment framework as presented in Figure 1 (**STEP 1-5**).

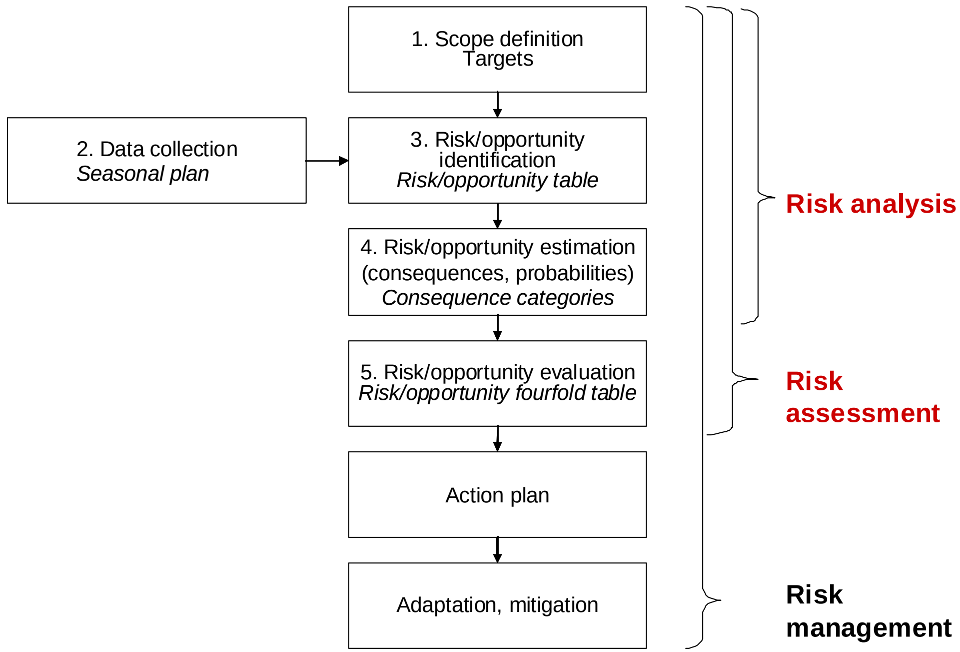


Figure 1. Risk assessment framework.

STEP 1

Select relevant test case(s) – seek out an ***energy production company****, and identify 1-2 associated power plants.*

Case description:

- organisation name, ________________________
- relevant details. ________________________ (e.g. *location, description of the environment & region, etc.*)

Scope definition:

- energy source, ________________________ (*e.g. hydro, wind, biomass, etc.*)
- power plant, ________________________ (*e.g. name, briefly describe the process, etc.*)
- distribution network ________________________ (*e.g. describe the energy market, and how & where the energy is used, etc.*)

Targets of the analysis:

- What are the main reasons for performing the analysis? (i.e. the main interest/focus/expectations of the company.)

  ☐ developing adaptation plan ☐ strategic decisions TIME PERIOD: __________ - __________

  ☐ mitigation ☐ political decisions

  ☐ upcoming investments ☐ other… ______________

- Why have these plants been selected ?
    - ___________________________

STEP 2

Data collection

- define the regional climate **scenarios**: (to Column 1 of Table 1).
    - What key changes are expected in the climate/weather/nature ? (list according to each scenario)
- Are relevant regional models available, for example, for:
    - hydrological models
    - evaporation models
    - flood models
    - temperature models
    - wind models
    - snow cover models
    - ice models
    - biomass growth models
    - diversity of species
    - forecasts of the need of electricity
    - …

  Can they be generated ? (*these will be very beneficial material for the brainstorming Risk Assessment sessions, and help produce a better overview*)

Create seasonal plan "clock" (see Figure 2)

- generate the seasonal issue overview by incorporating all relevant scenario and model information. Include all key expected climatic changes & associated effects.
- also note typical seasonal actions for the power plants, and the different periods of energy production.

