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THE ENVIRONMENTAL PERMIT PROCESS FOR THE HELLISHEIDI POWER PLANT IN ICELAND

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ABSTRACT

The use of geothermal energy for electrical production has increased rapidly during the last years. The first geothermal plants were built before the implementation of the act on Environmental Impact Assessment in 1994. Two geothermal power plants are now operated in the Hengill area at Nesjavellir and Hellisheidi in SW-Iceland. The Nesjavellir power plant was built before the implementation of the act but Hellisheidi after. The process and research for both plants were similar but the process is more formal due to more complicated licence procedure. This formal process on the other hand opens for others views and angles which can lead to better project.

1. INTRODUCTION

The use of high enthalpy geothermal resources in Iceland has increased considerably last years. In the year 2005 the generation of electricity by the use of geothermal energy was about 200 MWe. Today the installed capacity has increased to about 400 MWe (Orkustofnun 2006). There are plans for further increase in production of electricity in Iceland using geothermal energy.

The first geothermal power plants were built before the act on Environmental Impact Assessment (EIA) was implemented in 1994. In the Hengill area the Nesjavellir power plant started operation with hot water production in the year 1990. Prior to electrical production in 1998 EIA was made for that plant including also all the previous activity.

The National Planning Agency oversees the EIA process in Iceland. The process developed during the following years and a new EIA Act was implemented in 2000 and revised in 2005.

According to the older act the National Planning Agency decided upon whether the proposed development would have such environmental impact that the project should be rejected. That decision could be appealed to the Minister for the Environment. According to the revised EIA act the National Planning Agency shall deliver a reasoned opinion on whether the environmental impact statement meets the criteria of this Act and regulations issued on the basis of the Act, and whether the environmental impact is satisfactorily described. The final decision is however in the hands of the relevant local authority through development consent or building permit.

2. THE HENGILL SYSTEM

The Hengill geothermal area is one of the largest high temperature geothermal fields in Iceland, covering about 110 km^2. It lies in the middle of the western volcanic zone, on the plate boundary between North America and the European crustal plates. The rifting of the two plates has opened a NNE trending system of normal faults and frequent magma intrusions. The bedrock in the Hengill area consists mostly of palagonite formed by volcanic eruptions below glaciers during the last ice ages. This rift zone is also highly permeable and numerous fumaroles and hot springs emerge at the surface.

Geothermal activity is associated with three volcanic systems of different age within the complex (Figure 1). The geothermal heat source in Reykjadalur and Hveragerði is related to Grensdalur, the oldest of the three volcanoes. North of Grensdalur lays Hrómundartindur, which last erupted about 10,000 years ago, and which provides the heat for geothermal activity around Ölkelduháls. West of these volcanic systems is the Hengill system, with volcanic features and faults stretching from south-west to north-east through Hellisheidi and Nesjavellir.

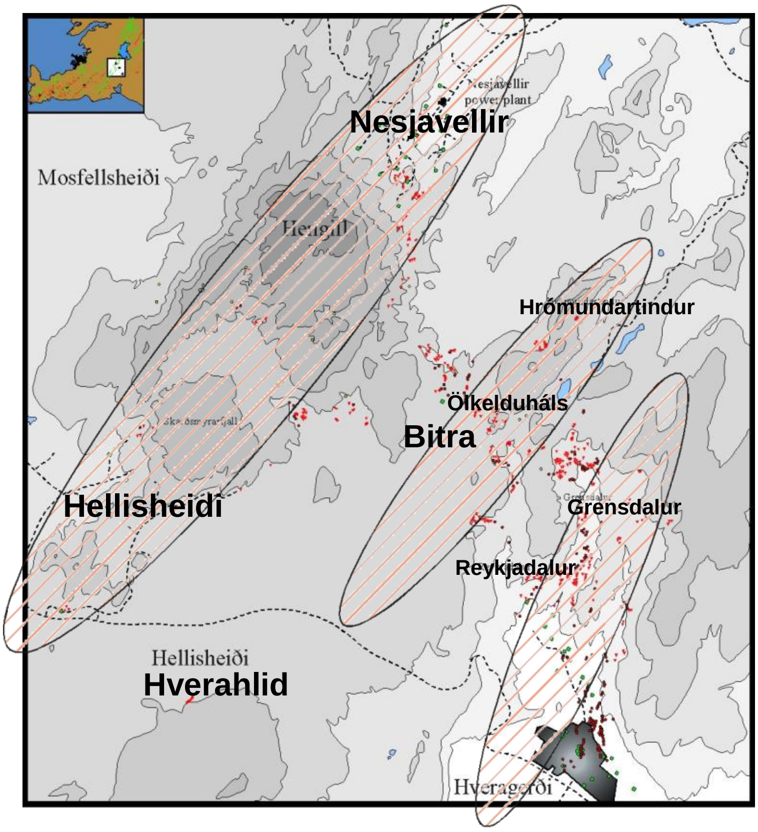

FIGURE 1: Location of the Hengill geothermal field. Hot springs and fumaroles are indicated by red dots. The volcanic systems are shown with shaded areas.

2.1 Utilization at the Hengill system

A fault zone associated with the Hengill Volcano cuts through the volcanic zone from southwest to northeast. The most interesting geothermal prospects are those associated with this fault zone, Nesjavellir farthest to the north, and Hellisheidi on the southern side.

Several potential geothermal fields can be distinguished within the Hengill complex. Three of these areas have been developed, one for space heating, industrial use and greenhouse heating in the town of Hveragerdi. At Nesjavellir Orkuveita Reykjavikur operates a geothermal power plant with 120 MWe

of installed capacity and a 290 MWth plant for hot water used in space heating. At Hellisheidi Orkuveita Reykjavíkur opened a 90 MWe power plant in 2006.
Orkuveita Reykjavíkur is now planning to build two new power plants in the Hengill area and is now in the stage of Environmental Impact Assessment process for these plants. These are the plant at Bitra, 120 MWe in the eastern part of the field and Hverahlid, 90 MWe in the southern part of the field. Both these plants are planned to be on line late 2010.

