UNITED NATIONS
UNIVERSITY
UNU-GTP
Geothermal Training Programme

Orkustofnun, Grensasvegur 9,
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Reports 2015
Number 7

ENVIRONMENTAL MANAGEMENT OF ASSAL-FIALE GEOTHERMAL PROJECT IN DJIBOUTI: A COMPARISON WITH GEOTHERMAL FIELDS IN ICELAND

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ABSTRACT

The geological characteristics of the Assal rift are favourable for the development of geothermal energy in Djibouti. The Government plans to exploit the geothermal resources in the Assal region to enable public access to a reliable, renewable and affordable source of energy. The Assal-Fiale geothermal project is located on a site that has scientific, ecological and tourist importance. Using the geothermal resource is believed to be a positive way to generate electricity in the area but improper management of the resource can cause possible negative impacts on the environment. Environmental impacts assessment will help to understand and minimize negative impacts of the project and with good management can support the environmental, economic and social goals of sustainability. This report presents the possible environmental impacts of the project and their management which aims to minimize them in accordance with national and international regulations and the geothermal utilization experience gained in Iceland.

1. INTRODUCTION

1.1 Purpose of this study

The geothermal potential in Djibouti is estimated around 1000 MWe, distributed among thirteen sites and mainly located in the Lake Assal region. The government's plans, with its first geothermal project, are to exploit the geothermal resources in the Lake Assal region to enable public access to a reliable, renewable and affordable source of energy. The aim of the project is to quantify the technical and financial feasibility of using geothermal resources of the Assal Rift for mass production of electricity. The project includes an exploration drilling program of four production wells in the area of Fiale, north of Lava Lake.

The Assal-Fiale geothermal project is located on a site that has scientific, ecological and tourist importance. Using the geothermal resource is believed to be a positive way to generate electricity in the area but the utilisation of the resource can cause possible negative impacts on the environment.

Therefore, the evaluation and the management of environmental impacts will help to minimize the possible negative impacts of the project and can support the environmental, economic and social goals of sustainability. The study will provide information on the process of assessing the environmental impacts and implementing appropriate mitigation actions and their management.

1.2 Objective

The goal of this study is to:

i. improve knowledge regarding the EIA process and implementing appropriate mitigation actions;
ii. improve the monitoring at the different stages of the projects development;
iii. create an Environmental Management Program which identifies the possible key environmental and social impacts associated with the development of the geothermal field in Assal-Fiale in Djibouti and minimises negative impacts with good management. Some comparison will be to Hellisheidi, Svartsengi and Reykjanes geothermal fields in Iceland.

1.3 Scope/methodology

The research work consists of a literature review, observing the similarities with comparable projects in Iceland and other countries in order to find the most common and important impacts. Leading experts in the geothermal field in Iceland, including chemists, geologists and experts on environmental impact assessments were consulted to understand better the possible effects of a geothermal development in the area and how to prepare the project to minimize negative impacts.

The environmental aspects of the Assal project are essentially covered in the following sources: (Fichtner, 2012), (REI, 2008) and (AFDB, 2013). Other main sources used are (Van Nguyen et al., 2015) and (Hunt, 2000).

In the table below is a list of the persons that were interviewed or got written questions and whose answers are in Appendix I.

TABLE 1: Persons interviewed or contacted

Person interviewed	Organisation	Type of function	Date	Contact information
Thoroddur F. Thoroddsson	National Planning Agency	Specialist, Environmental Assessment	August-October	doddifr@gmail.com
Jónas Ketilsson	Orkustofnun	Expert geotherm. utilization	October	jonas.ketilsson@os.is
Ómar Sigurdsson	HS Orka	Reservoir engineer	September – October	os@hsorka.is
Hólmfrídur Sigurdardóttir	Reykjavik Energy	Head of Environmental Affairs	September	holmfridur.sigurdardottir@or.is
Halldór Ármannsson	ISOR	Geochemist	October	halldor.armannsson@isor.is

2. LITERATURE REVIEW

2.1 Geothermal system

Geothermal energy is described as a clean, sustainable and renewable resource that provide energy using heat derived from the earth. An important exploitable source of geothermal energy are the reservoirs that form underground when groundwater trapped along fault lines, fractures in the rocks and porous rock is heated by magma that has been pushed up from the earth‘s core (Van Nguyen et al., 2015).
The use of geothermal resources is divided into two main groups:

- Direct use: geothermal reservoirs of low to intermediate temperature (20-150°C) are exploited, either with heat pumps or directly for heat production (houses in cold climates). Electricity is also generated using intermediate-temperature (70-149°C) geothermal resources (and binary electric generation).
- Power generation: High temperature geothermal reservoirs (150-300°C) are exploited for indirect use by producing electricity.

There are three main categories of geothermal power plants, depending on the chemistry, fluid temperature and pressure involved (Van Nguyen et al., 2015):

- Condensing power plants, with dry steam and single- or double-flash systems;
- Back-pressure turbines, which release into the atmosphere; and
- Binary plants, which use lower temperature water or separated brine.

2.2 Geothermal energy development

Whatever technology is applied (which is mainly depending on the properties of the geothermal fluid), the main phases of the development are (Rybach, 2003):

1) Exploration:
This is the first step in the development of a geothermal area and the goal is to gather as much information on the geological, geophysical and geochemical characteristics of the field to help reduce the risk in the next phase (the drilling). The impacts of this phase is generally temporary and of relatively small magnitude, because of the little interaction with the environment or the short duration of these activities. Impacts resulting from exploration activities can be associated with the development of access roads, if needed, including: localized ground clearing, vehicular traffic and noise producing activities.

2) Production test or drilling and well testing:
Most impacts resulting from these activities can be associated with the development of access roads, exploratory and flow testing wells (Ármannsson and Kristmannsdóttir, 1992). These include: localized ground clearing, vehicular traffic, seismic testing, positioning of equipment, drilling and emission of non-condensable gases and drilling muds. Most of these impacts can be mitigated or reduced by the use of good industry practices and by restoring the disturbed areas once the drilling and testing have been completed.

3) Construction:
Impacts during construction phase are more extensive but similar to the ones present during the exploration and drilling/testing. Most of the land disturbing activities occur during the construction phase because the need of removing and contouring land and the use of heavy equipment. The workforce needed during this phase is also high, compare to other phases. Depending on the location of the site it could cause negative impacts. Activities during the construction that may cause impacts include site preparation (e.g., clearing and grading); facility construction (e.g. geothermal power plant, pipelines, transmission lines, drill pads); and vehicular and pedestrian traffic. The construction of the

typical 50 MW geothermal power plant would disturb about 6 to 10 hectares of land. Transmission line construction would disturb about 0.5 hectares of land per mile of line.

4) Operation and maintenance:
Normal activities during this phase, in a typical power plant could be, operation and maintenance of production and injection wells and pipeline systems, operation and maintenance of the power plant, waste management, and maintenance and replacement of facility components. Possible impacts due to these activities are related to noise, water demand, waste management, land use conflicts, visual effects of facilities and steam plumes, potential spills and increased traffic at the project site.

5) Decommissioning and site reclamation:
Geothermal power plants have to be dismantled and removed from their sitting sites after their normal useful life, this procedure is known as the decommissioning, after this the site has to be restored to its original state (or approximately its original state in accordance to what has been stated in the environmental national and local law) in a process known as reclamation. Typical activities during the decommissioning/reclamation phase include closure of all facilities and wells; removal of above ground components and gravel from well pads, access roads (if not maintained for other uses), and other ancillary facility sites; re-contouring the surface; and re-vegetation. Also, remediation of contaminated sites is an activity done in this phase if any accidental spillage of toxic substances occurred during the other phases and has not yet been cleaned or dealt with. The impacts caused by these activities would be similar to those listed for the construction phase because the use of heavy machinery is also needed; however, most of these impacts would have a lower magnitude and because of the relatively short period of time in which this phase is completed. The procedure of restoration of the environment during the decommissioning and reclamation phase would have to ensure that the impacts of the geothermal development would not go beyond the life span of the power plant and that those impacts remaining after the removal of all structures are minimized, mitigated and compensated if necessary (Hunt, 2001).

2.3 Potential environmental impacts of energy development

The potential impacts of geothermal energy development depend on many factors, such as how special the environment is, how sensitive it is, the use of the land, people affected, and the size of land used for access roads and drilling, the construction activities implemented, the number of well pads and the technology in the power plant. The environmental impacts may be positive or negative, temporary or long term, irreversible or not and include e.g.:

- *Landscape and land use:* due to the land disturbance related to the construction of power plants and transmission lines. Pressure drop and decreased production of wells in the area, can call for new wells to be drilled every year. This could lead to expanded production area or increased pressure to drill in more sensitive areas than was originally planned.
- *Ecological resources:* when construction activities destroy or disturb wildlife by disturbing feeding, breeding and migration patterns, reduce habitat quality and species diversity, both flora and fauna.
- *Gaseous emissions:* resulting from the discharge of non-condensable gases. The most common gases are carbon dioxide (CO), hydrogen sulphide (H_2S) and other low-concentration gases such as methane, hydrogen, sulphur dioxide and ammonia (Van Nguyen et al., 2015).
- *Water pollution:* dissolved minerals in the geothermal water, both high quantity of common minerals like in sea water and low concentration of heavy metals that can be poisoning e.g., boron, mercury and arsenic. The chemicals in the geothermal fluid generated during exploration, testing and production phases may poison surface or groundwater. They can harm people, drinking water and also flora and fauna on dry land or in lakes and rivers (MIT-led interdisciplinary panel, 2006; Van Nguyen et al., 2015).
- *Noise pollution:* primary sources of noise are associated with exploration activities such as the well drilling and testing when noise levels are in the range of 80-115 decibels at the site boundary

(Van Nguyen et al., 2015). Severe noise can also be during maintenance in the power plant during operation time.

- *Solid waste: e.g. c*uttings from the drilling, used oil and building materials.
- *Land subsidence, seismicity:* during the production phase the pressure drop in the geothermal system has in some areas lead to land subsidence, increased seismic activity is e.g. known in connection with reinjection, especially if the injection water is pumped down in large amounts and under high pressure.

2.4 Environmental Impact Assessment (EIA)

Focus on environmental protection has increased more and more in the last 40-50 years and was the goal of the United Nations Summits in Rio (1991), Kyoto (1997) and Johannesburg (2001). In 1971 the first act of EIA came in to force in USA. In the following years the EIA process was introduced in the legislation of many countries, e.g. in Iceland 1994 which is in accordance with EU-directives. Many countries have adopted their own Environmental Impact Assessment (EIA) procedures and it is now as a tool that is most widely used in the preparation stage of projects and a part of environmental management.

The World Bank and several other financing institutions have also adapted the EIA process to their standard procedure which must be fulfilled if the plan is to get a project financed by them. All of this is supporting nations to take better care of the environment in the spirit of the UN summits.

The EIA process identifies the impacts of a proposed project during construction and operational phases. An EIA considers short-, medium-, and long-term impacts, local and global impacts, as well as direct, indirect, secondary, cumulative, permanent and temporary, positive and negative effects of the project (Heath, 2002). It is known that exploration and later utilisation of geothermal areas, can have negative impacts on the environment. Possible impacts must therefore be identified, quantified and if necessary avoided or mitigated in order to comply with environmental regulations.

3. OVERVIEW OF GEOTHERMAL EXPLORATION IN DJIBOUTI

3.1 History of geothermal exploration

The Republic of Djibouti has an exceptionally geological context favourable for the development of geothermal energy. Djibouti is located in the Afar depression at the junction of three important tectonic structures: The Eastern Africa Rift zone, the Red Sea Rift and the Gulf of Aden (Figure 1). The rift zone is still expanding by about one millimetre per year. This geodynamic context of rifting is characterized by intense volcanic activity and geothermal manifestations marked by fumaroles and hot springs found in different parts of the country. The exploration of the geothermal activities has a 40 year long history in Djibouti and can be divided into six major steps:

- ❑ 1970 to 1975: The first exploration drilling was in 1975 by BRGM including two exploration wells in the Assal area (Assal 1 and 2). The two wells have shown good temperatures but only one of them has produced geothermal fluid (Assal 1) but too salty.
- ❑ 1980 to 1985: The Djibouti government conducted a detailed general inventory of geothermal resources and several areas of interest were identified, including Assal, Hanlé, Lake Abbé, Obock, North Goubbet, Dorra, and Arta.
- ❑ 1987 to 1988: The second deep geothermal exploration was conducted by AQUATER. Two wells were drilled in Hanle (Hanle 1 and 2) and three wells in the Assal Rift (Assal 3, 4, 5). One exploration well was also drilled by ISERST in the Assal Rift (Assal 6). The Hanlé wells were

negative (no geothermal gradient). The wells Assal 3 and 6 have proven to be productive but the wells Assal 4 and 5 dry but with too high temperatures (359°C).

- 1989 to 1990: A geothermal scaling/ corrosion study was carried out on well Assal 3, with the objective to assess the effect of scaling and corrosion and to study possible ways to reduce the negative impact of the salinity (Virkir-Orkint, 1990).
- In 1995: Further TEM measurements were carried out in a part of the Assal region in order to understanding better the sub-surface structures (Árnason and Flóvenz, 1995).
- 2007 to 2008: A prefeasibility study was carried out in the Assal rift by Iceland GeoSurvey and Reykjavik Energy Invest (REI). The geological (Khodayar, 2008) and geophysical (Árnason et al., 2008) results of the prefeasibility phase identified Fiale caldera in the Assal rift as a favourable production sector. (Figure 2).