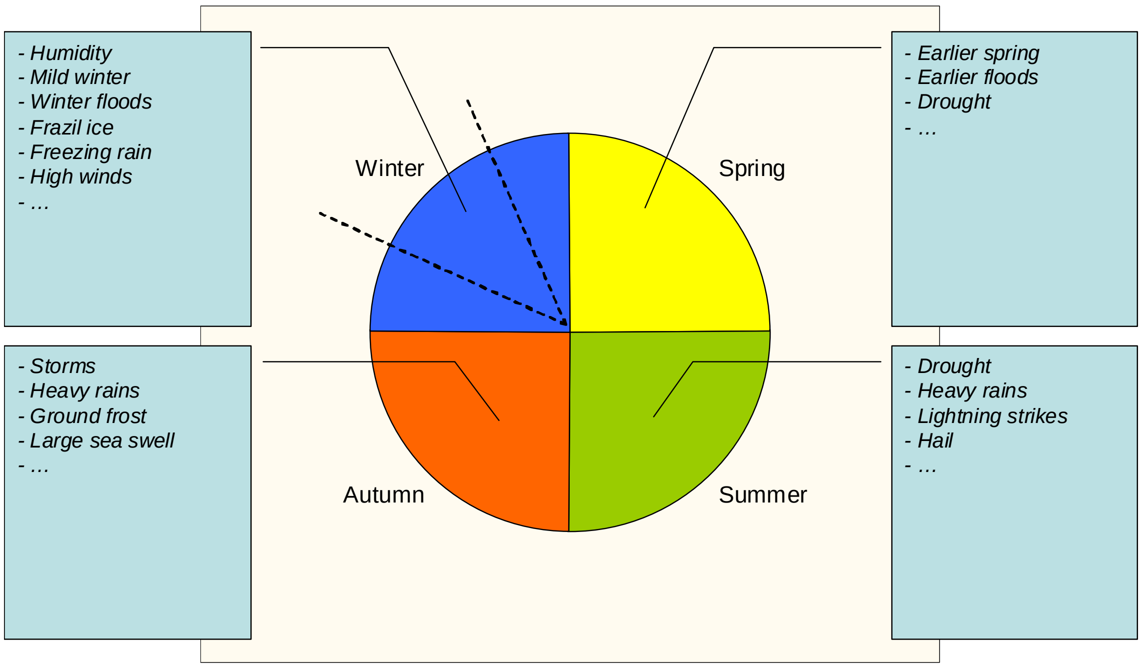
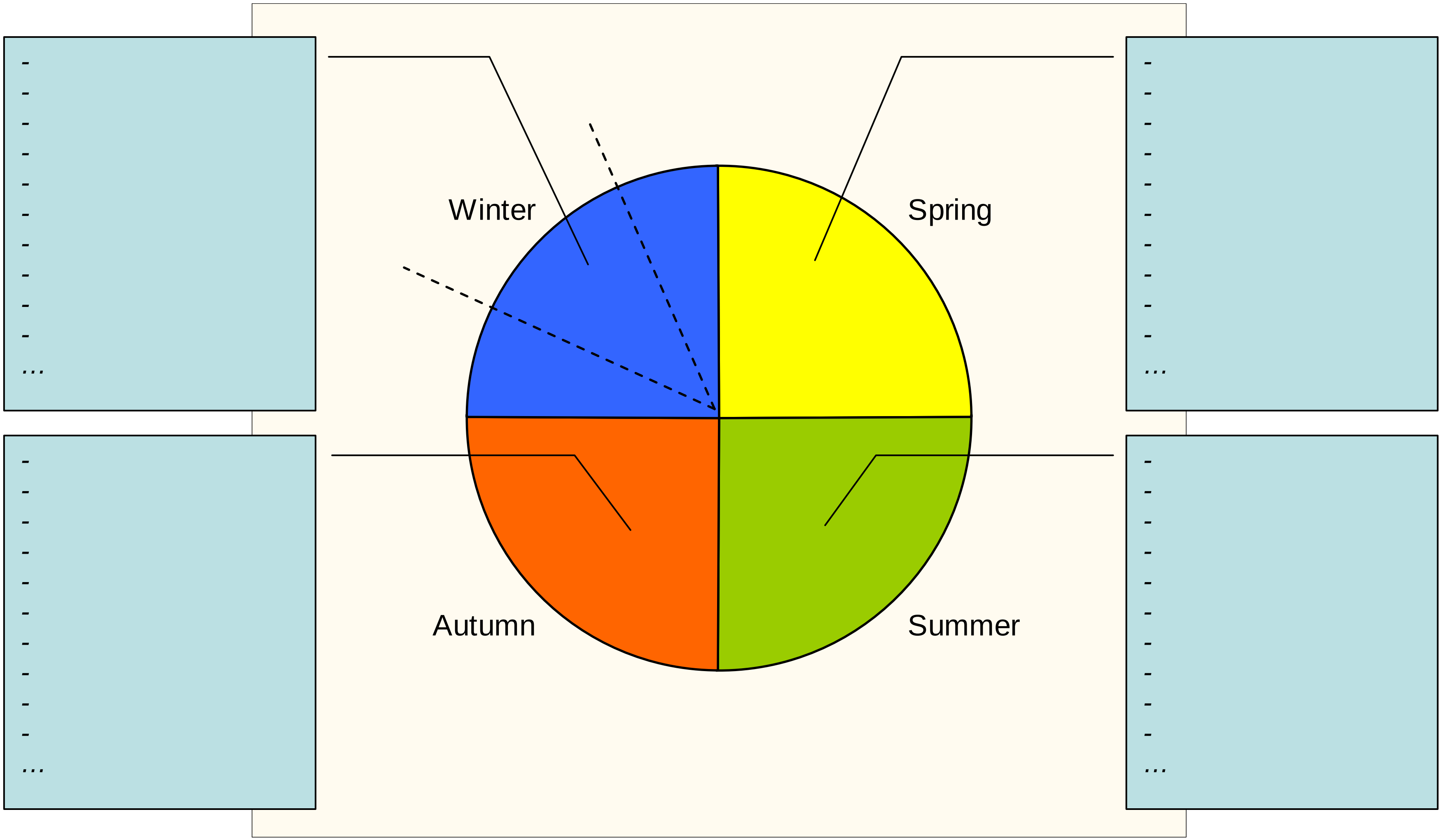


Figure 2. Example of the Seasonal plan.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Risk/opportunity identification

- Assemble a working group for the brainstorming sessions. A group (*of about 5*) should include the following:
    - group leader / secretary / plant personnel / modellers / …
- Generate a CTO guide for the regional climate change aspects (***CTO = changes/threats/opportunities***) (see Figure 3)

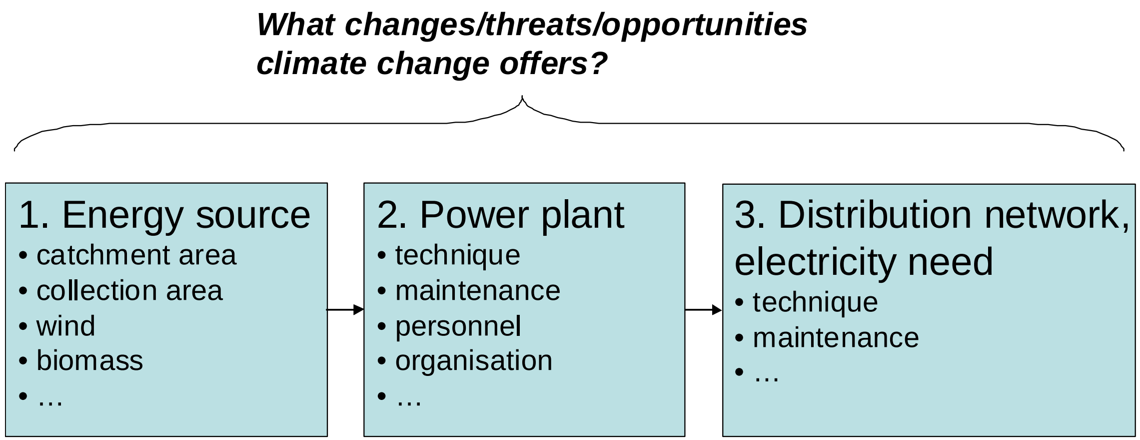

Figure 3. Sample input for the three dimensions of risk identification.

