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PLANNING OF GEOTHERMAL PROJECTS IN ICELAND

Halldór Ármannsson, Benedikt Steingrímsson, Ásgrímur Guðmundsson
ISOR – Iceland GeoSurvey
Grensásvegur 9
108 Reykjavík
ICELAND
halldor.armannsson@isor.is

ABSTRACT

Geothermal energy supplies about 65% of the primary energy used in Iceland. The most important use is for space heating but geothermal power production is increasing rapidly. Exploration and development of the geothermal fields are divided into several phases starting with preliminary studies and continuing with appraisal study, project design, construction and operation of a power plant. Earlier the development strategy was to fully utilize the generating capacity of each field in one“large” power plant. This meant that the generating capacity of the field had to be known prior to the decision on the installed capacity of the power plant to be built. This strategy required an immense effort in exploration and testing to determine the optimum generating capacity of a field, requiring a large investment in exploration, drilling, reservoir testing and monitoring. A multi-step strategy is considered more suitable and more cost-effective for geothermal development than one large (full) step strategy. Stepwise development means that the geothermal field is developed in relatively small (20-50 MW_e) steps. The response of the reservoir to this production is then monitored and evaluated and used for deciding if and when the next development step is taken. In this way, the power plant is in operation (and earning money for its owners) while the field is being tested. Stepwise development of geothermal resources has been applied in Iceland during the last 15-20 years.

1. INTRODUCTION

Iceland is a volcanic island that lies astride the Mid Atlantic Ridge, the rift zone along the constructive boundary between the American and the Eurasian tectonic plates which move apart at an average rate of 2 cm per year. The presently active zone of rifting and volcanism crosses Iceland from southwest to northeast.

Iceland is rich in geothermal resources due to the volcanic activity, and heat flow through the crust is several times higher than world average. Traditionally the geothermal fields are divided into *high temperature fields*, in which temperatures above 200°C are found at 1 km depth and *low-temperature fields*,in which temperatures are lower than 150°C in the uppermost kilometre. Some 30 high temperature fields have been described in Iceland, all within the active volcanic zone (Figure 1). The low temperature activity is highest on the flanks of the volcanic zones but low temperature resources are found in most parts of the country (Figure 1).