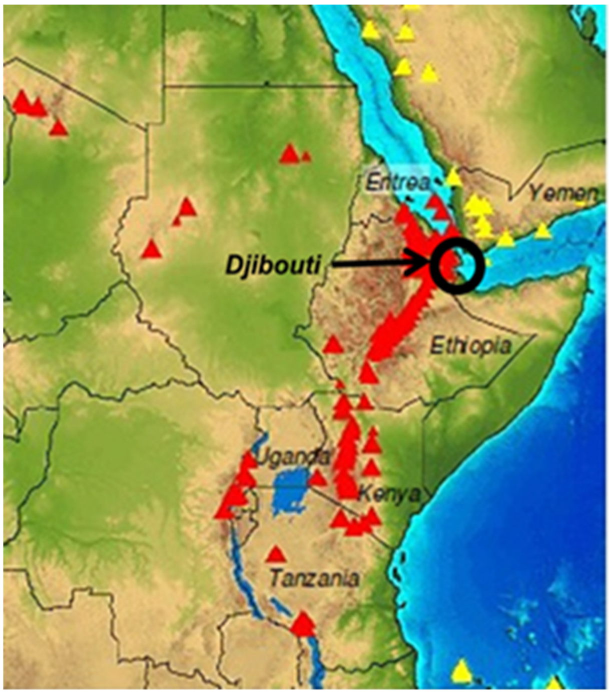

FIGURE 1: The East African Rift and location of Djibouti. Volcanoes (red triangles) with known inferred Holocene eruptions (Smithsonian Institution, 2013)

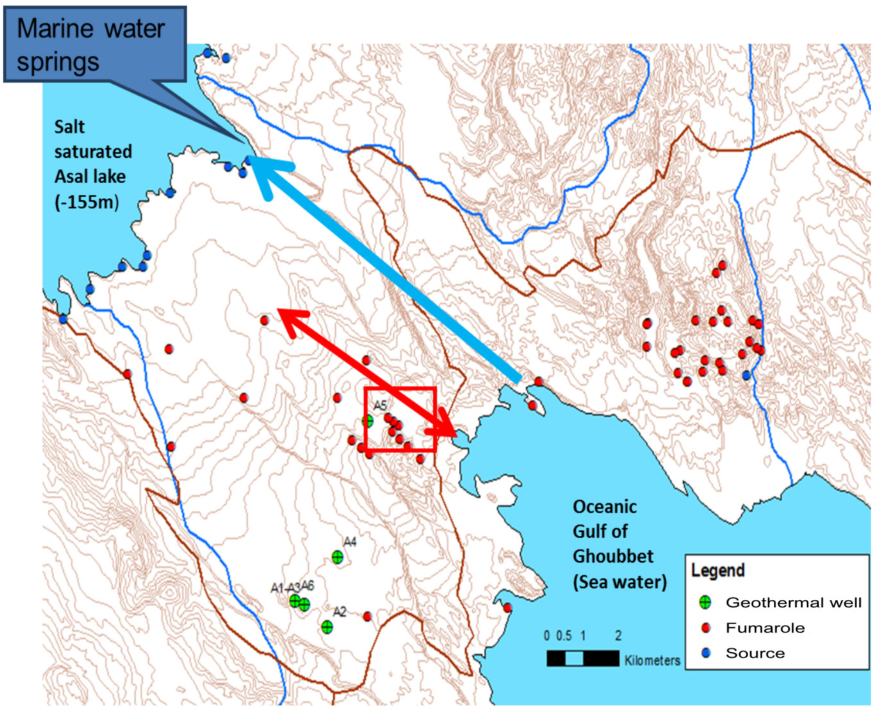

FIGURE 2: Location of the drilled sites (in green, numbered) and main fumaroles (red dots) of the Assal rift on the topographic map. The first wells (A1 to A3) and later A4 et A6 were drilled on the SE side of the rift, at a fair distance from the active volcanic axis of the rift (double red arrow) as well as from the seismo-tectonically active axis along which an important ground sea water flow cross through from Ghoubbet to Lake Assal -155m b.s.l. (blue arrow). The site of the present feasibility project is the red square (source: J. Varet ARGeo-C5)

The results from these six wells have shown the existence of a shallow geothermal reservoir and a deep reservoir. The shallow reservoir at depth ranging from 240 m to 600 m is showing high permeability and temperatures between 140 and 190°C, but has not been tested. The deep reservoir is situated below 2000 m depth with temperatures ranging from 250 to 360°C. The geophysical data correlated with the well logs is suggesting a continuity of the shallow reservoir in the whole rift area, which is not the case for the deep reservoir (Orkustofnun, 1988). Comparison of the chemical and temperature data shows that the shallow reservoir was thermally protected and with a salinity around 50g/l. The depth to the magma chamber is between 2 and 5 km depth. The geothermal gradient observed, has a thermal anomaly characteristic of large global geothermal fields, it is 25°C/100 m. The values of the heat flow obtained are 3.9 Mcal/cm^2/s. The seawater flowing through fractures in the rift of the centre tends to lower the surface gradient.

The geophysical survey done by ISOR for Reykjavik Energy Invest (2008) enabled the elaboration of a new conceptual model taking into consideration available data including the results from the previous deep drilling. This allowed sitting the 4 exploration wells that are now planned in the central part of the rift axis within Fiale caldera and its immediate surroundings. After REI withdrew its interest in the project, the program was taken as a base of reference for the World Bank to propose the feasibility study presently being engaged. Following these references, 4 wells have been planned to be drilled down to 2800 m with large production diameters (9 inches) and deviated in the reservoir (below 2000 m) in order to maximize the chances to intersect open productive fissures supposedly vertical in this axial part of the rift.

3.2 Assal-Fiale geothermal project

3.2.1 Objective and location

The Assal-Fiale geothermal project is located in the Fiale area, with a focal point in Lava Lake, a circular depression filled with young lava flows, where maximum spreading takes place in the Rift and with intensive micro earthquake activity. This area is the focus of the planned exploration-drilling project due to a set of observations that point towards a possible good resource. Firstly, coexistence of large and active faults, intersection of fault systems, a high resistivity anomaly underneath a low resistivity layer, lava production centre and seismic and fumaroles activity. Secondly the brine is expected to have salinity close to that of seawater and lower than in wells 1 and 2 in the old wellfield and therefore better suitable for utilization. Finally, the Lava Lake resistivity anomaly appears to be on the order of 4 km^2 at 1000 m depth and enlarges when going deeper. It should therefore prequalify as a resource that can support a minimum of 50 MW station, using a conservative 10 MW/km^2 generating capacity as a reference.

Based on the conceptual model from pre-feasibility study four well locations were determined and drilling targets were specified.

The objective of the planned exploration-drilling project is to quantify the technical and financial feasibility of using the geothermal resources of Assal rift for mass production of electricity. The project comprises an exploration drilling program of 4 production wells in Fiale region north of the Lava Lake.

The primary objective is to reach and test the intermediate/shallow reservoir (at 240 to 600 m). The temperatures there are ranging from 140°C to 190°C which is high enough to generate electricity for commercial purposes using a binary cycle power plant.

3.2.2 Project phases

The Assal-Fiale geothermal project is part of a geothermal energy development program aimed at improving the quality of life for the public in Djibouti by increasing access to electricity through an expansion of the national energy production capacity. Structured as a public-private partnership (PPP), the programme will be executed in 3 phases:

(i) Phase I comprises the exploration of the Lake Assal geothermal vapour field and confirmation of the characteristics of the field's geothermal resources;
(ii) Phase II involves the development of the geothermal field and construction of a geothermal power station with an installed capacity of 20 MW;
(iii) and Phase III will involve expanding the capacity of the geothermal power station to 50 MW.

Phase I, financed with concessional resources, is currently ongoing and is aimed to minimise exploration risks in order to pave the way for private sector participation under Phases II and III.

3.2.3 Main components and activities in Phase I

Phase I of the project will comprise the following components: (A) Drilling activities; (B) Technical assistance; (C) Project implementation; and (D) Environmental and social management. This phase will be executed until May 2016. The geothermal power station, which will be developed in Phases II and III, and financed by a private investor, is planned to be implemented once the geothermal resource has been confirmed by the feasibility study in Phase I.

TABLE 2: Description of activities in Phase I

No.	Component name	Component description
A	Drilling activities	Execution of a drilling programme for 4 exploration/production wells, including civil engineering works, drilling services, procurement of equipment and testing.
B	Technical assistance	Recruitment of an expert to develop the exploration programme, including drilling, testing and the feasibility study for the geothermal power station
C	Project implementation	Operation of the Project Implementation Unit (PIU), including costs related to the recruitment of the International Manager of the PIU.
D	Environmental and social management	Execution of the Environmental and Social Management Plan

Main construction phases:

- Construction of an access road from the Djibouti-Tadjourah RN9 highway to the drilling sites;
- Opening of one or more quarries to obtain backfill material;
- Construction of 4 drilling platforms, each having a surface area of 6,000 to 10,000 m^2. To each platform will be added two watertight tanks, one for mud (1,000 m^3), and the other for collecting geothermal fluids produced during production tests (2,000m^3). In event of a positive drilling result, the equipment needed to conduct various tests, such as a separator and a silencer, as well as fluid processing equipment, will also be installed on these platforms.
- Preparation of the land at least for storage of equipment and/or temporary premises for the drilling team;
- Drilling works (4 boreholes created through rotary directional drilling with an initial diameter of 23 inches, a final diameter of 9 inches, and a target depth 2000 to 2,500 metres).
- Laying of discharge pipes for geothermal fluids, and a water intake pipe for preparation of drilling mud;
- Establishment of a camp for workers and security officers.

3.2.4 Development phase

The intermediate goal is to commission a 50 MW plant in Djibouti. Once the capacity of the source has been confirmed with drilling, the project will proceed by continuing drilling production and re-injection wells in the area as well as having conceptual design done of the resource and the power plant (Figure 3). The development consists of access roads, service roads, production wells, water supply system, steam transmission pipes, steam separator stations, power house, cooling towers/units, steam exhaust stacks, a groundwater supply system, water tanks, hot-water transmission pipe, quarrying, storage site, discharge system, injection areas and connection to the power grid (Hjartarson et al. 2010).

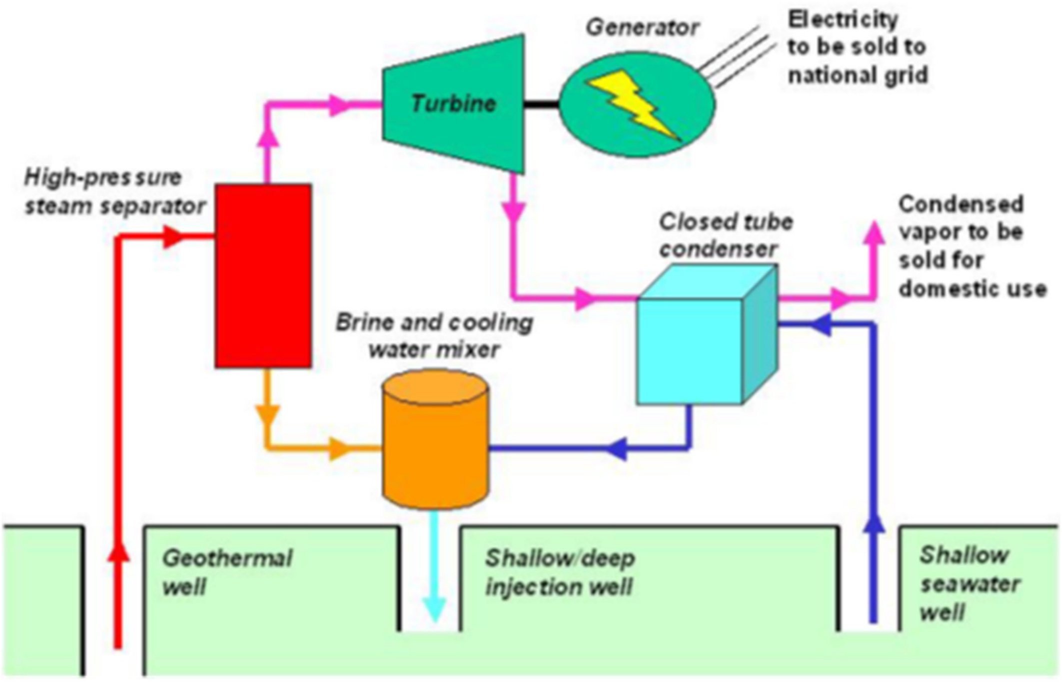

FIGURE 3: A conceptual design of a power plant proposed by Reykjavík Energy Invest, 2009 (Hjartarson et al., 2010)

4. ENVIRONMENTAL CHARACTERISTICS OF THE ASSAL GEOTHERMAL AREA

4.1 Physical environment

Geology

The Assal geothermal system is located on the isthmus between Lake Assal and Ghoubbet el Kharab gulf (Figure 4) at a distance of about 120 km from Djibouti City. Altitudes range from -151 m at Lake Assal to +300 m at the highest point of the Rift valley floor. The area is bounded by the high plateaus of Dalha to the north (above 1000 m elevation) and by 400-700 m high plateaus to the south. The most remarkable signs of recent and current volcanic activity in the Assal Rift are the presence of hot springs, fumaroles, various craters and the Ardoukoba volcano that started erupting in November 1978.