List the aspects to be considered…

1. Energy source

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• …

2. Power plant

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• …

3. Distribution network, electricity need

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• …

What changes/threats/opportunities does climate change offer?

- Identify risks from the point of view of: 1) energy source, 2) power plant, 3) energy distribution.
- Complete the risk/opportunity table in brainstorming sessions. (see Table 1)

Table 1. Sample risk/opportunity table.

Scenario	**Probability of the scenario**	**Energy source, e.g. catchment area**	**Power plant**	**Distribution network**	**Risk reduction / control / potential**	**Probability of the consequences to the energy production**	**Consequence category** **(* see Step 4)**
1. warmer climate							
1.1 - higher temperatures, especially during winter	very likely, the probability that the next decade is warmer is 90%.	increasing water capacity	hot weather decreases the lifetime of transformers	increased electrical resistance → energy losses	increase turbine capacity	very likely	3
1.2 - …							
2. increased precipitation							
2.1 - More rainfall: annual runoff will increase 0-8 %	very likely						
2.2 - …							

Scenario	Probability of the scenario	Energy source, e.g. catchment area	Power plant	Distribution network	Risk reduction / control / potential	Probability of the consequences to the energy production	Consequence category (* see Step 4)
1. ______________________________							
1.1 -							
1.2 -							
1.3 -							
…							
2. ______________________________							
2.1 -							
2.2 -							
2.3 -							
…							
3 ______________________________							
3.1 -							
3.2 -							
3.3 -							
…							

STEP 4

Risk/opportunity estimation

- Define consequence and probability value for each identified risk/opportunity. (see Table 2)

i.e. complete Column 8 of Table 1 using the numbers 1, 2, or 3.

Table 2. Consequence categories.

	Consequence	Risk colour	Opportunity colour
1	Minor		
2	Moderate		
3	Major		

See also IPCC 2007:

“A set of terms to describe uncertainties in current knowledge is common to all parts of the IPCC Fourth Assessment, based on the *Guidance Notes for Lead Authors of the IPCC Fourth Assessment Report on Addressing Uncertainties*, produced by the IPCC in July 2005.

Description of confidence

On the basis of a comprehensive reading of the literature and their expert judgement, authors have assigned a confidence level to the major statements in the Technical Summary on the basis of their assessment of current knowledge, as follows:

Terminology	*Degree of confidence in being correct*
Very high confidence	At least 9 out of 10 chance of being correct
High confidence	About 8 out of 10 chance
Medium confidence	About 5 out of 10 chance
Low confidence	About 2 out of 10 chance
Very low confidence	Less than a 1 out of 10 chance

Description of likelihood

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. In the Technical Summary, when authors evaluate the likelihood of certain outcomes, the associated meanings are:

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

Risk/opportunity evaluation

- Map the risks (identified in Table 1) according to the "values" from Columns 2 & 7 (also of Table 1), i.e. estimated risk/opportunity consequences & probabilities, into the fourfold table (see Figure 4).

