

PHASES OF GEOTHERMAL DEVELOPMENT IN ICELAND

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ABSTRACT

Geothermal energy supplies over 50% 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 “big” power plant. This meant that the generating capacity of the field had to be known prior to deciding the installed capacity of the power plant to be build. This strategy required an immense effort in exploring and testing the field to determine the optimum generating capacity of a field. Knowledge which takes a decade or so to get and a large investment in exploration, drilling, reservoir testing and monitoring.

A multi-step strategy is considered more suitable for geothermal development and more cost-effective than one large (full) step strategy. Stepwise development means that the geothermal field is developed in relatively small (20-50 MWe) 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 under 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 10-15 years.

1. INTROUCTION

Iceland is an island that lies across 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. Iceland resides on a mantle plume and a hot spot in the rift zone and has been formed in frequent volcanic eruptions continually from Miocene time to present. This explains why this part of the ridge rises above sea level and forms an island of an area larger than 100.000 km². The presently active zone of rifting and volcanism crosses Iceland from southwest to northeast. Volcanic eruptions are very frequent in this zone and take place typically every few years. The Icelandic crust is therefore very young on the geological time scale and rocks on surface range in age from zero near recently active volcanoes to 15-16 million years in the coastal areas furthest away from the volcanic zone in the east and the west.

Iceland is rich of 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*, where temperature above 200°C is found at 1 km depth and *low-temperature fields*, in which temperature is lower than 150°C in the uppermost kilometre. Some 30 high temperature fields have been outlined in Iceland, all within the active volcanic zone as shown in Figure 1. The low temperature activity is highest on the flanks of the volcanic zones but some low temperature resources are found in most parts of the country (Figure 1).

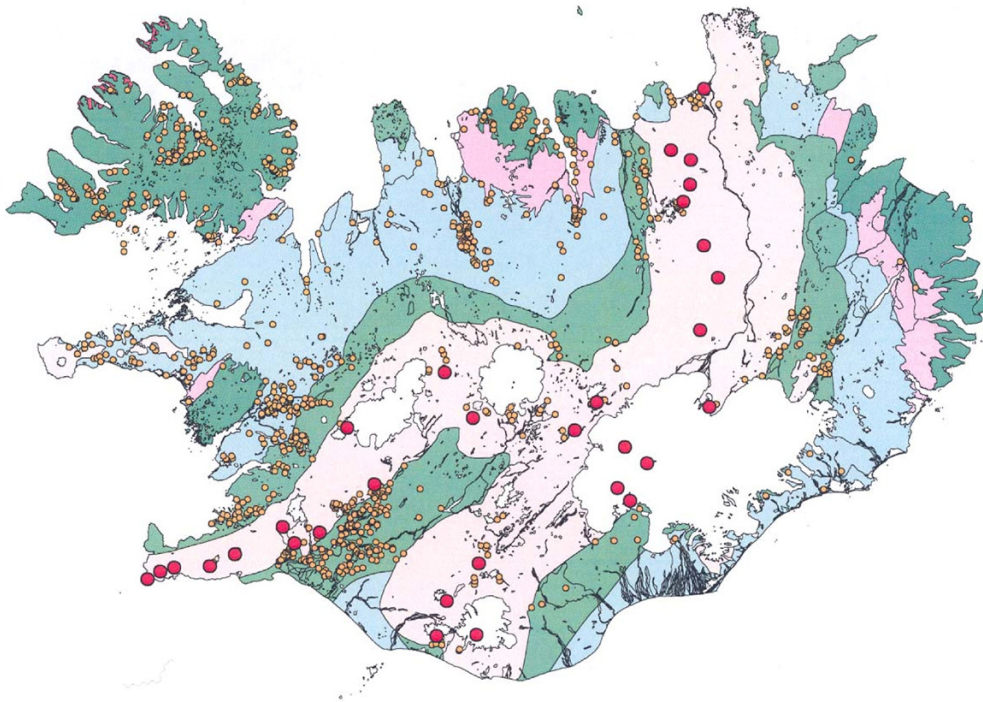


FIGURE 1: Geothermal map of Iceland. High temperature fields inside the active volcanic zone are shown as red circles, and hot and warm springs as yellow circles.