2.1.1 Nesjavellir

The Nesjavellir Geothermal Power Plant, which is about 30 km east of Reykjavik, was commissioned in 1990, following an intensive drilling and testing phase in the 1980's (Gunnarsson *et al*., 1992). By that time 14 production boreholes had been drilled, and all except one were successful. Initially the plant produced about 560 l/s of 82°C hot water for district heating (100 MWt), using geothermal steam and water to heat cold groundwater. In 1991 the capacity was expanded to 150 MWt, and in 1998 to 200 MWt. At that time the production of electricity commenced with the installation of two 30 MWe turbines. In 2001 the third turbine was installed, increasing the capacity to 90 MWe. In 2003 the hot water production was increased to 290 MWth and the fourth electricity turbine started production in 2005, bringing the capacity to 120 MWe.

Initially only four geothermal wells were connected to the plant, but gradually more wells have been connected as the capacity of the power plant has been increased. Presently 14 boreholes are connected to the Nesjavellir plant, including 5 wells drilled in 1999- 2003 (Gislason *et al.* 2005).

The modular development of the Nesjavellir Power Plant is a good example of the development of a geothermal resource. Initially the reservoir was tested with relatively small discharge/production, but with an intensive monitoring programme and revisions of a numerical model of the resource has allowed increased production in line with the known potential of the field.

2.1.2 Hellisheidi

Orkuveita Reykjavikur is now developing the Hellisheidi field, which is only about 25 km east of Reykjavík. During the planning stage the company bought up the land and conducted extensive research in the area. In 2001 the company's board of directors decided to start preparations for building a combined heat and power plant at Hellisheidi (Gunnlaugsson and Gíslason, 2005). Initial estimates were for an installed capacity of 120 MWe and 400 MWt. The first stage of this new plant was commissioned in 2006.

By extending the well field it was decided to enlarge the power plant by 90 MWe. The environmental impact assessment has been carried out in two steps first for the initial plant and later for the enlargement.

3. PERMITS NEEDED FOR NEW POWER PLANTS

Development of a new geothermal field requires careful planning of the project. This includes making time schedule for the project taking into account the permits procedure which is needed for the project. Simplified diagram of a project is shown in figure 2.

3.1 Permit from landowner and research permission

Landowners can undertake research on their properties without a special research permit. The research by landowners do not include right to utilize the resource. All others than owners have to apply for a research permit from the Ministry of Industry. The ministry call for opinion from the Ministry of the

Environment and the National Energy Authority. Usually the Ministry for the Environment asks for the opinion of The Environment and Food Agency of Iceland. In the application most often the developer applies for priority for development if research will give satisfactory result. So far the research permits have been issued with priority to develop within certain time limit. The selection of site to apply for research and development permit has until now been in accordance with the interest of the developer.

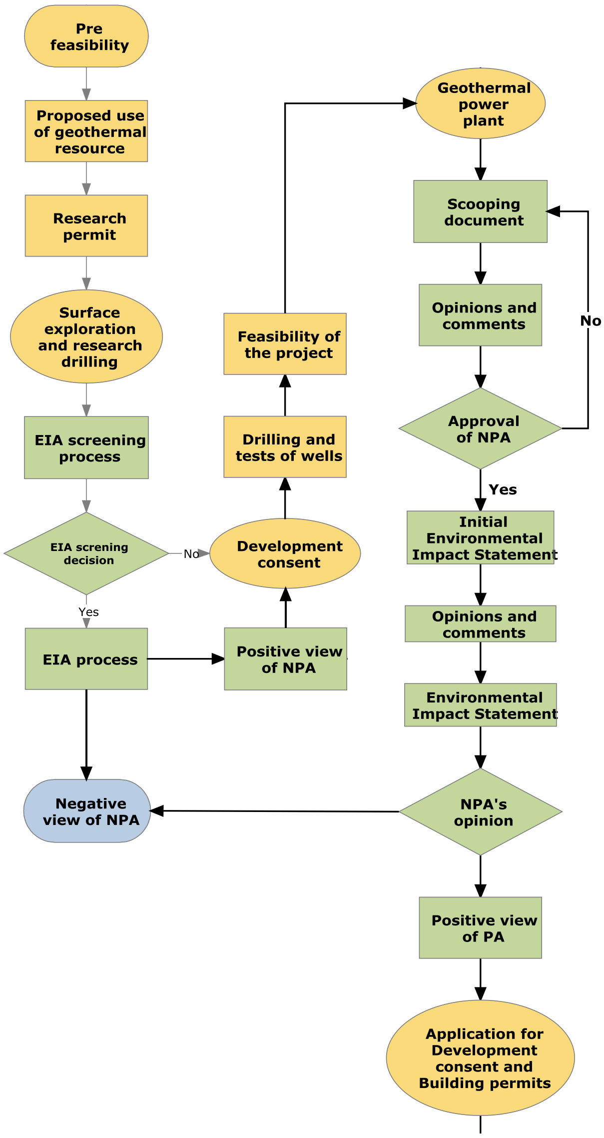

FIGURE 2: Simplified diagram of a geothermal project. Green boxes indicate the EIA process.

Developing of a framework where geothermal fields are categorized either for utilization or protection has now started. It has been announced that no research permit will be issued in new fields until after completion of that work.

3.2 Utilization permit

In Iceland utilization permit is issued for all use of geothermal energy other than electrical production. If co-generation is planned two permits are needed, i.e. utilization permit for all direct use or cascading use and permit for power utilization. When developer applies for research permit it is usually connected to some priority for utilization. Following research, the developer has to formally apply for utilization permit to the Ministry of Industry. In the application the utilization is described and a monitoring program of the resource is introduced. This application usually follows the Environmental Impact Assessment. The ministry goes for opinion of the local authority, National Energy Authority and The Environment and Food Agency.

3.3 Master Plan (municipal plan)

The master plan is in the hands of the municipality. If the developer discovers that the master plan does not include the proposed geothermal utilization the municipality has to be contacted and the policy regarding this project required following amendment of the master plan. Figure 3 shows the minimum time needed for minor and major amendments of master plans.