Seismicity

Because of the peculiar tectonic situation, the Assal Rift is impacted by tectonic faults, that are still active and the area is a very seismically active region. Earthquakes are quite frequent although their intensity is low. The region was hit by an earthquake in March 1992 that rippled through the Gulf of Tadjourah, with its epicentre located at sea, 2 km off the coast of Arta, and seismic tremors that exceeded 4 on the Richter scale. These earthquakes did not cause much damage. The average period of occurrence of an earthquake with a magnitude exceeding 5 in a given region is estimated 16 years (± 5

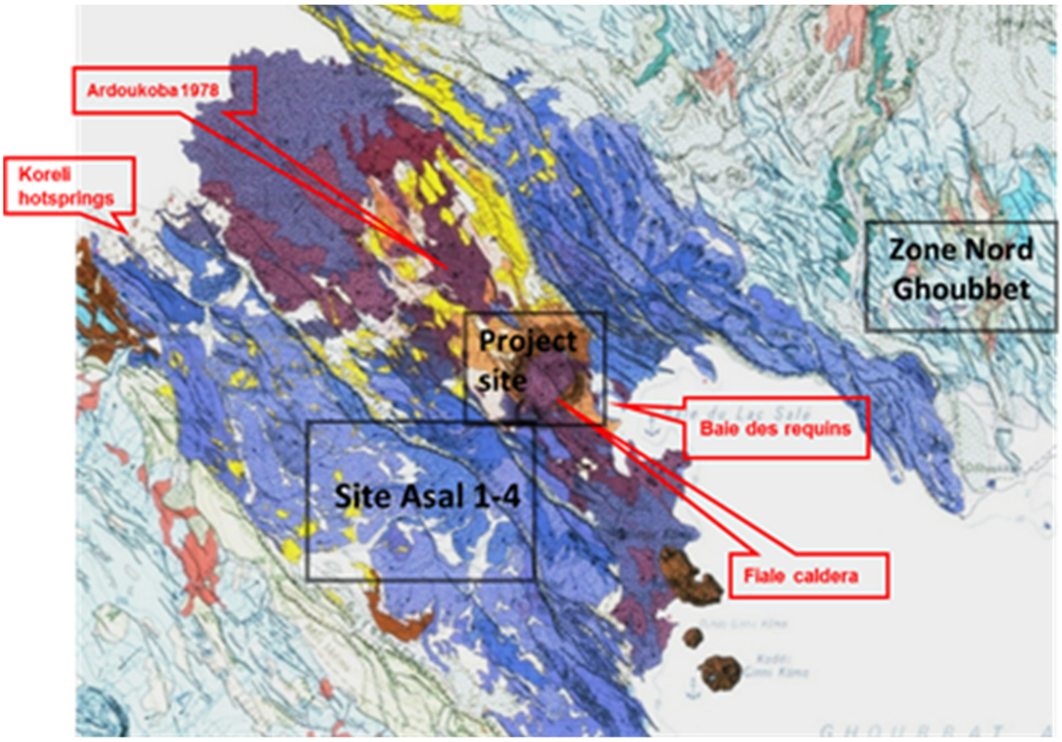

FIGURE 4: Geological map of the Assal Rift (Stieltjes, 1978); hyaloclastites are in orange, recent basalts in deep blue and violet. Early rift basalts (300.000 – 100.000 y.) are in pale blue; the stratoid series (3 to 1 My) is in very pale blue colour; lacustrine deposits (diatomite) in yellow

years). A magnitude of 6 on the Richter scale is estimated to be the maximum for the Gulf of Tadjourah (Didier, 2001).

Climate and water resources
The region is arid desert, with an average rainfall of 130 mm per year, but can be highly variable in certain years. The climate, which is far from uniform all over the national territory, varies over time and with each region. Generally, the climate in the coastal regions is characterized by a cold season (from October to April) and a hot and dry season (from May to September).

Humidity ranges between 40% and 90%, while average air temperature is 25°C in winter and 35°C in summer. The quantity of fresh water resources in the project area is very limited because of low rainfall. The groundwater in the Lake Assal region is of poor quality, with a salinity of >2.000 mg/l (CERD, 2009). Hydrogeological studies of the region show a general groundwater flow towards Lake Assal, which is the lowest point of the area, and is a salty lake saturated with sodium chloride and calcium sulphates.

4.2 Protected areas and ecosystems

Djibouti has currently 7 protected areas comprising 4 on land (Day and Mabla forests, Lake Abbé and Lake Assal) and 3 at sea (the Islands of Musha and Maskali, Sept-Frères-Khor Angar-Godoria and Harramous). They are all classified as protected areas under Djibouti law, but do not directly match the categories of the IUCN.

Lake Assal
Lake Assal, is situated 155 m below sea level in a volcanic area. It is the third deepest depression in the world and is considered to be one of the geological wonders of the country. Lake Assal is surrounded by an expanse/area of solid salt of variable thickness that exceeds 60 metres at certain points with a surface area of 60 km^2. This briny body of water, which is saturated with mineral salts (up to 340 g/l), has a surface area of 50 km^2 and a maximum depth of 25 m. Its reserves are deemed to be inexhaustible,

since 6 million tonnes of salt flow in each year (filtering in from Ghoubbet sea and from brackish hot springs). From time immemorial, this lake has always been a focus of interest to the nomadic peoples of the region whose main livelihood is small-scale mining of salt that is exported by caravan to Ethiopia.

Lake Assal has been declared a protected area under Articles 1 and 7 of Law No. 45/AN/04/5L. Nevertheless, the exact boundaries of the protected areas and their managerial measures/conservation strategy have not yet been defined. There is no accurate map of protected areas in the country. The statute determining the protection boundaries of Lake Assal has not been adopted, but provision is made for protecting the lake itself and its salt banks (solid salt expanse). The distance between the drilling site and the banks of Lake Assal is approximately 8 km. The proposed drilling site is located (maximum 1 km) close to the area where water from Ghoubbet sea filters into Lake Assal.

Ghoubbet-Kharab
Ghoubbet is a sensitive ecological area separated from the Gulf of Tadjourah by a narrow strait that is 40 m wide and 40 m deep. Ghoubbet sea is more than 200 metres deep. Sea water salinity ranges from 39.3 g/l at a depth of 125 m in November to 37.7 g/l at the surface in June. Surface temperatures fluctuate between 28°C and 30.5°C. Ghoubbet is a potential marine protected area according to Ministry of Housing, Urbain planning and Environment (MHUE). The distance between the drilling site and Ghoubbet-Kharab is an approximately 2 km airline and 5 km by road.

4.3 Biological environment

Flora
In general, the vegetation of Assal-Ghoubet region is grass and shrub steppe with *Dracaenae ombet*, *Acacias tortilis* and *mellifera* as well as *Acacia asak* in the more humid areas. Acacia leaves are the main food for goats. The land around the proposed drilling site and around "Lava Lake" is uneven terrain, covered mainly by basaltic lava with very little vegetation in general.

Fauna
The presence of wildlife in the Lake Assal is limited to the confluence of springs flowing into the lake where the water is less saline. The presence of small fish (*Cyprinodon* sp.) has been confirmed.

The Ghoubbet marine basin is a spawning area for most pelagic fish and coral reef fish of Djibouti (National Monograph, 2000). Ghoubbet is the habitat of several species mentioned in Decree No. 2004-0065/PR/MHUE on the protection of biodiversity, especially dugongs, dolphins, turtles, sharks and whale sharks *(Rhincodon typus)* which deserve special protection.

4.4 Socio-economic environment

The Fiale caldera, located near the scheduled drilling area, is used as pastureland by the local community and transhumant herds. At the same time, the site is also traversed by the access road leading to the Ardoukoba volcano and Lava Lake which are sites of touristic interest (African Development Bank, 2013).

Human and socio-economic environment
The project is located in Tadjourah region, 79 km from Tadjoura town and 127 km from the capital. It is 7 km away from the border of the Arta region and 25 km away from Karta village (Arta region), where the nearest school is found. The closest community is currently located at Daba le Gahar (76 households) on the former camp site of the Yugoslavian company that built the RN9 highway, situated approximately 5 km from the proposed drilling site. The total population of the villages of Daba le Gahar, Laïta and Ardoukoba (called Carrefour) is 298 "sedentary" households who still mine salt using caravans. In addition to the settled population, 248 "semi-nomadic" households (practicing

transhumance) live in the area. The population of the study area is 546 households, the closest of which live in Daba le Gahar, 5 km from the proposed drilling site. Traditionally, the Assal zone is not recognized as a permanent settlement site because of its harsh climatic conditions, lack of drinking water and scanty vegetation.

In the past, it used to be a periodic transit area between two seasons (cold season and hot season) used by transhumant herders as they moved from North to South or from South to North. There are no basic services, no basic infrastructure, no health posts or schools. However, it was also the area that experienced the first intensive salt extraction activities. The region had the greatest number of caravans travelling from the salt banks of Lake Assal to Ethiopia.

The important archaeological sites within the region are concentrated along the Ghoubbet coast, South-East of the study area.

In the project area, there are several tourist attractions of varied potential:

- Lake Assal and the salt caravans;
- "Lava Lake";
- Ardoukoba volcano with its peculiar geology;
- Ghoubbet-el-Kharab, the shark pool, Devil Island;
- The camps of "Dankalêlo / Ghoubbet" and "Afar Rift".

Drinking water
The leading priority for the local population is drinking water. There is no drinking water source, since groundwater is saline. The villages are supplied with water only once a week by a tank truck from the regional administration.

Education
There is no school in Assal sub-prefecture. Children from the villages attend the nearest school in Karta (15 km). Out of the 170 in the communities, 59 children attend school. Since there is no school bus, the children trek to and from school.

Health
There are no statistics on the health situation of Assal region. Public health is not developed. There is no dispensary/health centre in Assal sub-prefecture. In theory, an ambulance service exists in Tadjourah town, but because of the long distance, it is expensive and in fact unavailable.

Electricity
The villages have electricity only when there is gasoil for an existing generator (at least for some households). The project for building interconnection lines from the future geothermal power station will not improve the situation in the villages unless a low-tension line for rural electrification is constructed.

5. ENVIRONMENTAL REGULATION APPLICABLE TO THE ASSAL-FIALE PROJECT

Djibouti's environmental policy is based on laws, agreements and international treaties that contribute to socioeconomic development of the country. Since the 2000s, many national and international laws were adopted.

5.1 National legislation

The Assal geothermal project will have to comply with the following regulations regarding the environment:

- Act No. 106/AN/00/4L on the environmental CODE 2009;
- Act No. 45/AN/04/5L on terrestrial and marine protected areas;
- Act No. 66/AN/94/3L on the mining code;
- Decree No. 2004-0092/PR/MHUE establishing the National Commission on Sustainable Development (CNDD);
- Decree No. 2001-0011/PR/MHUE on environmental impact studies;
- Decree No. 2011-029/PR/MHUE revising the assessment procedure of environmental impact.

Environmental Code Act:
Law No. 51/AN/09/6th L on the Environmental Code is to set the ground rules and basic principles of national policy in the field of protection and management of the environment in order to ensure sustainable development, in accordance with multilateral environmental agreements.

In this project, the Articles 19-26 concerning the protection and preservation of water resources as well as Articles 27-31 concerning the protection and conservation of the soil and subsoil require special consideration.

In Articles 75-88, the Environmental Code specifies the status and treatment of waste.

In Articles 39-41, the Act to the Environmental Code also strengthens the protection and preservation of plant and wildlife.

According to the Environmental Code, the creation of protected areas Land and Marine enacted thereunder Law No. 45/AN/04/5th L remains in force.

Protected Areas Act:
Act No. 45/AN/04/5th L Establishment of Protected Land and Marine Areas. Under the special provisions of the Convention on Biological Diversity, the Ramsar Convention on Wetlands and the Framework Law on the Environment, Terrestrial Protected Areas, and the sites below have been listed:

- Forest Day;
- Forest Mabla;
- Lake Abbé;
- Lake Assal.

The draft report the Ghoubbet-Kharab as a marine protected area has been communicated by the MHUE, but to date there is no documentation of these forecasts.

Mining Code:
The Mining Code No. 66/AN/94/3L, establishes the exclusive ownership of the state over all land resources and the earth and marine subsoil whose management and operation are ensured by public authorities (Article 2 of Law No. 66/AN/94/3L).

The Code grants licenses for prospection ("research"), exploration, mining development, and refining and smelting.

Articles 11-13 of the Code specifically apply to mineral and geothermal waters and brine. These grant the Government the right to authorize prospection, exploration and development/utilisation of these resources according to rules and formalities to be specified by specific Government order. Accordingly, the Government may decree the provisions of the Law that it deems appropriate to be applicable. The volume of mineral water, geothermal fluid, or brine to be produced and its calorific value will be subject to government authorization. The mode of extraction of secondary products (contained minerals) and of the production and use, as well as the reinjection of waste geothermal fluid may also to be determine.

This Code is supplemented by Decree No. 97-0064/PR/MIEM "permit and the taxation of research-related activities, exploration and mining".

Environmental Impact Studies (2001/2009/2011):
A national law and two decrees address the issue of environmental impact studies:

a) The Law No. 51/AN/09/6th L Environmental Code Chapter VII: "Integration Mechanisms for Environmental" provides details with respect to environmental studies and evaluation. The environmental impact study should include at least:

- An analysis of the initial state of the site and its environment;
- A project description;
- A study of changes that the project is likely to generate, and measures considered to remove, reduce or offset the negative impacts of the activity on the environment and health;
- A cost of these measures before, during and after the project;
- An achievement of an environmental management plan;
- A public hearing.

b) Decree No. 2001-0011/PR/MHUE is concerning definition of the environmental impact assessment procedure and the environmental management of major projects. This decree targets mainly:

- The integration of environmental concerns in all phases of a project, from design to post-closing through its operations;
- Inventorying all change vectors in the project area;
- Identification of any negative impacts and/or positive and suggest consistent and sustainable mitigation.

The decree emphasizes the obligation of the environmental impact study and due process for all projects, whether public or private, consisting of works, facilities, agricultural, mining, crafts, commercial or transport, whose implementation is likely to harm the environment.

c) Decree No. 2011-029/PR/MHUE revises the environmental impact assessment procedure and specifies as follows:

- in Article 4, the Ministry of Environment is responsible for the categorization of EIA. The decree divides the EIA in 2 categories (summary and detailed);
- in Articles 5 and 6 the necessity and procedure of environmental permit by the Ministry in charge of environment. The environmental permit is issued for a period of five years from the start of the project and is renewable after an environmental audit.

The procedure for developing and approving the impact study is defined in Title IV, Articles 12-29 of the Decree, including information on public participation and organization of a public hearing meeting. Surveillance and environmental monitoring are covered in Articles 30-34, stating the specifications, institutional responsibility and the Environmental and Social Management Plan (ESMP) accommodations. A possible modification of original project requires a new environmental impact assessment according to Article 37.