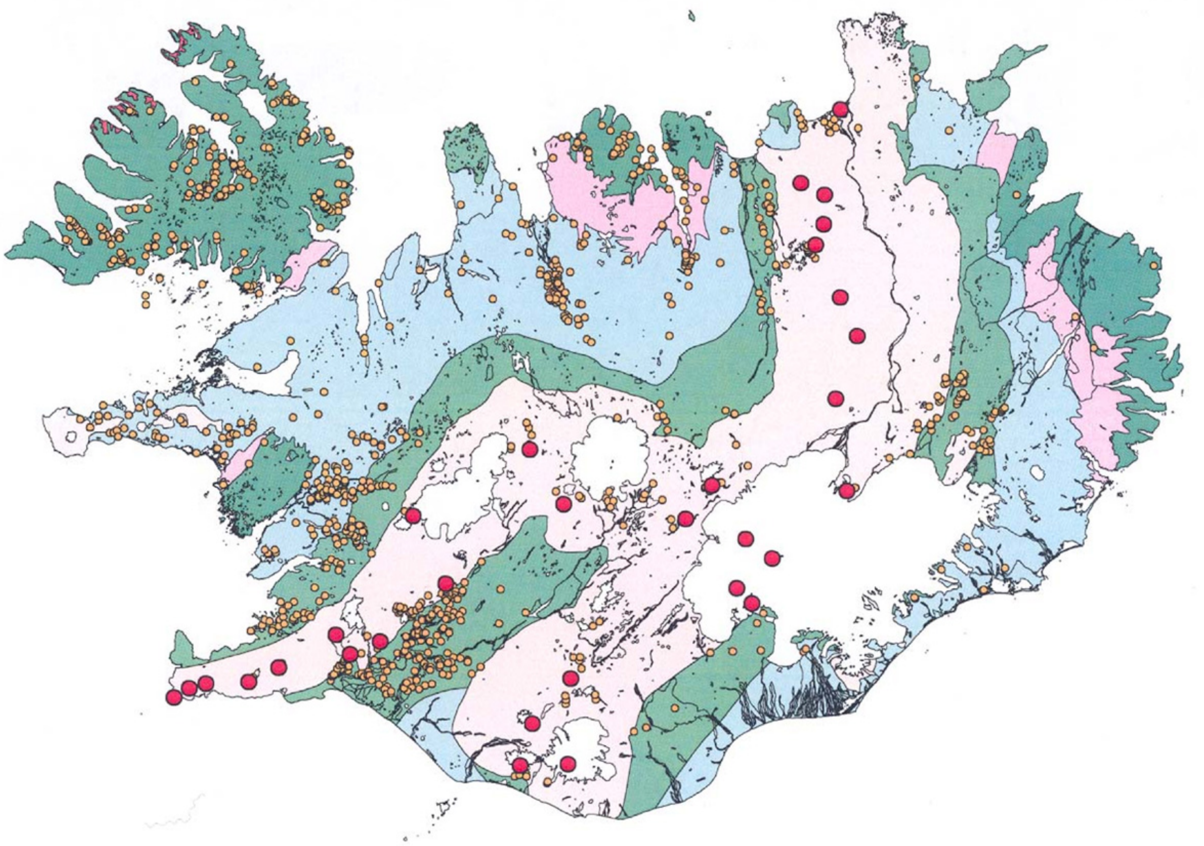

FIGURE 1: Geothermal map of Iceland. High temperature fields inside the active volcanic zone are shown as red circles, and hot and warm springs as yellow circles

2. GEOTHERMAL UTILIZATION

Through the centuries there was little utilization of geothermal energy in Iceland. Hot water from warm springs was, however, used locally in some areas for bathing, cooking and washing and sulphur was mined from a few of the high temperature areas and exported. Large scale utilization started initially with the utilization of low temperature resources for space heating. Later utilization of high temperature resources for electrical generation, space heating and some industrial uses followed. Cascaded use of geothermal water became common in the late 20th century.

Large scale utilization of geothermal resources in Iceland began in 1930 when a district heating system started operating in Reykjavik supplying hot water to a hospital, a school, a swimming pool and some 70 homes. The extent of utilization grew over the next decades (Figure 2). During the energy crisis in the 1970´s, an effort was made to abandon the use of oil for space heating and replace it with geothermal energy. Today almost 90% of houses in Iceland are heated by geothermal energy and electricity serves the remaining 10%. Now (2008) the installed geothermal power capacity is 500 MW_e. Geothermal energy has become the main source of energy in Iceland supplying about 65% of the primary energy used in the country (Figure 3). The most important uses are still for space heating, but electricity generation is growing rapidly and amounts to more than 20% of the utilization. Figure 4 shows a pie chart on how the geothermal energy was utilized in Iceland in 2007.

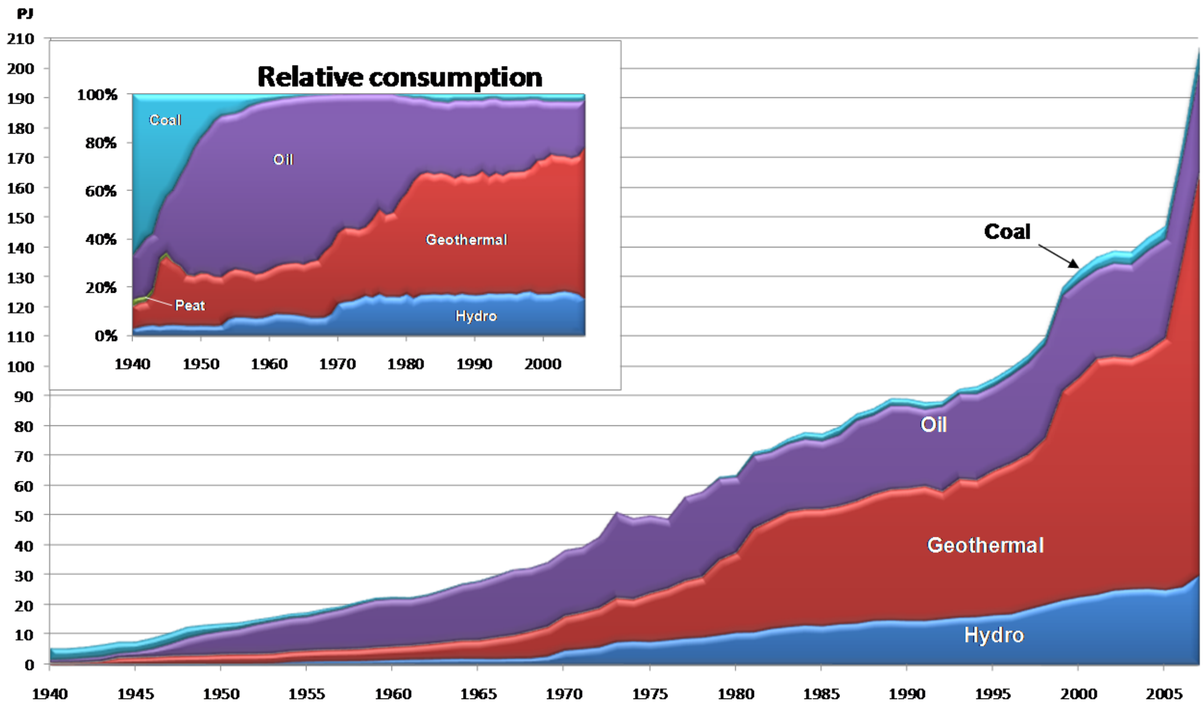

FIGURE 2: Primary energy consumption in Iceland 1940-2007. Source: Orkustofnun (National Energy Authority)