If a local authority considers that an approved municipal plan needs to be amended but that the amendments are so insubstantial it shall send a proposal on the amendments, with reasons, to the Planning Agency. The Environment and Food Agency is asked for their opinion. The Planning Agency shall forward the proposal to the minister together with its comments within a week of receiving the proposal from the local authority. If the minister approves the proposal, it shall be advertised. If no objections are received within three weeks of the advertisement, the proposal shall be regarded as adopted. If objections are received to the proposal after it has been advertised, the local authority shall hold one discussion on the objections. The local authority's conclusion shall be sent to the minister for approval.

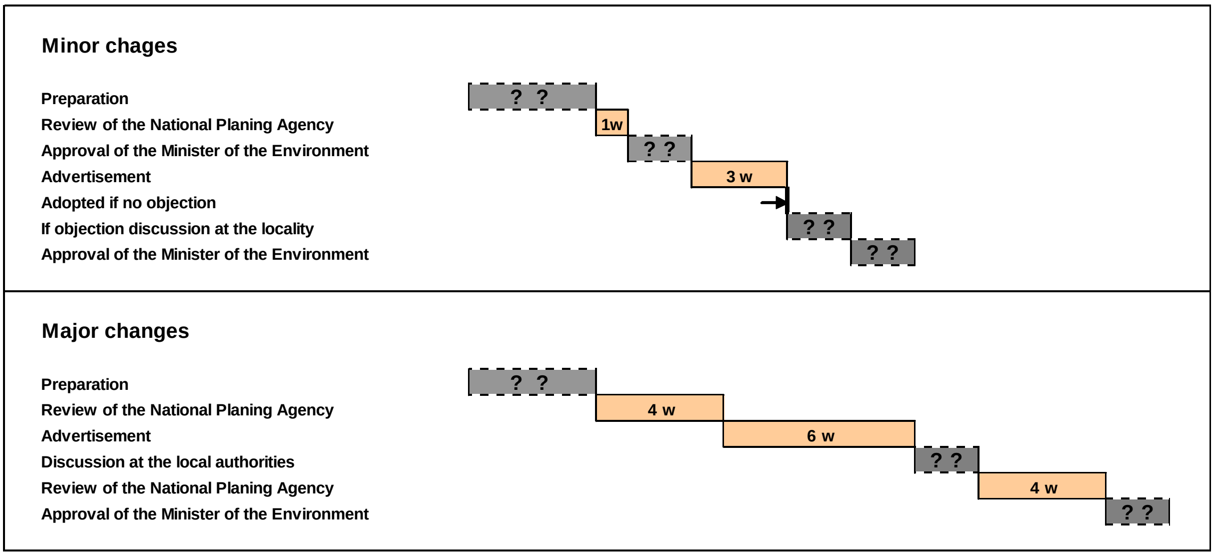

FIGURE 3: Minimum time for minor and major changes of municipal master plans in Iceland.

If on the other hand the local authority considers it necessary to amend an approved municipal plan, the whole procedure takes longer time. Preparation of amendment of a master plan includes strategic environmental assessment (SEA) according to new law implemented in 2006.

The process is that first the proposal and its objectives and premises shall be presented to the inhabitants of the municipality at a public meeting or in another satisfactory manner. The presentation shall be advertised in a conspicuous way. The advertisement shall give any interested party the chance to make objections to the proposal before a certain time limit, which shall not be less than six weeks after the publication of the advertisement.

After a public presentation, the proposal shall be presented to the local authority for discussion. Following discussion, the local authority shall submit the proposal to the National Planning Agency for examination. If the National Planning Agency makes no comments within four weeks of its receipt of the proposal, the proposal shall be advertised without amendment.

Strategic Environmental Assessment is needed for master plans and has to be included in the documentation when the plan is proposed.

3.4 Local plan

Local plans are made on the basis of the municipal plan in a statement and on a land use map. The Environment and Food Agency is asked for their opinion. When the local authority has agreed to advertise a local plan proposal, it shall be advertised and publicised in the same way as of a municipal plan. This process can take 8 to 12 weeks.

3.5 EIA process

The objective of Environment Impact Assessment is to ensure that, before starting of a project the assessment of the environmental impact has been carried out in order to minimise as far as possible the negative environmental impact of the project.

Examples of projects which are always subject to the Environmental Impact Assessment are geothermal power plants and other thermal power installations with a heat output of 50 megawatts or more and other power installations with an electricity output of 10 megawatts or more. The whole process of EIA can take more than a year depending on how much research has to be carried out.

In Annex II of the EIA Act there is a list of projects that may have significant effects on the environment and are therefore subject to an EIA. These projects are assessed on a case-by-case basis depending on their nature, size and location and other criteria presented in Annex III of the EIA Act. Examples of projects in this category are deep drilling projects, in particular the drilling of production wells and exploration wells in high-temperature geothermal regions. It is within the National Planning Agency’s purview to decide whether these projects are subject to an EIA. The decision by the National Planning Agency on whether a project is subject to assessment may be appealed to the Minister for the Environment.

The Environmental Impact Assessment process is divided into several steps which are described in more detail in following chapters. Figure 4 shows the outline of the process and figure 5 the time schedule for the process as it is described in the act on Environmental Impact Assessment (The National Planning Agency Website).

3.5.1 Screening process

The first step in the process is to find out if a project is subject to EIA. Among projects which always are subject to EIA are geothermal power stations and other thermal power installations with a heat output of 50 megawatts or more and other power installations with an electricity output of 10 megawatts or more.

Other projects which may have substantial effects on the environment are assessed on a case-by- case basis. Drilling of production holes and research holes in high-temperature geothermal fields fall under this section as well as geothermal drilling in low- temperature geothermal fields close to geothermal manifestations.

Within four weeks of the receipt of data on the project, the National Planning Agency shall give notification as to whether the project shall be subject to assessment.