In accordance with Articles 35-38, the sponsor must at the end of the project, conduct an environmental audit, the implementation arrangements will be decided by the Ministry of Environment in environmental technical guidelines. The audit report must be submitted to the Ministry of Environment for review and issuance of environmental discharge.

The audit and its environmental management plan are sanctioned by an environmental discharge by the Ministry for the Environment. The Environmental Management Plan resulting from the audit is a set of specifications for the developer.

National Action Program on Biological Diversity:
The Government also adopted Decree No. 2004-0065/PR/MHUE of 22 April 2004 on the protection of biodiversity. The decree made under the Convention of Biological Diversity, lists the animal species, endemic or endangered, and as such benefiting from special protection.

The decree stipulates that the hunting, capture, trade, export, and import of these species and their products are prohibited. The decree also states that the felling, removal, bleeding, and plucking of endemic or endangered plant species is strictly prohibited.

The enforcement of this decree is provided by Directorate of Physical Planning and Environment with the support of the departments concerned.

In accordance with Articles 1 and 7 of Law No. 45/AN/04/5L, Lake Assal is a protected area. The exact boundaries of protected areas in Djibouti and management measures are not yet established and there is no exact map of protected areas and will be detailed in regulations. The regulation determining the Lake Assal protection limit has not yet been enacted.

5.2 International legislation

International Conventions and Treaties which Djibouti has signed and ratified will also need to be respected during the execution of the project:

- The United Nations Convention on Biological Diversity (1992);
- The United Nations Framework Convention on Climate Change (1992);
- The Kyoto Protocol to the United Nations Framework Convention on Climate-change;
- The RAMSAR Convention on Wetlands and bird species that live there (1971);
- The Basel Convention on the Control of Transboundary Movements of dangerous waste;
- The Convention on Migratory waterbirds;
- The United Nations Convention on the Law of the Sea;
- The International Convention on trade in animal and plant species with extinction (1973).

World Bank Operational Policies applied in the Environmental Assessment:

a. 4.01 "Environmental Assessment";
b. 4.04 “Natural Habitats”;
c. 4.11 “Cultural Property”;
d. 4.12 “Involuntary Resettlement”;
e. 4.10 “Indigenous People”;
f. Environmental, health and safety guidelines of the World Bank group for geothermal power generation (DRAFT Environmental and Social Management Framework for the ARGeo project);
g. The “Equator Principles”.

5.3 Standards

The Assal geothermal project must comply with the following regulations regarding the effluent discharge, gases emissions, and noise:

- Environmental, Health and Safety Guidelines Mining, IFC/World Bank, 2007;
- Human exposure limit of WHO, IFC/WB;
- The World Bank and the African Development Bank safeguard policies.

5.4 Environmental screening

According to the decree no. 2001-0011/PR/MHUEAT on Environmental Impact Assessment, thermal power stations (category 7 of the Annex) are subject to environmental impact study. However, drilling of geothermal wells is not listed in the Annex.

The World Bank undertakes environmental screening of each proposed project to determine the appropriate extent and type of Environmental Assessment. The Bank classifies the proposed project into one of four categories, depending on the type, location, sensitivity, and scale of the project and the nature and magnitude of its potential environmental impacts (The World Bank Operational Manual OP 4.01, 1999).

a. Category A: If the proposed project is likely to have significant adverse environmental impacts that are sensitive, diverse, or unprecedented. These impacts may affect an area broader than the sites or facilities subject to physical works. The proposed project requires full Environmental Assessment.
b. Category B: If the proposed project's potential adverse environmental impacts are less adverse than those of Category A projects. These impacts are site-specific; few if any of them are irreversible; and in most cases mitigation measures are readily designed. The proposed project requires a more targeted Environmental Assessment or just an EMP.
c. Category C: If the proposed project is likely to have minimal or no adverse environmental impacts. The proposed project is beyond screening, no further Environmental Assessment actions are required.
d. Category FI: If the proposed project involves investment of Bank funds through a financial intermediary, in subprojects that may result in adverse environmental impacts.

It should be stressed here that according to the Icelandic Environmental Impact Assessment Act no. 106/2000, which is in accordance with the European Union Directive 85/337/EEC and 97/11/EC the following applies:

- Drilling of production/research wells in high-temperature geothermal regions are projects which *may be subject to* environmental impact assessment and are assessed on a case by-case basis.
- Geothermal power plants with a heat output of 50 MW or more and other power installations with an electricity output of 10 MW or more *shall always be subject to* Environmental Impact Assessment.

When considering the type and scale of the drilling and testing of the four geothermal wells in the Assal area, the rating of the sensitivity of the proposed site and taking the experience of the impacts of similar projects in Iceland into account, REI's opinion is that the drilling and testing of the feasibility study should be classified, according to the World Bank as Category B project.

5.5 Responsible authority

The Ministry of Housing, Urban Development, Environment and Land Use Planning (MHUEAT) is in charge of environmental issues. According to article 5 in the decree no. 2001-0011/PR/MHUEAT the Minister for the Environment grants a development permit.

The implementation of the national policy for the protection of the environment and for a sustainable development of the country is under the responsibility of the Prime Minister. A decision on

Environmental Assessment and grant of a development permit for drilling and testing of geothermal wells has to be based on a common decision between numerous administrations like:

- The Ministry of Housing, Urban Development, Environment and Land Use Planning (MHUEAT);
- The Ministry of Interior;
- The Ministry of Energy and Natural Resources;
- The Ministry of Water, Agriculture, Livestock and Sea;
- The Ministry of Youth, Sports and Tourism;
- The municipalities Tadjourah and Dikhil. The proposed drilling and testing site for the drilling operation of the feasibility study is in the Tadjourah municipality. The Dikhil municipality border is only few km away as the border between these two districts runs alongside Lake Assal's southern shore and ends at the Ghoubbet El Kharab basin. Both communities will be actively involved in the project as the camp sites and other logistic activities may be in the Dikhil municipality.

5.6 Comparison of EIA process in Iceland and Djibouti

The first law on Environmental Impact Assessment in Iceland is from 1994. Major changes were done in the new law no. 106/2000 when the scoping process was introduced but the latest change is in law 60/2013 when the main change is that projects are in three groups instead of two.

In article 12 of law 60/2013 it says that in Annex 1 there are projects in three groups/categories A, B, and C. Projects in category A are always subject to an EIA but projects in category B and C may be subject to an EIA and that is assessed in every case with respect to the type /nature, scale, and location of the project. Following is the list of geothermal projects and projects related to geothermal utilization (Table 3).

TABLE 3: Categories of projects subject to an EIA in Iceland
(Law on EIA nr. 106/2000, changes by law 138/2014)

Paragraph	Projects	Category
2.06	i. Drilling of exploration and production wells in high temperature areas.	B
	ii. Drilling in low temperature areas where mineral water sources, hot pools or hot springs are on the surface or in the nearby vicinity.	B
3.02	Geothermal power plants with a heat output > 50 MWh or more and other power plants with electric output > 10 MWe or more.	A
3.07	Industrial installation for production of electricity, steam and hot water and thermal processing from geothermal areas, 2.500 kW gross power or more.	B
3.08	Overhead transmission lines 66 kV or more. Submarine cables for transport of electricity 132 kV or more, 20 km or longer.	A
3.09	Pipes for carrying gas, steam or hot water in connection with industrial projects.	B

The Figure 5 shows that developers in Iceland, have to apply first for a research license from the Ministry of Industries and Innovation. Then, the developer notifies to the National Planning Agency (NPA) of the proposed exploration drilling project and the NPA decides whether the project needs to be subjected to an EIA. If the project is subjected to an EIA and, it is accepted, or if it was not subjected to EIA, the developer needs to apply for a development permit to the National Energy Authority in order to start exploration drilling. After the exploration drillings and a feasibility study the developers have to submit a scoping document for the EIA for a proposed power plant that needs to be revised and accepted by the

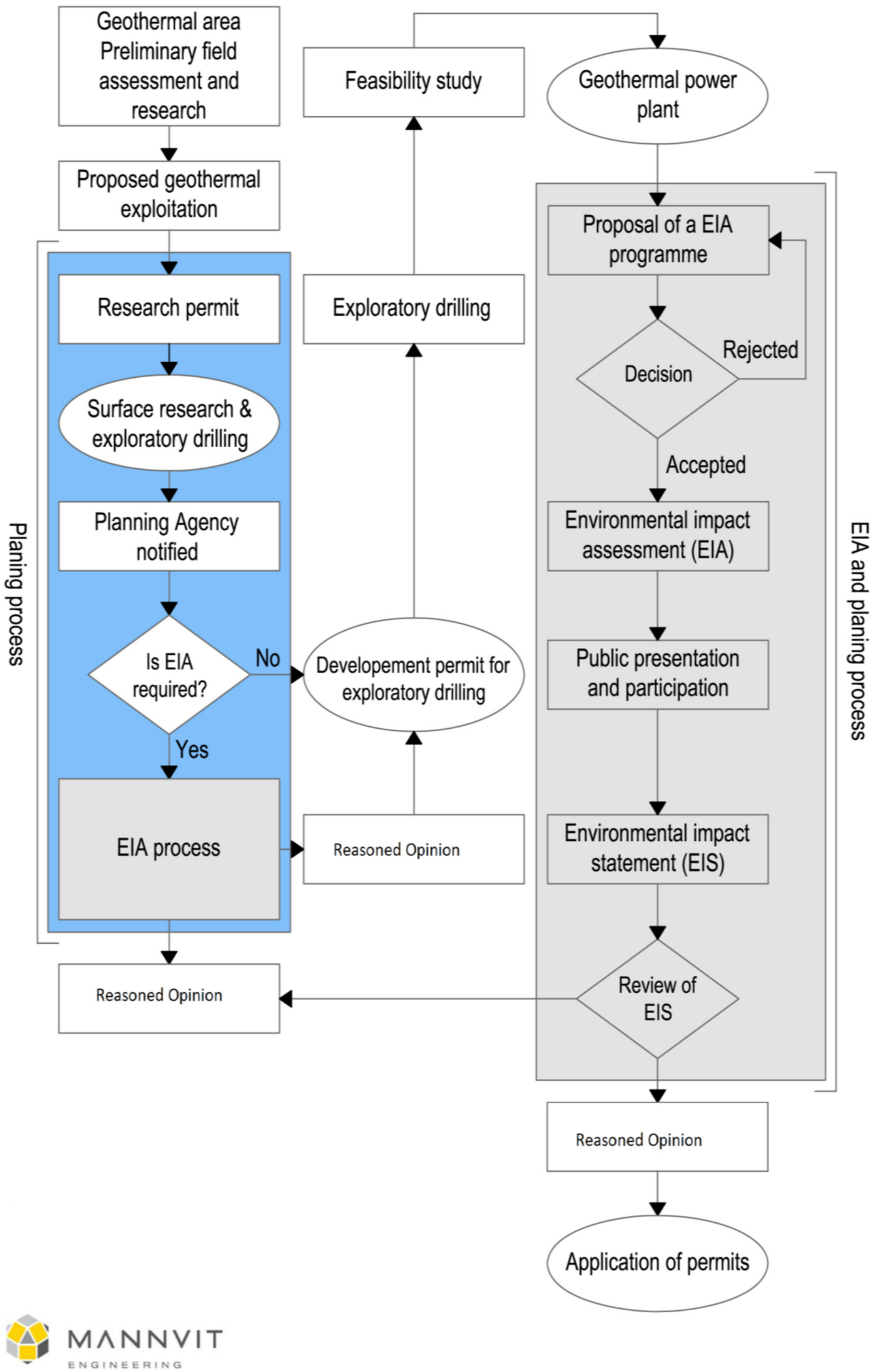

FIGURE 5: Flowchart of regulatory framework of EIA in Iceland (Rodas, 2015)

NPA. When the ruling is positive the developer carries out the EIA and goes through the normal stages of presentation and public participation before the preliminary EIA statement/document (EIS) is sent to the NPA for revision. The NPA makes the preliminary EIS public, seeks comments from other statutory agencies and delivers, with the publics comments included, to the developer. The developer inserts all comments and his responses to them into the preliminary EIS and sends the final EIS to the NPA. The NPA gives a reasoned opinion on the project's EIS which is the basis for development permits published by the local municipality. The project must also be in accordance with spatial plans, regional and municipal development plans, but if not then the planning process must be considered as part of the preparation stage. The last step is to apply for all necessary permits like operation and utilization permits to the National Energy Authority, the environmental permit to the Municipal Health Committees and construction and building permits to the local municipalities.

In Djibouti, the Ministry of Environment holds the responsibility to revise and approve the Environmental Impact Assessments.

The first difference that can be noticed when reviewing the law in both countries is that in Djibouti the resources of the subsurface belong to the State no matter if the resource is located on a private land or if it is located under the territorial sea. On the other hand, in Iceland the ownership of the underground resource is linked to the owner of the land in which it is located, if the resource is in a public land then it is property of the State. Nevertheless, the development and use of the resource is subject to licensing. The EIA process in both countries presents the same principle, unless the state or one of its organisms are the developers. In conclusion, the main difference between the EIA processes in the countries that could affect the development of geothermal energy, is the absence of specific norm to different resources in Djibouti.

6. POSSIBLE ENVIRONMENTAL IMPACTS OF THE ASSAL-FIALE PROJECT

The potential impacts, positive and negative, can be classified into 3 categories:

- physical,
- biological, and
- social and economic impacts.

6.1 Positive impacts

The Assal-Fiale project will have significant positive impacts including stabilization of electricity generation in Djibouti, promotion of economic growth in the country and contribution to the Government revenue. The project will also be improving socio-economic conditions of the local population by the creation of employment, access to social amenities (education, health, water, transport, and roads), development of tourism, and the improvement in gender equality. The project will offer opportunity for training and acquisition of skills.

6.2 Negative impacts

6.2.1 Potential impacts on physical environment

Geology and land

During exploration: Exploration can be divided into two phases. First is the surface geophysical studies which will not have any significant impact on geology and land. The second part of exploration includes drilling experimental wells to obtain a geothermal gradient map which can have some impact such as soil disposal.

