Climate and Utility Operations

Towards informed decision-making for utility operations in the context of weather and climate changes

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1 Introduction

1.1 Motivation

In this paper, we present the initial results of a recently started effort to develop intelligent decision-making assistance, based on artificial intelligence and detailed weather modeling, for utility operations. This initial effort focused on studying the Icelandic utility operations, with the primary objective of understanding whether and how the advanced computer technology in question could be utilized.

Energy production in Iceland is primarily from renewable sources. In 2004, the primary energy supply was made up of 54% geothermal, 17% hydropower and 29% fossil fuels . Currently, approximately 85-90% of the production of electricity is from hydropower, although the market share of geothermal power has increased considerably in recent years. Most of the heating energy used in Iceland comes from geothermal sources and in some cases the same geothermal fields provide energy for both electricity production and heating. These facts make the Icelandic energy system quite dependent on weather in the short term and climate changes in the long term.

Climate changes are clearly taking place at this time. Rainfall patterns, glacial melting, temperature and many other factors are changing and the effects can already be seen on utility operations. Consequently it is very important to take long-term climate changes into account when planning and operating utilities in Iceland. Furthermore, the changing weather patterns may change what options are best in short-term operations. Finally, weather can play an important role in very short-term operations and more exact forecasts can permit more effective operations.

Utility infrastructure, such as hydroelectric dams and geothermal powerplants, are tremendously large investments and must therefore be utilized as effectively as possible. A small increase in efficiency can provide additional energy at a much lower cost than building new infrastructure. In addition, decisions about building new infrastructure can be made more intelligently if more elements of climate variations and potential efficiency enhancements can be taken into account.

Artificial intelligence (AI) has already made inroads into the operation of complex systems. In recent years, NASA has developed and incorporated AI technology into its operations, both to increase efficiency and to reduce risk. Most recently, an

AI-based application was certified for assisting mission controllers with operating the Solar Panel Array on the International Space Station (ISS). In addition to increasing efficiency and reducing risk, the AI technology is an excellent complement to the human intelligence.

Climate modeling and weather forecasting has also seen great progress in recent years. Increased computational power and better understanding have facilitated both better weather forecasts and better long-term climate modeling.

1.2 Objectives

The primary objective of the initial project was to gather the information required to define a framework for a system that can evaluate and predict impact of different climate change scenarios on energy production and distribution. Without this preperatory work, it would have been difficult to define a suitable approach to evaluating climate change impacts.

The objective for this initial work consisted of four major parts:

1. Develop a clear definition of energy companies' operations, as it concerns factors that are impacted by climate change and weather. This concerns infrastructure, operations, production and distribution. In this phase, we will work with energy companies and distributors to identify operations elements. The main results will be identification of variables, relations and constraints that define the elments of these operations.

2. Gather the required information about those models that already exist and can be utilized for the development of a capable system for evaluating impact of climate change on energy company operations. Specifically, this concerns:

   - Models that determine local weather pattern, given climate elements
   - Models that determine impact of local weather on production
   - Models that determine impact of local weather and weather changes on other factors such as enexpected events, demand fluctuations, distribution issues, etc.
   - Models that determine the impact of agents in the production/consumption system, in response to events, weather changes, distribution problems, demand fluctuations, etc.

3. Collect information about climate change scenarios, which vary greatly in timescales and severity, so as to develop a picture of the range of scenarios that must be handled.

4. Define a framework for the predicting system, with reference to models, variables, decisions and methods for answering questions about climate change impact, given different scenarios and assumptions.

Based on this work, the team will undertake a larger project for defining and implementing the decision-framework, in collaboration with the Icelandic energy industry.

1.3 Outline of Paper

Due to the nature of this pilot study, a significant part of this paper is devoted to describing our findings of the models available at the three major utility companies in Iceland and the support companies that handle models for them. This analysis was focused on the models and how environmental factors affect the diverse input variables the models use, ultimately defining a framework that can automatically reach the right decision given a set of factors to work with. The work on understanding the environment has been based on the long-term plans for developing intelligent decision-making technology that takes into account climate changes, weather forecast and many other factors. We therefore also outline the climate modeling and weather forecasting technology, and outline a framework for intelligent decision-making.

In the next chapter we outline the power production environment, the stakeholders and the variables the environment adheres to. In chapters 3 through 11 we describe briefly the players on the Icelandic energy market and identify the variables that affect the production and management, along with their supporting companies and their models. In chapter 12 the models are listed and in chapter 13, their variables are identified along with relations and constraints. In chapter 14, climate change scenarios are discussed. In chapter 15 the definition of the suggested framework is addressed and laid out. In chapter 16 the results are presented.

2 Overview

The Icelandic energy market has 3 major producers of energy. Two of them (Orkuveita Reykjavíkur and Hitaveita Suðurnesja) produce both warm water and electricity, while Landsvirkjun produces only electricity. A variety of variables are factors for running each utility. Some of the parameters are common between the three, and others are unique to one producer. In the following chapters, the known variables and models for each producer are clarified, as well as their relationship with engineering firms specialising in environmental and/or flow modelling.

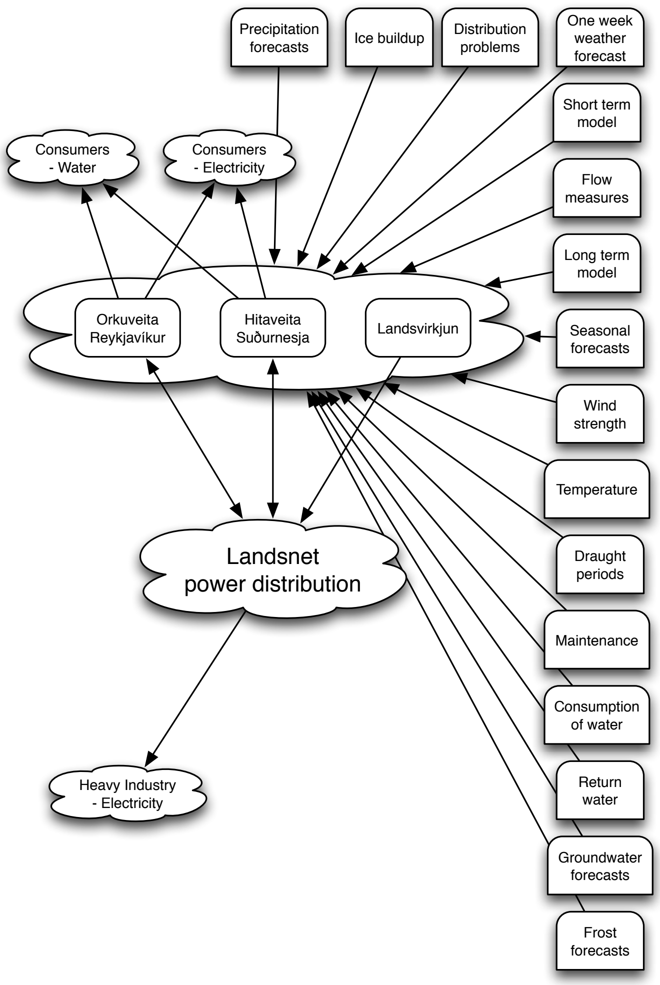

Figure 1: Overview of the national production and distribution of energy

3 Landsvirkjun

3.1 About Landsvirkjun

Landsvirkjun (LV) is a wholesale producer of energy. LV produces a pre-set amount of energy, including an amount of regulating energy (umframorka) to meet fluctuations in the grid and usage. This regulating energy is sold to customers who can handle immediate cut-off like smelters, kettles[1] and heated swimming pools, and is around 400GWH/year. Cut-offs of regulating energy have been infrequent.
One of LV's obligations is to guarantee power to their aluminium smelter customers, and is contractually bound to keep blackouts shorter than 4 hours. The guaranteed energy supply does not include regulating energy.

3.2 Objectives

"Our goal is to offer optimum energy solutions, providing a modern foundation for quality living."(*Landsvirkjun - About us*, 2009)

As part of the objectives, utilising the plants as well as possible on a long-term basis. Around 2 weeks per year, the inflow in reservoir of Kárahnjúkavirkjun is such that it could propel 4 such power plants. Knowledge of such spikes in inflow beforehand might enable the utilisation of much of that spike by running on full production with a low reservoir for some time before the spike.

[1] kettles refer to heating kettles in fish-meal factories

3.3 Key Operations Elements

The operation of Landsvirkjun is as follows:

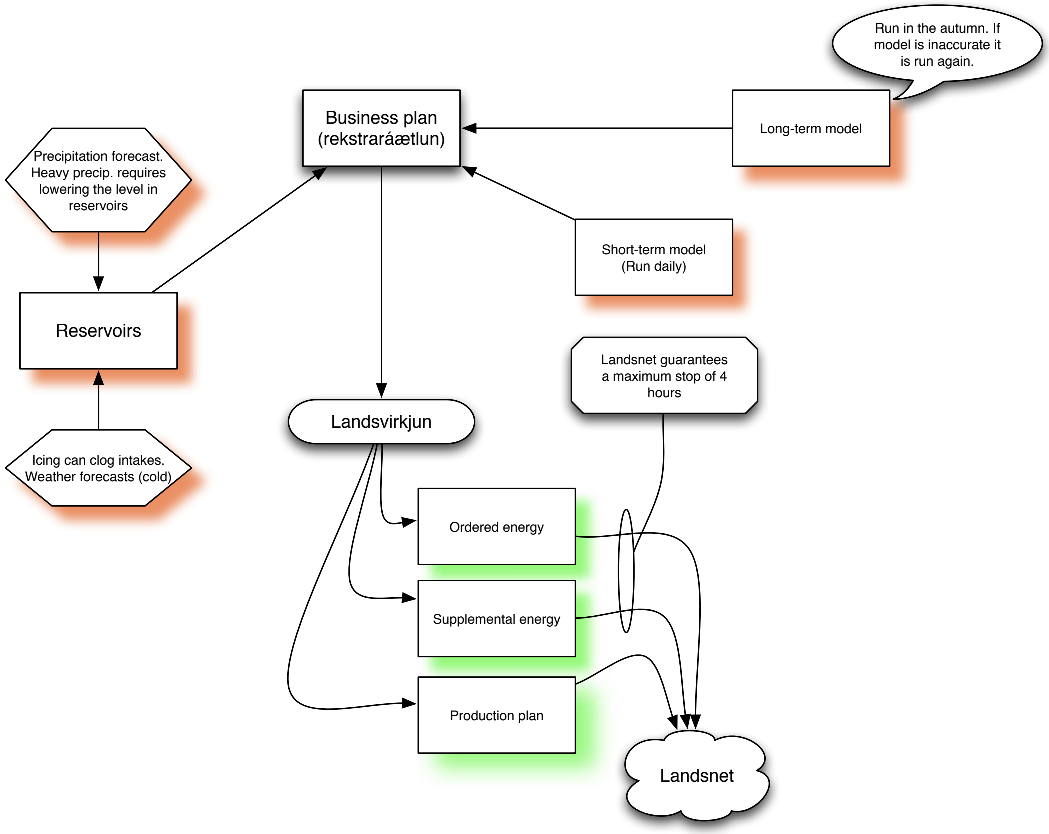

Figure 2: Landsvirkjun Key Operations Elements

3.4 The Models

In the autumn, LV runs a long-term model which estimates the water supplies and weather conditions for the next year. The production is based on these estimates. The short-term model is run every day. If the long-term model is found to deviate too much from reality, it may be run again at any point in time. The simulation time of these models is relatively short, so running them is not an issue.
There is a runoff model as well, based on historical data. Formerly, this model was

based on data in the period 1950-2006, but due to ongoing climate changes resulting in a reduction of cold spells relative to the sixties and seventies, the model was considered being overly optimistic and the period was reduced to 1985-2006. Precipitation forecasts have been used to predict increased water in the reservoirs. The water level of the reservoirs is lowered before such rain periods start. Attempts are made to keep the water level of the dams at a steady level.