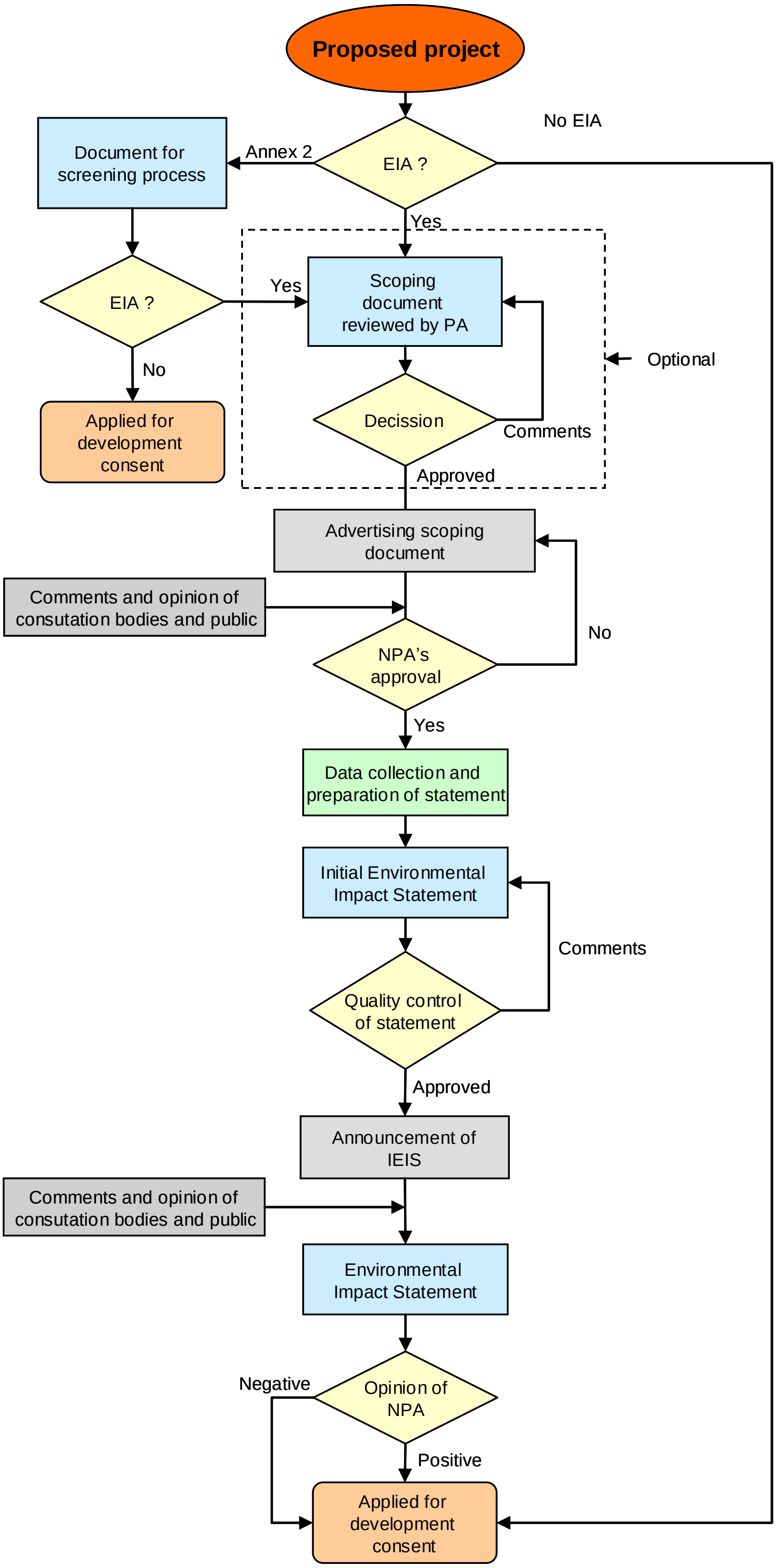

FIGURE 4: The Environmental Impact Assessment process in Iceland.

3.5.2 Scoping Document Proposal

If a proposed project is subjected to Environmental Impact Assessment the developer shall submit a scoping document proposal to the National Planning Agency as early as possible in the preparatory stage of the project. In this proposal, the developer shall describe the project, the project site and alternatives which could be considered and provide information on the planning of the project site and how the project will comply with development plans. The plan shall also propose which aspects of the project and of the environment should be emphasised, describe what data are already available, which data will be produced where and how and have a plan for making information available and for public consultation. The developer shall make the scoping document proposal known to the consultation bodies and to the general public and may consult with the National Planning Agency. The scoping document is the most important document regarding the Environmental Impact Assessment where on this stage is decided and agreed upon which research and data is needed for the assessment.