During drilling: Road construction and preparation of drill sites can cause unstable earth conditions and change or damage geological formations. During well testing, care should be taken not to discharge the wastewater directly to steep areas, but sumps should be made to contain this waste water, as failure to do this can cause serious gullying.

During operation: Subsidence and induced seismicity are the main possible effects on the land around the power plant and the surrounding areas. A monitoring program for subsidence in this area is recommended.

Effects on air

During all phases: Gas emission into the air would take place during all phases of the proposed project.

During the construction and decommissioning phases: Dust would result from surface disturbances and vehicle travel on unpaved roads.

During well drilling and testing and during power plant operations: Non-Condensable Gases (NCGs), including hydrogen sulphide (H_2S) and carbon dioxide (CO_2), will be released from the geothermal fluid.

During all phases: Oxides of Nitrogen, Carbon monoxide, and oxides of Sulphur emitted from internal combustion engines will be released during all phases of the project.

A summary of the effects on air during such a project:

- Small quantities of critical air pollutants will be released from mobile construction equipment and other vehicles, but this impact will be below the level of significance;
- Large quantities of critical air pollutants, in particular oxides of nitrogen (NOx), will be released from drilling rig engines during well drilling operations, but this impact will not be significant if wells are drilled one by one, and only one active drill rig is operated at any one time;
- Hydrogen Sulphide will be released during well flow testing from well pads and during power plant operation, and it is necessary to control the concentration of H_2S in the atmosphere and keep it below levels specified in international standards;
- The project will release "greenhouse gases" which will contribute to global warming. These gases consist mainly of carbon dioxide (CO_2) and some methane (CH_4). But a prediction of the amount of carbon dioxide released to the atmosphere per kilowatt of electricity shows it to be approximately 20 times smaller than the amount of "greenhouse gases" released from a fossil-fuel power plant for an equivalent amount of electricity.

During drilling test and operation, a monitoring programme, including the monitoring of pollutant gases such as H_2S in the atmosphere, should be carried out, and if the concentrations of these gases become higher than limits set by standards, measures must be taken to reduce their amounts in the atmosphere.

Effects on water

The wells, which will be drilled in this area for high-temperature geothermal fluid will be deep and may require up to 50 l/s of water for periods of several months, depending on the number of wells to be drilled. The amount of water used as drilling fluid is enormous and should be recycled or discharged with utmost care into well-designed sumps, or possibly re-injected as this can affect the quality of the groundwater in the area.

The concentration of dissolved solids and gases in geothermal water and steam are greater than in shallow ground water. Therefore, it is necessary to monitor the effect of geothermal fluid on surface water and shallow groundwater after the installation of a power plant.

Noise effects
In the Assal-Fiale geothermal field, there will not be serious noise impacts during geothermal project activities such as drilling, well testing, and operation. Only during well testing will there be some temporary noise, which will affect wildlife in the vicinity of the drill rig. Workers on-site will need to wear appropriate hearing protection as a necessary safety precaution. The greatest noise effects during power plant operation are from the cooling tower, transformer, and turbine-generator building. When power plant operation starts, noise mufflers must be used to keep the noise level below the 65 dB limit set by the U.S. Geological Survey (Kestin et al., 1980). With a reduced level of noise, workers, tourists, and wildlife will not be seriously affected.

6.2.2 Potential impacts on biological environment

The Assal-Fiale geothermal project can have potential impacts on the ecosystems. In case of negligent treatment, muddy waters from drilling and geothermal fluids generated during the trial phase could potentially flow over the land's surface or through shallow faults into Lake Assal. Given the probability that the heavy metal content (or other dangerous substances) of these fluids exceed that of the receiving waters of Lake Assal, it is imperative to ensure that such fluids and other waste or dangerous substances do not reach the lake.

The drilling project could have a high negative impact on protected areas, the sensitive ecosystems and the coastal areas, especially if drilling sludge and geothermal fluids are dumped into the waters of Lake Assal or Ghoubbet el Kharab. Although the latter has not yet been declared a protected area, it is the habitat of several vulnerable species that are on the red list of the International Union for the Conservation of Nature (IUCN), such as the whale shark and the dugong.

6.2.3 Potential impacts on socio-economic environment

Potential loss of part of the transhumance corridor
Part of the transhumance corridor runs over the drilling project area. The length of the corridor in the potentially affected drilling area is approximately 2-3 km, starting from the seismograph station up to the great fault behind the former Assal 5 drilling site. The passage of animals requires a corridor that has a minimum breadth of 2 m (when limited to a short distance); on flat land, animals need a larger corridor that is 1 to 2 km wide. The herds pass along the current access road and its surrounding area where the land so permits. Herders from the northern part of Tadjourah region and from the south of Dikhil region use the transhumance corridor regularly, at least twice (and often 3 to 4 times) a year, depending on the abundance of rainfall, which has remained irregular in recent years. Route No. 7 transits directly through the project area. During consultations with the affected population, the sub-prefect of the region stated that several thousands of animals transit regularly through the project area and pass through the drilling project site.

Closure of the transhumance corridor would imply that the population will no longer have access to this important transhumance resource. Under the customary law of the Afars, right of passage is defined by the Sultan of Tadjourah. If the transhumance corridor along the current route is effectively closed, an alternative route will need to be constructed.

Visual impacts
The drilling facilities and pipes will leave an enormous visual impact on the area.

Impacts Related to STDs/HIV-AIDS
Workers' camps are often a potential source of negative impacts on local women: sexual harassment, prostitution and sexually-transmitted diseases (AIDS, etc.). Women are often vulnerable to single workers living without their families in the camps and have to be protected against all forms of abuse. Given the drilling project's limited number of workers, short duration of construction activities, and recruitment of local labour, this impact is evaluated as low. An awareness-raising drive on sexually-transmitted diseases will be conducted by a local NGO to be jointly selected with the Ministry of Women's Advancement.

6.3 Risks of accidents

According to the report of the Environmental and Social Management Plan of the African Development Bank, the main environmental risks/accidents of the project are:

Well blowouts
Well blowouts may occur during drilling of wells, leading to the emission of drilling and geothermal fluids. Rising drilling fluids may have high temperatures with risks of burning for workers. The risk of an induced phreatic or volcanic eruption is low, but the impact on staff is potentially harmful and provision should be made for mitigation measures.

Accidental fluid emissions
Pipes may break during well drilling or testing, causing emissions of geothermal fluids and hydrogen sulphide from the geothermal reservoir. The potential impact of a broken pipe on staff and the environment is deemed to be high, and provision should be made for mitigation measures.

Seismic and volcanic events
Considering that the project is located in a zone of intense seismic and volcanic activities, there is a certain risk of seismic (earthquakes) and volcanic incidents. The consequences of such an incident are potentially catastrophic for the staff and local population.

7. COMPARISON OF SVARTSENGI, REYKJANES, AND HELLISHEIDI TO ASSAL-FIALE GEOTHERMAL FIELDS

7.1 Facts about geothermal energy in Iceland

Geothermal development in Iceland begins around the mid-20th century when low temperature geothermal fields were utilized for space heating in public areas such as schools, state hospitals and swimming pools. Presently, 90% of all houses are heated with geothermal energy. In the last decade of the 20th century, high temperature geothermal fields were developed and now geothermal energy accounts for 24% of the country's installed capacity with a total electrical power production of 665 MW (Björnsson and Steingrímsson, 1991. This success was achieved through the following strategies:

1. Power potential for each geothermal field analysed through detailed surface exploration and drilling. Design and construction of power plant;
2. Testing of the field by small power plant until full potential of the geothermal field was developed;
3. To keep the production constant, 1-2 wells drilled per year e.g. Hellisheidi.

Despite this strategy, the building of the geothermal power plants at Reykjanes and Hellisheidi were done in large initial steps. Reykjanes produced 100 MWe from the start and Hellisheidi 120 MWe which expanded to 303 MWe in 2011. This lead to dropping pressure which is still dropping and new wells are needed, probably earlier than was planned in the beginning. In the case of Hellisheidi, the utilization has increased and steam is piped from longer distance than planned in the beginning to keep up the electric production.

Orkustofnun (the national energy authority in Iceland) is the authority that issues licenses for research and utilization of the geothermal resources. Decisions, in this regard, made by Orkustofnun can be appealed to the ruling committee for the resources act.

According to Jónas Ketilssson (personal communication, October 2015) from Orkustofnun, the utilization licenses sometimes stipulate limitations for the acceptable pressure drawdown if deemed necessary by Orkustofnun due to the rate of exploitation. This applies in particular to geothermal power plants. An example is the Theistareykir geothermal field in north Iceland where the pressure drawdown is not allowed to be more than stipulated. It is also stated that the annual decrease in steam production cannot be more than 3% per year on average over the past five years.

If these requirements are not met the situation is analysed. Firstly, the models are re-calibrated and if issues for long-term utilization are below thresholds the license holder may have to increase reinjection, enlarge the production area and possibly even change utilization strategy.

In Hellisheidi the pressure drawdown is not more than predicted and allowed in the license. But at Reykjanes there is no limit in the utilization license that was published by the Ministry for industry in year 2004. However, in a new license issued by Orkustofnun in 2011, there are limitations, but that license is not in effect until the power plant is enlarged.

Two of the geothermal areas, Svartsengi and Reykjanes are on the southwest tip of the Reykjanes peninsula. The third geothermal system is Hellisheidi which is located on the northeast part of the peninsula.

7.2 Svartsengi geothermal field

The first electrical power plant in Svartsengi was built in 1976-1978. It was the world's first geothermal power plant utilizing high-temperature geothermal systems to produce electricity and hot water for district heating. Since 1976, the power plant has been upgraded in six stages. The current capacity of the plant is 150 MWth for district heating and electrical power capacity is 74.4 MW. At the moment the Svartsengi power plant is utilizing high and low pressure steam as well as binary units for the waste heat from the condensing units. Some 30 geothermal wells have been drilled by Iceland GeoSurvey (ISOR).

In an interview with Mr Ómar Sigurdsson (personal communication, September-October 2015), a reservoir engineer at HS – Orka, he said that in 2014 the average year production was 488 kg/s and the injection 293 kg/s. As the Svartsengi is a liquid dominated reservoir the reinjection plays a large role there in holding the drawdown rate at an acceptable stabilization. The future plan is to increase reinjection slightly (10-15%). Some effluent is used by the Blue Lagoon and is disposed to shallow formations, the rest will be discharged to the sea. He was also asked about surface subsidence in the centre of the area and if it has had any problems for the utilization and he said that the total subsidence at Svartsengi is on the order of 45-50 cm. It has so far not caused problems as constructions in the area have been in steps so it has compensated for much of this subsidence (Appendix I).

It shall be noted that the Blue Lagoon is a world famous tourist destination with probably over 700.000 visitors per year with significant economic and social impacts in the area and for the tourism in Iceland.

7.3 Reykjanes geothermal field

The Reykjanes geothermal system is located at the tip of the Reykjanes Peninsula, while the Svartsengi geothermal system is found about 10 km to the east-northeast of it. Geothermal fluids in Reykjanes have the same salinity as seawater but in Svartsengi the salinity is about 2/3 of seawater as mentioned above.

The Reykjanes reservoir fluid, has reacted with the basaltic host rock at temperatures between 270-340°C. The concentrations of metals and trace elements in the reservoir fluid collected at 1350–1500 m depth are; Cu ~15 mg/kg, Zn 5-25 mg/kg, Fe 10-140 mg/kg, Mn ~2.5 mg/kg, Pb 100-300 µg/kg, Ag 30-100 µg/kg and Au 1-6 µg/kg (Hardardóttir et al., 2010). Its chemical properties have long been studied for the purpose of producing salt and valuable minerals.

According to Mr Ómar Sigurdsson a reservoir engineer at HS-Orka, the geothermal reservoir fluid of Reykjanes geothermal reservoir is a steam dominant two-phase zone in the top part while the reservoir is liquid dominated at greater depth. Most of the production wells have some connection to the steam zone as it is not cased off in them. Of the current 16 producing wells there are 3 shallow wells that only produce from the steam zone.

Presently, the pressure drawdown in the central part of the production field is about 40 bar and becomes less with distance from the centre. The drawdown was very rapid during the first 2-3 years but has almost stabilized now at a rate of about 1 bar/year.

As reinjection is used as a tool to work against the pressure drop in the geothermal system, Mr Sigurdsson pointed out that in 2014 the average year production was 518 kg/s and the reinjection 82 kg/s. This is an infield injection and can therefore not be increased as it can cool wells and quench steam. Reinjection wells are under construction at the outskirts of the field and plans are to triple the injection using these outer wells.

It is a known fact that the Reykjanes area is a tourist attraction and geological features are of special interest, such as geothermal manifestations, lava flows, craters and open fissures which are the results of plate tectonics and the fact that the Mid Atlantic ridge "coms on shore" there. There have been changes in the geothermal manifestations on the surface and Mr. Sigurdsson was asked how much surface area is impacted by increasing heat from the start of the power plant and what could be the main reasons. He replied that the changes in thermal surface manifestation have been very dynamic over the decades. Therefore, the selection of a reference point matters and the difference is only true over the compared period. Over longer or different time period the results may be quite different. If the reference is the start of the power plant the change in surface area that has been impacted by thermal activity has about doubled. The size of influenced area is today around 0.3 km^2.

What is of special interest at Reykjanes is the salinity of the brine as is the case in the Lake Assal region in Djibouti and therefore important to learn from the experience at Reykjanes.