A short-term model from Vatnaskil[2](VSSTM) is run every morning. As input it takes from a weather forecast for the next week the temperature and precipitation. The model contains surface-flow, runoff and more, and outputs the estimated net flow at certain given locations. The flow output from the VSSTM is used as input into the Landsvirkjun Short-Term Model (LVSTM) along with measurements such as reservoir height, orders of electricity from retailers and industry and maintenance plans. The output from the LVSTM is amongst other things estimated reservoir status for the next days, production curves, estimates on how well reservoirs are kept within constraints and graphs of in-flow. The LVSTM is used to make decisions on a day-to-day basis, with a 1-hour resolution. The construction of the model can be seen in Figure 3.

Lastly, seasonal forecasts are utilised to predict when spring and winter start (sharp increase or decrease in water flow).

3.5 Parameters

- Precipitation — Heavy precipitation may lead to distribution reservoirs being overly full. This requires LV to let water pass the intake reservoir or dam without producing any power. If long-term planning can foresee heavy precipitation, distribution reservoirs can be run at low water levels to allow for both usage and collection of water when such a precipitation period starts.
- Ice build up — In cold periods, ice may build up to clog the intakes or damage the buoyancy balloons of the dams. This is a low-frequency high-impact problem, and should be dealt with as such.

[2]See chap.7,

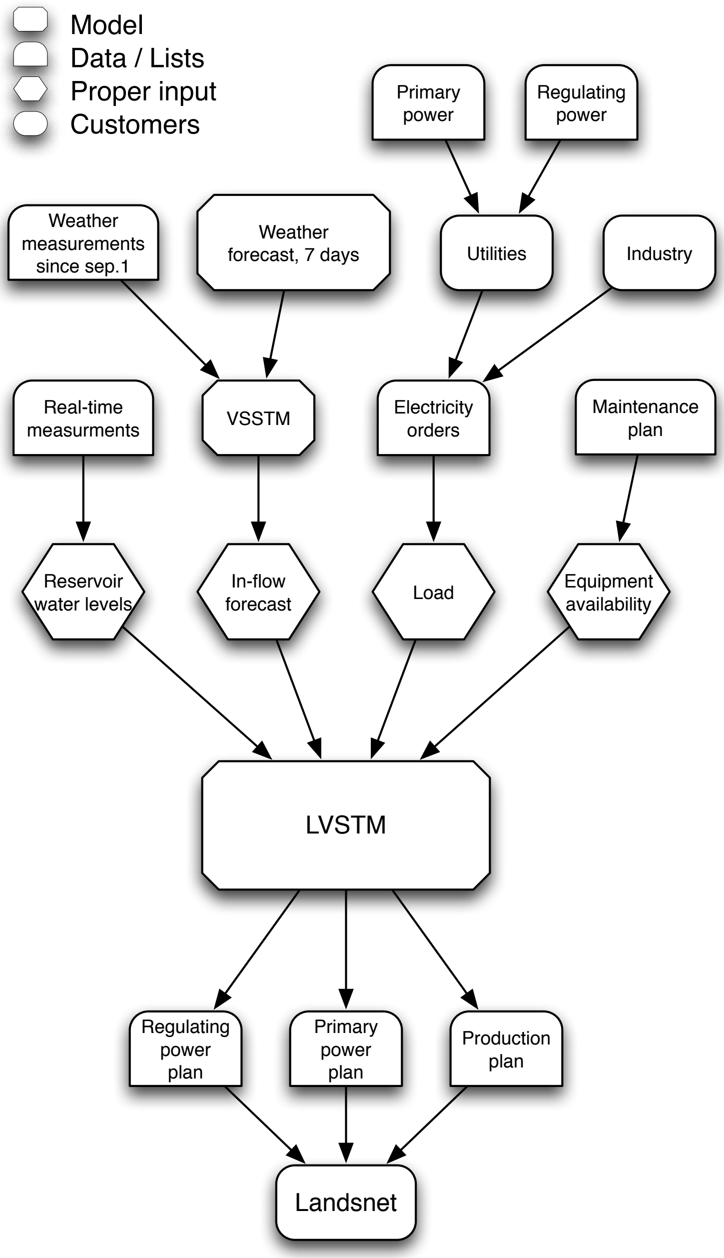

Figure 3: Landsvirkjun Short-term Model (LVSTM)

- Distribution problems — If the distributor has connectivity or distribution problems, these problems propagate back to LV. If problems on the distributors end may be predicted, LV can compensate for such problems in their plans.

- One Week Weather Forecast — Input for the short term model which is run daily.
- Short Term Model — Affects the business plan if deviations are found from the long term model.
- Run-off Measurements [1985-2006] — Input for the long term model which is run annually.
- Long Term Model (Run-off Model) — Is a base for the yearly business plan.
- Seasonal Forecasts — To predict the start of spring and winter.

3.6 Facts

- LV is already doing research on the effects of global warming on precipitation on a long-term scale.
- Ice build-up in long cold spells may clog the intakes.
- The benchmark period was reduced from 1950-2006 to 1985-2006 since the longer period was too skewed towards colder years.
- A 3-week weather forecast is considered an interesting option for LV, but isn't done at the moment.
- Precipitation forecasts are used to foresee heavy precipitation and lower the water levels of reservoirs to counteract it.
- Of the 270 measured groundwater holes LV owns, only 118 contain usable data.
- Almost none of the high-temperature thermal measures are usable.
- Almost none of the run-off measurements are usable.

	2008	2007	2006	2005
Total production	—	8.482	7428	7.143
Purchased	—	422	463	504
Sale on public market	—	2.645	2.498	2.454
Sale to industries	—	6.258	5.393	5.193
Sale increase from prev. year	—	12,8%	3,2%	1,4%

Table 1: Electricity, purchase and sales (all numbers in GWh)

3.7 Missing Information

- Information on the long term models could be more precise, both what variables are used as input, and what output the models create.
- Although the LVSTM gives good information about the basis of the day-to-day decisions made at LV, more information about their decision processes would be of great use.

4 Landsnet

4.1 About Landsnet

Landsnet is the largest power distributor in Iceland. They receive energy from power plants 7MW and larger, and distribute the energy to large consumers and smaller distributors. Their distribution lines are all 66KV and larger, except for two lines, Húsavík which is 33KV and the link to Vestmannaeyjar.

Landsnet is the primary wholesale power distributor in the country, with 1770km of power lines across the country (numbers from 2004).

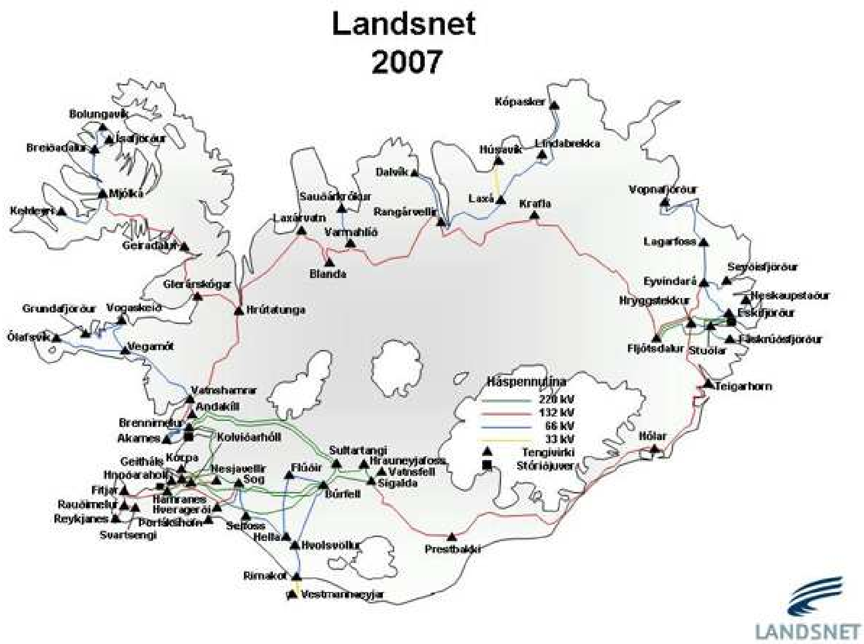

Figure 4: The power grid of Landsnet

4.2 Objectives

"Establishment of Landsnet is based on the Electricity Act set by Althingi, the Icelandic Parliament, in the spring of 2003. The law stipulates the role of Landsnet in the electrical environment of Iceland. Landsnet is owned by three major participants on the Icelandic electrical market.

The company has monopoly status for transmission of electricity in Iceland. Landsnet operates in a specially licensed environment and is under the surveillance of the National Energy Authority (Orkustofnun). Therefore it can only practise activities necessary to fulfil its duty in accordance with the law. The law stipulates independence of Landsnet from other market participants to ensure equal opportunities on a free electrical market."(*Landsnet - Frontpage*, 2009).

4.3 Key Operations Elements

Indirect effect on the design of the power grid is the fact that in the past Landsnet (as Landsvirkjun) could lay down their lines pretty much as they saw fit, while under current conditions, decisions are made on a political (environmental) basis as well as through negotiations with land owners on where and how the lines may (or may not) go through the land. These changes to the model complicate the selection of good power routing and decrease the available options. It may also affect the lines due to options requiring Landsnet to lay the lines in breach of best practises (e.g. in regard to protection against icing).

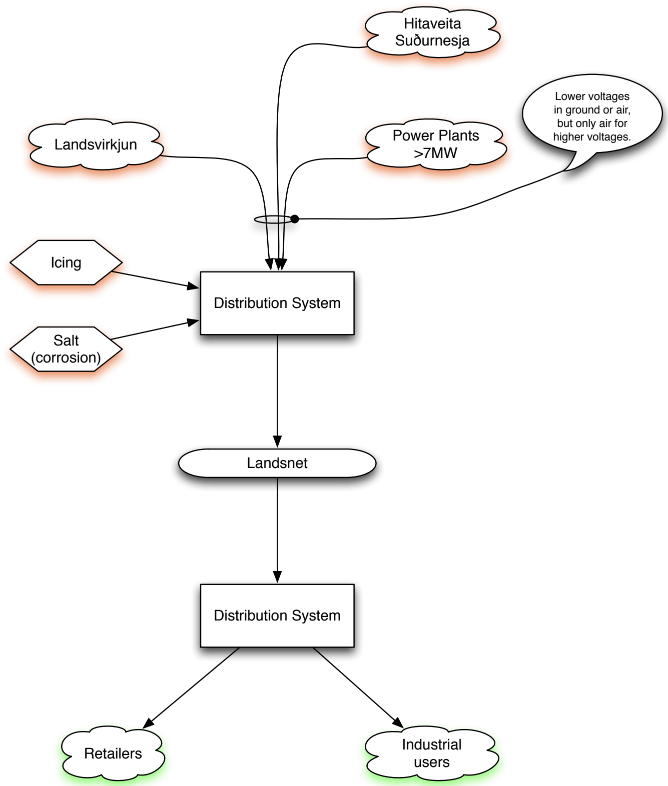

Figure 5: Landsnet Key Operations Elements

4.4 Parameters

- Wind strength and icing — Power lines are primarily affected by supercooled precipitation in strong wind conditions (wet snow icing). Predicting wind strength and the dominant wind direction under strong wind conditions can help in designing the grid in such a way to avoid icing conditions. When icing builds up on power lines, they risk breaking. Icing is in most cases monitored by torque-measuring equipment (stationary) and in a few places by cameras.
- Saline air in below $-5°C$ - according to (Hermannsdóttir, Jónsson, & Pálsdóttir, 2008), the risk of saline air is negligible - only a handful of incidents in 55 years where the temperature is below $-5°C$ accompanying a strong storm with a NNE-bound wind. This applies to the southwest of the country, no other mention is of saline air in the report.