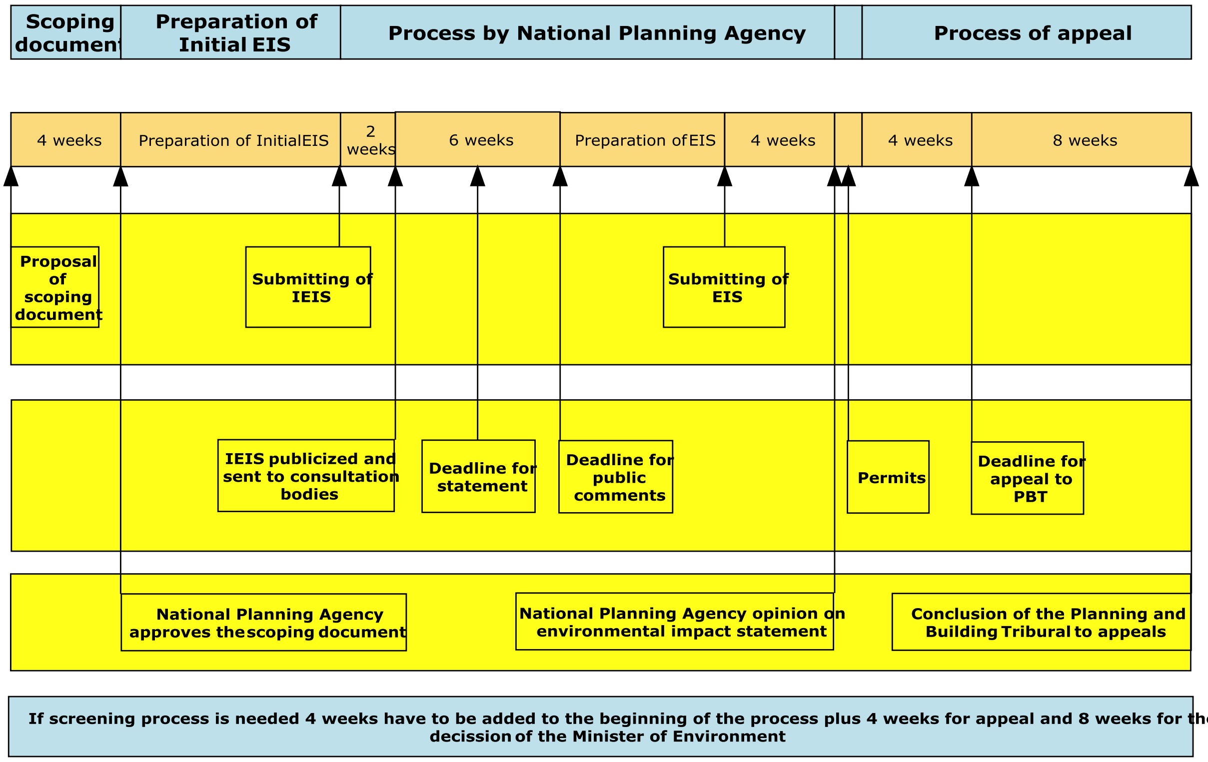

FIGURE 5: The time schedule for the Environmental Impact Assessment process according to the law.

The National Planning Agency shall make a decision on the developer's proposal within four weeks of its receipt, having received the opinion of the licensors and other parties, as appropriate. For geothermal power plants the principal consultation bodies are the local government, The Environment and Food Agency of Iceland, National Energy Authority, The Archaeological Heritage Agency and the Division of the Environment of the local community or the region. The National Planning Agency can approve the scoping document proposal with or without comments. Should the Agency make comments, they shall become part of the scoping document. If the National Planning Agency does not approve the scoping document proposal, the Agency must provide grounds for its decision, indicate what it deems to be deficient and instruct the developer as how the scoping document should be further elaborated. Approved scoping document proposal is then made known to the licensors and consultation bodies.

When the scoping document has been approved the main work is to collect information according to the document. Some of the data needed can only be collected during certain period of the year. This includes mapping and research on the flora and birds have to be counted during the nesting time.

3.5.3 Initial Environmental Impact Statement (IEIS)

Work on data collection and its interpretation and preparation to the Environment Impact Statement can take several months depending on availability of data.

The report shall specify the effects, direct and indirect, which the proposed project and related activities may have on the environment and the interaction of individual environmental factors. The report shall also explain upon what premises the assessment is based. It shall describe the aspects of the proposed project which are regarded as most likely to have an impact upon the environment, including its scale, design and location and what environmental monitoring are planned. The main alternatives considered, and their environmental effects, shall always be explained and compared. A non technical summary shall be prepared describing the report's main findings.

When the developer is ready with the initial environmental impact statement it is submitted to the National Planning Agency. Within two weeks of the National Planning Agency receiving the initial environmental impact statement, the agency shall assess whether the report meets the criteria and is consistent with the scoping document.

The agency may refuse to accept the initial environmental impact statement for review in those cases when it does not meet the above- mentioned criteria. In such cases the National Planning Agency shall provide guidance to the developer regarding further elaboration of the initial environmental impact statement. When the National Planning Agency has approved that the statement meets the criteria and is consistent with the scoping document it shall publicise the proposed project and the initial environmental impact statement.

The initial environmental impact statement shall be made easily accessible at a location near the project site and at the National Planning Agency for six weeks, which shall also be the time limit for submitting written comments to the National Planning Agency. Anyone may comment on the initial environmental impact statement which has been made public. The National Planning Agency shall call after the opinion of the licensors and other parties as appropriate. The consultation bodies shall express their view as to whether the initial environmental impact statement has discussed aspects within their area of concern in satisfactory manner and, furthermore, whether the proposed mitigating measures are satisfactory. They shall, if there is cause for so doing, specify what should be investigated further and point out possible mitigating measures.

3.5.4 Environmental Impact Statement (EIS)

The National Planning Agency shall send to the developer the opinions and comments it receives. When the developer has received the opinions and comments, the developer produces a final environmental impact statement on the basis of the initial environmental impact statement. In the environmental impact statement the developer have to discuss the comments and opinions given, and express its position regarding the comments and opinions. The report is then submitted to the National Planning Agency.

Within four weeks of receiving the environmental impact statement, the National Planning Agency shall deliver a reasoned opinion on whether the report meets the criteria of this Act and regulations issued on the basis of the Act, and whether the environmental impact is satisfactorily described. The opinion shall explain the main premises of the assessment, including the quality of the data on which the assessment is based, and its conclusions. The opinion also discusses the developer's response to the comments and opinions received when the initial environmental impact statement was made public.

If the National Planning Agency view is that further conditions should be laid down for the project, or that other and more extensive mitigating measures are required than those for which provision is made in the environmental impact statement, the Agency have to specify such conditions and mitigating measures, and the reasons for them. If the National Planning Agency find that the developer's environmental impact statement is inconsistent with the preliminary assessment report in important aspects, it shall be presented again to the public.

When the National Planning Agency has given its opinion, this shall be made known to the Minister for the Environment, the developer, the licensors, the consultation bodies, and also those who made comments on the initial environmental impact statement during the period of public presentation. The public shall have ready access to the National Planning Agency opinion and the environmental impact statement, and the Agency shall advertise in a national newspaper that the opinion and environmental impact statement are complete. The final decision upon development is in the hand of local authorities as development permit.

3.6 Permit for power utilization

The permit for power utilization is issued by the Ministry of Industry after obtaining view of the National Energy Authority.

3.7 Permit from the Archaeological Heritage Agency

If archaeological heritage are likely to be disturbed or damaged during development a special permit is needed form The Archaeological Heritage Agency.

3.8 Special permits according to special laws

In some cases special laws may be dealing with specific areas. In such cases special permits may be needed. An example is a law regarding groundwater around the lake Thingvallavatn just north of the Hengill Mountain.