The salinity of the brine can create big problems of scaling in the wells and that has been studied at Reykjanes and what happens there is that as the fluid ascends from a well it starts to boil due to pressure decrease resulting in precipitations of mainly sphalerite (Zn,Fe)S) up the well from about -1200 m depth. At surface downstream of an orifice plate a sudden decrease in pressure from ~37 bar down to 22 bar, results in rapid boiling (flashing) resulting in abundant precipitation of sulphides. In order to better understand the build-up of scales and the resulting decrease in fluid-flow in the surface pipeline, a detailed geochemical and mineralogy study has been done on the scales by Hardardóttir (2011), and her co-workers (Hardardóttir et al., 2010). The scales are primarily composed of sphalerite, less of chalcopyrite ($CuFeS_2$) with minor of galena (PbS) and traces of other sulphides (mainly Cu-sulphides like bornite (Cu_5FeS_4) and digenite (Cu_9S_5) (Hardardóttir, 2011).

The wells RN-12 and RN-11 are currently the most productive wells of the Reykjanes power plant in terms of electricity and in amount of scaling (Sigurdsson, 2015).

The existence of TENORM in the Reykjanes scales with a higher value in the activity of Po-210 has now been confirmed for the first time in Iceland. NORM and TENORM is included in the Icelandic Act on Radiation Protection and any potential radiation protection issues associated with TENORM in geothermal applications will be addressed as needed by the Icelandic Radiation Safety Authority (Sigurdsson, 2015).

Because of the expected high salinity at Assal-Fiale it was decided to contact Dr Halldór Ármannsson who has worked in Djibouti and studied the chemistry of the older wells and done experiments to find out solutions regarding scaling and reinjection of the geothermal water.

According to Dr Halldór Ármannsson (Appendix I): It can be expected that quite a high salt concentration will be in the geothermal fluid in Assal-Fiale and that there may be problems in getting rid of the fluid on the surface, immediately during the testing of wells. Therefore, it is correct to assume that it may be necessary to drill injection wells for the fluid, especially if the testing of the wells lasts for months as would be desirable. Further studies / experiments on deposits from the geothermal fluid are needed to ensure a suitable permanent way of disposal. Disposal of the geothermal fluid in the sea may cause deposit problems and negative effects on the ecosystem in the vicinity of the outlet, because of chemicals in the liquid.

- The sulphide scaling can be dealt with by inhibition, but iron silicates and amorphous silica deposits by pressure (temperature) control.
- As the plan in Djibouti is to drill four exploration wells in the Assal-Fiale area Halldór recommended that two wells would be drilled in the beginning and after testing 6-12 months (flowing) the other two wells would be drilled in the light of the results from the first ones.
- Regarding the problems associated with gas from geothermal fluids, as the high content of H_2S coming from the Hellisheidi Power plant, Halldór believes that based on available data that problems because of H_2S is very unlikely and as the area is considerably windy the risk of accumulation should be low.

The attention came also to the radioactivity measured in deposits from wellheads in Reykjanes Power plant and that it is worth to have such measurements as a part of the monitoring program at the Assal-Fiale geothermal area.

7.4 Hellisheidi geothermal field

The Hengill Area is an active volcanic systems consisting of Mt. Hengill and fracture zone to the NW and to the SW (Sæmundsson, 1967, Franzson et al., 2005). Two power plants have been built in the area; one in Nesjavellir in the northern part of the area and one in Hellisheidi in the southern part. At least two other geothermal fields in the area are believed to be feasible for electrical power production; the Bitra and the Hverahlíd Fields (Gunnarsson, 2011). The total production capacity of the Hellisheidi Power plant is 303 MWe (Gunnarsson, 2011). The power plant also consists of a heating unit with 400 MWh capacity.

The history of energy utilisation on Hellisheidi is short and considerable uncertainty is expected in forecasting what will be the respond of the geothermal system to extraction in future. Measurements in 2014 show that the drawdown in the system is following the forecasts as in previous years and within limits under development license. Studies show that the current processing area will not cover the full production of Hellisheidi power plant permanently. The energy production area that was estimated for the plant is smaller than the preliminary research expected. Therefore, it was considered to be better to enlarge the extraction area and provide additional steam for the production of electricity and hot water by utilizing wells who had already been drilled at Hverahlíd rather than drilling new wells in the existing extraction area (Sigurdardóttir and Thorgeirsson, 2014).

According to Hólmfrídur Sigurdardóttir (personal communication, september2015, Appendix I), head of environmental affairs at Reykjavík Energy, the need for new wells will be 1-2 wells per year to keep the production at 300 MWe and they will probably be both at the Hellisheidi power plant production area and nearby areas.

The reinjection has posed a major problem in the operation of the Hellisheidi Power Plant. The temperature at the originally planned reinjection zone proved to be very high (>300°C) when injection wells were drilled there. In order to be able to use that zone for production a new reinjection zone was planned. The new zone has been promising despite problems in operating the new injection wells. The wells are drilled into a fault that is active and injection tests have resulted in swarms of small earthquakes. The injectivity of the wells in the new reinjection zone is highly dependent on temperature of the reinjected water. This dependence can be explained by thermo-mechanical effects on fractures in the fracture governed reservoir. Thinning the geothermal brine with condensate water and cooling it with heat exchangers makes it possible to inject it all into the reservoir and solve the environmental problem of brine disposal. The long term effects of this solution on the geothermal reservoir are not known and have to be studied further by monitoring the system's response and by simulations (Gunnarsson, 2011). According to Hólmfrídur Sigurdardóttir (personal communication, septembre 2015, Appendix I) 17 injection wells had been drilled at the end of 2013 and she explains the history of reinjection experiments.

According to Gunnar Gunnarsson (2011), the rate of silica precipitation from the separated water was slowed down substantially under laboratory conditions by lowering the pH of separated water from pH 9.3 to below 6.3. Dilution of the separated water with 15% condensate water additionally decreased the precipitation rate making it a favourable inhibition method to prevent silica scaling from spent geothermal brine at Hellisheidi power plant. Prevention of silica scaling is in the case of Hellisheidi a key element for successful injection of brine.

Future experiments to prevent scaling from the geothermal brine involve injecting sulfuric acid, produced in other experimental facilities at the Hellisheidi power plant, into the separated water and pumping the water to reinjection wells.

Hólmfrídur Sigurdardóttir was asked how many wells have been drilled and how many are used as production wells and reinjection wells and she answered that at the end of 2013, a total of 57 steam wells had been drilled south and east of the mountain Hengill. This includes 47 at the current Hellisheidi power plant production area, 3 in the Bitra area, 6 at Hverahlíd area and 1 by Gráuhnúkar area. In November 2014, a total of 33 wells were connected to the plant. Many wells are drilled in the same drilling site/well pad to reduce the environmental impact of the plant. The wells are not all connected to the plant as some are drilled to explore the edge of the area and others have not produced as much as hoped. Some of these wells are used for monitoring as it is important that some wells will be used to monitor temperature and pressure conditions in the area. Two steam wells that did not serve as production wells were connected with the reinjection system in 2014. A new steam extraction hole was drilled in the summer of 2015.

As it is known that the amount of H_2S and CO_2 from the Hellisheidi power plant is critical, Hólmfrídur Sigurdardóttir (Appendix I) was asked what the current amount of CO_2 is coming from the power plant and how much of it is reinjected. She said that in 2014, 2400 tonnes of CO_2 were pumped back down into the bedrock and since the CarbFix project started until the end of August 2015, 3600 tonnes of CO_2 have been pumped down to the bedrock. According to Reykjavík Energy homepage the amount of CO_2 from the power plant in 2014 was 55.440 tonnes.

She was also asked about the H_2S and reinjection of that and she answered that in the year 2014, 1500 tonnes of H_2S was pumped back down to the bedrock (since the CarbFix project started until the end of August 2015 about 2750 tonnes of H_2S have been pumped down to the bedrock). According to the Reykjavík Energy homepage the amount of H_2S released to the atmosphere from Hellisheidi and Nesjavellir power plants was 17.760 tonnes in 2014.

7.5 Subsidence and gravity changes at Reykjanes

The subsidence at Reykjanes has been studied since 1986 with a maximum of 6 mm/year (Eysteinsson, 2000).

- The subsidence bowl around the Svartsengi field is connected to the Eldvörp geothermal field. That, along with the fact that those two geothermal systems are pressure related (Björnsson and Steingrímsson, 1991), suggest that the two fields have a common origin. This is further confirmed by a resistivity survey in the area (Eysteinsson, 2000). The total integrated subsidence volume around Svartsengi is 10% of the total volume of fluid subtracted from the reservoir. Although the fluid production for the power plant at Svartsengi has been explained as the cause of the subsidence, another possible source could be a reduced pressure in a solidifying magma chamber within the crust beneath Svartsengi (Eysteinsson, 2000).
- The gravity changes on the outer part of the Reykjanes peninsula are small and mainly limited to the Svartsengi and Eldvörp geothermal areas. The maximum reduction in gravity is located at the same place as maximum subsidence where it is around 5 μgal/year. The integrated gravity reduction is equivalent to 2.4 Mt/year mass loss in the area. This is about 30% of the total mass drawn out of the geothermal field. No gravity change is observed at the Reykjanes geothermal field.
- The subsidence at Svartsengi is greater than has been observed in other utilized geothermal fields in Iceland. At Nesjavellir (SW Iceland) small subsidence has been observed over a limited area around the power plant at the rate of 5 mm/year, but recent observations show that the land is rising, probably due to natural tectonic processes in the area. No gravity changes have been observed in the area that could be related to the exploitation of the geothermal field. In Krafla geothermal field (north Iceland) there have been large elevation and gravity changes over the last 25 years due to the volcanic eruption period from 1975 to 1985. In this area land has lifted over 3 meters and in limited area there has been subsidence of over 1 meter. Since 1989, when land lifting reached the peak, and to 1995, land has subsided up to 250 mm. During this period a subsidence bowl is observed around the bore field in Krafla which corresponds to 30 mm/year subsidence, a part of that is probably related to utilization of that field. Observed gravity changes in Krafla field are only related to tectonics during the eruption period.

7.6 Comparison of the geothermal fields

- All the fields are within volcanic areas;
- All fields are considered to be high-temperature areas with a geothermal fluid >200°C at 1000 m;
- Assal-Fiale and Reykjanes are in coastal areas with reservoir fluids with high salinity which especially creates scaling problems and can have complications with disposal of the geothermal water, especially reinjection. Disposal of the water on the surface can create lagoons which can harm the environment but can also be utilized as the Blue lagoon in Svartsengi.
- Permeability, reinjection and earthquakes, scaling and corrosion are all common factors that makes utilization of the geothermal resources complicated.
- In Hellisheidi the amount of H_2S is higher than in the other areas and creates specific mitigations.
- The proposed development site in Djibouti is in a protected area and the three power plants in Iceland are all in areas of natural interest mainly because of volcanic craters, lava flows and

geothermal activity on the surface like fumaroles, mud pots and colourful transformations and precipitations.

- Vegetation in the Assal-Fiale is scarce because of hot climate, lack of water and unfertile soil. But the Bay of Ghoubbet has a sensitive ecosystem. The three areas in Iceland have lava fields with sensitive moss and some contain ecosystems that depend on the geothermal heat, warm soil, especially at Reykjanes.
- All the areas are tourist attractions although the number of tourists in Assal-Fiale is still very low. The area in Svartsengi was not a tourist, or recreation area, before the power plant was built and the geothermal water created the Blue lagoon in the lava field. Hellisheidi area was a ski resort and highly used for outdoor recreation, now it is still a recreation area and the powerhouse is a popular tourist attraction. Reykjanes was a tourist area before the power plant was built and still is and the powerhouse is a popular tourist attraction.

7.7 Environmental parameters to be considered in management programme Assal-Fiale geothermal development

- Managing of the scaling and reinjection;
- Survey of the effects of different reinjection schemes on the properties of the reservoir;
- Monitoring of the system response, simulations and radiation.

8. ENVIRONMENTAL MANAGEMENT AT ASSAL-FIALE GEOTHERMAL PROJECT

8.1 General

Environmental Management is a set of policy, regulatory, advocacy and market based mechanisms which transforms human behaviour to achieve society's goals for the environment. As with all management functions, effective management tools, standards and systems are required. The Environmental Management System (EMS) based on the ISO 14001 involves all aspects of the operation of the geothermal development in order to manage and to minimize the environment impact.

EMS of ISO 14001 requirements include the following stages (Figure 6) (Moeljanto, 2004):

1. **Planning**
   - Environmental aspects
   - Legal and other requirements
   - Objective and targets
   - Environmental management programmes
2. **Implementation and operation**
   - Structure and responsibility
   - Training, awareness and competence
   - Communication
   - Environmental management system documentation
3. **Checking and corrective action**
   - Monitoring and measurement
   - Non-conformance and corrective and preventive action
   - Records
   - Environmental management system audit
4. **Management review**

FIGURE 6: EMS of ISO 14001 (Moeljanto, 2004)

8.2 Environmental Impact Assessments

A full EIA should be carried out prior to the drilling and plant construction should include Environmental Management Plans and costs in the project's design and budget. The ecosystems should be mapped and ranked in order of protection value or sensitivity before project starts and the results used to decide mitigations before commencing any activities of the project.

8.3 Best practice, mitigation measures and monitoring

Best practice is the way a project is carried out according to all laws and regulations, the practice that may be learned from previous projects etc. If despite that a project will have negative impacts of some sort, then mitigation measures must be found to reduce the impact and if that is not enough the impacts may be compensated e.g. a land is bought from the landowner. All these actions are designed to prevent, decrease or reduce negative environmental impact.

8.3.1 Protective measures for local ecosystems

In order to protect the area's ecosystems, it is recommended that the sensitive ecosystem of the Bay of Ghoubbet should not be affected and that water for drilling purposes should rather be pumped from a well near the drilling site. It is also recommended to reinject fluids into their reservoir of origin or dispose of/inject treated fluids into shallow wells.

8.3.1.1 Measures for the development of drilling infrastructure

To minimise the impact of access road and field development, the following best practice measures should be envisaged:

- Design the road alignment in such a way as to limit impact on the landscape and geology to a strict minimum;
- Carry out minimum excavation works to protect the geology, soils, topography, landscape and vegetation;
- Take appropriate erosion-control measures and avoid vegetation areas;
- Follow the alignment of the existing road where possible. For the areas where the current road crosses over Lava Lake, there are plans to change the alignment and avoid the lava area;
- Alignments of the current road that have been replaced should be closed.