4.5 Facts

- The power grid is under constant (re)development.
- The management at Landsnet can shut down power plants connected to the grid if necessary[3].
- The power grid contains safeguards[4].
- High voltages are only carried above ground while lower voltages can be transmitted either above or below ground.
- Environmental (political) and land-owner issues are recent problems when designing the power grid.
- The direction of the power lines is important with consideration to icing and wind.
- Icing measurements are done in 40 places, using tension measuring equipment in most places.
- Some icing surveillance is done via cameras.
- In areas where avalanches are a possibility, special avalanche masts are used.

[3] A shutdown may be necessary e.g. in case of rupture in the transport facilities.
[4] Exactly which safeguards isn't clear.

- Lightning's are taken care of by installing lightning rods.

Power line	Year	Voltage kV	Length	Poles	Avg.Spc.	Wood/Steel	Interr.	Minutes	Avg.Interr.
Sogsl 2	1953	132	44.38	169	0.2626	S	7	131	18.71
Jblendil 1	1978	220	4.45	13	0.3423	W	0	0	0.00
Hamraneslr 1 og 2	1969	220	15.12	46	0.3287	S	0	0	0.00
Sultatangal 2	1999	220	12.47	35	0.3563	S	15	1387	92.47
Sultatangal 1	1982	220	121.55	389	0.3125	S	15	1387	92.47
Blsl 2	1973	220	103.29	258	0.4003	S	4	407	101.75
Blsl 3	1992	220	117.3	317	0.3700	S	3	489	163.00
Teigarhornsl 1	1981	132	49.66	264	0.1881	W	4	3559	889.75
Bll 1	1977	132	32.73	180	0.1818	W+S	4	259	64.75
Korpul 1	1974	132	6.01	53	0.1134	W	0	0	0.00
Krl 1	1977	132	82.12	603	0.1362	W	5	93	18.60
Hrauneyjafossl 1	1982	220	19.46	53	0.3672	S	3	145	48.33
Mjrl	1981	132	80.79	631	0.1280	S	15	1387	92.47
Glerk 1	1978	132	33.54	254	0.1320	W	4	1612	403.00
Krl 2	1978	132	142.34	1175	0.1211	W+S	4	164	41.00
Sogsl 3	1969	220	35.84	93	0.3854	S	1	6	6.00
Blsl 1	1969	220	60.85	151	0.4030	S	4	315	78.75
Bll 2	1991	132	32.39	158	0.2050	W+S	1	1036	1036.00
Sigl 4	1984	132	78.14	325	0.2404	W+S	7	376	53.71
Prestbakkal 1	1984	132	171.76	640	0.2684	W+S	1	1502	1502.00
Vatnshamral 1	1977	132	20.22	139	0.1455	W+S	7	1727	246.71
Hrngul 1	1976	132	77.07	424	0.1818	W+S	2	5	2.50
Brennimelsl 1	1977	220	58.61	165	0.3552	S	1	7	7.00
allr 1 og 2	1969	220	2.36	7	0.3371	S	0	0	0.00
Lax 1	1976	132	72.72	452	0.1609	W	3	49	16.33
H 1	1981	132	75.15	396	0.1898	W	1	9	9.00
Geiradalsl 1	1980	132	76.67	344	0.2229	W+S	32	1304	40.75
Norlsl 1 og 2	1998	220	4.1	14	0.2929	S	0	0	0.00
Vatnsfellsl 1	2001	220	5.76	21	0.2743	S	0	0	0.00
Rangallal 1	1974	132	87.48	671	0.1304	W	2	1892	946.00
Sigl 2	1982	220	8.65	28	0.3089	S	0	0	0.00
Sigl 3	1975	220	36.8	102	0.3608	S	2	83	41.50
Mean values		(count) 32	55.30	267.81	0.25		4.60	604.09	187.89

Table 2: Key data for the Landsnet Power grid for years 1999-2004

(*Landsnet*, 2009)

4.6 Missing Information

- Information about models, if any, at Landsnet is missing.
- There has been no response to emails sent to Landsnet.

5 Hitaveita Suðurnesja (HS Veitur and HS Orka)

5.1 About Hitaveita Suðurnesja

Hitaveita Suðurnesja (HS) is a retailer and supplier of electricity, warm water and cold water. Their production is tightly coupled to their market.
Recently, according to new regulations on power companies in Iceland, HS was divided into two companies, HS Veitur which handles the retail and distribution of energy, and HS Orka which handles the production of energy.

5.2 Objectives

HS states their objective "is to be the most efficiently run energy company in Iceland".

According to their web-page:

> "To achieve this goal:
>
> - We customise our service and production to satisfy the needs of the customer, constantly striving towards that goal with constant changes for the better.
> - We ensure our customers in delivering our product, that we deliver it safely.
> - We wish to guarantee our customers the lowest energy prices in the country.
> - We provide our customers with a personal and educational service.
> - We ensure that the our customer's energy needs are fulfilled with stringent quality demands.
> - We utilise the natural resources of Iceland in a sensible manner.
> - We aim to lead the market in technical expertise and all production procedures.
> - We strive to be a reliable, responsible company of integrity with a progressive vision."

(*HS hf.*, 2009)

5.3 Key Operations Elements

HS is tightly coupled to its market. The primary goal is warm water production, and when the requirements for warm water increases critically (in lasting cold spells) the production of electricity is cut back. Under such circumstances, HS may be forced to buy electricity through Landsnet (from any of the other electricity producers), especially if not all generators are running.

The total electricity capacity of HS is 173MW whereof 127.6MW goes directly to the Norðurál aluminium smelter in Hvalfjörður, which leaves 45.4MW peak for the retail market, including loss in transit.

HS has no warm water reservoirs, and as such, all changes in warm water usage must propagate instantly.

There is a set of small buffer tanks at Flugvallarvegur which handle the instant changes while pressure is built up at the plant. HS is currently run at peak utilisation in transport, production and resource utilisation, and would not be capable of handling a significant market growth or a long cold spell.

Netorka[5] makes predictions for HS Veitur on how much energy will be needed for the upcoming week, and orders from Landsnet will be based on these forecasts.

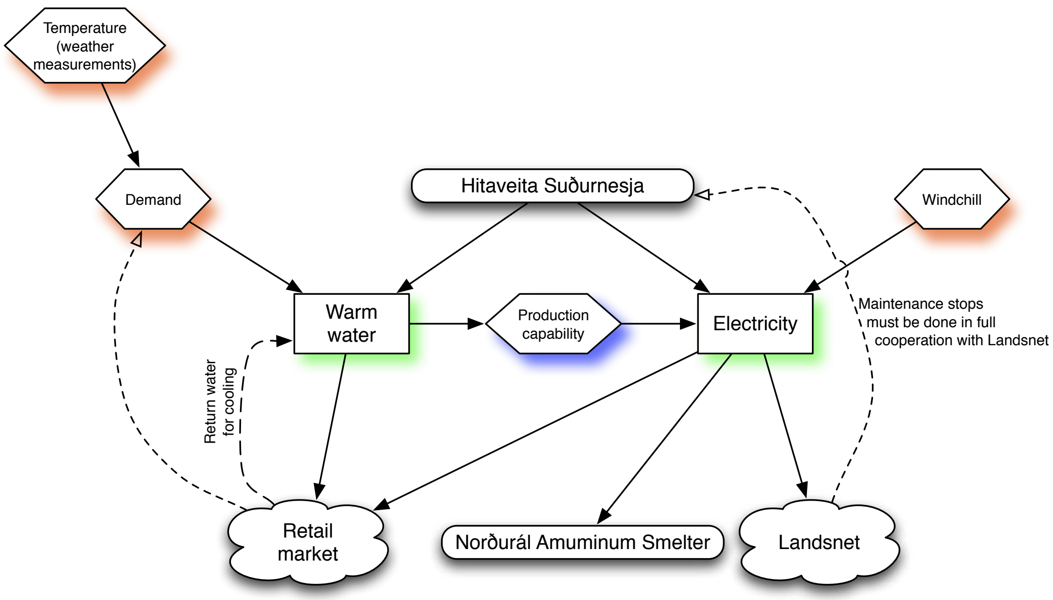

Figure 6: Hitaveita Suðurnesja Key Operations Elements

[5] See chp.8

5.4 Parameters

- Wind — Strong wind in warm weather affects the generators, lowering their mean production (thermal feedback, only about 1.5MW affected).
- Temperature — Cold weather calls for more water production which impacts electricity production.
- Daylight — Short days call for more electricity consumption.
- Draught periods — Long periods of draught may affect the groundwater reservoirs.
- Landsnet — All maintenance must be done in full co-operation with Landsnet to secure the national energy requirements.
- Consumption of water — The consumption and production of warm water is on a 1:1 basis.
- Return Water — Return water (from the former Airbase and Ásar residential area) is used to cool the warm water down to $70-80$°C from $102-105$°C

5.5 Facts

- The only buffer available are water tanks at Flugvallarvegur. These tanks are pressure buffers only.
- No reservoir tanks are available at the time being.
- The warm water supply to customers is pressure controlled. When pressure drops (due to increased usage), the buffer tanks add to their flow to maintain pressure.
- The return water from the customers at the former Airbase and the Ásar residential area is used to cool the warm water down to $70-80$°C from $102-105$°C.
- All other "return water" ends in the spill water system (fed into the ocean).
- At the loss of the return-water feed no impending changes would occur other than a change in feed temperature to the consumers.

- H_2S (Hydrogen Sulphide, a corrosion inhibitor) is not added to the water. Instead, the oxygen levels of free oxygen in the water is kept within levels by regulating the pressure of the feed.
- Around 55% of the ground-sea-water that is pumped up is pumped back into the ground (approx. 7 million ton out of 13 million ton).
- The aim is to increase the percentage of ground-sea-water return.
- All extra electricity goes to Landsnet. There is registered a substantial loss of energy as thermal loss in the Landsnet hub.
- If there is a crisis in water production, the production of electricity must be reduced.
- The total production capability is 273MW.
  - Thermal capability is 150MW while practical utilisation is around 100MW
  - Electricity capability at Reykjanes is 100MW
  - Electricity capability at Svartsengi is 73MW
- Due to the tight coupling between market and production, drastic changes would prove difficult or impossible to handle.
  - In very cold weather, one challenge is to feed enough water through the distribution system.
  - Additionally, the production is already running at peak values, making it difficult to increase the production.
  - As noted by HS staff members, an extreme winter like the one in 1918 would prove impossible to handle.
- All maintenance stops must be done in full co-operation with Landsnet.
- A model of the geothermal system was done at Vatnaskil. Work is in progress simulating the system using the TOUGH2(*TOUGH2*, 2009) reservoir model.
- Under strong wind conditions in warm weather, the production of electricity is affected on the older generators from 1.4MW down to 0.7MW due to warm air feeding back into the cooling system. An increase in the number of generators that are not affected by weather is decreasing this factor. Currently there is a replacement generator in place which can take over for most of the weather affected generators. It has yet to be activated.

- At colder temperatures, usage of warm water increases. As a side effect, the production of electricity has to be decreased and additional electricity bought through Landsnet[6]. Ducts that only produce steam are increasing in numbers, lowering and eventually eliminating the thermal effect.
  The weather is monitored by a weather station. A colder temperature calls for increase in water temperature. The effects of temperature changes take around 3 hours to propagate to customers.

- A change in the quantity or quality of the return water does not affect the quality of the warm water feed, although it may affect the temperature. A full cut-off in return water will not affect the feed directly, but it may get cut off by management due to high water temperature.
- Projections are made on electricity consumption by NetOrka.
  - Projections are made for:
    * One year ahead - made in the fourth quarter
    * Three months ahead - made quarterly
    * One week ahead - made weekly
  - HS uses these projections to plan their purchase and sales of electricity.
- Vatnaskil[7] does research for HS where they investigate amongst other things
  - The status of the geothermal areas
  - Drainage-pollution tests (how much and how widely can the freshwater bubble be drained before pollution becomes an issue)

5.6 Missing information

- More data is needed on the scalability of the current system due to its tight coupling with the market.
- What data is collected at HS for storage and/or future use?
- Further information about the models in use at HS is missing.