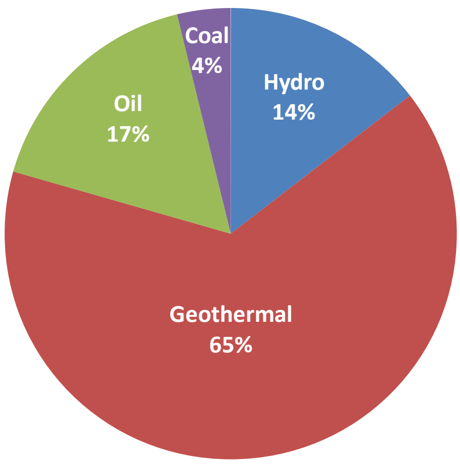

FIGURE 3: Sources of energy used in Iceland in 2007. Source: Orkustofnun (National EnergyAuthority)

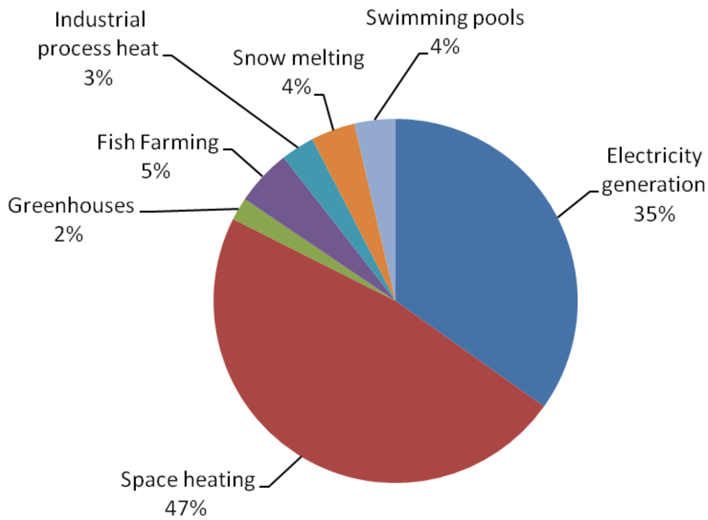

FIGURE 4: Geothermal energy uses in Iceland in 2007. Source: Orkustofnun (National Energy Authority)

3. GEOTHERMAL PROJECT STRATEGY

3.1 Exploration programme of 1969

Methodology of the exploration of Icelandic geothermal areas has been under discussion and development since their utilization started. It was soon evident that the geothermal areas were an important source of energy for the nation. It was also clear that a considerable effort of costly exploration, drilling and testing of wells had to be carried out for years before it was possible to evaluate the feasibility of utilizing the geothermal fields, in particular the high temperature fields.

The first exploration programme, for development of the geothermal fields, was proposed by Orkustofnun (the National Energy Authority) in 1969.To organize and accelerate the utilization of the fields exploration was divided into three phases (Björnsson 1970):

- Regional Survey, during which all relevant methods of geology, geochemistry and geophysics should be applied to obtain a conceptual model of the geothermal field and locate production sites.
- Exploratory Drilling to obtain information on the geological structure, temperature and pressure distribution and fluid characteristics of the geothermal reservoir and use it to modify the conceptual model of the field, to design production wells and to carry out a preliminary plant design and a pre-feasibility study of the field.
- Production Drilling and Testing; carried out in steps to test the production capacity of the field if the results of the pre-feasibility are promising.

In the time frame for the exploration it was estimated that the regional survey could be completed in 1-3 years, the exploration drilling would take 1-2 years and the production drilling 1-3 years. The exploration of each area would therefore take up to 8 years before the capacity of the field would be confirmed and the feasibility of a utilization project could be determined.

The development strategy of the 1969 program was used as a guideline for the exploration of several high temperature areas in Iceland in 1960-1980, including the Reykjanes, Námafjall, Svartsengi, and Krafla fields.