Before and during operation of a quarry, the following mitigation measures should be taken:

- Establish a General Safety and Health Plan (GSHP) for the operation of the quarry;
- Optimize the planning of proposed extractions to minimize impacts on geology, topography, vegetation, etc.;
- Choose adequate extraction equipment and techniques to minimize impacts on noise levels and air quality and reduce the risk of accidents;
- Accurately plan extraction works to avoid all types of accidents caused by rockslides, landslides, etc. especially after the use of explosives;
- Regulate access of quarry trucks to national highways (road signs, speed limits, etc.).
- Reduce noise by using appropriate equipment;
- Provide noise protection gear;
- Reduce dust generation;
- Provide protective respiratory masks for workers;
- Ensure proper transportation and storage of explosives;
- Secure the quarry site against all types of accidents or subsequent damage, and rehabilitate the site upon completion of the works.

Specific measures for drilling operations:

- **Management of drilling fluids**

Best practice measures for drilling fluid management include the following:

- Use of storage tanks or special basins lined with a water-tight membrane for collection and storage of fluids, mud and spoils;
- Re-utilisation of drilling fluids as much as possible;
- Use of water-tight casing to line the walls right down to the appropriate depth of the geological formation to avoid leakage of drilling fluids at levels far above the geothermal reservoir;
- Preference for biodegradable products when manufacturing drilling mud;
- Where a decision has been taken to dispose of the liquid resulting from separation, the quality of effluents must be up to standards; this could involve treating fluids prior to disposal;
- The quality of liquids to be disposed must be controlled regularly;
- Where foam would be used, special measures must be taken to protect against wind;
- The drilling mud treatment facilities and water intake and/or drilling fluid disposal pipes must be dismantled upon completion of works.
- The treated effluents must be disposed/injected into shallow wells.

- **Management of geothermal fluids**

The option to dispose of geothermal fluids into the Gulf of Ghoubbet or Lake Assal, even when treated, is not feasible. It is recommended that the technical study should investigate whether the Assal 5 well can be used for reinjection of treated fluids.

The treatment method to be adopted depends very much on the chemical composition of the geothermal fluids, and should be determined by the drilling contractor once the geothermal drilling fluids have been analysed through laboratory tests:

- If all the geothermal fluids are not re-injected into their reservoir of origin, the quality of effluents must be up to standard. This may imply bringing the temperature and concentrations of effluent down to the prescribed limits. The quality of water that is disposed of must be controlled regularly;
- If it is decided that the fluids will be re-injected into their reservoir of origin, the groundwater contamination potential must be reduced to a minimum by lining the injection wells with water-tight case right down to the level where the geological formation containing the geothermal reservoir is located;
- Where applicable, the temporary treatment facilities and pipes for disposal of geothermal fluids produced during the tests must be dismantled after completion of works.

Protective measures against risk of water and soil contamination

- Regular maintenance of machines;
- Proper transportation and storage of fuels;
- Collection and proper disposal of used and potentially polluting fluids (oils, break fluids, etc.).

8.3.1.2 Solid waste management

The drilling contractor should present a Waste Management Plan that includes dangerous waste, prior to commencement of drilling works.

In case of dangerous waste, adequate management must include its proper onsite storage and confinement prior to its final treatment and disposal in an appropriate waste management facility. Waste treatment essentially includes dewatering of sludge. Assuming that the waste contains heavy metals mainly composed of sulphides and hydroxides, any waste stabilized in this manner may be disposed of in a household waste treatment facility, so long as it is protected from rain water. Given the low rainfall in Djibouti, the risk of heavy metal build-up is generally deemed to be low.

The decision on the final destination of dangerous waste disposal must be taken by the Djiboutian authorities. The main options are landfilling or export. Considering that there is no controlled landfilling in Djibouti to date, the export of small quantities of potentially dangerous waste is probably the preferred option. Mitigation measures on household waste management comprise at least:

- A program to minimize waste, including waste sorting, reuse and recycling;
- On site waste collection;
- Transportation of the waste to a household garbage dump.

With regard to wastewater, the measures to be envisaged are:

- The installation of mobile toilets on the project site;
- Regular evacuation to a wastewater treatment plant.

8.3.1.3 General safety and health plan (GSHP)

After preparing the technical study and selecting the drilling methods, the drilling consultant should prepare a general safety and health plan (GSHP) prior to commencement of works. The role of the GSHP is to highlight the general risks on the project site. It comprises a detailed analysis of the risks, and defines safety and health measures, covering aspects related to drilling machinery, external companies, work equipment, individual protection gear, noise, explosives, vehicles, surface traffic, asbestos, ionizing radiation, electricity, protection against corrosion, protection against explosions, evacuation and rescue means, safety drills, drilling programme, installation and dismantling, casings and general safety of the site.

The specific health and safety problems of geothermal products could result from exposure to:

- Gas coming from the geothermal reservoir;
- Heat; and
- Noise.

The problems could also be caused by exceptional accidents (breakage of pipes, well blowouts, volcanic eruptions, earthquakes, etc.).

Exposure to gas
As regards the risk of exposure to dangerously high concentrations of hydrogen sulphide, it is necessary to envisage the following measures:

- Install a non-stop surveillance and early-warning system. Where the H2S concentration exceeds the WHO guideline value of 10 ppm, the drilling works or testing should be halted;
- Prepare an emergency intervention plan in case of accidental hydrogen sulphide emission, covering all the necessary aspects from evacuation to resumption of normal operations;
- Install hydrogen sulphide detectors or distribute personal detectors, and also install autonomous respiratory equipment in areas with high risk of exposure;
- Install adequate ventilation mechanisms to prevent a build-up of hydrogen sulphide;
- Distribute brochures or any other information medium to workers on the chemical composition of liquid and gaseous phases, explaining their potential risks to health and safety.

Exposure to heat
Accidental exposure to heat may occur during drilling in case of well blowouts and malfunction of heat confinement and conveyance mechanisms. Recommendations on controlling exposure to heat include the following:

- Reduce work time in high temperature environments and provide access to drinking water points;
- Establish protective surfaces in areas where workers work near hot equipment, especially pipes;
- Use appropriate individual protection gear, especially insulated gloves and shoes;
- Follow appropriate safety procedures during drilling works.

Exposure to noise
Noise is usually generated by well drilling works and vapour expulsion. The noise level can temporarily exceed 100 dB(A) during certain drilling and vapour expulsion operations. Workers operating in the drilling area should use individual protective gear such as ear defenders if the noise level exceeds 85 dB (A).

Well blowouts
The drilling consultant should cover these risks in his Emergency Intervention Plan (EIP). The plan should specify the following:

- Define measures for controlling a blowout using a blowout preventer stack and stocking of material for quelling the blowout (water, barite);
- Define personal safety measures;
- Define other emergency measures;
- The staff working on the drilling site should be trained on the measures to be adopted.

Volcanic eruptions and earthquakes
The following mitigation measures should be taken:

- Establish an evacuation plan;
- Develop emergency measures;
- Train staff on the risks and the measures to be adopted.

The GSHP, including the EIP, should be included in the Bidding Documents for the drilling contractor.

Socio-economic measures
Compensate for or avoid the transhumance and tourist routes
Two alternatives were discussed in the impact assessment: constructing a new route (recommended by the local population); and leaving the current road open to herders during the project.

It is recommended that the technical drilling study should select drilling sites in such a way as to maintain a safe distance without closing the route used by transhumant livestock. Where possible, the transhumance route should be slightly modified, but it must still pass through Fiale in order to guarantee access to pastureland and the traditional right to the transhumance route. The specific ESMP of the drilling contractor should specify mitigation measures, where necessary.

Although the impact assessment recommends that the current route should be left open, the matter has not yet been concluded and requires closer consultation with the PMU, the local population and the Directorate for the Environment.

Similarly, the project should not block the route that leads to Lava Lake and Ardoukoba Volcano. The passage should remain open, but a safe distance must be maintained during construction of the drilling platforms. If this is not possible, an alternative route should be constructed. It would be appropriate to install display and information panels.

Prior to implementation of the project, it is mandatory to display a detailed plan of the project sites and consult the local population and local administrative authorities. It should be explained that landowners newly settled on the proposed drilling sites will not be compensated.

Institution of a procedure for "chance finds" of cultural monuments
The proposed sites (access roads, drilling area, quarry etc.) should be inspected by an archaeologist prior to commencement of construction works. In case of a chance find during the project, all works should be suspended and an archaeologist called in. However, a procedure for "chance finds" historical sites or cultural monuments has been suggested for use during the eventual modification of the current alignment of the access road, the selection of a quarry, etc.

Temporary abandonment
In case of temporary abandonment of the site, the following measures should be taken:

- Installation of a blowout preventer to reduce the risk of blowout;
- Regular surveillance of temporarily abandoned wells;
- Construction of a fence around the drilling site to prevent access by unauthorized persons or animals.

Temporary abandonment is possible only when:

- The casings are properly installed;
- Cementation between the casing and the soil ensures the insulation of the permeable levels;
- The duration of temporary abandonment should be agreed upon with the competent authorities.

Permanent abandonment
Where a well turns out to be unproductive or where the risk of blowout is too high, the geothermal well should be abandoned permanently. Once such a decision is taken, the products needed to insulate the permeable levels should be used to cover/fill the entire initially drilled section of the well. After complete closure of the well, a closure file should be prepared by the drilling consultant giving an exhaustive and precise description of the status of the well and all details of the closure procedure. After completion of the works, the drilling site should be rehabilitated.

8.4 Monitoring programmes

Monitoring of the environmental effects of the geothermal utilization can be carried out through programmes which consist of systematic observation, measurements and evaluation of the various parameters using appropriate methods and technology. A monitoring programme must cover all aspects of the physical, biological and socioeconomic environment for the exploration, construction, utilization/operation and decommissioning project phases.

8.4.1 Preliminary action

Before the exploration activities is commenced, baseline data must be gathered to validate and assess the environmental impacts. The objective of this is to be able to compare detailed information on the geothermal areas prior to, during and after geothermal utilization.

8.4.2 During the production test / drilling and well testing

During the production test, the following operations are to be implemented:

a. *Planning phase (prior to the works)*
   - The Djiboutian Office of Geothermal Energy Development (ODDEG) should ensure that the technical solution proposed by the drilling consultant is in conformity with environmental and social standards;
   - A detailed Environmental and Social Management Plan (ESMP), a General Health and Safety Plan (GHSP), an Emergency Intervention Plan (EIP) and a Solid Waste Management Plan (SWMP) should be prepared and validated;
   - Commencement of the institution of support projects for the local population.

b. *Preparatory works phase*
   - Monitoring of the application of health and safety standards and measures;
   - Consultation with the local population to verify whether the problem of the transhumance corridor and the tourist route has been solved;
   - Consultation with village communities of Assal area (Daba le Gahar, Laïta, Carrefour) and local authorities, traditional institutions and women/men's associations to find out whether mitigation measures have been implemented.

c. *Drilling works phase*
   - Control of the application of the best technology, control of the application of the environmental precautions (works, storage of chemical substances, treatment of drilling mud and geothermal fluids, storage of materials, etc.);
   - Control of the implementation of safety measures at work: noise, heat, geoth. gas emissions, etc.;
   - Regular analysis of the chemical composition of emitted gases;
   - Quality control when disposing of fluids resulting from treatment of drilling mud;
   - Analysis of generated waste (drilling spoils) to determine means of disposal;
   - Visual control of the drilling site and storage and/or treatment facilities;
   - Control of protective measures for wells, in case of temporary or permanent abandonment of the drilling site.

d. *Testing phase*
   - Control of the implementation of safety measures at work; noise, heat, geothermal gas emissions;
   - Quality analysis of geothermal fluids prior to commencement of testing;
   - Regular visual control of the processing facilities, pipes, etc.;
   - Regular quality control for treated fluids prior to disposal (where applicable);
   - Regular analysis of the chemical composition of emitted gases;
   - Analysis of the waste generated (precipitates, residue from geothermal fluid treatment) to determine means of disposal;
   - Consultation of the population concerned to verify whether the mitigation and support measures have effectively been implemented and whether the implementation process was transparent.

e. *Completion phase*
   - Control of site rehabilitation (quarry, drilling, etc.);
   - Project appraisal;
   - Planning of subsequent stages.

8.4.3 During the operation

During the operation phase, the following monitoring programs must be carried out at Assal-Fiale geothermal project:

1. Monitoring of the wells, during testing and later production, heat, pressure, amount of water, modelling of the geothermal reservoir;
2. Monitoring the social impacts, jobs, tourism (increase/decrease), transhumance route etc.
3. Monitoring of noise emissions at sensitive receptor sites;
4. Hydrogen Sulphide gas monitoring;
5. Meteorological weather monitoring;
6. Precipitation chemistry monitoring;
7. Chemical elements of environmental significance in wastewater, soil and vegetation;
8. Monitoring of vegetation patterns;
9. Monitoring of water quality (surface and groundwater);
10. Monitoring of subsidence.

8.5 Other environmental tools

Environmental baseline studies
Prior to any final decision to proceed with full development, a number of studies would be required to

verify that resources at risk are properly characterized and that impacts can indeed be reduced to acceptable levels:

- Hydrologic studies of ground water, including their categories, flow patterns qualitative and quantitative indicators, water use, water discharge/disposal, water system or its separate parts and other characteristic features, including an assessment of potential effects of development on the hot springs;
- Detailed surveys of flora and fauna within a kilometre of the plant site and at transmission line tower sites, including specific flora composition and habitat conditions;
- Detailed survey of the plant site and the transmission line route for physical artefacts and historical sites or cultural monuments value;
- Detailed evaluation of potential induced development in the region or elsewhere in Djibouti;
- Evaluation of emissions of carbon dioxide or other greenhouse gases, as levels of CO_2 from geothermal development may be an appreciable fraction of that generated by an equivalent fossil fuel plant.