2. GEOTHERMAL UTILIZATION

The utilization of the geothermal resources of Iceland was very limited through the centuries. Hot water from warm springs were, 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 to Denmark. It was, however, not until in the last century that large scale utilization of the geothermal resources started. Initially the geothermal development focused on the utilization of low temperature resources for space heating. Later utilization of the high temperature resources for electrical generation, space heating and some industrial uses followed. Cascaded use of geothermal water became common in the last three decades of the 20th century as outlined in the Lindal diagram (Figure 2).

Large scale utilization of geothermal resources in Iceland began in 1930 when a district heating system started operation in Reykjavik (capital of Iceland) supplying hot water to a hospital, a school, a swimming pool and some 70 homes. The utilization grew gradually over the next decades (Figure 3). During the energy crises in the 1970s an effort was made to exclude uses of oil for house heating and replace it with geothermal energy. This was a very successful development and today almost 90% of houses in Iceland are heated by geothermal energy and electricity serves about 10% the heating market. During the last few decades the geothermal utilization has continued to grow as geothermal power production has increased. In 2005 the installed geothermal power capacity is 200 MWe but with two new geothermal power stations under construction this will be doubled before the end of 2006. Geothermal energy has become the main source of energy in Iceland supplying over 50% of the primary energy used in the country (Figure 4). The most important uses are still for space heating, but electricity generation is growing rapidly and amounts now to some 20% of the utilization. Figure 5 shows a pie chart on how the geothermal energy was utilized in Iceland in 2004.

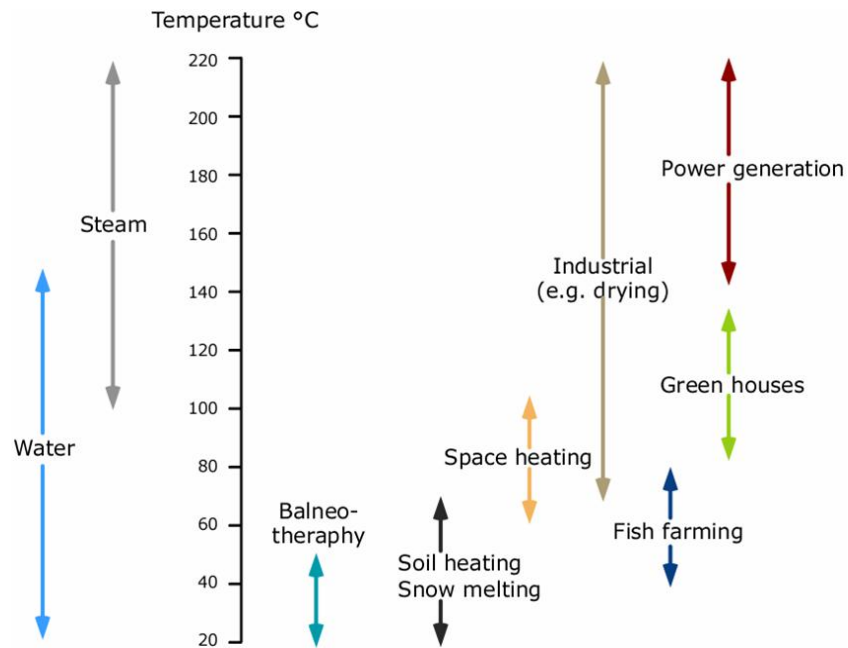


FIGURE 2: Lindal diagram.