The Krafla power plant is an example of a project originally planned in accordance with the 1969 Exploration Programme but its development was subject to interferences due to management and natural causes. Surface exploration was carried out in accordance with the programme 1970-1973. At that time a hydropower project in nearby River Laxá was reduced in scale due to local opposition and there was concern about dearth in power supply in North Iceland and therefore it was decided to speed up operations in Krafla. Two relatively shallow exploration wells were drilled in 1974 and based on the results for these and the known character of the nearby Námafjall geothermal system (where 9 relatively shallow wells had been drilled) the decision was made to purchase two 30 MW double flash turbines to be on line in 1977. In 1975 a volcanic eruption started in the neighbourhood causing excess gas in the fluid and the clogging up of wells due to deposition. In 1978 the first turbine was started but the steam available was only sufficient for 7 MW_e production. Another well was drilled in 1978 but its steam caused problems and the increase in production was small and it was decided to put a halt to drilling. Fumarole gas was investigated and the existence of steam producing areas where volcanic influence was absent proved. In 1980 drilling was resumed and in 1984 the first turbine was producing 30 MW_e. The volcanic activity lasted till 1984 and the second turbine was put in storage for the time being. As most of the later wells were high enthalpy wells a problem arose as there was not sufficient steam for the low pressure part of the double flash turbine and two low enthalpy make up wells were drilled as well as two exploratory wells until 1997 when it was decided to drill for steam to supply the second 30 MW_e turbine which was commissioned in 1999 when 8 more wells had been drilled. Thus it had taken nearly 30 years to get full production from the Krafla power plant.

3.2 Systematic exploration programme of 1982

The Parliament of Iceland made a resolution in 1981 that the government, should set up and implement an exploration program for the high temperature areas in such a way that the feasibility study for utilization of two areas should be carried out within five years and five more areas within ten years. In late 1981 the Ministry of Energy and Industry asked Orkustofnun to set up a systematic exploration programme for the high temperature fields according to the goals of the resolution. A task force of six geothermal specialists was allocated the job and completed it in a year (Stefansson et al., 1982). The programme was never executed due to lack of funding in the following years. However the strategy for exploring high temperature fields was analysed and a generic plan put forward for the development of geothermal fields. (Figure 5) in five phases: *Preliminary study* starting with a reconnaissance study of the field, an *appraisal study*, followed by *project design*, a *construction phase*, and finally the *operation* of a geothermal plant. A time frame was estimated for the development according to which a decision can be made on how the field should be utilized after 10 years of exploration.

Surface exploration of the Hengill geothermal area started in the 1940s but seriously in Nesjavellir in 1964 when Reykjavík Heating Company (now Reykjavík Energy) acquired the Nesjavellir land. Exploratory drilling was carried out and a pilot plant run until 1982 when a full scale development plan for hot water production for the Reykjavík area using heat exchangers was put into action in accordance with the 1982 Systematic Exploration Programme. Several appraisal wells were drilled from 1982 to 1986 when a decision to build a 100 MW_{th} heating plant was made. This plant was commissioned in 1990 and expanded to 150 MW_{th} in 1992. In 1996 a decision was made to build a 60 MW_e power plant and expand the heating plant to 200 MW_{th} and this addtion was commissioned in 1998. The plant was further expanded to 90 MW_e/290 MW_{th} in 200 and to 120 MW_e in 2005.