3.9 Development consent

The development consent is obtained from the relevant local authority. The project has to be in accordance with master plan of the municipality as well as the local plan. Development consent may not be issued until the opinion of the National Planning Agency on the environmental impact assessment has been given. When issuing development consent the licensor shall examine the developer's environmental impact statement on the project, and adopt a reasoned view on the National Planning Agency opinion on the assessment of its environmental impact. The licensor shall publish its decision on the issue of a permit and the findings of the National Planning Agency opinion on the environmental impact assessment within two weeks of the permit being issued. The decision shall specify authorities for appeal, and deadline for appeal, where relevant. The development consent may be appealed to the Planning and Building Tribunal.

3.10 Building permit

A building permit from the local authority is required for construction of all buildings and has to be issued before excavation for foundations. A building permit incorporates the approval of general drawings and intended construction of a building. It can be issued when the local authority has confirmed the decision by the building committee to grant a building permit, the building officer has signed the general drawings and the building permit fee has been paid in accordance with the valid rules, or agreement has been reached on their payment. A decision by a local authority to issue development and building permits under the Planning and Building Act for a project subject to environmental assessment may be appealed to the Planning and Building Tribunal within a month of the decision of the local authority to issue a development permit.

3.11 Operating licence

When starting up the operation business which may have polluting affect on the environment it is necessary to apply for an operating licence from the Division of the Environment of the local community or the region. Before issuing operating licence the licensor have to ask for opinion of the National Planning Agency and The Environment and Food Agency.

3.12 Summary of permits for geothermal utilization

As seen from above the whole process require careful planning and clear view of the project to estimate the time it takes to receive all the permits needed for geothermal projects. Some of the licences can be applied for at the same time but most often data is needed and cannot been obtained without some prior permits. The minimum time required for permits according to laws and estimated time needed is listed in Table 1. In some cases the Environmental Impact Assessment process is needed for exploration drilling. The data obtained from the exploration drilling are needed to evaluate the geothermal field. After feasibility study Environmental Impact Assessment is always needed for the power plant. This process can therefore take considerable time. Figure 6 shows the timeframe for the permit process for the 1st stage of the Hellisheidi power plant.

TABLE 1: Summary of estimated time required for permits needed for geothermal development in Iceland.

Permits	Minimum time according to laws (weeks)	Estimated time (weeks)
Research permit		16
Utilization permit		
Environmental Impact Assessment	50	56
Permit for power utilization		32
Master plan	22	22
Local plan	8	22
Building permit		2
Operating licence		12

4. THE ENVIRONMENTAL IMPACT STATEMENT OF THE HELLISHEIDI POWER PLANT

The main environmental factors which usually have to be dealt with in the environmental impact statement are:

- *Geological factors* including the geothermal field, its size and impact on the reservoir.
- *Water resources and disposal*. This includes extensive knowledge of the groundwater systems, their size and flow patterns.
- *Landscape and visual effects*. This is one of the main factors where the public is concerned.

- *Tourism and recreation*. Often there may be conflict between developer and other uses of the land such as tourism.
- *Biology*. Vegetation, hot spring microbiology and - fauna have to be studied
- *Other parameters* such as noise, pollution, air quality and cultural relics.

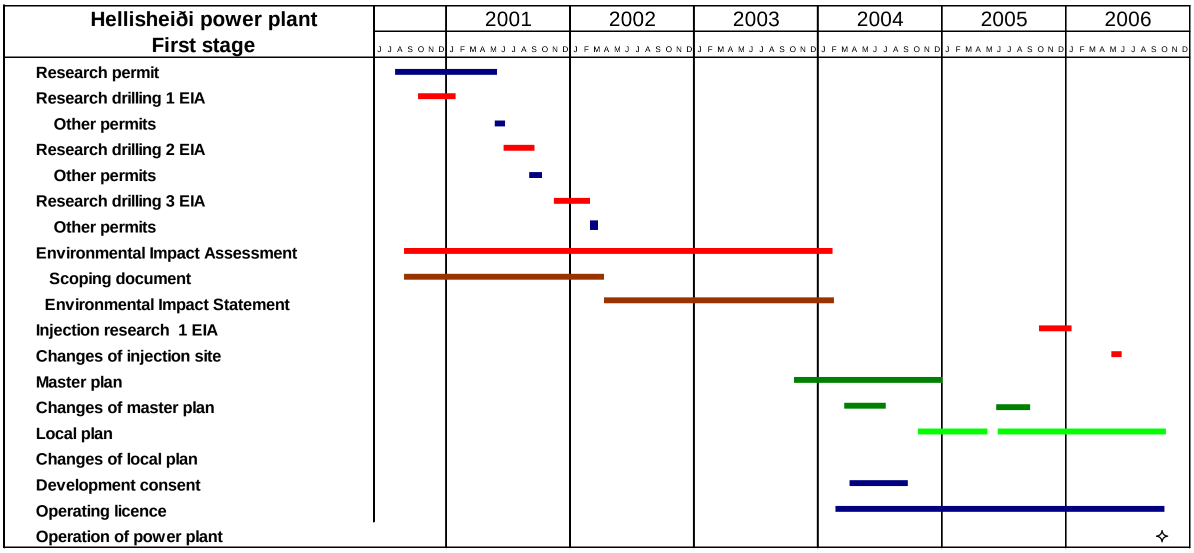

FIGURE 6: Timeframe for different permits for the 1st stage of the Hellisheidi power plant

4.1 Geothermal field

The Hengill volcano has been studied extensively from as early as 1947. Initial work focused on geological, geophysical and geochemical studies, which led to the drilling of a few shallow exploratory wells. Based on these, a 30 MWe unit was proposed in the Hveragerdi region, although pumping hot water to Reykjavik was considered uneconomical at the time (Bodvarsson, 1951). More wells were, however, drilled at Hveragerdi as a spin- off from the initial exploration phase. These wells have been used for space heating as well as for heating greenhouses.

Extensive geological, geophysical and geochemical surveys have been carried out throughout the Hengill area in conjunction with the Nesjavellir and Hellisheidi projects. The pioneering work of Saemundsson (1967) became the foundation of the present full-size map database, including all major geological units, location of hot springs and fumaroles, fault lines and thermally altered grounds.

