Challenges for geothermal energy - experience from Iceland

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Abstract

Environmental impact in developing geothermal fields can be split into five phases. The First Phase Surface Exploration, the First Phase Exploration Drilling, the Second Phase Surface Exploration, the Second Phase Exploration Drilling and finally the Appraisal and Operational Phase. Geothermal energy differs from most other sources of renewable energy as the size and characteristics of the geothermal resource cannot be directly assessed and measured. Indirect investigation, such as geological, geochemical and geophysical mapping are used in the First Phase Surface Exploration to estimate the capacity of geothermal fields, while drilling of exploration wells during the First Phase Exploration Drilling is needed to prove the existence of the field and gather actual data on temperature, pressure and chemical composition of the fluid. The EIA legislation in Iceland requires drilling of exploration wells to be reported to the National Planning Agency. The Agency decides whether an EIA for the exploration well needs to be completed before drilling. EIS is prepared during the Second Phase Surface Exploration. Even after the Second Phase Exploration Drilling there is considerable uncertainty on the energy that can be harnessed. Geothermal fields are often developed in stages (often 40 – 50 MW) to reflect this. The estimate of the sustainable production capacity will change over time in accordance with the behaviour of the reservoir during production.

Introduction

In terms of the population size, Iceland has a vast potential of untapped renewable energy resources. The technical potential for hydro and geothermal has been estimated at 114 TWh/year, of which 71 TWh/year is economically feasible[i&ii]. Obviously nature conservation, environmental and social impact will limit the use of the resources that are considered economically feasible. Over the past 13 years Icelandic authorities have been preparing a Master Plan for hydro and geothermal resources. A proposal for phase 2 of this work was presented last year.

All stationary energy used in Iceland is provided by renewable energy resources, geothermal and hydro and these two cover 81% of the primary energy consumption. Geothermal energy currently provides 66% of the primary energy consumption. The breakdown of the utilization of geothermal energy in 2010 is shown in figure 1. Almost 90% of Iceland's houses and buildings are heated directly by geothermal water and 10% by electricity. Electricity generation in Iceland in 2011 was 17,210 GWh of which 72.7% (12,507 GWh) was by hydro and 27.3% (4,701 GWh) by geothermal. Only 2 GWh were generated by oil. Use of geothermal for electricity production has increased significantly over the past two decade, from 230 GWh in 1992 to 4,701 GWh in 2011 and according to the Master Plan further increase is to be expected in the coming years.

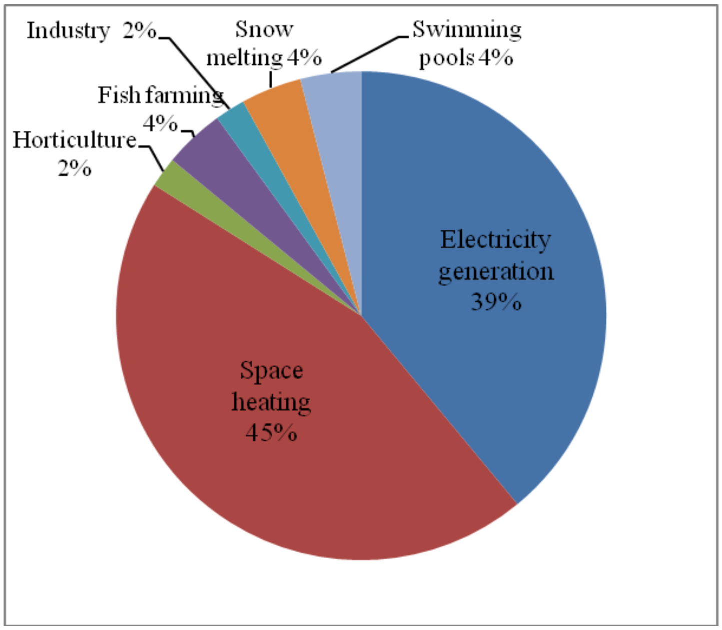

Figure 1 Use of geothermal energy in Iceland in 2010

Landsvirkjun (The National Power Company of Iceland) generates 72.5% of the electricity produced in Iceland in 2011. The mix was 96% hydro and 4% geothermal. The share of geothermal in the pipeline portfolio is much higher and the share of geothermal is thus expected to increase.

Environmental Impact of the use of Geothermal Energy for Electricity Generation

In this paper the discussion will be limited to the use of geothermal energy for electricity generation. Furthermore social and economical impact of the use of geothermal energy will not be addressed, that would need another paper. In this context it should though be stated that use of geothermal energy for heating of houses has saved the nation large amounts. The impact on lifestyle is demonstrated by large apartments, high indoor temperature and number of outdoor swimming pools and soccer fields both outdoor and indoor heated by geothermal water. As early as in the 1930s large schools complexes were placed in close vicinity of geothermal resources. The use of geothermal has thus enhanced the quality of life in the country. Industries such as tourism have also benefited from the utilization.

The geothermal exploration strategy[iii] used at Landsvirkjun is obviously to meet the requirement of the developer to maximize knowledge at the same time as minimizing cost and risk of failure, as well as to fulfil the need for information required by the provider of the exploration license, the National Energy Authority. The preparation is divided into five phases:

1. First Phase Surface Exploration. Harnessing geothermal energy involves various challenges, especially as the resource is only directly assessable for exploration after drilling of expensive wells. During the first phase of the preparation, “First Phase Surface Exploration”, relative low cost exploration methods are used. These include:

- Geothermal and geological mapping which gives indication about the size and nature of the geothermal field.

- Geophysical surveying, such as resistivity measurements. These studies give for example indication on temperature in the bedrock.
- Geochemical surveying including sampling and analyzing of natural outflows. The chemical analysis yields an estimate of the likely temperature in the geothermal reservoir. These geochemical studies provide baseline for the EIA.