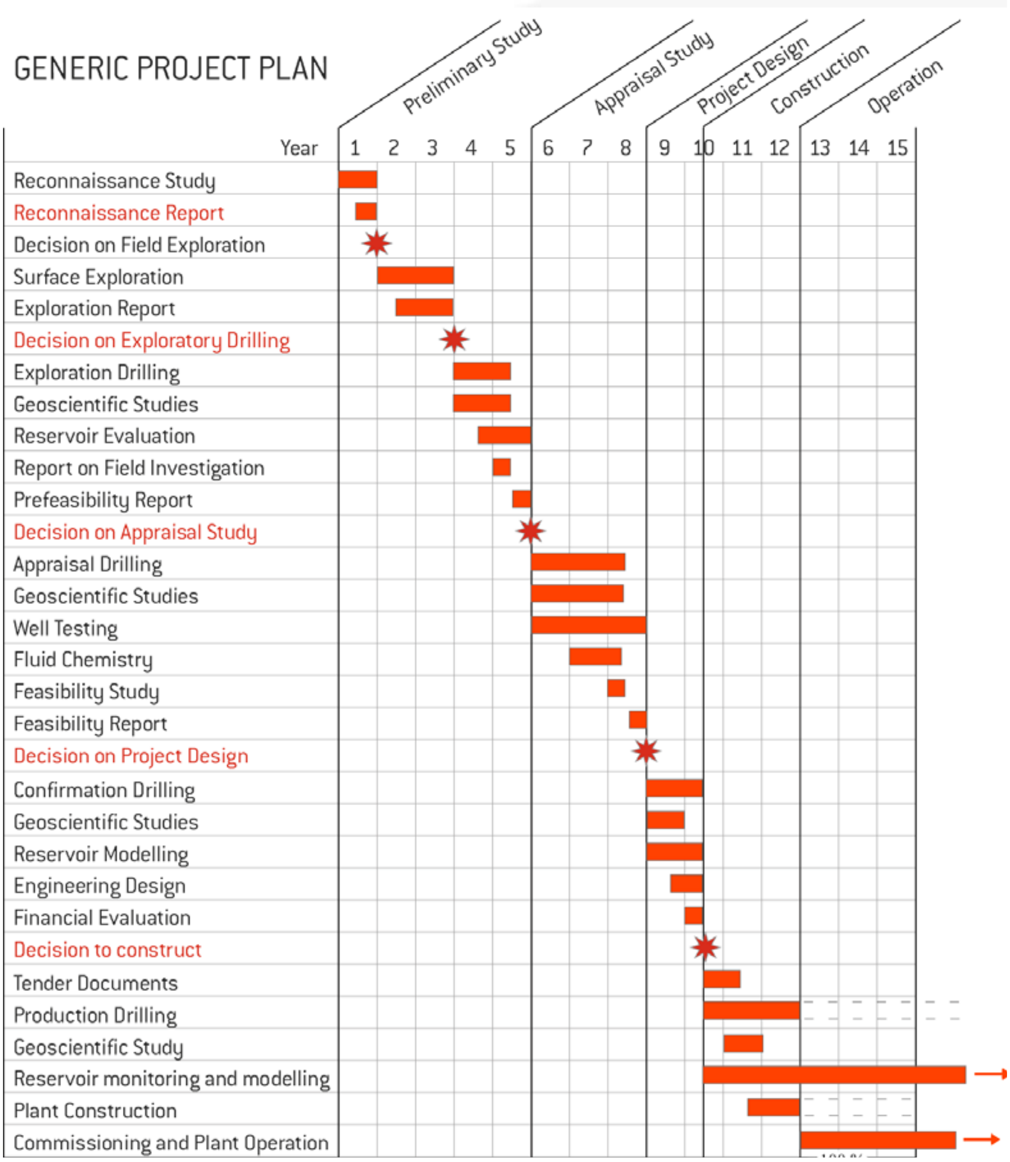

FIGURE 5: Generic phase plan of 1982 for geothermal development

3.3 Stepwise development strategy

The development strategies described above assume that the production capacity of the geothermal field is known when a decision is made regarding utilization. A generating capacity of the power plant is subsequently selected to fully match the field potential. This strategy is borrowed from hydropower development for which the determination of production capacity is rather easy and is known at a relatively early stage in the exploration programme. This is, however, not the case for the geothermal areas for which reliable knowledge on the generating capacity can only be obtained through detailed exploration of the field, drilling and monitoring the of response of the geothermal reservoir to production lasting for some years. In the generic plan of 1982, it is after 10 years of intensive exploration, drilling and testing that a decision is made on whether to go ahead with the power plant.

Stefansson (1992) discussed several examples of geothermal projects worldwide and pointed out that a stepwise development strategy for geothermal resources has considerable economic benefits compared to full utilization of the field capacity in one large power plant. By following the generic plan of Figure 5 but selecting a relatively small (20-50 MW_e) power plant as a first step, the time scale can be reduced and the plant commissioned and put into operation much earlier than for a "full" size plant (Stefansson, 2002). Monitoring of the field response to the first development step is then used to determine if and when the next step can be taken and so on until the total reservoir capacity is reached. Thus the generating capacity is first known when the field is fully utilized, whereas in the one step strategy the production capacity is determined before the power plant is constructed. A comparison of these two strategies is shown in Figure 6.