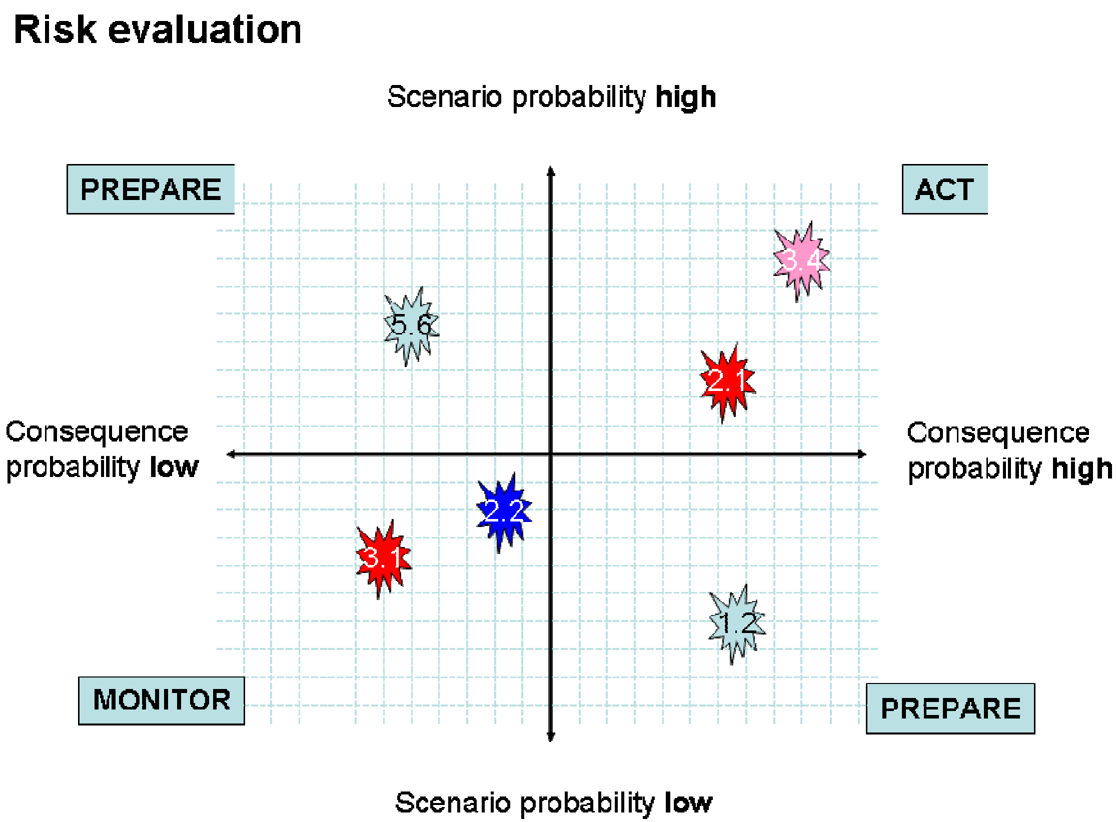
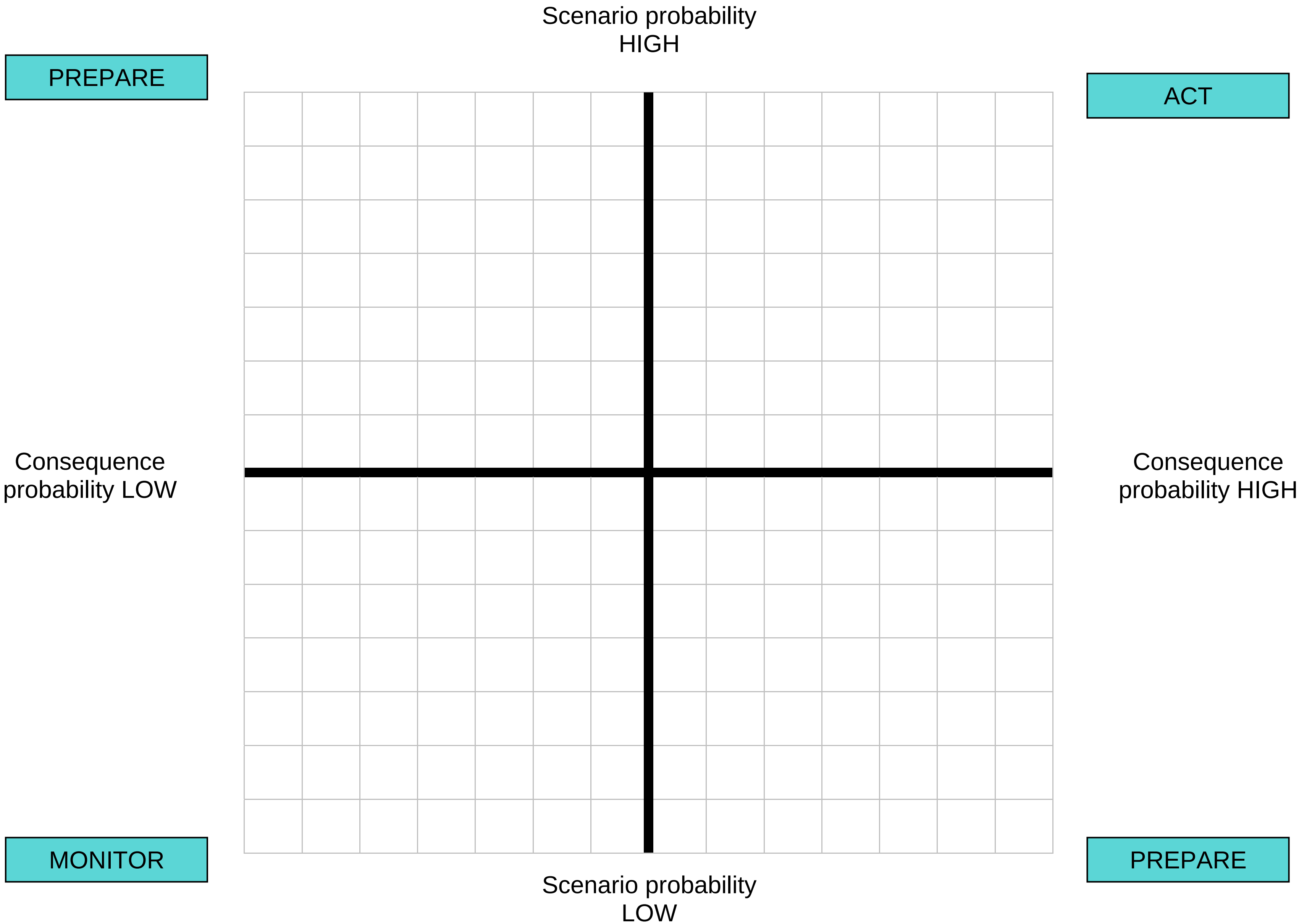


Figure 4. An sample risk/opportunity fourfold table, mapping various scenario aspects according to the scenario and consequence probabilities.

- Input the risk identifier into the following grid. (Colours can also be assigned according to Step 4.)



Appendix III: Risk/Opportunity table

***Climate change 1:* Temperature**	**Probability of change**	**Energy source**	**Power Plant**	**Distribution network**	**Risk reduction / control / potential**	**Probability of the consequences**	**Consequence category**
1.1 Higher temperatures: Norway (year 2100): + 2.5-3.5 oC[1] Bergen (year 2050)[2]: Annual: +1.7oC *[3] MAM: +1,7 oC * JJA: +1,3 oC * SON: +1.9 oC* DJF: +2.0 oC *	Very likely (>90%)	No impact.	No impact.	Heat decreases lifetime of transformers. Higher temperatures expand the distribution lines and may lead to a problem with sagging lines.	Invest in fans to cool down transformers. Reinforce the distribution network (more solid poles, more poles per km line, new networks).	1	Source and Plant: 0 Network: -1
***Climate change 2:* Precipitation**	**Probability of change**	**Energy source**	**Power Plant**	**Distribution network**	**Risk reduction / control / potential**	**Probability of the consequences**	**Consequence category**
2.1 More rainfalls: + 20% in western Norway (2100)[4] +10-25% in the southern Norway (2050)[5]	Very likely (>90%)	20% increase in water inflow to magazine. Changes in seasonal pattern –relatively	Increased production and changes in optimal seasonal production patterns.	Increased transportation and changes in seasonal transportation pattern.	Source/Plant: Increase magazine capacity (if politically feasible), increase production capacity and/or	Source and Plant: 5 Network: 4	Source and Plant: +3 Network: -1

[1] Source: http://regclim.met.no

[2] Haugen, J. E. and T. Iversen (2008)

[3] Numbers are the mean value of eight time-scaled responses. The star indicate that the mean response is statistical significant at 95% confidence level using Student t-test.