Aeromagnetic, gravity and DC-resistivity surveys were carried out between 1975 and 1986. These delineated a 110 km^2 low-resistivity area and showed a negative and transverse magnetic anomaly coherent with the most thermally active grounds (Bjornsson et al., 1986). Transient electromagnetic soundings (TEM) were carried out between 1986 and 2000 to revise the resistivity map. Approximately 100,000 micro- earthquakes vibrated the Hengill area between 1994 and 2000. The quakes group together on lines striking either E-W or N-S, but surprisingly not to the NNE, as seen in the surface geology (Arnason and Magnusson, 2001). A geochemical study was carried out using gas chemistry from fumaroles to predict temperature (Figure 7) and to distinguish between different sub-fields (Ívasson 1998). The study indicates the existence of three different centres with higher temperature, coinciding with the volcanic centres.

Exploration drilling started in 2000, although one well had already been drilled in 1986. By the end of 2003 seven deep exploration wells had been drilled. Now 40 drill holes have been drilled south of the Hengill Mountain for the Hellisheidi power plant and its extension and for the two new proposed power plants south and east of the Hengill Mountain. The drilling targets are the young faults traversing the field, especially the faults that acted as magma feeders during the latest eruptions. Most of these wells are productive and have been tested in order to characterize the Hellisheidi resource. The majority of the wells have been drilled directional but a few boreholes were drilled vertically. The emphases on directional drilling are to minimize the effects on the environment. Our experience is also that the directional wells are better producer with increasing possibility of intersecting almost vertical faults and fissures. The length of the boreholes is in the range of 1800 - 2800 m. Up to 1000 m have been drilled without any return of drilling fluid and rock cuttings. Down hole measurements show that the temperature range in the aquifer zone is 255- 320°C.

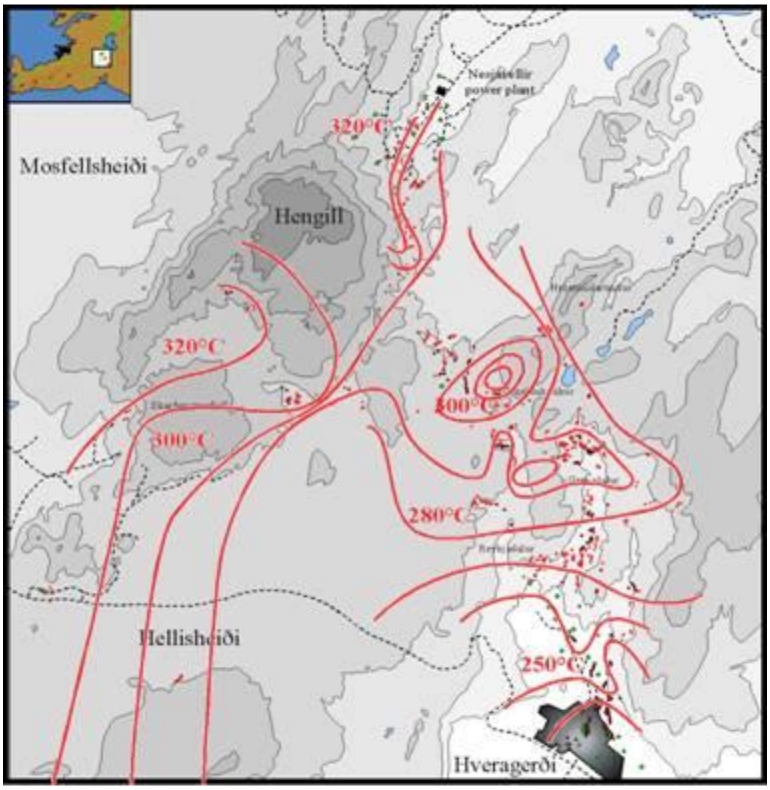

FIGURE 7: Distribution of temperature based on the concentration of CO_2 gas (Ívarson 1998).

A flow test has not been completed for all the wells. The enthalpy during the tests is in the range 1150-2600 kJ/kg and the total flow ranges from 11 to 80 kg/s. Well outputs range 3-25 MWe and 30-150 MWt. The geothermal fluid is relatively dilute, as is common in high- temperature fields in Iceland, with total dissolved solids of <1000 ppm and quite low non-condensable gas in the steam (<0.5 %). Special emphasis is laid on recording pressure transients, which are induced by temporary production from new wells. These data are considered extremely valuable by providing permeability constraints for the numerical reservoir model that is currently under calibration.

Reservoir simulation models have been part of reservoir assessment and management in the Hengill area since 1986. Initially the modelling effort focused on the Nesjavellir site (Bodvarsson et al., 1990a, 1990b). An intense field monitoring program was set up in order to gather data for future maintenance and recalibration of the numerical model. In 1992 the model was recalibrated (Bodvarsson, 1993) and the second update of the model was carried out in 1998 (Bodvarsson, 1998). Drilling of new wells in the Hellisheidi field, together with surface exploration activities, indicate that the Nesjavellir and the Hellisheidi fields can be regarded as belonging to the same system, with a common up flow zone under the Hengill Mountain. The numerical model was recalibrated once more and extends over the entire Hengill geothermal field (Bjornsson et al., 2000, 2003).

The financial risk increases with the size of the construction stages because of the uncertainty in the number of production wells that will be needed. According to the model, discharge of separated geothermal water will not increase over the production period. The indications are that geothermal production in the Hellisheidi power plant will be sustainable. If the power plant is shut down after 30 years of operation the pressure and the volume of the geothermal fluid in the reservoir are predicted to recover quickly and return almost entirely to their original levels within a lifetime. The temperature of the reservoir will have dropped from 270°C to 260 °C during the 30-year production period, but the area will recover completely in 1000 years assuming there is no external heat injection as a result of volcanic activity. The environmental effect of the project on the geothermal reservoir is assumed to be reversible.

4.2 Groundwater

Groundwater research is important for geothermal utilization in high-temperature areas especially if the energy is going to be used in combined heat and power plant. Geothermal water from high-temperature fields cannot be used directly for heating and large volumes of groundwater are needed. Cold water is also needed for drilling and the groundwater flow has to be well-known for planning disposal or reinjection of the geothermal fluid.