[6]Electricity is bought from other producers like Landsvirkjun, and delivered through Landsnet.
[7]See chap.7

6 Orkuveita Reykjavikur

6.1 About Orkuveita Reykjavíkur

Orkuveita Reykjavíkur (OR) is a retail company of warm and cold water and electricity, as well as a wholesale producer of electricity to heavy industry . Their current capacity is around 300MW in electricity and over 390MW in warm water. Their production of electricity covers their retail area. The customer base of OR is about 67% of the Icelandic population, making them the largest retail supplier of electricity and water in the country. OR has two geothermal power plants — at Hellisheiði and Nesjavellir. In addition they have two hydropower stations — Andárkílsvirkjun and Elliðaárvirkjun, as well as a first in Iceland — Álfsnesstöðin, which is a methane power plant with a 840kW capacity.

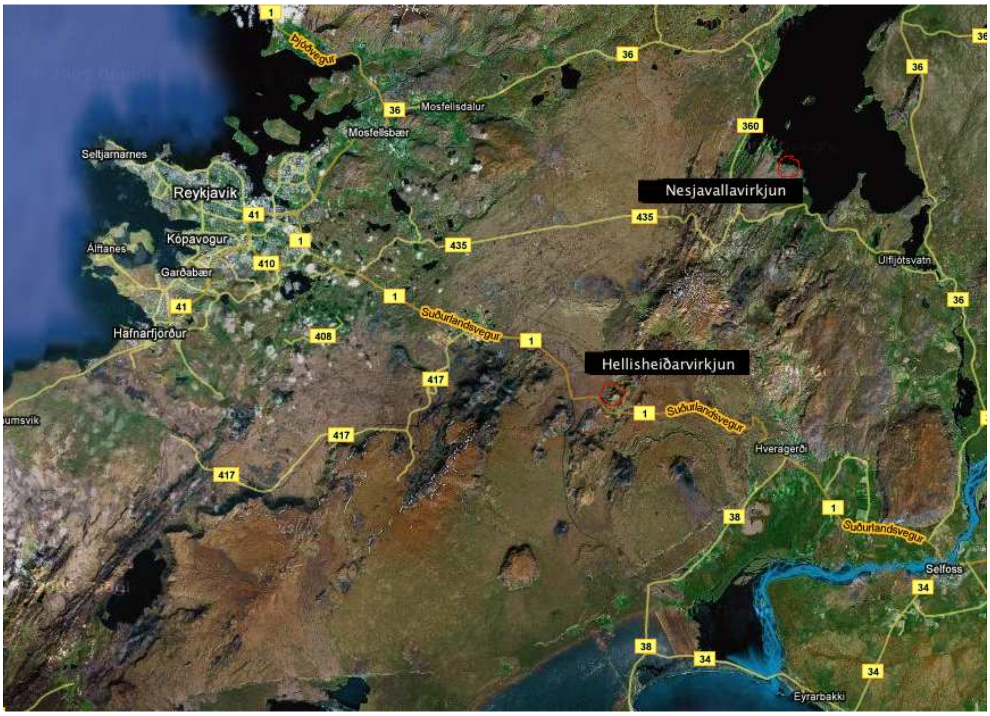

Figure 7: Location of Hellisheiðarvirkjun and Nesjavallavirkjun

As stated on OR's web-page:

> "Orkuveita Reykjavíkur provides electricity, geothermal water for heating, and cold water for consumption and fire fighting. Our service area

extends to 20 communities, covering 67% of the Icelandic population. We harness hot water from geothermal fields in Reykjavík and distribute to our customers. In addition, we operate geothermal plants at Hellisheiði and Nesjavellir where we heat groundwater and distribute to the district heating. We produce electricity by using geothermal, high-pressure steam at our plants at Hellisheiði and Nesjavellir. We distribute cold water from our groundwater reservoir." (*OR.is :: Reykjavik Electricity, geothermal water for heating, cold water, geothermal fields in Reykjavik. :: About*, 2009)

6.2 Key Operations Elements

- Electricity
  Currently, OR produces electricity at four sites — Hellisheiði, Nesjavellir, Andárkílsvirkjun, Elliðaárvirkjun and Álfsnesstöðin, around 300MW capacity. The production is divided as such

Power plant	Trb.	Cap.MW
Hellisheiði	4	45
	1	33
Nesjavellir	4	30
Elliðaárvirkjun	4	3.16
Andárkílsvirkjun	?	8.2
Álfsnesstöðin	1	0.84

Table 3: Breakup of the electricity production of OR

  Predictions are made about future electricity usage. The predictions along with orders from heavy industry make up hour-by-hour orders which are sent to Landsnet. Historical data for the load from recent years and the current week from last year gives a good estimate for the electricity usage, since deviation in the prediction model is within 1% of correct values. The predictions are then evened out by use of a Kalman filter.
  A part of the production requirements are to produce electricity to pump water. Under cold spells, these requirements increase.
  The wells used in the high-heat geothermal areas each produce on average 5-6MW. These numbers include unused and damaged wells. A well may peak around 20MW.
  Historically, the wells have been drilled straight down, at around 2000m. Straight wells require distributed production and/or collection systems. To minimise the effect on the nature, recent wells are drilled at a slant, 3000m deep, enabling aggregation of collection and production systems into few spots.

  The diagonal wells are somewhat more expensive than the straight wells. There exists a lot of data at OR about electricity usage from a project that ran in 2002, where OR sampled several sites and collected the data. This data is accessible through OR for research purposes. The effects of weather on production are about 4-5MW (2-3%).

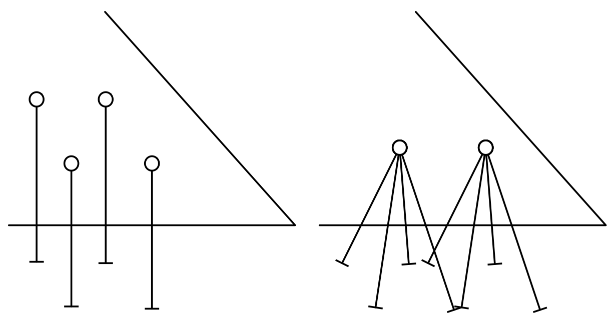

Figure 8: Straight and diagonal wells, showing aggregation of wells

- Water
  OR is the largest distributor of warm and cold water in the Reykjavik metropolitan area.
  The water comes from the low-temperature thermal areas near Reykjavik and the high-temperature wells at Nesjavellir. Plans are to use the Nesjavellir wells exclusively in the summertime to rest the low-temperature wells. This does however not work in all areas since mixing water sources increases the risk of deposits.
  In cold spells like the one experienced in 1918, the oil-kettles might be started, and if the low-temperature areas run low, water may be mixed in from the Reykir farming and recreational area, which is moderately rich in geothermal water supply.
  OR has a model similar to the future electricity usage model, where future water usage is estimated. Production is based on the estimates, and in accord to the status of the water supplies.

- Planning for the future
  In addition to the future usage models previously listed, OR plans for the future on a longer time scale. This planning mostly happens in accord with plans for new geothermal power plants, especially since the geothermal models span a time-frame of up to 40 years, and as such, the production limit is known for a long time to come. The high-temperature geothermal models are located at Vatnaskil (chp.7). On a shorter time scale, OR does groundwater forecasts to predict how the low-temperature areas can be utilised, draught forecasts to predict when the Nesjavellir power line may be in danger of thermal damage (an additional line is being planned) and frost forecasts to predict if long cold spells may be likely.

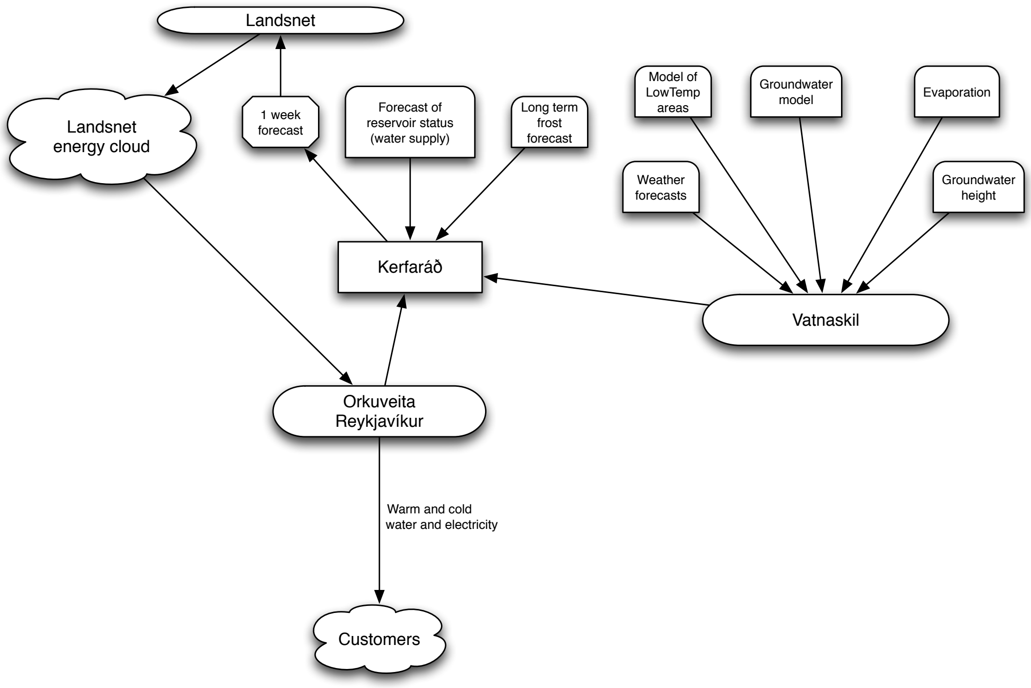

Figure 9: Orkuveita Reykjavíkur Key Operations Elements

6.3 Parameters

- Weather forecasts — as weather heavily inflicts changes on the required production of both warm water and electricity.
- Groundwater forecasts — to predict how each low-temperature area can be utilized.
- Draught forecasts — to predict when workload has to be transferred from Nesjavellir to other plants.
- Frost forecasts — to foresee long frost periods, as long periods of frost may require OR to start their fossil-fuel thermal generator which can heavily impact OR's bottom line.

Complete models are at Vatnaskil, and these should be considered as input variables.

6.4 Facts

- Models on warm water usage have been developed at the University of Iceland.
- Vatnaskil has a model of the low temperature areas of Reykjavík.
- Vatnaskil has a model of the groundwater of Reykjavík.
- Nesjavellir produces 120MW electricity and up to 300MW in heat (warm water).
- As much heat as possible is produced at Nesjavellir in the summer to rest the low temperature areas.
- Water from high temperature and low temperature areas may not be mixed at risk of build-up of deposits.
- Increased water usage implies lower electricity output capability since electricity is needed to pump the additional water.
- Production capability in the winter is 150MW$\pm$3MW
- Low-temperature wells are measured at the beginning of each month by technicians. If abnormalities are detected, they repeat the measurements.
- Measurements are scrutinised by the production division, and if they are found to be abnormal, geologists are called for assistance.
- Given a possibility of long frost periods, the low-temperature reservoirs are evaluated to see if they can supply the needed additional water at the estimated increased demand. If the load is estimated near the peak of the power-plants capability, the fossil-fuel kettles are put on stand by.
- If there is in conjunction with the cold spell, any possibility of a water shortage with customers, representatives from Sale & Distribution are called for assistance and a joint decision taken.
- The time of the year impacts the production capability of the low-temperature wells, otherwise the response to cold spells is generally the same.