[4] Source: http://regclim.met.no.

[5] Haugen, J. E. and T. Iversen (2008).

Bergen (year 2050)[6]: Annual: +1.5 mm/d*[7] MAM: +0.9 mm/d * JJA: +0.7 mm/d * SON: +2.2 mm/d* DJF: +2.0 mm/d *		more rain in the autumn/winter. See comment 4.1 Glaciers reduction.		Increased humidity -> ice on net, corrosion and weak support for trees as well as electricity poles. Difficulties in maintaining the network because 1) wet ground can not carry heavy vehicles; and, 2) maintenance on networks in use can not be done when it rains (high voltage).	increase utilisation period. Networks: Invest in underground cables, reserve cables, parallel networks and/or reinforce existing networks.		
2.2 More days of extreme rainfalls: Western Norway (2100) +15 days with more than 20 mm/day[8] Western Norway (2050) +6-10 days with more than 20 mm/day[9]	Very likely (>90%)	<u>Åskåra I and Mel:</u> Reservoirs allows water to be retained in flood periods and released in drought periods. <u>Åskåra I;</u> The drainage basin is characterized by gravels and smooth	If the reservoir reaches its regulated upper filling limit, the water outflow may exceed the production capacity – and a proportion of the water outflow may not be used in power production.	The occurrences of land slides, snow slides etc. will increase. See comment 2.1 More rainfalls.	See comment 2.1 More rainfalls.	Source and Plant: 4 Network: 5	Source and Plant: -1 Network: -2

[6] Haugen, J. E. and T. Iversen (2008)

[7] Numbers are the mean value of eight time-scaled responses. The star indicate that the mean response is statistical significant at 95% confidence level using Student t-test.

[8] http://regclim.met.no

[9] Haugen, J. E. and T. Iversen (2008)

		rock slopes which quickly leads the water to the magazine. Thus, the reservoir filling will vary more directly with the amount of rain. See comment 4.1. Glacier reduction.					
***Climate change 3:* Wind**	**Probability of change**	**Energy source**	**Power Plant**	**Distribution network**	**Risk reduction / control / potential**	**Probability of the consequences**	**Consequence category**
3.1 Increased wind Bergen (year 2050)[10]: Annual: +20.1% *[11] MAM: +17.5% * JJA: +11.0% * SON: +23.7%* DJF: +24.4% *	Very likely (>90%)[12]	Access to water magazines and installation in the mountains will be reduced. These installations are often accessed by helicopter.	No impact.	The occurrence of landslide and snow slide may increase. Falling trees may harm the networks. The poles may fall down. Maintenance is made more difficult. Strong wind will make the problem	The regulator NVE may set requirements of a broader deforested trasé. Build cottages in the mountains so that personnel can stay several days for inspection etc. Invest in underground cables, reserve	5	-1

[10] Haugen, J. E. and T. Iversen (2008)

[11] Numbers are the mean value of eight time-scaled responses. The star indicate that the mean response is statistical significant at 95% confidence level using Student t-test. 10 m wind speed.

[12] Haugen, J. E. and T. Iversen (2008) find that wind increase in Bergen will be statistical significant at 95% level.

				of ice on networks more severe.	cables, parallel networks and/or reinforce existing networks. Choose new trasés.		
3.2 Extreme wind Norway (2100): + 4 days with more than 15 m/s wind[13] In the autumn the wind will increase most along the cost and in Langfjella.		See comment 3.1 Increased winds.	No impact.	See comment 3.1 Increased wind.	See comment 3.1 Increased wind.	5	-2/ -3
Climate change 4: Snow and glaciers	**Probability of change**	**Energy source**	**Power Plant**	**Distribution network**	**Risk reduction / control / potential**	**Probability of the consequences**	**Consequence category**
4.1: Glaciers reduction: In 100 years 98% of the glaciers in Norway may have disappeared if summer temperatures increase with 2.3 oC and precipitation in winter increases with 16% (Regclim's forecasts).[14]	Very likely (>90%)	The glaciers serve as an extra reservoir, and a reduction of the glaciers may strengthen the effect on reservoirs of extreme rainfalls. A reduction of glaciers will make the inflow during spring thaw start earlier and increase the inflow in the	Changes in the reservoir filling throughout the year, imply changes in optimal production pattern.	Changes in the production pattern imply changes in the transportation pattern.	Invest in increased magazine capacity (if political feasible and profitable). Politically it may be desirable to dampen the effect of flooding.	5	0

[13] Source: http://regclim.met.no. Klima 2-2008.

[14] http://regclim.met.no.

		autumn. It is difficult to tell whether the water inflow pattern will become more volatile when the glaciers are reduced.					
4.2: Less snow: Norway (2100): The snow frontier may increase with 500 meter (if +3oC), and the season for snow be shorter.[15]	Very likely (>90%)	Water inflow pattern will change.	As a consequence optimal production pattern will change	Wet snow combined with wind may increase the need for maintenance and investments.	If economically profitable	2	0
Climate change 5: Sea and rivers	**Probability of change**	**Energy source**	**Power Plant**	**Distribution network**	**Risk reduction / control / potential**	**Probability of the consequences**	**Consequence category**
5.1 Sea level increase Global (2100): + 19-58 cm. Perhaps more. Norway (2100): +29-68 cm. More in Western Norway[16].		No impact	Åskåra I: If sea level increases, the vertical distance between the water outflow under the turbine and the sea level may become so small, that it becomes difficult to get rid of the outflow water.	No impact on transmission or regional network. But, the distribution network to the end user may be affected since most villages/towns in the county are situated along the fiord/sea.	Invest in pumps to bring the outflow water to the sea. Reinforce the distribution network. .	Sea level increase will happen slowly. It is possible to gradually adjust.	-1
5.2 Small changes in storm surge and waves:	The referred study found no	No impact.	Small impact.	Small impact.	No action.	**1**	**0 / -1**

[15] Roald, L. A., S. Beldring, T. Engen-Skauen and Eirik J. Førland (2008). ”Flere vinterflommer.” Klima 2/2008. Downloadable at http://regclim.met.no.