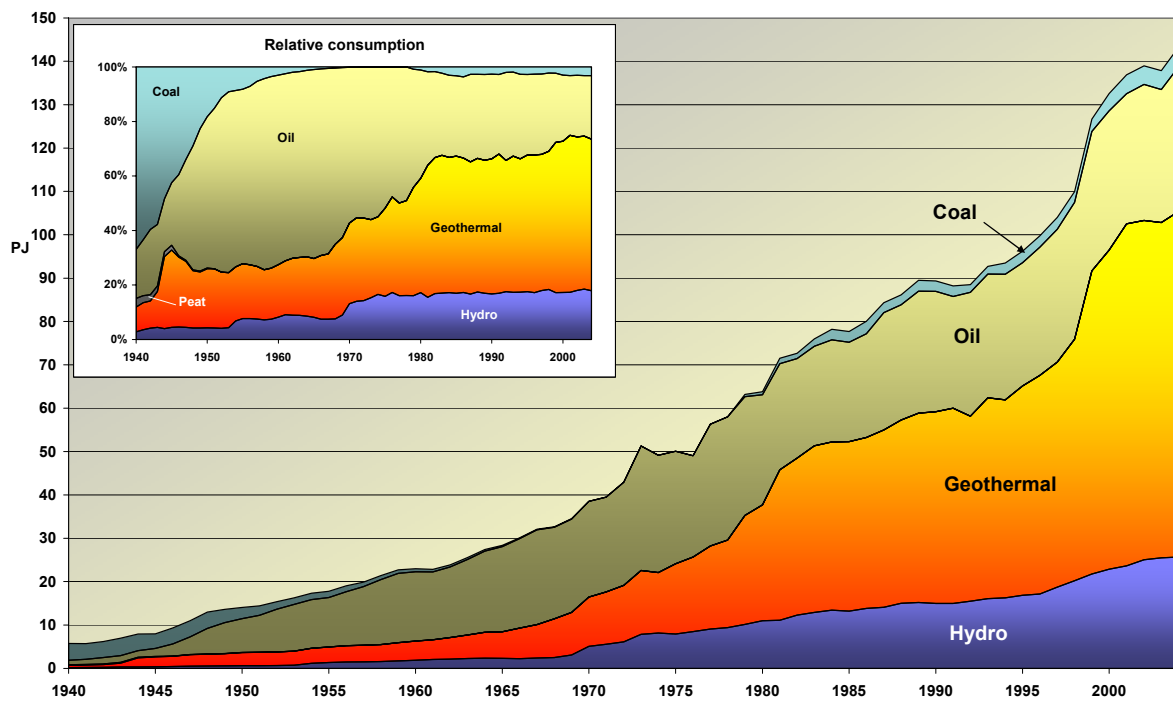


FIGURE 3: Primary energy consumption in Iceland 1940-2004. Source: Orkustofnun (National Energy Authority)

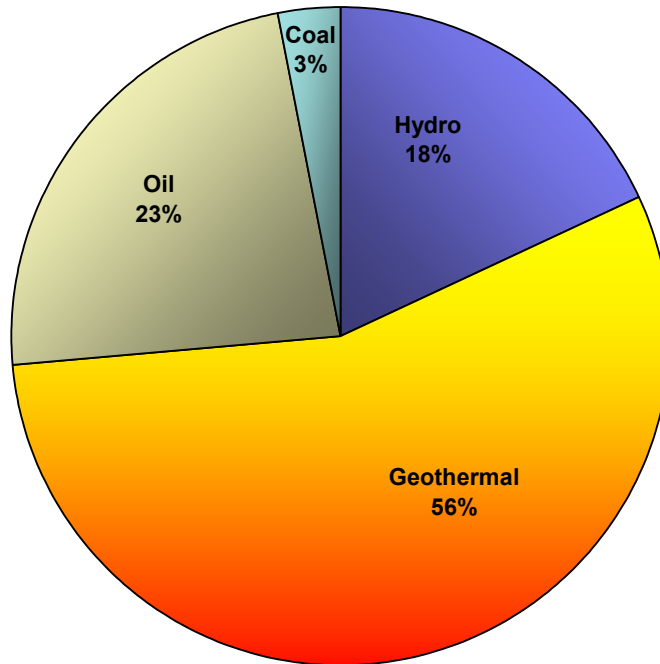


FIGURE 4: Sources of energy used in Iceland in 2004. Source: Orkustofnun (National Energy Authority)