6.5 Missing Information

- It is still somewhat unclear how decisions are made within OR, and how the usage of models comes into the decision process.
- More information is needed about the role of Vatnaskil in regard to the operation of OR.
- More information is needed on the effect of weather on power and water production.
- Information on the internal structure of OR is insufficient.
- Contact at the University of Iceland for the warm water usage models is currently unknown.
- We need to talk to Kerfaráð to get a better understanding of the systems of OR.

7 Vatnaskil

7.1 About Vatnaskil

“Since 1982 Vatnaskil Consulting Engineers has provided specialised consulting, simulation and modelling services to private corporations and governmental organisations in Iceland and abroad. We specialise in geothermal reservoir, groundwater, surface runoff, air pollution and environmental modelling. Our employees have a strong educational background and extensive experience within the fields of civil engineering, hydraulics, hydrology, and geothermal reservoir engineering.

Ideally situated in Iceland, a geothermal hot spot where high emphasis is placed on environmentally friendly practises, our employees have been involved in most major projects in Iceland where highly sophisticated modelling service are required.

Vatnaskil’s specialists also have years of experience teaching at the Engineering Department at the University of Iceland, the United Nations University (UNU) Geothermal training program in Iceland, and at various seminars and courses in England in cooperation with our associates at Land and Water Resource Consultants in Cambridge, England. Vatnaskil has also cooperated with the Division of Applied Mathematics and Computer Science at the Science Institute of the University of Iceland in development of numerical methods for hydrodynamic simulations.” (*Vatnaskil - Home*, 2009)

7.2 Key Operations Elements

Vatnaskil (VS) performs services to the utility companies covered in this paper. They don’t perform any direct decision-taking activities for the utilities, but the output from their models may play a part in the decision-making process at the utilities.
VS performs extensive research on groundwater, flow, geothermal areas and pollution distribution for HS. VS keeps flow models, groundwater models and geothermal models for OR. The services grated to OR are to update the models’ historical data once a year, and to run the models on the past year.

7.3 Models

- Groundwater model (various sites)
- High-temperature geothermal model (various sites)
- Surface runoff model
- Air-pollution model (H_2S)
- Groundwater pollution model for HS
- Short-term model (for LV)

7.4 Facts

- VS produces and executes models for all of the energy producers covered in this paper
- VS produces pollution models for geothermal plants, aluminium smelters and towns.
- Input into these models are amongst other things weather reports and/or forecasts.
- The geothermal model is on a scale of decades. The model is therefore not important as such, but the output of the model is (that is, enthalpy and lifetime of the geothermal area).
- The H_2S model isn't important for day-to-day operations, but is important when considering new sites.
- The short-term model takes as input temperature and precipitation from weather data from Veðurstofan.
- The short-term model will in the future take as input the data from the HRWM at RV.
- The short-term model contains all conceivable flow-models for all the catchments of LV.
- The output of the short-term model are flows for specific locations, which acts as input into the LVSTM.

8 Netorka

8.1 About NetOrka

"All citizens have the option of selecting which utility they purchase electricity from. The sale of electricity is not limited to the utility distributing to the particular area, but open to all licensees.

The purpose of Netorka hf. is to be a joint metrics and accounting company for the Icelandic electricity market in a commercialised environment. Netorka takes care of the accounting and calculation of sales metrics and stores changes in the business of the utilities and customers. Netorka also produces utilisation forecasts for the utilities, based on historical data, social behaviour and weather forecasts.

The installation of a central database and a simple message-passing system at Netorka is unique, and the first of its kind in the world in the utility sector. The system provides simplification, flexibility and efficiency in the accounting of the Icelandic utility market, far better than in other countries." (Original text translated (*NetOrka*, 2009))

8.2 Facts

Netorka is jointly owned by the utilities and wholesale distributors. Their main service is bookkeeping of sales of electricity within the sector. A secondary service to the sector (e.g. HS) is to provide utilisation forecasts which the utilities can use to predict their production requirements.

8.3 Models

- Estimated demand model

8.4 Missing information

- Information about the model

9 EFLA

"What is EFLA ?

EFLA is a general engineering and consulting firm with a staff of professionals well trained to provide quality service in a wide variety of fields. The Company's 270 employees, 50 of whom work in foreign subsidiaries, offer wide-ranging and reliable expertise that enables the Company to carry out a number of unlike projects simultaneously, both in Iceland and in many other countries. The Company places strong emphasis on innovation and research. The Company regards its employees as its most valuable resource.

EFLA was formally established on October 10, 2008, with the merger of four engineering and consulting firms – AFL Engineering Office (founded in 1987), Línuhönnun (founded in 1979), RTS Electrical Engineering Office (founded in 1988) and the Sudurlands Engineering Office (founded in 1973) – making the new company one of the largest consulting firms in Iceland.

EFLA now has 6 marketing divisions: Power and Utilities, Industry, Construction, Communication and Transportation, Environmental Concerns, and Project Management, comprised of 28 service divisions with designated core activities, together with the Staff, Business Development, and Research and Innovation Divisions.

EFLA has subsidiaries and associated companies in Norway, Russia, France, Poland, Slovenia, Turkey and Dubai that work on consulting and development projects." (*What is EFLA ?*, 2009)

9.1 Facts

Although EFLA is a very large engineering firm with connections to the geothermal- and hydro-power industries, currently the largest known service important to this project is the making of the report for Orkusparnefnd (chp.11). In conjunction with the energy forecasts, EFLA may have several models which are currently unknown.

9.2 Missing information

It should be investigated further if EFLA does indeed perform services for OR, HS or LV. no such services have however been mentioned by the respective companies.

10 Verkís

“About us

Verkís is an employee-owned engineering firm who provides a wide range of services in most fields of engineering and related disciplines. At Verkís, about 350 employees work with a wide variety of projects, both in Iceland and abroad.

Verkís was established in November 2008 by the merger of five well established engineering firms, VST, Rafteikning, Fjarhitun, Fjölhönnun and RT-Rafagnatækni. Decades of experience benefit our clients and we strive to provide high quality, innovative, technically advanced and comprehensive services. As one of the largest engineering firms in Iceland, Verkís always seeks to provide the best and most economical solutions, thus building a long term relationship with our clients. Continuous improvement and innovation are central to how we do business.

As a fully employee-owned company, we value each member of our staff and maintain a climate of openness, while encouraging professional and personal development.” (*About Us | Verkís*, 2009)

10.1 Parameters

Verkís has flow models for OR.

10.2 Missing information

No reply has come from Verkís about the flow model. Currently it’s expected to have similar parameters as the flow models at Vatnaskil.

11 Orkuspárnefnd

11.1 About Orkuspárnefnd

Orkuspárnefnd (en. Energy Forecast Comity) is a cooperative ground for some of the main companies in the energy sector, institutions and government sectors. The comity produces on a regular basis an energy forecast for the country. Recent forecasts include a fuel consumption forecast for 2008-2050 and electricity forecast 2008-2030.

11.2 Energy and Geothermal forecasts 200x-2030

The energy forecast spans the years 2008-2030. The basis for the energy forecast is very wide. The input comes from forecast models and estimates that span

- GNP
- Population and number of homes
- Businesses
- Heated houses and energy usage in heating
- Domestic electricity usage
- Industrial electricity usage
- Electricity usage in the service sector
- Utilities
- Fisheries
- Transport and distribution losses
- Electricity usage in heavy industry

Another forecast is the geothermal forecast (2003-2030) which has an equally wide input from models and forecasts that span

- Domestic heating
- Swimming pools
- De-icing systems
- Heated produce farming
- Fish farming
- Industry
- Geothermal electricity production
- Other*
- Transport and distribution losses
- Unused thermal energy

*This section is for any category of geothermal usage that doesn't fall within any of the other categories

The prerequisites for the model are found in (Orkuspárnefnd, n.d.) with a detailed description of each prerequisite.

More detailed information about what data is output from a model and which data are estimates is needed.

12 The models

In this chapter the currently known models are listed, along with their inputs and outputs.

Models from Landsvirkjun

Short-term model for hydroelectric production (LVSTM)	
Input	Reservoir status Discharge forecast (from VS Short-term model) Load Maintenance plans
Output	Production plan to Landsnet Primary power plan to Landsnet Regulating power plan to Landsnet
The Primary and Regulating plans cover on a hourly basis, the power sold through Landsnet	

Surface-runoff Model	
Input	High-resolution weather forecast
Output	VS (or) * RV
The surface-runoff model is with regard to melting, precipitation, temperature etc. Precise parameters are needed, both input and output.	

Long-Term Model (LVLTM)	
Input	Seasonal forecast
Output	Estimated runoff in the coming year
The model is run in the autumn. If the model is deviating too much from reality, it may be run again as needed	

Models from Orkuveita Reykjavíkur

Low-Temperature Model	
Input	UNKNOWN
Output	UNKNOWN
The LTM and the areas it covers rarely deviates from expected values	

Groundwater model (cold water)	
Input	Water pumped up Weather data (precip., temp.) Groundwater measurements Surface runoff
Output	Groundwater forecast
Impact factors on the groundwater model are several consequent dry years	

PSS/E power systems simulator (used by OR distributors)	
Input	Resistance of power lines Load capacity of power lines
Output	Distribution capacity of power lines Short-circuit threshold
The model is used to perform load-capacity and short-circuit threshold calculations to guide in future investments in the distribution system.	
In the summer-variation of the model, the load is slightly lower than in the winter-variation due to temperature factors.	

Hengill high-temp geothermal model	
Input	Pressure Temperature Geology * Fractures * Movement * Tension In-Flow
Output	UNKNOWN

Models from Hitaveita Suðurnesja

NO KNOWN MODELS	
Input	—
Output	—
To our knowledge, Vatnaskil and Netorka host all models for Hitaveita Suðurnesja	

Models from Vatnaskil

Geothermal model (VS)	
Input	Pressure at given depth Temperature at given depth Pumping k/s of liquid at surface level
Output	UNKNOWN
The output variable(s) is still missing.	

Groundwater risk analysis model for Suðurnes	
Input	UNKNOWN
Output	UNKNOWN
All information about this model is missing	

Short-term model (VSSTM)	
Input	Weather measurements since Sept. 1 Weather forecast for the next 7 days
Output	Expected discharge for the next days at select areas

Air-pollution model (H_2S)	
Input	UNKNOWN
Output	UNKNOWN
Information about the air-pollution model is missing. The model is used primarily when deciding on new plants, drilling sites and expansion of current plants.	

A complete model of the Reykjavik Metropolitan Area (VS - in progress)	
Input	UNKNOWN
Output	UNKNOWN

Low-Temperature Area Model	
Input	UNKNOWN
Output	UNKNOWN
The model takes into account Surface model, Simple weather model, Snow-melt	

Production plan for HS	
Input	UNKNOWN
Output	UNKNOWN

Groundwater (cold) model for HS	
Input	UNKNOWN
Output	Status of the groundwater
The model is run once a year	
The output is an estimate - further information is needed	

Groundwater model for LV	
Input	UNKNOWN
Output	UNKNOWN

Surface flow model for LV	
Input	UNKNOWN
Output	UNKNOWN

Energy-exchange model for LV	
Input	UNKNOWN
Output	UNKNOWN

Long-term model for LV (VSLTM)	
Input	UNKNOWN
Output	UNKNOWN
This model acts as input into the LVLTM	

Skaftár-model for LV	
Input	UNKNOWN
Output	UNKNOWN
This is a flow-model of the Skaftá catchment	

Hvítár-model for LV	
Input	UNKNOWN
Output	UNKNOWN
This is a flow-model of the Hvítá catchment	

Þórisfljóts-model for LV	
Input	UNKNOWN
Output	UNKNOWN
This is a flow-model of the Þórisfljót catchment	

Models from Reiknistofa í Veðurfræði

High-resolution weather forecast	
Input	Data from global forecasting models * Temperature * Wind * Geo-potential height * Humidity Output from soil-simulation model (*optional*)
Output	Weather forecast which constitutes of +50 variables calculated for a n by n km square.
The HRWF is hosted by RIV	
* Both at surface level and at standard pressure levels	

Models from EFLA

NO KNOWN MODELS	
Input	—
Output	—
Further information about the part of EFLA is needed	

Models from Verkís

Flow-model for OR	
Input	UNKNOWN
Output	UNKNOWN
Further information about the model is needed.	