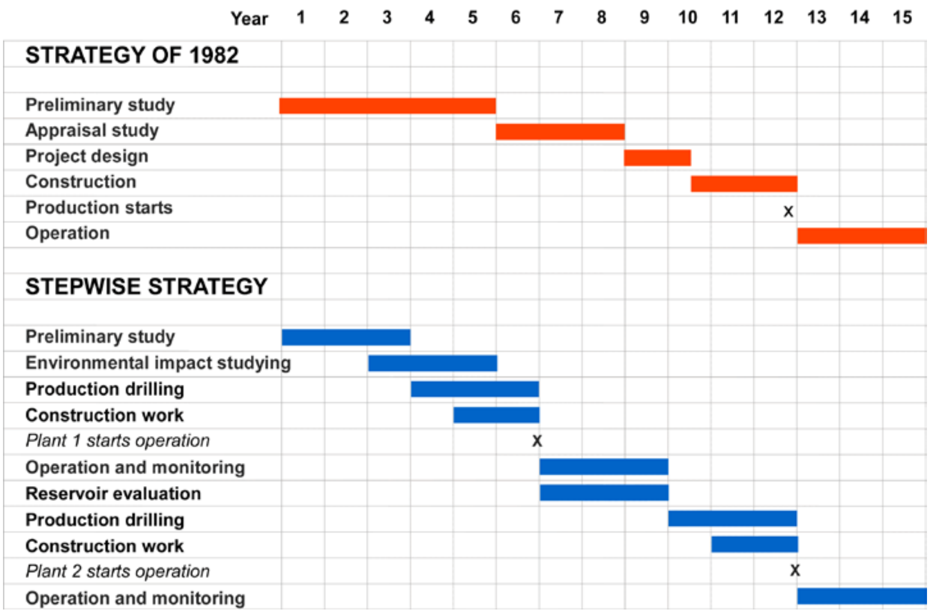

FIGURE 6: Comparison of the stepwise development strategy (lower part of the figure) and the conventional development strategy (upper part of the figure)

As mentioned above exploration of the Hengill area started in the 1940s. Exploratory wells were drilled in the Hellisheiði area in 1985 and 1994, but a concerted exploration effort was started in 2001 and 5 exploration wells were drilled 2001-2002 the results of which provided grounds for the decision to build a power plant in stages. In 2006 2 45 MW_e units were commissioned, a 30 MW_e low pressure turbine in 2007 and two more 45 MW_e units in 2008 and a hot water plant is planned for 2009. The estimated production potential is 300 MW_e and 400 MW_{th}.

A modification of the stepwise development strategy is the 5 MW_e portable power unit of Kaldara plc (www.kaldara.com) which may be a condensation or a binary power plant placed at the wellhead of a particular well whose steam is utilised. Such turbines can be started after 2 years of exploration and can thus give some return on investment much earlier than conventional turbines. One possibility is preliminary production during the construction of a power plant. An example is the procurement of such a unit for the Bjarnarflag power plant where steam acquisition is now underway and about half the steam for a 90 MW_e power plant has been obtained. The use of this unit is planned for 3.5 years or until the power plant has been built. Then it is planned to move the unit to Theistareykir where steam is being acquired for another power plant and use it there until that plant is commissioned. And so on.

3.4 Research permits

Before a project proponent can obtain a Research Permit for a geothermal area he is interested in developing from the Ministry of Industry he needs to present a detailed research plan describing the objective of the project, the areal extent, the time plan, possible effects on neighbouring areas, previous research in the area and research and operations plans. Orkustofnun (www.os.is/page/ald_leidb) has published guidelines for applications for research permits.

3.5 Environmental impact studies

Project proponents are subject to restrictions due to planning decisions that have been made for the area to be developed. Recently Act No. 105/2006 on Strategic Environmental Assessment (SEA) was passed in Iceland. SEA is carried out at the planning stage and is described as a set of processes, documents and analyses that help the public administration to reach its environmental goals. To this purpose scientific data, data on environmental issues, local and national policies, and information about international laws and regulations are consulted.

According to the Act on Environmental Impact Assessment No. 106/2000, the Act on Changes to the Act on Environmental Impact Assessment 74/2005, and the Act on Planning and Building No. 73/1997, all projects, which may have a significant effect on the environment, natural resources or community, shall be subject to an Environmental Impact Assessment (EIA). Skipulagsstofnun (the Planning Agency) monitors the application of laws and regulations on planning, building and Environmental Impact Assessment. The Minister for the Environment has the supreme control of planning and building under the Planning and Building Act and EIA programmes under the Act on Environmental Impact Assessment. The assessment must be a part of the planning process.

Appendix 1 to a regulation supplementing the environmental act states which projects are compulsory for an EIA. Other projects, which may or may not be subjected to an assessment, depending on their magnitude, are listed in Appendix 2 of the regulation. These include "*drilling of production wells and research wells in high enthalpy fields*", and "*plants for production of electricity, steam and hot water, hydropower plants with installed capacity of 100 kW or more or geothermal exploitation of 2500 kW or more*". Initial drilling thus falls under projects listed in Appendix 2. In such cases the executing party prepares a report, the Environmental Impact Statement, to inform the Planning Agency of the intended project. The report must include a detailed description of the proposed project, in accordance with the procedure outlined in the regulations. After evaluation the Agency makes a decision on whether the project is exempted from EIA.