The parameters acquired by these studies include for example resistivity maps and reservoir temperature which are used to create a preliminary model for the reservoir.

2. First Phase Exploration Drilling. If the results of the "First Phase Surface Exploration" are positive the next step is to prove the existence of the geothermal reservoir by drilling and testing wells. According to the EIA legislation[iv] in Iceland the National Planning Agency must be notified of the drilling. Before the Agency gives a notification to whether the project shall be subject to an assessment it seeks the opinion of the licensors, the developer and other parties, depending upon the nature of the individual case.

This phase is expensive compared to the "First Phase Surface Exploration" but enhances the knowledge of the geothermal field, the pressure, temperature and the chemical composition of the geothermal fluid. Usually 3 – 6 wells are drilled in this phase.

3. Second Phase Surface Exploration – Environmental Impact Assessment. Information gathered during drilling of the exploration wells is used for improving or constructing a new reservoir model and to plan further surface exploration, for example additional geophysical measurements and well tests. At this stage the size of the reservoir and the potential power production capacity is estimated, obviously still with large uncertainties.

During this phase the work on a full environmental monitoring program is initiated. The main purpose is to identify baseline conditions. The work includes monitoring of groundwater, both groundwater flow and chemistry of the water, air quality, noise, fauna, wildlife, geological features, archaeological heritage and other land uses.

Environmental Impact Statement is prepared during this phase, and the Environmental Assessment Procedure started. The impact can be divided into:

- Issues related to the production capacity of the geothermal field.
- Emission of gases, including greenhouse gases.
- Chemical composition of the fluid and discharge of waste water.
- Groundwater.
- Noise.
- Other land uses.
- Visual impact.
- Landscape.
- Subsidence.
- Geological formations.
- Natural geothermal activity.

- Flora.
- Fauna.
- Thermal microbiological organism (geothermal microbial ecosystem).
- Natural risk (for example seismic activity).
- Archaeological heritage.

During this phase various studies are performed and a baseline established. For some of these items one can make use of methods that are not specially developed for harnessing geothermal energy while others are specifically developed for geothermal. The fact that the geothermal resource is usually at 1.5 – 2 km depth makes it difficult to estimate the production capacity of the field and chemistry, temperature and pressure of the fluid. Work on the EIS is thus very challenging. A few examples to illustrate this:

- Models are used to estimate the production capacity of the field and impact of that production on the geothermal aquifer. As these models will always be based on limited data the results can be undermined and questions raised regarding the sustainability of the project.
- Usually the plan is to reinject the effluent water, but at this stage information on how the aquifer will react to the injection is limited. Will the injection have some negative impact on the geothermal field, for example cooling effect, or trigger earthquakes?
- Emissions of gases, mainly carbon dioxide (CO_2) and hydrogen sulphide (H_2S), are also estimated often based on rather limited data. Questions on how the emission will evolve with production and what part of the emission is natural and what is artificial also need to be addressed. Dispersion of H_2S in the vicinity of the power plant is modelled.
- Will the production impact natural mud pools, hot springs and fumarole activity in the area? In this context it should be mentioned that it is difficult to isolate the impact from the utilization from natural changes.
- Measures are needed to lower the noise level in the vicinity of the power plant and the wells. The noise level can be a delicate issue, especially as many of the geothermal fields are in nature conservation areas. So-called silencers are a part of the wellhead equipment to lower the noise level.

To demonstrate the uncertainties connected to harnessing geothermal energy, an EIA has been carried out four times for a geothermal power plant at Bjarnarflag in North-East Iceland[v]. First for a 20 MW_e plant (one unit) in 1995, the second for two 20 MW_e units in 1996, the third for a 40 MW_e (one unit) in 2000 and finally the forth one for a 90 MW_e (two units) in 2003. Today one would probably go even higher. This increase is mainly based on more information on the geothermal field. This example also illustrates the technical development in turbines over time to save costs.

4. Second Phase Exploration Drilling. Following the EIA but prior to a final investment decision on the project the geothermal field is further explored by drilling more wells, well tests i.e. to gather information on the response of the field to production.

5. Appraisal and Operational Phase. During operation constant re-evaluation of the geothermal resource is performed especially using data collected from existing wells on pressure, temperature and chemistry of the fluid, and information from additional wells that need to be drilled to replace production or reinjection wells. The estimate of sustainable production capacity will thus become better and better during the lifetime of the power plant.

Conclusion

Harnessing geothermal energy is quite different from other renewables, as the resource is not directly accessible for measurement. Geothermal power plants have various environmental impacts and EIA is only possible after drilling of several wells and even then the uncertainties regarding some of the items that need to be addressed in the EIS is high. It is thus easy to undermine the results presented in the EIS and question the sustainability of the project. Monitoring the aquifer during production both during the preparation phase and operation of the power plant will make the estimate on the production capacity more accurate over time. It is therefore recommended to develop geothermal fields in phases.

Geothermal fields are on sites that have other interest, sites of natural interest, tourist attractions etc. It is thus extremely important to use all measures to minimize impact from the first field studies through operation. This is especially the case during the first phases when the existence of the geothermal field has not been confirmed, the potential project has not proven to be economical, the EIA process been completed or licenses obtained. A Regional plan where potential drilling areas and areas of special concerns have been marked facilitate efficient preparation and during drilling various measures can and need to be taken to reduce the impact.

Permitting process for harnessing geothermal is more complex for geothermal than other renewables. There is an opportunity and a need for streamlining. One example is to allow an EIA process for the project based on the estimated capacity of the field - not the proven capacity. The authority that issues exploitation license would then need to decide in what steps and how fast the field is developed. Such a decision should be based on actual data on the response of the aquifer to production.

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