Models from Orkuspárnefnd

NO KNOWN MODELS	
Input	—
Output	—
Further information about the models Orkuspárnefnd uses is needed	

Models from Veðurstofa Íslands

One-Week Weather Forecast (from Veðurstofa Íslands)	
Input	UNKNOWN
Output	Weather forecast for 7 days
The weather forecast is used as input into several models residing at VS, OR and LV	

Frost forecasts (Veðurstofa Íslands)	
Input	UNKNOWN
Output	Likelihood and length of cold spells

Seasonal Forecast (Veðurstofa Íslands)	
Input	UNKNOWN
Output	Est. precip. and temp. for the season

Models from Netorka

Estimated Demand Model	
Input	Historical utilisation data Social behaviour data Weather forecasts
Output	Utilisation forecast
This model resides at Netorka, which we haven't been able to interview	
The existence of Netorka as a supplier of information was apparent in the last few weeks of the project, and as such, time didn't allow for further data acquisition. The currently defined inputs and outputs are estimates based on interviews with Hitaveita Suðurnesja.	

Legend

Legend	
Abbr.	Utility/Distributor/Support
HS	Hitaveita Suðurnesja
LN	Landsnet
LV	Landsvirkjun
NO	Netorka
OR	Orkuveita Reykjavíkur
VS	Vatnaskil

13 Variables, constraints and relations

13.1 Overview - Vision for framework

Traditionally, models are utilized to run simulations with no uncertainty; i.e., given a combination of input values, the simulation will give the same results on any run. Furthermore, no explicit "decision making" is done within the calculations of the model. That means that the simulation is "non-intelligent", as all responses are pre-coded in the model.

This approach works well for short term weather forecasts, for calculating runoff for the inflow of a hydroelectric dam, for estimating draw on geothermal reservoirs, etc., but only if the desired result is only based on the initial conditions given and the pre-defined inputs for the process. Consider, for example, the modeling of a reservoir level. On one hand, a model is used to calculate water flow into the reservoir, given inputs about water tables, expected weather, etc. On the other hand, we have some predefined expectation of how much water is allowed to flow out of the reservoir. The difference essentially determines the expected level. That in turn can either validate the planned use of water or require it to be replanned.

In practice, external uncertainty is addressed by running multiple inputs for the model. However, the inputs are determined by the users and may not identify transitions between optimal plans or even critical decision-points such as maximal risk. Furthermore, the results are analyzed by users and thus the purpose tends to be validation of a single pre-defined plan, as opposed to an iterative process for finding the very best plan.

In stark contrast to this approach, the latest technology in automated decision-making is working towards methods that can find the best plans, even taking into account uncertainty in the environment and internal decisions that may vary depending on the external factors. The foundation for these methods is automated planning.

Some of the key work done in this area has been performed at NASA research centers. The motivation for NASA is similar to the motivation behind this work; spacecraft are expensive and complex systems that must be operated in dynamic environments with high degree of reliability. As noted before, there are three key NASA projects the serve as examples for this work. The MER project and the ISS solar array projects demonstrated how automated planning can assist humans with decision-making. The LORAX project showed how uncertainty can be taken into account in the planning process, both upfront and during execution.

The basis for each of these projects is the EUROPA framework. A EUROPA planner works with a large set of possible states and operations, the combination of which is restricted by constraints that identify both relations between operations and states and what is safe and legal. Relations in a model are an example of such constraints. A final element of the information behind a planning process is the evaluation of a plan; i.e., how good or bad it is. Such evaluations can take into account value generated, cost, risk and many other factors. The power of an automated planning system is both in the ability to exclude invalid options automatically and the ability to find good plans with limited or no human participation.

The vision of this effort is to utilize a planning platform to assist with decision-making for utility operations. To do that requires specifying the information needed by the planner, such as the operations, actions, variables, constraints, relations, functions and uncertainties involved. It also requires building a tool that is helpful to the user, allowing the user to engage in various efforts, ranging from evaluation of a hand-crafted plan to fully automated plan optimization. In between is a particularly important range of capabilities where the user can engage in "what if" analysis, examining both different plan options and different assumptions about external factors such as weather and climate.

13.2 Example

Based on what we have noted in the previous chapter, the information retrieved about currently existing models is incomplete. We have identified several models at the various utilities; however, in most cases, much more precise information is needed to fully define a model that can be used for planning. Acquiring and utilizing that information is a significant effort, but will provide a great deal of advantage in optimizing operations.

Nonetheless, for illustrative purposes, let us take one example of a simple model, identifying at least the variables and constraints, to give us a a feel for what is involved. In the LVSTM we have a chain of events which exhibits a behaviour which can be explained as the sum of its parts — e.g. the weather is rainy for a period of time in one part of the country and dry in another, leading to decisions that move production to sites that have more resources and away from those that have less.

The chain of models in the LVSTM includes:

- Log of weather measurements since Sept.1 → VSSTM
- Weather forecast - 7 days → VSSTM → (In-flow forecast) → LVSTM
- Electricity orders from utilities and industry → (Load estimate) → LVSTM
- Maintenance plan → (Equipment availability) → LVSTM
- Real-time measurements → (Reservoir water levels) → LVSTM
- LVSTM → (Regulating power plan)
- LVSTM → (Primary power plan)
- LVSTM → (Production plan)

The output from the weather forecast is used as input to the VSSTM.

The output from the Runoff model is used as input to the Groundwater model, Inflow model.

13.2.1 Variables

Each of the variables in table 4 has a direct consequence on the production, except "Production/MW" which is an output variable (listed for the sole purpose of verifying that one of the constraints - the required production - has been met).

We need more variables to do planning — one kind of variables needed is the feasibility to do one thing or the other; expressing the need for a change, or the lack thereof.

Variables concerning the feasibility of production
These variables describe the feasibility for production. At a certain level, the variable may indicate that production should be increased or decreased.

Origin	**Variable**	**Scale**
7-day forecast	temperature	°C
-‘’-	precipitation	mm/h
Electricity orders	power	MW
Maintenance plan	availability	0/1 or 0..1
Real-time measurements	height	m
Real-time measurements	Water temperature	°C
Flow	Flow	m^3/s
Real-time measurements	Displacement Δ	mm
Production	Production	MW

Table 4: Variables (LVSTM)

Variable	Constraint	Feasibility	Description
Reservoir water level	Above and rising Below	feasible infeasible	An overfilling reservoir is energy wasted An empty reservoir is a turbine about to run dry
Environment temperature	Above and rising Below a certain level	less feasible more feasible	
Flow m^3/s	Below	less feasible	
Load	increasing	more feasible	

13.2.2 Constraints

Several constraints considering finances should also be taken into consideration e.g.:

- the cost of maintenance
- the cost of overproduction
- the cost of underproduction (loss of contracts, fines etc.)

Not all factors are known at the moment.

Constraint	Description
Production capacity	The production capacity is defined in time t by the production capacity of each turbine TC_n and the availability of said turbine TA_n at the defined time, as well as the transport capacity of the grid: $PC_t = \sum_{n=1}^{p} TC_{n,t} TA_{n,t} GT_t$
Ordered energy (Load)	The ordered energy is the sum of retail regulating, retail ordered and industry ordered energy: $OE_t = O_t^{rreg} + O_t^{rord} + O_t^{ind}$. The set of power plants available should not produce less than OE_t at any time t, and preferably no more either.
Available energy	The available energy is defined by the amount of water available to production, current and estimated future.

Constraint	Description
Production feasibility	Several variables affect the feasibility of production. Some increase the feasibility, such as a full reservoir, while others decrease the feasibility, such as polluted well-water or low reservoir level.
Hydro-electricity	*Low Reservoir*: A low water level at a reservoir decreases the feasibility for production at the particular plant, esp. when coupled with decreasing water level or expected draught periods. *High reservoir*: A high water level at a reservoir increases the feasibility for production at that particular plant, esp. when coupled with increasing water level or expected high in-flow. *Surface flow m^3/s*: *Surface flow water level*: *Environment temperature*: High and low temperatures inversely affect the production requirements. *Groundwater height*: The groundwater height is a indirect variable. It affects the flow models which in turn may affect wells and/or reservoir in-flow.

13.3 Relations

The production capability is directly related to the available stored energy (geothermal or hydro), the availability of turbines, transport capability of the grid, production at other plants and the total ordered energy.

Constraint	**Description**
Alert factors	Some factors don't impact production until a certain critical level is reached. The variables below are such variables.
Hydro-electricity	*Reservoir water temperature*: At temperatures close to 0°C or below, ice may start to build up on the buoyancy balloons of the reservoir. This may directly impact production. *Displacement* Δ: Measured displacement in the dam over a certain level may directly impact on production and safety

The available stored energy at hydro-power plants is directly related to the in-flow into the reservoirs for the plant, the current passing flow that is not part of the production, and the current production.

The in-flow to reservoirs is directly related to run-off, precipitation and temperature.

The electricity demand is for domestic use, inversely related to the season and number of sunny days. Summertime with many sunny days requires low lighting, while wintertime with few sunny days requires constant lighting, but directly related to the day of week and holidays, while industrial electricity requirements are constant and contract-bound for an extended period of time.

Heavy industry is a constant in short term production planning, while public consumption fluctuates greatly. The public consumption does however only account for a fraction of the total production.

14 Atmospheric Models

An atmospheric model is a mathematical model constructed around the full set of primitive dynamical equations which govern atmospheric motions. It can supplement these equations with parameterizations for turbulent diffusion, radiation, moist processes (clouds and precipitation), heat exchange, soil, vegetation, surface water, the kinematic effects of terrain, and convection. Most atmospheric models are numerical, i.e. they discretize equations of motion. They can predict micro scale phenomena such as tornadoes and boundary layer eddies, sub-microscale turbulent flow over buildings, as well as synoptic and global flows. The horizontal domain of a model is either global, covering the entire Earth (cf. Fig. 10), or regional (limited-area), covering only part of the Earth (cf. Fig. 11).

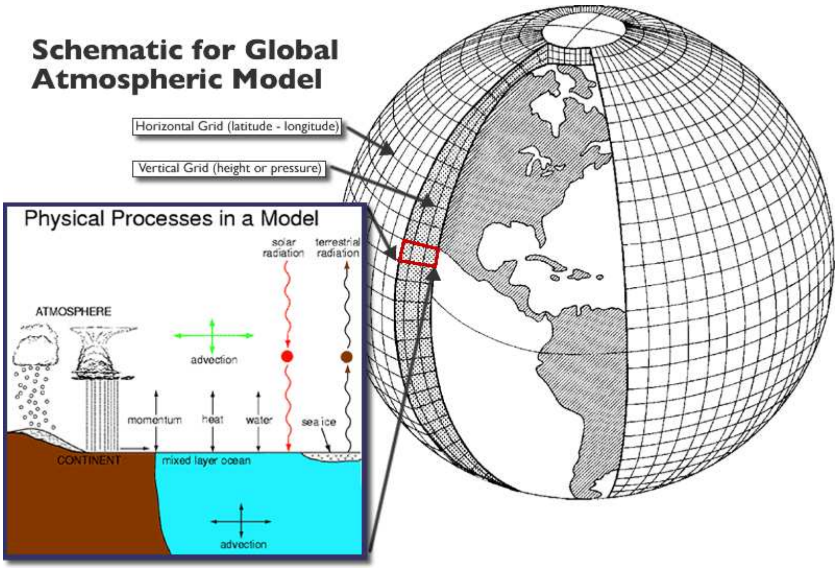

Figure 10: Climate models are systems of differential equations based on the basic laws of physics, fluid motion, and chemistry. To "run" a model, scientists divide the planet into a 3-dimensional grid, apply the basic equations, and evaluate the results. Atmospheric models calculate winds, heat transfer, radiation, relative humidity, and surface hydrology within each grid and evaluate interactions with neighboring points.