[16]Sources: IPCC and Bjerknes senteret. See also: http://regclim.met.no.

Norway: the occurrence of extreme waves and storm surge may increase. There is a great uncertainty.[17]	significant (95% confidence) results for the Norwegian coastline.		See comment 5.1 Sea level increase.	See comment 5.1 Sea level increase.	See comment 5.1 Sea level increase.		
5.3 More winter flooding: Mild winters and increased precipitation gives increased flow of water in winters. More dangerous flooding in the autumn and winter especially in the western and northern part of Norway.[18]		See comment 2.2 More days of extreme rainfalls.	See comment 2.2 More days of extreme rainfalls.	Flooding may damage underground cables, link boxes, basement transformers and weaken the support for trees and electricity poles.	The concession rights require the energy company to take actions to prevent damages caused by flooding and to take part of the cost of cleaning up after flooding.	**5**	**-1**
5.4 Earlier and smaller springtime flooding Springtime flooding caused by snow melting will come earlier and have a smaller volume.[19]		Small impact. See comment 2.1 More rainfalls.	Small impact. See comment 2.1 More rainfalls.	Small impact. See comment 2.1 More rainfalls.	Small impact. See comment 2.1 More rainfalls.	**1**	**0**
5.5 Reduced water		Small impact.	Small impact.	Small impact.	Small impact.	**1**	**0**

[17] Røed, L. P. And J. B. Debernard (2008). This paper is based upon the global climate scenarios produced in IPCC, 2007: The Physical Science Basis. Contribution of Working group I and the downscaled regional climate scenarios in Haugen, J. E. and T. Iversen (2008).

[18] Roald, L. A., S. Beldring, T. Engen-Skauen and Eirik J. Førland (2008).

[19] Roald, L. A., S. Beldring, T. Engen-Skauen and Eirik J. Førland (2008).

flows in summer Caused by less precipitation and increased evaporation [20]		See comment 2.1 More rainfalls.	See comment 2.1 More rainfalls.	See comment 2.1 More rainfalls.	See comment 2.1 More rainfalls.		

References

IPCC, 2007: The Physical Science Basis. Contribution of Working group I

Haugen, J. E. and T. Iversen (2008). ”Responses in extremes of daily precipitation and wind from a downscaled multi-model ensemble of anthropogenic global climate change scenarios.” *Tellus*, 60 A.

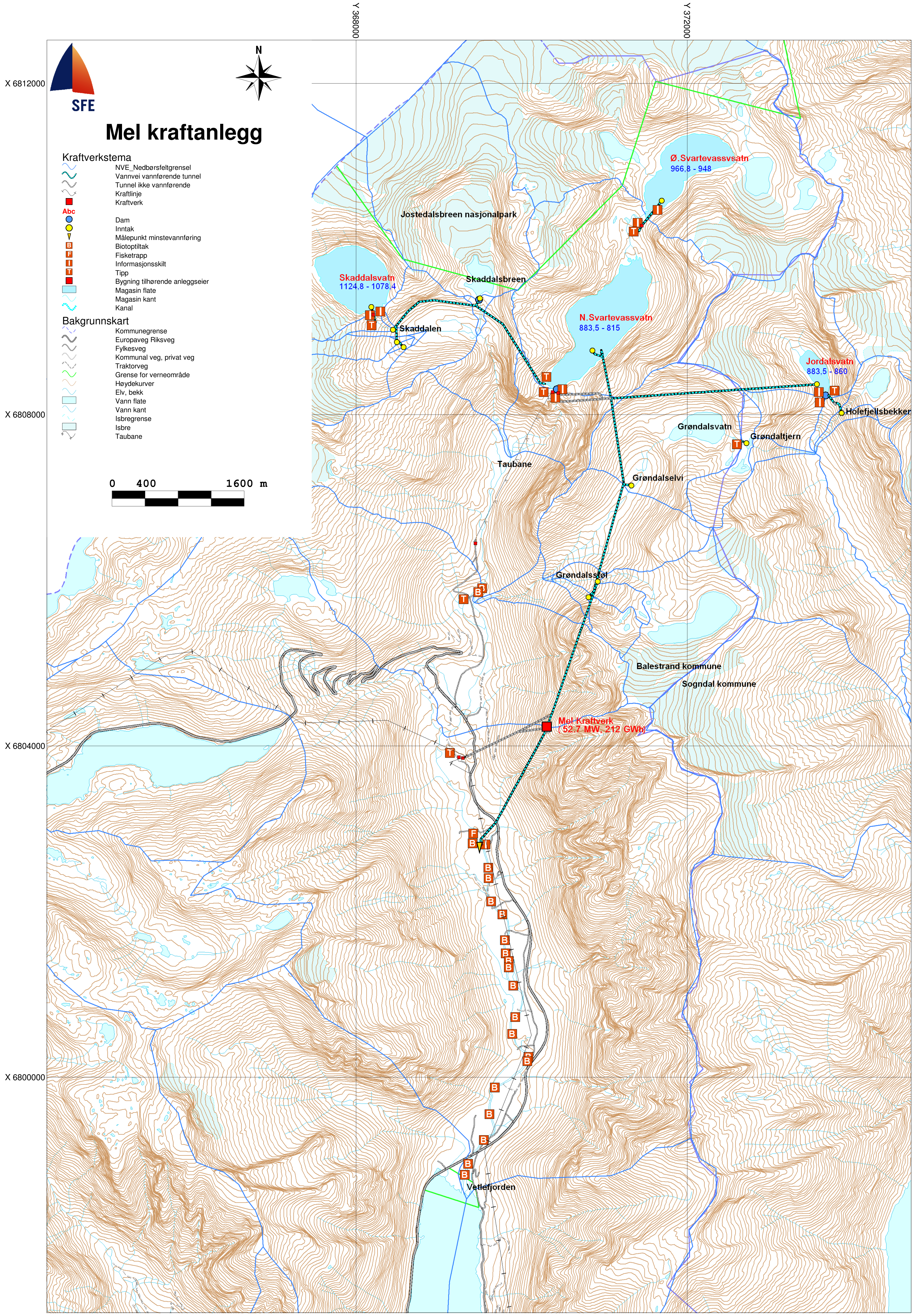
Roald, L. A., S. Beldring, T. Engen-Skauen and Eirik J. Førland (2008). ”Flere vinterflommer.” Klima 2/2008. Downloadable at http://regclim.met.no.