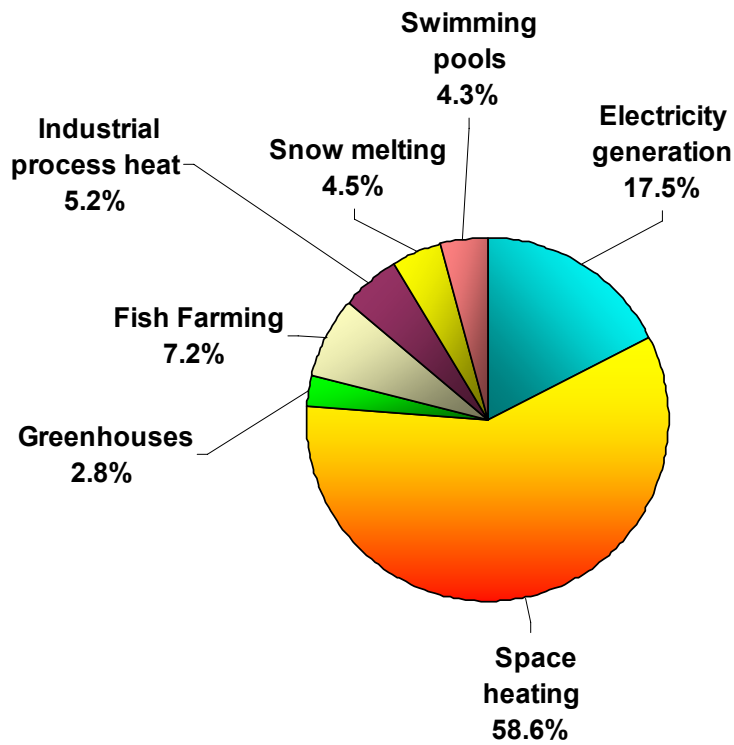


FIGURE 5. Geothermal energy uses in Iceland in 2004. Source: Orkustofnun (National Energy Authority)

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 the development of the high temperature areas in Iceland was proposed by Orkustofnun (the National Energy Authority) in 1969 in order to organize and accelerate the utilization of the fields (Björnsson, 1970). In the programme, exploration was divided into three phases:

- (1) 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.
- (2) Exploratory Drilling in order to get information on the geological structure, temperature and pressure distribution and fluid characteristics of the geothermal reservoir. This information should be used to modify the conceptual model of the field, to design production wells and to do a preliminary plant design and pre-feasibility study of the field.
- (3) If the pre-feasibility study gave promising results the third phase, Production Drilling and Testing, should be carried out in steps in order to test the production capacity of the field.

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 in the exploration of several high temperature areas in Iceland in 1960-1980, including the Reykjanes, Námafjall, Svartsengi, and Krafla fields.

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 program 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 program was never executed due to lack of funding in the following years. This often seems to be the fate of parliamentary resolutions, not only in Iceland. It was, however, important that during the work of the specialist group the strategy for exploring high temperature fields was analysed and a generic plan put forward for the development of geothermal fields. This plan is shown in Figure 6. There the development is divided into five phases: *Preliminary study* which starts with a reconnaissance study of the field. The next phase is an *appraisal study*, which is followed by *project design, construction phase*. and finally the *operation* of a geothermal plant. A time frame was estimated for the development according to which that it is not until after 10 years of exploration that a decision is made on how the field should be utilized.