State-of-the-art climate models now include interactive representations of the ocean, the atmosphere, the land, hydrologic and cryospheric processes, terrestrial and oceanic carbon cycles, and atmospheric chemistry. The accuracy of climate models is limited by grid resolution and our ability to describe the complicated atmospheric, oceanic, and chemical processes mathematically. Despite some imperfections, models simulate remarkably well current climate and its variability. More capable supercomputers enable significant model improvements by allowing for more accurate representation of currently unresolved physics.

At each grid point, e.g. for the atmosphere, the motion of the air (winds), heat transfer (thermodynamics), radiation (solar and terrestrial), moisture content (relative humidity) and surface hydrology (precipitation, evaporation, snow melt and runoff) are calculated as well as the interactions of these processes among neighboring points. The computations are stepped forward in time from hours to days (weather forecasts) to seasons to centuries (climate studies) depending on the study.

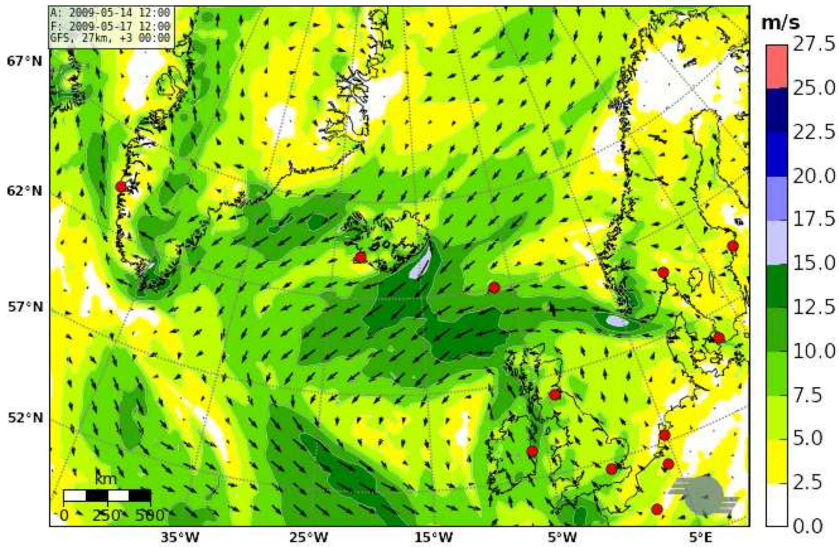

Figure 11: Three day forecast of surface winds over the N-Atlantic region. The forecast is made using the AR-WRF limited area model, forced with initial and boundary data from the NOAA/NCEP GFS global forecasting system. From the web www.belgingur.is.

Weather prediction models are initialized using observed data from radiosondes, weather satellites, and surface weather observations. The irregularly-spaced observations are processed by data assimilation and objective analysis, which performs quality control, and values at locations usable by the model are obtained (usually a grid). The data are then used in the model as the starting point for a forecast. Commonly, the equations used are known as the primitive equations. These equations are initialized from the analysis data and rates of change are determined. These predict the state of the atmosphere a short time into the future. The equations are then applied to this new state to find new rates of change, and predict the atmosphere at yet a further time. This time stepping procedure is continually repeated until the solution reaches the desired forecast time. The length of the time step is related to the distance between the points on the computational grid. Time steps for global climate models may be on the order of tens of minutes, while time steps for regional models may be a few seconds to a few minutes.

Atmospheric models are chaotic in their nature, both because of the limited data available for initialization and due to imperfections in the models themselves. A natural result is that weather forecasts become more and more degraded as time passes. Typically, all predictability is lost after fifteen days of integration, i.e. the forecast has less skill than if one would simply look at the mean state of the atmosphere for the given date.

The Lorenz attractor (cf. Fig. 12) corresponds to the long term behaviour of the Lorenz oscillator. The Lorenz oscillator is a 3-dimensional dynamical system that exhibits chaotic flow, noted for its lemniscate shape. The attractor itself, and the equations from which it is derived, were introduced by Edward Lorens in 1963, who derived it from the simplified equations of convection rolls arising in the equations of the atmosphere. This model is an explicit statement that planetary and stellar atmospheres may exhibit a variety of quasi-periodic regimes that are, although fully deterministic, subject to abrupt and seemingly random change.

Figure 12: The Lorenz attractor, or the Lorenz butterfly, is very significant because it illustrates the concept of "sensitive dependance upon initial conditions" which is inherit in the atmospheric system.

Accepting that weather forecasts are both sensitive to uncertainties in the initial conditions and model imperfections, it is becoming common now to run in parallel a set, or ensemble, of predictions from different but similar initial conditions and/or different atmospheric models. These Ensemble Prediction Systems (EPS) provide a practical tool for estimating how these small differences in the initial conditions can affect the forecast. Examples of such EPS are run by the European ECMWF (European Centre for Medium range Weather Forecasts) and US GFS (Global Forecasting System, NOAA/NCEP) weather prediction models. These models are run dozens of times from slightly different initial conditions and to take into account the effect of uncertainties in the model formulation, each forecast is made using slightly different model equations. These multi-scenarios can be combined into an average forecast (the ensemble-mean) or into a small number of alternative forecasts (the clusters), or they can be used to compute probabilities of possible future weather events.

The EPS can be used as a quantitative tool for risk assessment in a range of weather-sensitive commercial and humanitarian activities. The potential economic value of the EPS can be much higher than that of a forecasting system based on only a single deterministic forecast. One such system is currently being implemented in Iceland. With it, data from dynamically downscaled weather forecasts from the GFS ensemble-system are used to drive a novel runoff model covering the Þjórsár- Tungnaár catchment in S-Iceland. The 21 member forecast is being run two weeks ahead of time, giving valuable information regarding the possible distribution in runoff for the area. This information is than used to optimize the hydrolelectric production from the numerous power plants in the region.

15 Defining a framework

15.1 Motivation

Decisions in utility operations can involve both continuous and discrete variables. The objectives of the operations may be combined of meeting assured demand, maximizing revenue from additional energy production, minimizing risk of not delivering, etc. The objective of this work is to identify opportunities and mechanisms for using advanced technology to aid with those decisions, in particular in the context of weather and climate changes.

As we have seen in preceding chapters, the elements involved in the decisions can be abstracted into variables which may either be variables involved in decisions or variables controlled by other agents or systems, constraints that relate those variables and model-based simulations that serve to calculate relations between variables over time. In this chapter, we will outline the framework and mechanisms that could be applied to assist with decision-making for utility operations. Needless to say, the completed mechanisms will be a complex system, so this first cut is aimed at defining the framework involved.

It is essential to note that the decisions are not necessarily single decisions as they interrelate, both between different variables and across time. This means that the desired result is not simply a single decision, but a plan or a policy. Technically, a plan is a sequence of actions, each of which happens at a given time (or at some temporal function of other actions). A simple plan is just a set of actions over time, possibly connected by temporal constraints, but other plans can also be generated. Of particular interest are contingent plans that specify different actions in different circumstances. The contingent type of a plan is significantly more complex to build and describe, but it provides both key decision points and pre-defined resolutions. The extreme form of contingent plans is a *policy*, which specifies what to do in every possible state of the system.

A significant simplification of contingent trees and policies is the use of conditions without the contingency. In other words, there is no branching done at the given point, there is only one continuation, but the single option is annotated with the conditions for which it would be the choice. These additional conditions allow us to easily identify during execution when the plan ceases to be safe or optimal, and thus we should consider replanning.

15.2 Scope and outline of Framework

The framework being defined here is designed to be general and applicable to decision-making problems of various different scopes. Indeed, the scope of the problem being tackled could be from short-term decision-making for a single powerplant to long-term planning for a complete system. However, the scope does not change the essence of the problem involved, it only changes the size and complexity.

The framework is designed to handle a number of different elements related to modeling operations:

- Time horizon is a range over which the planning is taking place.
- Decision variables represent choices such as how much electricity to generate over a time unit such as a day. Each decision variable may be associated with a timepoint.
- External events represent variables that are outside of the control of humans, such as weather or fluctuations in demand. Again, each event variable may be associated with a timepoint.
- External event value distribution is a probabilistic distribution for possible values, e.g., the likelihood for any possible amount of rain over an area in a given time unit.
- Derived variables represent non-decision variables, whose value is determined from either decision variables or external event variables.
- Constraints and functions relating variables, both external variables, decision variables and derived variables.
- Evaluation functions that specify the goodness of a given solution, with respect to different aspects.
- Simulation model is an element that maps its input elements (which may be taken from different points in time) into values for other variables, which of course may be at different time points. Invariably, the assumption is made that each mapping in a simulation maps earlier timepoint values to later timepoint values.

- Decision-making model is an element similar to a simulation model, but rather than being a simple mapping, it takes a larger context into account and makes decisions about output variables mentioned, based on some intelligent evaluation, such as optimization, planning of reaction.

These elements are then used by an intelligent interactive planning engine to either automatically identify good options/plans or to work in conjunction with a human to evaluate possible decisions and find the most appropriate plan of action. The technical elements of the framework offer opportunities for significant advances in decision-making assistance. A great deal of work is ongoing in these areas today and there is significant interest in collaboration from faculty at both MIT in the USA and Strathclyde University in the UK.

But, even today, a workable baseline exists, namely the EUROPA planning framework, which has been used in multiple NASA applications and is now available as an open source system. The EUROPA framework uses variables over time and very expressive constraints to represent and reason about complex plans. The variables in EUROPA are sufficient to represent all the variable elements outlined above, both those under user control and those determined by external factors, simulations or internal decision-making. The constraints in EUROPA are also very flexible and permit attaching external modules, such as simulations, into the system. In one of the EUROPA applications, for example, the system easily handled an external black-box simulation for calculating the use and generation of electrical power on board the Mars Exploration Rovers. Thus we believe that the EUROPA framework has the representational capacity to handle the complexity of utility operations, with external simulations for modeling weather, climate, water flow, etc.

The main extensions envisioned to enhance the existing capabilities are in the area of more effectively handling uncertainty and risk analysis. In that respect, we look towards ongoing work at MIT on a related subject, namely the assignment of power generation to elements on a micro-grid, in such a way that risk is minimized while the overall effectiveness is maximized.

15.3 Example instantiation

To clarify the elements involved in instantiating the framework, let us consider a simple hypothetical example. The objective is to define a plan for operating a single hydroelectric powerplant over a period of a year. In this planning effort, the operators must consider variations in the weather, due to impact on in-flow and reservoir state, consider minimal and optional power generation (the minimal is the promised level and optional is additional power that can be sold), etc. Let us assume that the goal is to determine a nominal production plan satisfying the minimal power generation requirements, week by week. This is of course an unrealistic over-simplification, but the purpose is to illustrate the framework instantiation elements.

- Time horizon is a year, split into weeks.
- Decision variables are the planned power production each week,
- External variables include the inflow for any given week
- The external value distribution is a probability distribution where, for example, the expected inflow is more in the summer and less in winter.
- Derived variables include required flow for each week's production, as well as the reservoir state at that start and end of each week. Other derived variables could include probability of going below minimum reservoir levels, expected power above minimum production requirements, etc.
- The constraints include the relation between inflow, required production flow and start/end reservoir states for each week. The constraints may also specify limits on risk of going below minimum levels, etc.
- The evaluation functions may include the risk of not meeting minimum production, the amount of optional power generation, etc.
- An example of the simulation model would be a model to simulate weather patterns and resulting inflows.
- Finally, as an example of a decision-making model, we would have a model that emulates weekly decisions made by the operator. This model would take into account time-of-year and reservoir levels, as well as planned weekly production, and adjust the production based on a sensible policy. For example, a very simplistic approach would be to reduce production down to minimum if reservoir level is below some given level at a given time of the year.