Røed, L. P. And J. B. Debernard (2008) . “Små endringer i bølger og stormflo.” Klima 2/2008, downloadable at http://regclim.met.no .

http://regclim.met.no. RegClim (phase III: 2003-2006) is a coordinated research project with the overall aim to produce scenarios for regional climate change in Northern Europe, bordering sea areas and major parts of the Arctic, given a global climate change. Financed by The Research Council of Norway

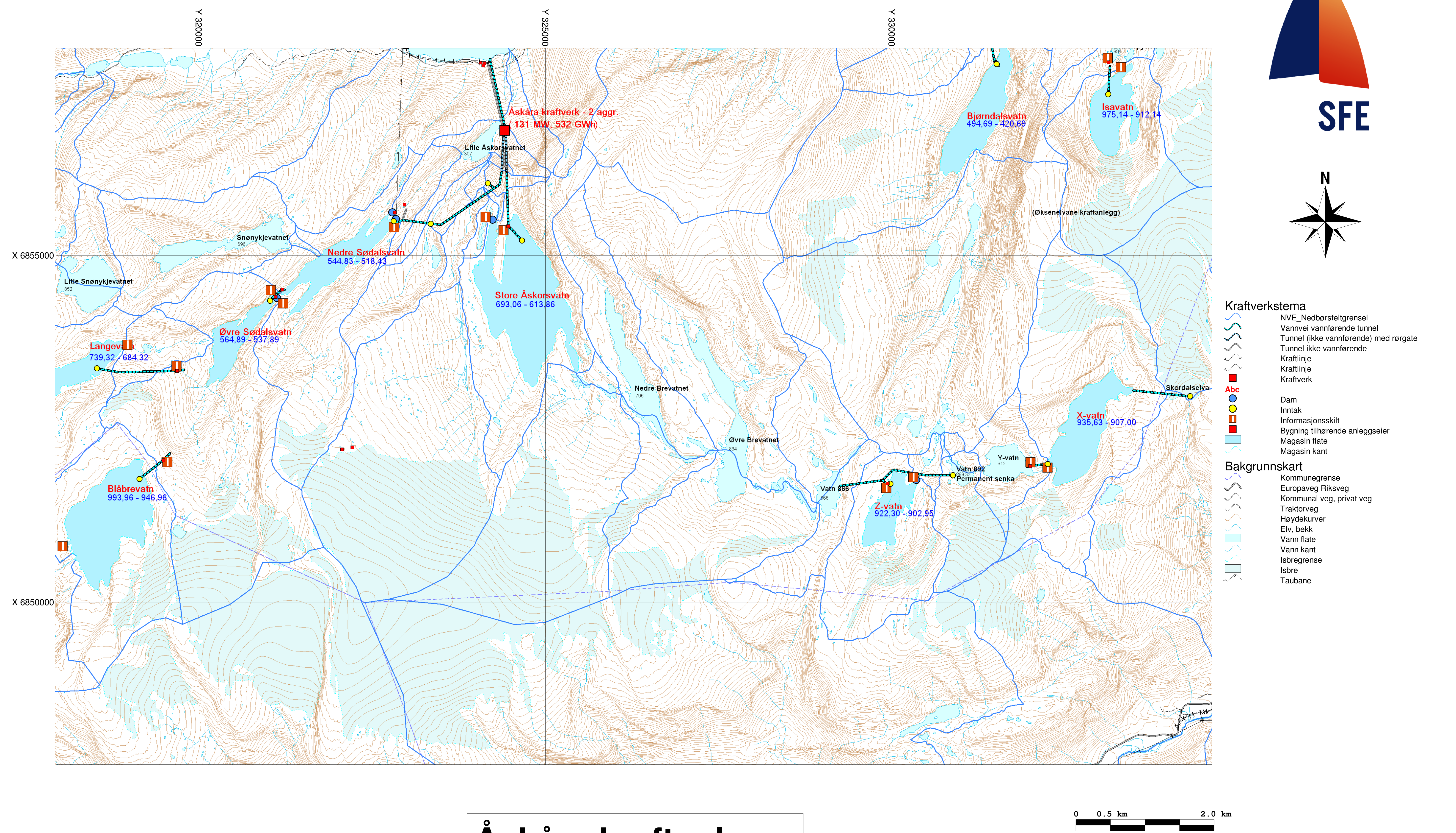
[20] Roald, L. A., S. Beldring, T. Engen-Skauen and Eirik J. Førland (2008).