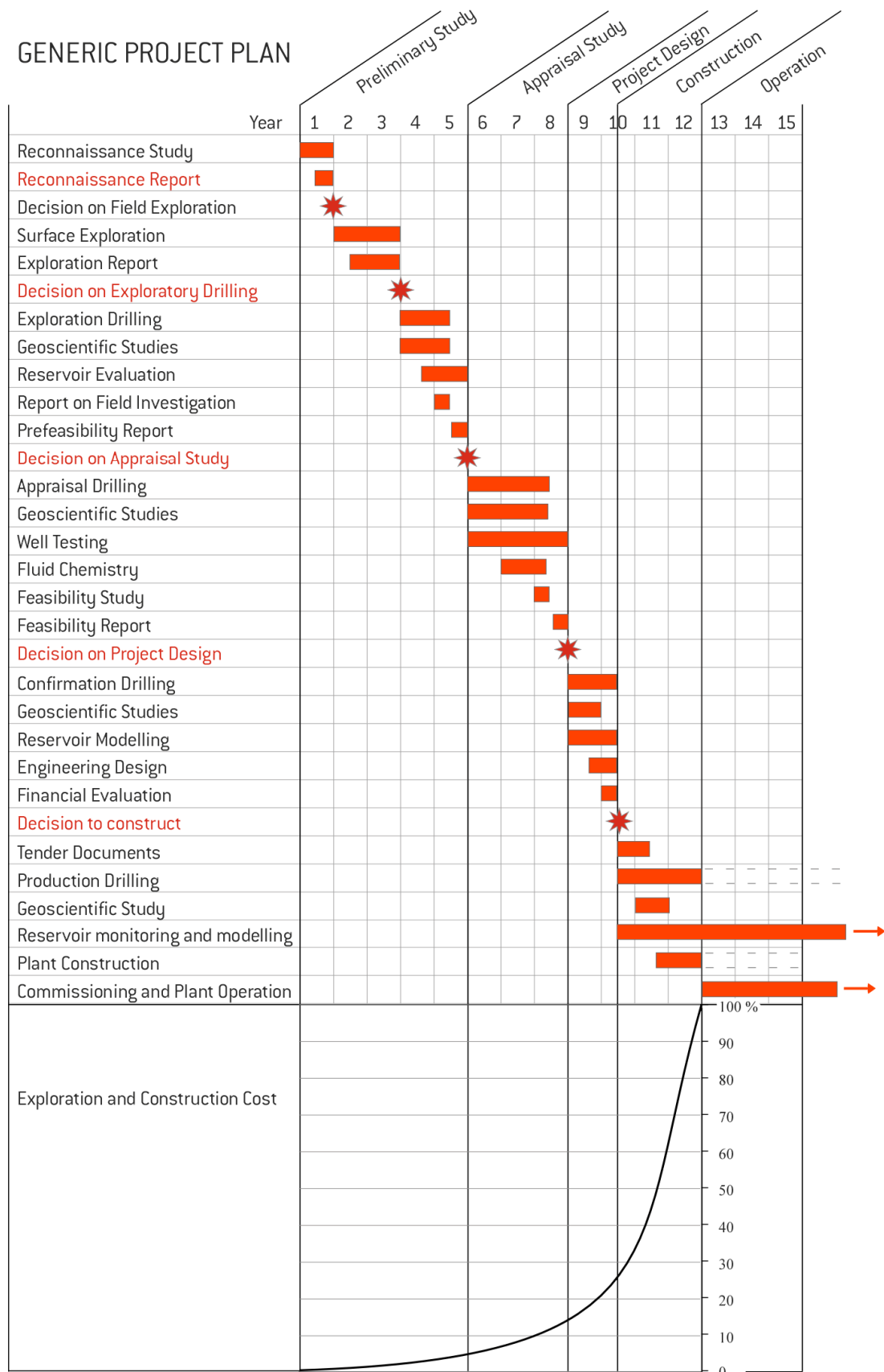


FIGURE 6. Generic phase plan of 1982 for geothermal development

3.3 Stepwise Development Strategy

The development strategies described above assume that the production capacity of the geothermal field is known when decision is made on the utilization. A generating capacity of the power plant is subsequently selected to fully match the field potential. This strategy is probably 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 phase. This is, however, not the case for the geothermal areas where a reliable knowledge on the generating capacity can only be obtained through a 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 first after 10 years of intensive exploration, drilling and testing that a decision is made on 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 utilization of the field capacity in one big power plant. By following the generic plan in Figure 5 but selecting a relatively small (20-50 MW) power plant as a first step, the time scale can be reduced and the plant commissioned and put into operation much earlier than is possible 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. One can say that in the stepwise strategy 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 built. A comparison of these two strategies is shown in Figure 7.