The groundwater system in the Hengill and surrounding area is very complicated. Precipitation in this area is among the highest in Iceland but runoff on the surface is very limited. Most of the runoff has thus to take place underground. Concurrent with geothermal reconnaissance, an extensive study is also being carried out on groundwater flow, including the drilling of 20-30 groundwater research wells.

The groundwater system in the investigated area is divided from southwest to northeast by a range of mountains formed by Hengill, and the mountain-range towards the south-west. On the eastern side, water flows from Hellisheidi to the east (Figure 8). On the western side the hydrology is characterized by area of 15 km^2 where the level of the groundwater table is the same, around 172 m above sea level. From there the ground water flows in three directions with the largest flow to the south where it reaches the sea.

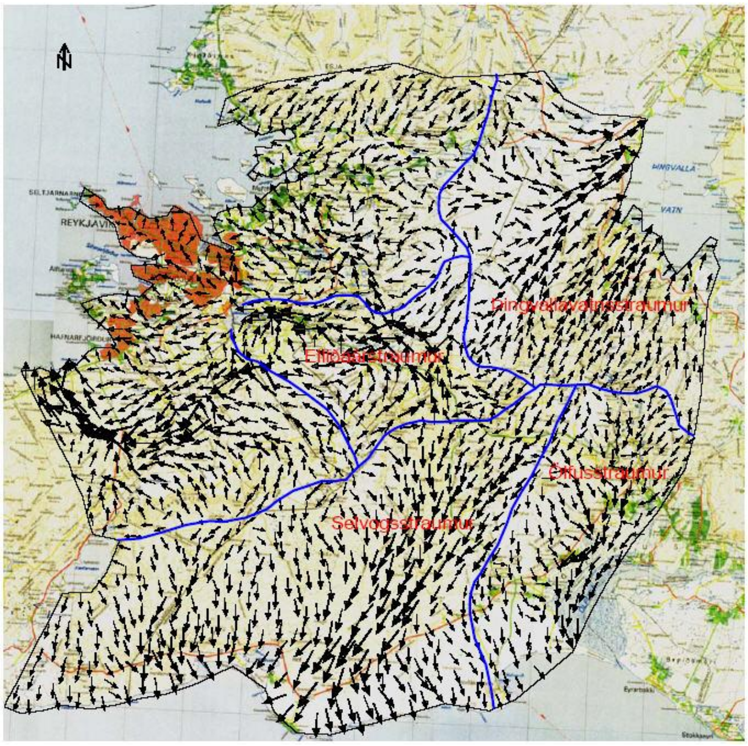

FIGURE 8: Flow of groundwater according to groundwater model of the area.

4.3 Other research and investigations

Other research and investigations were carried out such as landscape classification and visual effects, tourism and recreation, biology, noise, pollution, meteorological study, air quality, archaeological study and cultural relics.

The biological study included mapping of vegetation in the project area, study of bird live, study of invertebrates on land and in water and study of microbiology in hot springs. Vegetation in the developing area is mostly moss, grass and small shrubs. Grassland is less widespread than the moss-covered areas. About quarter of the area is lava with a moss covering. Animal live is rather scarce, possibly because of shortage of surface water in the area.

Landscape classification and visual effects is a major concern in all developments. Careful planning and design of power plants, pipes and drilling platforms can reduce the visual impact.

The air temperature is on average 2.6 °C lower than in Reykjavík. Humidity is higher and the wind speed is generally 70 % higher than in the capital area and rainfall is three time that of Reykjavík.

Cultural remains in the area are particularly linked to transportation and many old trails cross the area. The area is popular for recreation and marked hiking trails and publication of hiking maps have increased its accessibility.

The conclusion of an Environmental Impact Assessment is that the project will not have a significant effect on the environment.

5. COMPARISION OF THE PROCESS BEFORE AND AFTER THE IMPLIMENTATION OF ENIRONMENTAL IMPACT ASSESSMENT ACT

Two power plants are now in operation in the Hengill area, Nesjavellir on the northern side of the mountain and Hellisheidi on the southern side. The Nesjavellir power plant was constructed in 1986 to 1990 before the Environmental Impact Assessment Act was implemented. The preparation of the Hellisheidi power plant was on the other hand after the implementation of the act. The process of these two power plants is though very similar.

At Nesjavellir the surface exploration led to research drilling and environment became soon one of the main issues. Natural runoff from the geothermal field is towards the lake Thingvallavatn. The outflow was mapped and the chemical content was investigated as well as trace elements in the geothermal water and the ecosystem. These factors have been monitored since. All off-road driving was prohibited and emphasis on minimize the environmental impact.

The formality in the Environmental Impact Assessment Process opens for others views and angles in early stages of the development which can lead to changes of plans and design creating a better project.

Nesjavellir

1965	First drilling
1966	
1967	
1968	
1969	
1970	
1971	
1972	First deep drillhole (NG-5)
1973	
1974	Experimental plant
1975	
1976	
1977	
1978	
1979	Mapping of natural outflow into Thingvallavatn
1980	
1981	
1982	Drilling of NG-6
1983	Drilling of NG-7 , Trace elements
1984	NG-8, NG-9, NG-10, Thingvallavatn ecosystem Geophysics
1985	NJ-11, NJ-12, NJ-13, NJ-14, NJ-15, NJ-16, Groundwater, Geological map, Numerical model
1986	NJ-17 og NJ-18, **Decision on development**
1987	Seminar about the Nesjavellir power plant
1988	
1989	
1990	Opening of th power plant

Hellisheiði

1981	
1982	
1983	
1984	
1985	Drilling of first deep drillhole KhG-1
1986	
1987	
1988	
1989	
1990	
1991	
1992	
1993	
1994	Drilling of ÖJ-1
1995	Geological map of the Hengill area
1996	
1997	Archaelogical study
1998	
1999	
2000	Geophysics
2001	HE-3, HE-4, Biological research, Groundwater model, Numerical model
2002	HE-5, HE-6, HE-7, EIA - process, **Decision on development**
2003	
2004	
2005	
2006	Opening of the power plant

FIGURE 9: Comparison of the development of two power plants in the Hengill area.

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