Appendix IV: Mel kraftanlegg



Mel kraftanlegg
SFE
N
Kraftverkstema
NVE_Nedbørsfeltgrensel
Vannvei vannførende tunnel
Tunnel ikke vannførende
Kraftlinje
Kraftverk
Abc
Dam
Inntak
Målepunkt minstevannføring
Biotoptiltak
Fisketrapp
Informasjonsskilt
Tipp
Bygning tilhørende anleggseier
Magasin flate
Magasin kant
Kanal
Bakgrunnskart
Kommunegrense
Europaveg Riksveg
Fylkesveg
Kommunal veg, privat veg
Traktorveg
Grense for verneområde
Høydekurver
Elv, bekk
Vann flate
Vann kant
Isbregrense
Isbre
Taubane
0 400 1600 m
Y 368000
Y 372000
X 6812000
X 6808000
X 6804000
X 6800000
Ø.Svartevassvatn
966.8 - 948
Jostedalsbreen nasjonalpark
Skaddalsvatn
1124.8 - 1078.4
Skaddalsbreen
Skaddalen
N.Svartevassvatn
883.5 - 815
Jordalsvatn
883.5 - 860
Holefjellsbekken
Grøndalsvatn
Grøndaltjern
Taubane
Grøndalselvi
Grøndalsstøl
Balestrand kommune
Sogndal kommune
Mel Kraftverk
(52.7 MW, 212 GWh)
Vetlefjorden

Appendix V: Åskåra kraftanlegg



Åskåra kraftanlegg

Appendix VI: Risk/Opportunity table – revised

One table for each part of the value chain.

(1) Climate change (describe)	(2) Impact (describe)	(3) Control measures (describe)	(4) Prob. of climate change (1) (%)	(5) Prob. of impact (2) given (3) (%)	(6) Impact (MEUR)	(7)=(4)x(5)x(6) Expected impact (MEUR)
2.1 More rainfalls: + 20% in western Norway (2100)[22]	Increased production potential with 20%.	Increase magazine capacity (if politically feasible), increase production capacity and/or increase utilisation period. See comment on Networks.	90%	100%	10 MEUR	9 MEUR

References

IPCC, 2007: The Physical Science Basis. Contribution of Working group I

Haugen, J. E. and T. Iversen (2008). ”Responses in extremes of daily precipitation and wind from a downscaled multi-model ensemble of anthropogenic global climate change scenarios.” *Tellus*, 60 A.

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[22] Source: http://regclim.met.no.

Appendix VII: Value estimation

How to measure the impact of climate change

By Kristin Linnerud, November 3, 2008.

The procedure described below is based upon the most famous result in finance theory: The Capital Asset Pricing Model (CAPM). The model presents a theoretical based link between risk, the required rate of return and the value of an investment (or firm). For more information on CAPM see for example: http://en.wikipedia.org/wiki/Capital_asset_pricing_model

The method can be described in the following steps:

Step I: Calculate expected changes in future cash flows

Start with the most likely climate scenario for the actual geographical area. For each climate change aspect, calculate the expected change in annual cash flows for the different part of the value chain (energy source, distribution network and production). More formally,

(1) $$E(CF_t) = \sum_{s=1}^{S} Prob(s) * Impact\ (s)$$

where s denotes the different states of the world (say, high impact, medium impact and low impact).

For simplicity, investments should also be included as annual cashflows.Thus, an investment of 100 MEUR with a projected lifetime of 20 years should be included as -5MEUR.

Step II: Determine the risk measure β

Next, you make up your mind about risk. Financial risk is defined as the extent to which a company's rate of return will fluctuate with the economy as a whole. Financial risk is measured by β. If you consider all companies on the stock exchange the average β is 1 by definition. A company which is not influenced at all by changes in the overall economy will have a β of 0. And, a company which is negatively influenced by changes in the overall economy will have a negative β. If you take a look at the stock exchange pages in your newspaper you will see β estimates for most companies which are registered on your country's stock exchange.

A power company will typically have a β below 1 (say, β=0.75). If you think , as I do, that climate change makes power companies less sensitive to changes in the economy, then this measure should be revised downwards(say, β=0,40). In any case, the question of revising β in light of the climate change should be addressed!

The mathematical expression for company j's beta is:

(2) $$\beta_j = \frac{cov(E(r_m), r_j)}{var(r_m)}$$

where r_j refers to the required rate of return of power company j, r_m refers to the return on a diversified market portefolio (say, the Oslo stock market index) , $cov(r_j, r_m)$ is the covariance between the rate of return of company j and market portfolio m and $var(r_m)$ is the variance of the return on market portefolio m.

The determination of β can be estimated using linear regression on historical data or by finding β measures on similar companies in the newspapers. But since investor awareness of climate change may be quite recent this could result in a measure which does not reflect today's knowledge. Thus, I think you should anyway rely on your own judgments and revise these measures.

Step III: Calculate the required rate of return using CAPM

CAPM gives the rate of the return the investor will require on an investment with risk equal to β.

(3) $$k = r_f + \beta\left(E(r_m) - r_f\right)$$

Here r_f is the real (adjusted for inflation) risk free rate of return (on for instance state bonds), and $E(r_m) - r_f$ is the expected risk premium. Both should be measured based on historical data over a long period and over several countries. I suggest you use:

(3') $$k = 2\% + \beta * 5\%$$

Thus, the expected rate of return on the stock market is 7% and the required rate of return on a power company with β=0.5 for instance is 4.5%.

IV: Determine the Net Present Value (NPV)

Finally, you estimate the Net Present Value of the changes in expected cash flow due to climate change:

(4) $$NPV = \sum_{t=0}^{T} \frac{E(CF_t)}{(1+k)^t}$$

in which k is the required rate of return from step III. If we assume that annual cash flows are constant (in real terms) and that the time horizon is infinite, the net present value formula simplifies to:

(4') $$NPV = \frac{E(CF)}{k}$$

Thus, if I use k=4,5% and I expect the net change in expected cash flows due to climate change is 20 MEUR the NPV of these impacts is 20 MEUR/0,045=444 MEUR.

Note that according to finance theory we let the cash flow represent the most likely impact of future climate change, while the required rate of return captures that the actual cash flows may be both lower and higher than expected.

Some comments

Notice that I have just calculated the net present value of expected <u>changes</u> in future cash flows due to climate change. If climate considerations make the power company revise its β and thus its required rate of return, k, this will influence the value of the company's shares and it will also influence the value of a new investment.

In the spread sheet I have incorporated the control measures taken by the power company to increase/decrease the impact of climate change. An alternative would be to assume that the company took no actions; that is, to assume business as usual. This could then serve as a benchmark which the company could use to evaluate whether or not costly control measures should be taken.