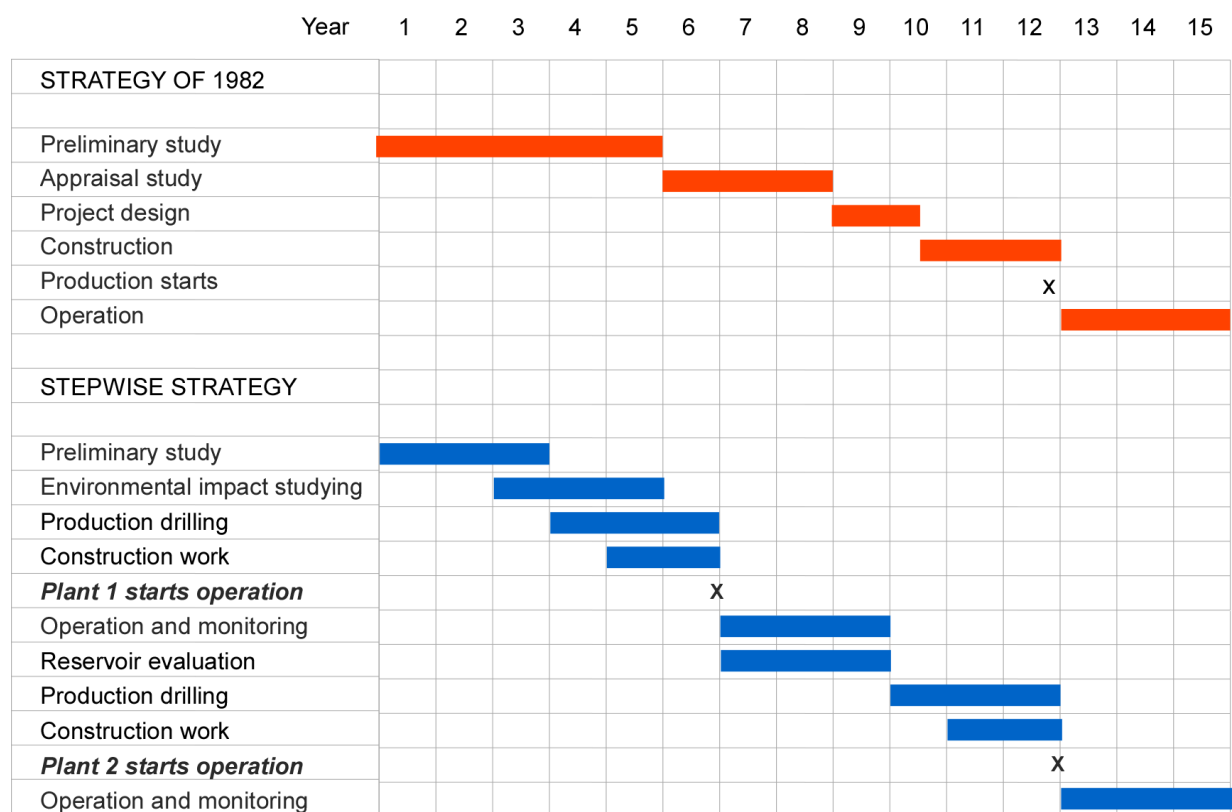


FIGURE 7. Comparison of the stepwise development strategy (lower part of the figure) and the conventional development strategy (upper part of the figure)

3.4 Environmental impact studies

According to the Act on Environmental Impact Assessment, No. 106/2000, and the Act on Changes to the Acts on Environmental Impact Assessment No. 106/2000 and on Planning and Building No. 73/1997, No. 74/2005, 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 law 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.

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. It includes “drilling of production wells and research wells in high enthalpy fields”, and “plants for production of electricity, steam and hot water, hydro 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 8 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.

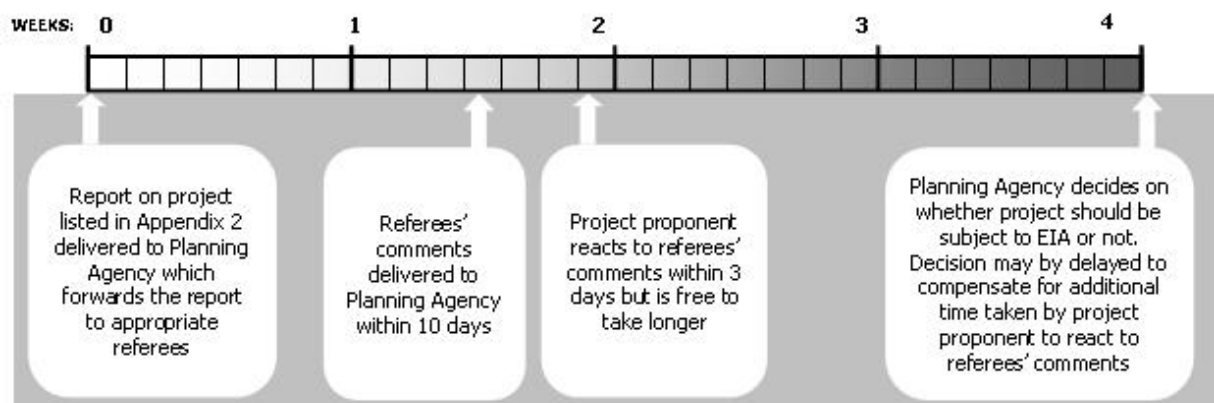


FIGURE 8. Procedure for projects listed in Appendix 2 of regulation to the Act on Environmental Impact Assessment, No. 106/2000

The EIA process itself is depicted in Figure 9 and may take 32 or more weeks if the verdict is disputed. A power production or a large scale industrial project would fall under Appendix 1 of the Act and EIA is thus compulsory.