15.4 User interactions

The purpose of an instantiation of this framework is to provide decision-making capabilities and assistance to the users. To achieve that, the user must have appropriate ways in which to interact with the system. The actual interface will depend on the application at hand, but there are some key elements that will be common.

In essence, the idea is that the users can set up configurations and external factors so as to set up the problem they desire to work on. Of course, in online applications, much of the external information can be gotten directly from measurements and systems, but that is a variation on the core concept.

The concept of operations is then to provide the user with a set of assistance tools for building, exploring, analyzing, changing, simulating and validating decisions and plans. The specific interface will be built in conjunction with the eventual users, but prior experience in providing critical tools to NASA missions, combined with user-driven interface design expertise available at RU, provides significant confidence in the solvability of that problem. It is also worth noting that in the case of one NASA mission, the Mars Exploration Rover mission, the intelligent decision-assistance tool was built into an existing tool. This approach could be appropriate in some cases for utility operations as well, where existing tools are in place and familiar to the users.

As examples of two closely related applications, let us look at the MAPGEN tool, which has been used in Mars Exploration Rover operations for over five years now, and the Solar Array Constraint Engine, which is in its last stages of installation in mission control center, to assist with International Space Station Solar Array operations.

The Mars Exploration Rover mission was of complexity not seen before in NASA missions as it combined complex rover operations with limited solar energy budget and a great deal of pressure for excellent science return. An artist's rendering of one of the rovers on Mars is shown in figure 13.

The primary problem with operating the Mars Exploration Rovers was that within a very tight temporal budget, with severe limitations on energy usage and thermal load, the scientists wanted to get as much science as possible. To address this problem, a new tool named MAPGEN was developed. The tool built on the EUROPA constraint-based planning engine, and allowed scientists and engineers

Figure 13: Mars Exploration Rover

to build and edit complex rover plans, thus working to achieve as much science as possible each day. The interface of the tool is shown in figure 14. The main screen shows the plan and in that window, users could add activities, move them, edit them, delete them, schedule them and unschedule them, and so forth. The blue side windows were used to allow scientists to add their own constraints on how activities should be scheduled, thus making sure any plans satisfied individual needs.

The International Space Station (ISS) is one of the most complex constructs that the human race has ever built. For many years, the ISS was limited in capability due to power restrictions but over the last two years, the space shuttle has made multiple trips to install new solar arrays to provide all the energy that the space station will need. However, it turns out that operating these solar arrays is tremendously complex. The arrays need to move to track the sun as best possible, but they are also very sensitive to damage from any external forces and materials. Water dumps, boosts, orbital debris avoidance, human space-walks and many many other factors can damage the arrays, if the arrays are in a vulnerable position. Thus, the controllers must constantly make sure that the arrays are in a

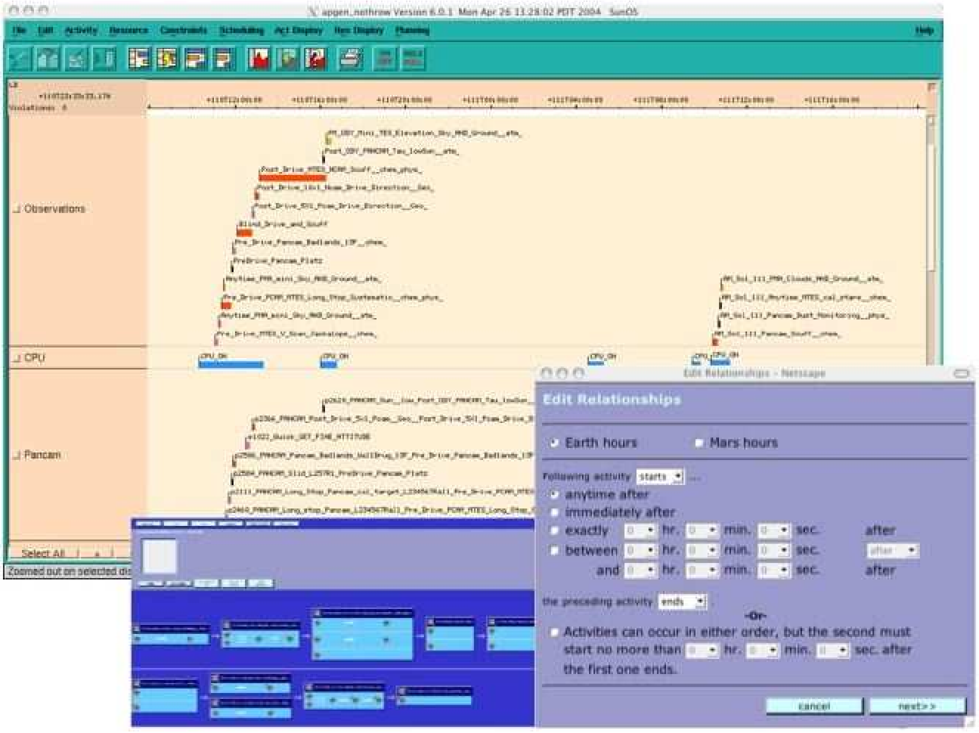

Figure 14: User Interface of MAPGEn tool

position and configuration that is safe for whatever activity is going on.

Flight controllers are Johnson Space Center in Houston realized that it would be impossible to operate the arrays effectively with only human decision-making. They turned to a group of AI researchers, led by Ari Jónsson, to develop a prototype of a tool that might assist them with this complex task. The prototype was so successful that a full-scale development effort was funded by NASA. The result was the Solar Array Constraint Engine (SACE), which is currently being infused into operations in Mission Control Center for the ISS.

The user interface of the SACE tool is shown in figure 16. There are three main elements to the tool. The first is that it will automatically build a plan that ensures safety of the solar arrays and present that to the user. The user can examine and modify the plan via interfaces that are similar to the real-time operations interfaces. The second interface is a real-time monitoring interface. This, called "telemetry", takes data from the space station and displays the current state of the solar arrays in a context that is readily interpretable by the operators, telling them quickly whether there is any problem with the current orientation. Finally,

Figure 15: International Space Station

Figure 16: Interface of Solar Array operations tool

the third interface is a real-time problem resolution interface that allows users to find the best position for the solar arrays at any given time. This capability is invaluable for responding to unexpected events and allows operators to find a safe solution in seconds rather than having to rely on own instincts or work for hours to manually construct and verify a safe solution.

These examples have demonstrated both the capability of AI technology to assist humans with complex operations and that for different applications it is possible to develop suitable interfaces to the technology. It should be noted, of course, that issues certainly arose in each deployment and lessons were learned. But the key result is that EUROPA is in use for multiple current missions and is baselined for additional missions, such as the Mars Science Laboratory (MSL).

Based on this history and the fact that one of the lead developers is involved in this effort, it is clear that if there is desire and funding for developing intelligent decision-making assistance tools for operating utilities in Iceland more effectively, then that can be done. And the results of this effort indicate that a great deal of benefit can be derived from doing so.

16 Concluding Remarks

The primary goal of the effort behind this paper was to build an understanding of utility operations, the decision-making involved and the relation to weather and climate. This, in turn, was done to support the objective of determining whether there is a need and technical capability for developing decision-making assistance for utility operations that assist operators in making decisions; in particular, decisions that relate to weather and climate.

The effort involved had three main elements. The largest one was to study and document the models and decision-making elements of the Icelandic energy system, covering all the major producers, distributers and associated partners. The second was to identify the connections to weather forecasts and climate models, with emphasis on identifying where improved weather information and climate change projects could help utility operations and what meteorological technology would be applicable. Finally, the third was to sketch out a framework for a system that would provide decision-making assistance to utility operators in time-scales from day-to-day control to long-term multi-year planning, taking weather and climate into account.

The study of Icelandic utility operations was very informative, even though the end result was far from being complete. The study showed that weather and climate play roles in almost all utility operations, giving us a clear indication that better integration of knowledge about weather forecasts and climate models would be of significant value to operators. The study also showed that the decision-making involved is complex and relies primarily on engineering expertise and forward simulations.

The analysis of meteorological techniques and decision-making techniques indicated that there exists technology that can be usefully applied to the problem at hand and provide significant value to utility operations. But even more can be done with some additional development of effective techniques and these are of such importance that faculty from University of Strathclyde and from MIT have shown significant interests in working with Icelandic partners on solving the research problems involved.

Our conclusion is therefore that significant value would be gained by improving utility operations, especially when done with respect to weather and climate information. It is therefore our intention to partner up with interested energy companies and the best decision technology experts in the international community to develop this capability and evaluate it in trial operations. For that, we will be seeking support from the energy industry, from Icelandic research funds and European Community funds.

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18 References

References

About us | verkís. (2009, June). Retrieved 2009-06-04, from http://www.verkis.com/about-us/

Bresina, J. L., Jónsson, A. K., Morris, P. H., & Rajan, K. (2005). Activity Planning for the Mars Exploration Rovers. In *15th International Conference on Automated Planning and Scheduling (ICAPS).*

Frank, J., & Jónsson, A. K. (2003). Constraint-based Attribute and Interval Planning. *Constraints*, 339-364.

Hermannsdóttir, K., Jónsson, T., & Pálsdóttir, Þ. (2008). *Greinargerð 08017: Veðurfarslegar álagsforsendur á raflínur (unnið fyrir landsnet 2007-2008)* (Tech. Rep.). Veðurstofa Íslands.

Hs hf. (2009, 01). Retrieved 2009-01-05, from http://www.hsorka.is/English/HSCompanyInfo/HSCompanyPolicy.aspx

Jónsson, A. K., McGann, C., Pedersen, L., Iatauro, M., & Rajagopalan, S. (2005, September). Autonomy Software Architecture for LORAX (Life On Ice Robotic Antartic Explorer). In *Int'l Symposium on Artificial Intelligence, Robotics and Automation in Space (iSAIRAS).* Münich, Germany.

Kim, J. H., & Han, C. (2001, March). Short-Term Multiperiod Optimal Planning of Utility Systems Using Heuristics and Dynamic Programming. *Industrial & Engineering Chemistry Research*, *40*(8), 1928-1938.

Landsnet. (2009, 01). Retrieved 2009-01-05, from http://www.landsnet.is/

Landsnet - frontpage. (2009, 01). Retrieved 2009-01-05, from http://www.landsnet.is/index.aspx?GroupId=320

Landsvirkjun - about us. (2009, 01). Retrieved 2009-01-05, from http://www.landsvirkjun.com/EN/category.asp?catID=78

Netorka. (2009, 05). Retrieved 2009-05-18, from http://www.netorka.is

Or.is :: Reykjavik electricity, geothermal water for heating, cold water, geothermal fields in reykjavik. :: About. (2009, 01). Retrieved 2009-01-05, from http://www.or.is/English/About/

Orkuspárnefnd. (n.d.). *Almennar forsendur 2008.* Retrieved 2009-06-02, from http://www.os.is/Apps/WebObjects/Orkustofnun.woa/swdocument/32836/Almennar+forsendur+2008.pdf

Russell, S., & Norvig, P. (2003). *Artificial intelligence, a modern approach.* Prentice Hall.

Tough2. (2009, 05). Retrieved 2009-05-20, from http://esd.lbl.gov/TOUGH2

Vatnaskil - home. (2009, 05). Retrieved 2009-05-18, from http://www.vatnaskil.is/Home/
What is efla ? (2009, June). Retrieved 2009-06-04, from http://www.efla.is/Pages/975

Several meetings with contacts at each of the involved power production and distribution firms.