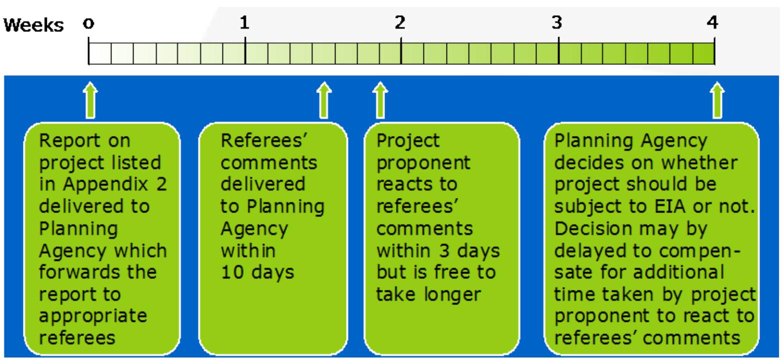

FIGURE 7: Procedure for projects listed in Appendix 2 of regulation to the Act on Environmental Impact Assessment, No. 106/2000

Figure 7 shows the progress of a project from proposal to EIA. If EIA is required the developer prepares an action plan for the EIA, which requires the approval of the Planning Agency. Figure 8 shows the progress of an EIA and the time required. The whole process from the time when the Planning Agency is handed the Environmental Impact Statement to a final decision of the EIA can be a minimum of 4 weeks if the reports are found to be sufficient and no verdict is disputed. The time required by the developer to prepare the reports is not included here, and the time required varies, depending on the size and complexity of the proposed project.

The EIA process itself is depicted in Figure 8 and will take more than 32 weeks and considerably longer if the verdict is disputed. Power production or a large scale industrial project would fall under Appendix 1 of the Act and EIA is thus compulsory.

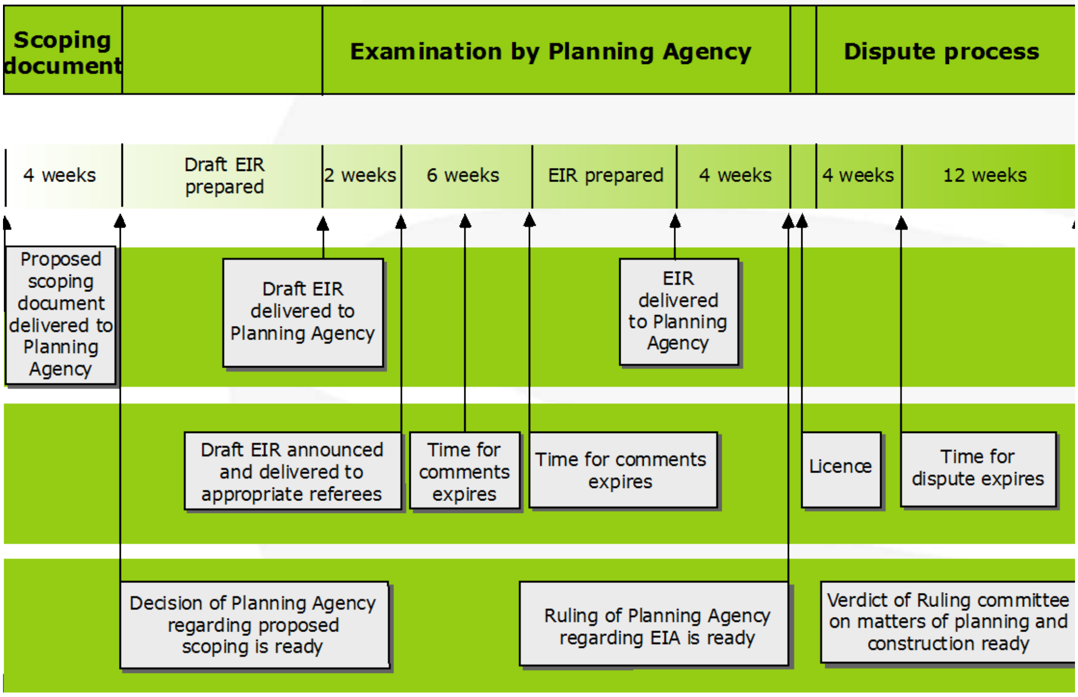

FIGURE 8: The EIA process

3.6 Master Plan for utilization of renewable energy resources

The Government of Iceland decided in 1999 to develop a Master plan for utilization of hydropower and geothermal resources. The Master Plan should be based on the best scientific information available and its development should be open to democratic involvement.

In the first phase of the Master Plan, a large number of proposed power projects were to be evaluated. The evaluation should involve the impact of the project on the environment, nature and wildlife, landscape, cultural heritage and ancient monuments, grazing and other traditional land use, outdoor life, fishing and hunting. The implications for employment and regional development were also to be accounted for. Finally the proposed projects should be categorized on the basis of efficiency and economic profitability, as well as how they will benefit the economy as a whole (The Minister for Industry, 1999). A more detailed description of the Master Plan was presented by Steingrímsson et al. (2008) and a special website, www.landvernd.is/natturuafl, was set up, for the project.