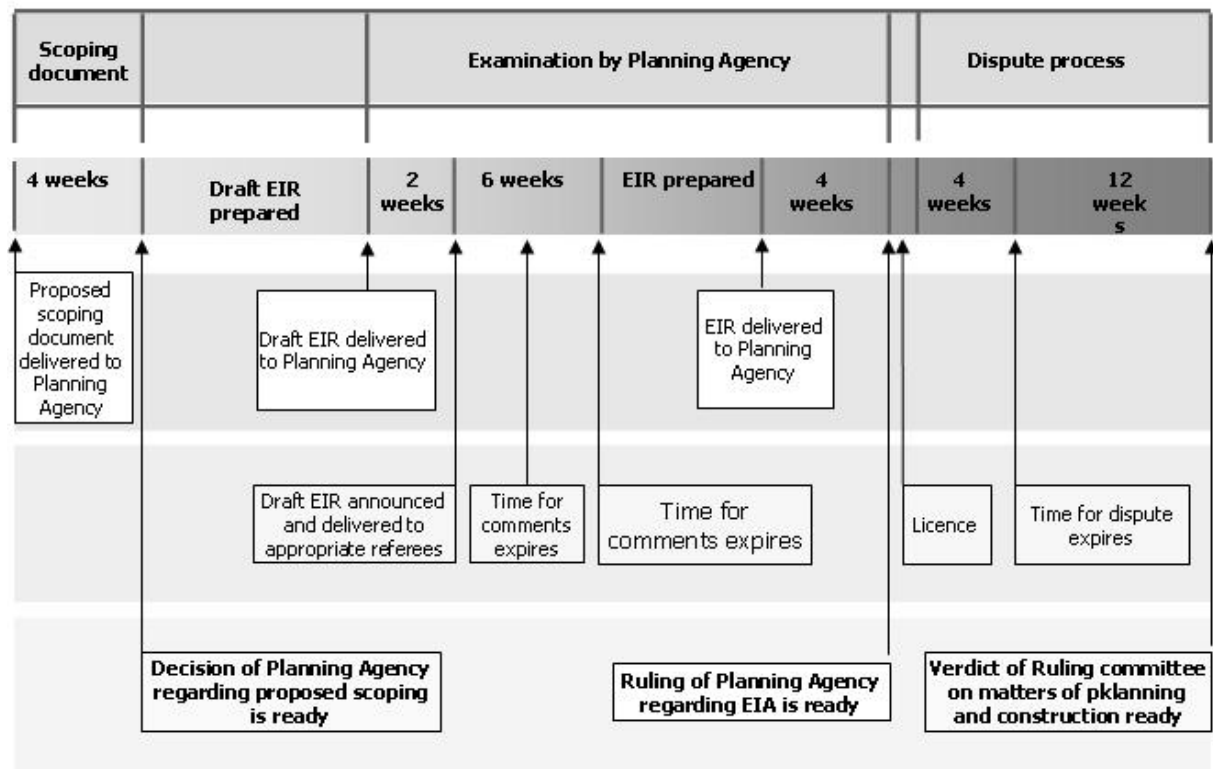


FIGURE 9. The EIA process

3.5 Master Plan for utilization of renewable energy resources

The government of Iceland decided in 1999 to develop a master plan for utilization of hydro and geothermal resources. The master plan should be based on best available scientific information and its development should be open for democratic involvement.

In the first phase of the master plan, a large number of proposed power projects should be evaluated. The evaluation should consider the impact of the project on the environment, nature and wildlife, landscape, cultural heritage and ancient monuments, grazing and other traditional land use, out-door life, fishing and hunting. Also considered should be the implications for employment and regional development. 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 (ref. Orkustofnun).

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 is supported by about 50 experts working in four different working groups:

1. **Working Group I** evaluates what impact proposed power projects will have on Nature, landscape, geological formations, vegetative cover, flora and fauna, as well as cultural heritage and ancient monuments.
2. **Working Group II** evaluates the impact on outdoor life, agriculture, revegetation, fishing in rivers and lakes, and hunting.
3. **Working Group III** evaluates the impact proposed power projects can have on economic activity, employment and regional development.
4. **Working Group IV** identifies potential power projects, both hydro and geothermal, 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 hydro 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 of energy developments. The second phase is expected to be completed in 2008-9. 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 over 50% 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 on the geothermal fields and the geothermal processes has improved.

It has proven 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 6 and 7.

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 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 hydro 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
- 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 crust (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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