The Ministry of Industry, in co-operation with the Ministry of the Environment, established in April 1999 a special Steering Committee for the project. . In its function the Steering Committee was supported by about 50 experts working in four different working groups for the first phase:

- **Working Group I** was to evaluate what impact proposed power projects will have on nature, i.e. landscape, geological formations, vegetative cover, flora and fauna, as well as on cultural heritage and ancient monuments.

- **Working Group II** was to evaluate the impact on outdoor life, agriculture, revegetation, fishing in rivers and lakes, and hunting.
- **Working Group III** was to evaluate the impact proposed power projects can have on economic activity, employment and regional development.
- **Working Group IV** was to identify potential power projects, both hydropower and geothermal energy, and carry out technical as well as economic evaluation of the projects.

During the development of the Master Plan Orkustofnun and/or power companies compile reports on project proposals they wish to have evaluated by the Steering Committee. These reports are made public, and as a first step of the process, the public and interested organisations will have an opportunity to review the reports and offer comments.

It is expected that a total of about 100 project proposals will be evaluated by the Working Groups and the Steering Committee. A report on the first phase of the work, comparing 19 hydropower projects with an energy potential of 16.600 GWh/a and 24 geothermal projects with an energy potential of 18.000 GWh/a, was issued in November 2003 (The Board for the Master Plan for the Use of Hydropower and Geothermal Energy, 2003). The hydropower projects were mainly in glacial rivers in the central highlands whereas most of the geothermal projects were in geothermal fields near to inhabited lowlands.

The second phase of the Master Plan began in 2005 and now the focus is on scientific exploration of the active geothermal systems in the central highlands of Iceland but also on the environmental impact and sustainability of energy development. The second phase is expected to be completed in 2009. The third phase is expected to include exploration of recoverable geothermal energy outside the active geothermal areas.

4. DISCUSSION AND CONCLUSIONS

Geothermal utilization on a large scale began less than 80 years ago in Iceland. Today, geothermal energy amounts to about 65% of the primary energy used in the country. The techniques and strategies on how to explore and utilize geothermal fields have been developed during these years as the knowledge of the geothermal fields and the geothermal processes has improved. It has proved useful to divide geothermal exploration and development into sequential phases, the first phase being a preliminary study of the geothermal field to be explored and the last being the operation of a geothermal installation in the field, as shown schematically in Figures 5 and 6.

The general structure of the generic plan of 1982 is still valid after more than twenty years. Increased environmental awareness and new law from the Icelandic Parliament on environmental impact studies have added various environmental studies and monitoring to the tasks in all the development phases. In 1982 the strategy was to develop the geothermal fields in one big step. In recent years it is generally accepted by the geothermal industry in Iceland that a stepwise development is more economical and better suited to the geothermal fields. It has been the policy of the Icelandic Government to promote the uses of geothermal resources in order to minimize import of oil. A governmental institution, Orkustofnun (The National Energy Authority), has been a major investigating agent in exploring the geothermal resources since their utilization began, separately or in partnership with the municipal or governmental energy companies. Orkustofnun also acted as a consultant to the energy companies until 2003 when the institute was divided into two; Orkustofnun (OS) and Iceland GeoSurvey (ISOR). Orkustofnun is now mainly an administrative and regulating agency whereas ISOR is the former geothermal specialist group of OS and carries out geothermal exploration consultant work for OS, the Icelandic energy companies and others. The role of the Icelandic state in the geothermal development in Iceland has gradually decreased with time. The energy companies are, however, still to a large extent owned by the state and/or the municipalities. The government initiated a few years ago the development of a Master Plan for the utilization of both hydropower and geothermal resources. This is in a way a pioneering work which calls for research in methodology in order to base decisions on scientific knowledge. The Steering Committee of the Master Plan project have supported several new research projects in order to evaluate the proposed energy projects. Examples of such research projects include:

- Methods to evaluate the conservation value of wilderness areas;
- Tourism and the value of an area for outdoor recreation;
- Methods to evaluate landscape; and
- The economic efficiency of power projects and their potential socio-economic impact.

The government has recently decided to participate with the energy companies in a large geothermal research project. The project is called the Iceland Deep drilling Project (IDDP) and aims at a better understanding of the geothermal resources below the relatively well known upper 3 km of the crustm (Fridleifsson and Elders, 2005). At 4-5 km depth within the volcanic systems it is expected to find fluids at supercritical pressure and temperature. Such deep unconventional geothermal resources are expected to produce super high enthalpy fluid at surface and result in a more efficient utilization of the high temperature areas.

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