These studies and others would inform the full feasibility study and ESIA and inform the final decision of the Government whether to proceed.

Environmental audits for operations
Internal and external audits covering all environmental aspects management must be realized at least twice a year.

Communication
Consultations with stakeholders is important in the development of the geothermal project.

9. DISCUSSION AND RECOMMENDATION

- ✓ The experience of the geothermal development in Iceland shows that the exploration and utilization of geothermal reservoirs are complicated and there are several uncertain and critical points in predicting production capacity of a geothermal resource and the response of the reservoir. The reality is often that things are more complicated than expected. For that it is important to conduct a progressive development of geothermal resources exploitation to earn good knowledge and control of the unforeseen with minimum negative environmental impacts and social and financial risks and for a sustainable energy production;
- ✓ The success of an environmental monitoring program depends on the baseline data gathering to establish the background information that is valuable for comparing changes in the environmental conditions during a geothermal development, as well as for identifying natural variations, not related to the activities of a proposed project;
- ✓ It is essential to implement an environmental management system for optimal environmental protection.

10. CONCLUSIONS

The proposed project has great economic significance to the country because of the increasing demand for electrical power. The environmental effects of developing the geothermal energy in Djibouti need to be investigated in full and a careful choice of electrical power and geothermal field has to be made. It is now generally acknowledged that geothermal fields have to be carefully monitored for several years prior to development in order to ensure the most viable field in environmental terms, as well as sustainable energy production and the least negative impacts on the environment in general. The Assal-

Fiale geothermal resources can be exploited in a sustainable way if all the preventive and protective measures for the environment are taken.

The regulatory institutions play an important role in the EIA process and decisions on exploration and utilization of a geothermal resource as well as in monitoring and follow up of a geothermal project and they must provide general guidelines for the developers to carry out monitoring surveys. Official monitoring reports are important tools in enabling relevant authorities to assess the management of a geothermal system under development. A very important factor in monitoring is that results and reports can be made available to the public and obtainable from the consent authority.

It is necessary that a monitoring program can be discussed and agreed upon so developers and regulatory institutions are able to state the monitoring parameters and frequency of data collection according to the interests of the parties. The responsibility for protecting the environment during a geothermal development rests with the developer that is working according to his consent and permits, this responsibility cannot be shifted to the regulatory authorities or the government.

The information contained in this report can be used as a general reference/guide by regulatory institutions in Djibouti to enhance the surveillance and follow up conferred upon geothermal projects.

ACKNOWLEDGEMENTS

I wish to extend my gratitude to the Government of Iceland and the United Nations University Geothermal Training Program, for the opportunity to participate in this training program. My sincere gratitude to the Director, Mr Lúdvík S. Georgsson and the Deputy Director Mr Ingimar G. Haraldsson, for their undivided dedication to this training. I am grateful to Ms Málfrídur Ómarsdóttir, Ms Thórhildur Ísberg, and Mr Markús A.G. Wilde, for their generous help, care and advice during the whole training period. Special thanks to my ministry in Djibouti for giving me the opportunity to participate in this program. To my dedicated supervisors, Mr Thóroddur F. Thóroddsson and Dr Brynhildur Davídsdóttir, this research could not have been completed without your guidance and input. Much appreciation goes to Ms Hólmfrídur Sigurdardóttir of Reykjavík Energy, Mr Ómar Sigurdsson at HS Orka, Ólafur Árnason at Efla Consulting, Dr Halldór Ármannson at ISOR and Mr Jónas Ketilsson at Orkustofnun for their generous information. Finally, my deepest thanks for my family, my lovely wife, Fatouma Barreh, my daughters, Taslim and Deksan, and my mother Aicha Waiss, for their unwavering support and encouragement, this report is dedicated to you.

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APPENDIX I: Interviews and discussions with experts from Reykjanes, Svartsengi, Hellisheidi power plants, ISOR and Orkustofnun

Interview 1: **Ómar Sigurdsson from HS Orka**

Reykjanes

1. How much the has the surface area which is impacted by heat increased from the start of the power plant? What is the main reason?

Ans: Changes in thermal surface manifestation have been very dynamic over the decades. Therefore, selection of reference point matters and the difference is only true over the compared period. Over longer or different time period the results may be quite different. If the reference is the start of the power plant the change in surface area that has been impacted by thermal activity has about doubled. The size of influenced area is today around 0.3 km^2.

2. What is the current situation with the pressure in the geothermal reservoir and how has it changed from the start of the power plant?

Ans: Currently the pressure drawdown in the central part of the production field is about 40 bar and becomes less with distance from the centre. The drawdown was very rapid during the first 2-3 years but has kind of stabilized now at a rate of about 1 bar/year.

3. What is the total amount of geothermal water from the power plant and how much of it is reinjected? What are the main results (lessons learned) of the reinjection?

Ans: In 2014 the average year production was 518 kg/s and the reinjection 82 kg/s. This is an infield injection and can therefore not be increased as it can cool wells and quench steam. Under construction is reinjection to wells at the outskirt of the field. Plans are to triple the injection with the main portion to these outer wells.

4. What is the number of wells, deep wells and shallow in to a steam pillow?

Ans: At Reykjanes we do not have steam cap or pillow as you call it. In the top part of the geothermal reservoir is a steam dominant two-phase zone while the reservoir is liquid dominated at greater depth. Most of the production wells have some connection to this steam zone as it is not cased off in them. Of the current 16 producers there are 3 shallow wells that only produce from the steam zone.

Svartsengi

5. What is the total amount of geothermal water from the power plant and how much of it is reinjected? What are the main results of the reinjection?

Ans: In 2014 the average year production was 488 kg/s and the injection 293 kg/s. Svartsengi is a liquid dominated reservoir and the reinjection plays a large role there in holding the drawdown rate at acceptable stabilization.

6. What will be the future solutions to dump the geothermal water?

Ans: Reinjection will be increased slightly (10-15%), effluent used by the Blue Lagoon and what goes to the lagoon from steering control of the power plant is disposed to shallow formations, the rest will be discharged to the sea.

7. How much is the surface subsidence in the centre of the area and has it had any problems for the utilization of the area?

Ans: The total subsidence at Svartsengi is on the order of 45-50 cm. It has so far not caused problems as construction in the area has been in steps so it has compensated for much of this subsidence.

Interview 2: **Hólmfrídur Sigurdardóttir, head of environmental affairs, Reykjavik Energy**

The answer to the first three questions are to be found in OR Environment report 2014 which is in English at the homepage: https://www.or.is/en/energy-environment

1. What is the current amount of CO_2 coming from the power plant and how much of it is reinjected?

Ans: See appendix 12 and 13 and the chapter Emissions of other geothermal gases (carbon dioxide, hydrogen and methane)

In 2014 2400 tonnes of CO_2 was pumped back down into the bedrock (since the CarbFix project started until the end of August 2015 3600 tonnes of CO_2 have been pumped down to the bedrock).

2. What is the current amount of H_2S coming from the power plant and how much of it is reinjected? See app 12 and 13 and the chapter Emissions of hydrogen sulphide.

Ans: The year 2014, 1500 tonnes of H_2S was pumped back down to the bedrock (since the CarbFix project started until the end of August 2015 about 2750 tonnes of H_2S have been pumped down to the bedrock).

3. How much is the pressure drop from the starting of the power plant?

Ans: See appendix 2b and discussion in the chapter managing high-temperature geothermal resources

4. How many wells have been drilled and how many are used as production wells and reinjection wells?

Ans: At the end of 2013, a total of 57 steam wells had been drilled south and east of the mountain Hengill; including 47 at the current Hellisheidi power plant production area, 3 in the Bitra area, 6 at Hverahlíd area and 1 by Gráuhnúkar area. In November 2014, a total of 33 wells were connected to the plant. Many wells are drilled in the same drilling site/well pad to reduce the environmental impact of the plant. The holes are not all connected to the plant as some are drilled to explore the edge of the area and others have not produced as much as hoped. Some of these wells are used for monitoring as it is important that some wells will be used to monitor temperature and pressure conditions in the area. 2 steam wells that did not serve as production wells were connected with the reinjection system in 2014. A new steam extraction hole was drilled in the summer of 2015.

At the end of 2013, 17 injection wells had been drilled to bring the separated water back into the geothermal reservoir. The wells have been drilled in four places. The first 3 wells were drilled in the Svínahraun lava field by the highway which is now abolished. The first two wells were vertical wells, but were not enough permeable/leaking to take the separated water. This area, and the wells have been used for the CarbFix project where the carbon dioxide is injected in order to bind it as mineral underground.
Next it was drilled in an area closer to the hillside under Gráuhnúkar. In this area have been drilled 6 wells that are accepting a lot of water.
By the hill Húsmúli north of the Hellisheidi power plant was drilled one exploratory well in order to explore the large faults that are in the Húsmúli area and are believed to be the western edge of the great rift valley which the geothermal activity is connected to. This well gave favourable hopes that there could be an area suitable for reinjection of the water from the separators. One another well was drilled in the same area, but its performance was not as good. In this area was then drilled 6 wells. Wells utilized as injection wells are 16 of which 2 are steam wells that did not serve as such and were connected to the injection system in 2014.

Over twenty groundwater holes have been drilled to explore the groundwater in the Hengill area plus other shallow wells, including wells for water for drilling and to lead the separated water from blowing wells below the surface.

5. What is the need for new wells pr. year/5 years to keep the production at 300 MWe? Will they be in the same area as the existing wells or is a need to expand the area?

Ans: 1-2 wells per year, cf. the chapter on geothermal power plants in the OR environmental report for 2012 : https://www.or.is/um-or/utgefid-efni#umhverfi.

As stated above, a new steam well was drilled on Hellisheidi summer of 2015. In 2016, 4 steam wells that were drilled few years ago at Hverahlíd area will be connected to the Hellisheidi power plant. Continued drilling steam wells will probably be both at the Hellisheidi power plant production area and other areas.

Minutes of the discussion with: **Jónas Ketilssson, Orkustofnun**

Orkustofnun is the authority that issues licenses for research and utilization of the geothermal resources. Decisions, in this regards, made by Orkustofnun can be appealed to the ruling committee for the resources act.

The utilization licenses sometimes specify limitations for the acceptable pressure drawdown if thought necessary by Orkustofnun due to the rate of exploitation. This applies in particular to geothermal power plants. An example is the Theistareykir geothermal field in north Iceland where the pressure drawdown is not allowed to be more than stipulated. It is also stated that the annual decrease in steam production cannot be more than 3% /year on average over the past five years.

If these requirements are not met the situation is analysed. Firstly, the models are re-calibrated and if issues for long-term utilization are below thresholds the license holder may have to increase reinjection, enlarge the production area and possibly even change utilization strategy.

Research on reinjection is recommended from the start of a power plant because it is a complicated process and needs normally some time consuming tests and even drilling of several wells.

In Hellisheidi the pressure drawdown is not more than predicted and allowed in the license. But at Reykjanes there is no limit in the utilization license that was published by the Ministry for industry in year 2004. However, in a new license issued by Orkustofnun in year 2011 there are limitations but that license is not in effect until the power plant is enlarged.

Link to the license of Reykjanesvirkjun:
http://www.os.is/media/leyfi-2011/Virkjunarleyfi-HS-Orka-fylgibref-15092011.pdf
Link to the license for Theistareykir:
http://www.os.is/media/utgefin%20leyfi/jardhiti-theistareykjum-ny%CC%81tingarl.pdf
http://www.os.is/media/utgefin%20leyfi/fylgibref-jardhiti-theistar.pdf
Link to the license for Hellisheidi:
http://www.os.is/media/leyfi-2011/virkjunarleyfi_OR_03.06.2011.pdf

Minutes of the discussion with: **Dr. Halldór Ármannsson, Iceland GeoSurvey**

Dr. Halldór Ármannsson took part in a comprehensive scaling/corrosion study in Assal, Djibouti (Virkir-Orkint 1990).

At the beginning of the conversation, the knowledge gained in previous research drilling and studies of precipitation associated with it was discussed. It was stated that of course is not possible to ascertain the composition of the brine from the wells in the new area until after drilling. Resistivity measurements and general geological studies on the surface can however give an indication of this, and are considered to suggest that a lower concentration of salt will be in the geothermal liquids in the Assal-Fiale are than in the areas where previous wells were drilled.

It can be expected that quite a high salt concentration will be in the geothermal fluid in Assal-Fiale and that there may be problems in getting rid of the fluid at the surface, immediately during the testing of wells. Therefore, it is correct to assume that it may be necessary to drill injection wells for the fluid, especially if the testing of the wells lasts for months as is desirable. Further studies / experiments on deposits from the geothermal fluid are needed to ensure a suitable permanent way of disposal. Disposal of the geothermal fluid in the sea may cause deposit problems and negative effects on the ecosystem in the vicinity of the outlet, because of chemicals in the liquid.

It emerged that that considerable deposits can be expected from the geothermal fluid and it is important what the wellhead pressure will be as well as the enthalpy. If there is high enthalpy (mainly steam) then the pressure matters little. Earlier studies in Assal (Geochemical patterns of scale deposition in saline high temperature geothermal systems: H. Ármannson and V. Hardardóttir Iceland GeoSurvey, Grensásvegur 9, IS-108, Reykjavík, Iceland) show that the pattern of deposition is such at pressure >16 bar that the major scales are sulphides, but at lower pressure iron silicate scales predominate down to amorphous silica saturation. The sulphide scaling can be dealt with by inhibition, but iron silicates and amorphous silica deposits by pressure (temperature) control.

As the plan in Djibouti is to drill four exploration wells in the Assal-Fiale area Halldór recommended that two wells would be drilled in the beginning and after testing 6-12 months (flowing) the other two wells would be drilled in the light of the results from the first ones.

Regarding the problems associated with gas from geothermal fluids, such as the high content of H_2S coming from the Hellisheidi Power plant, Halldór believes that based on available data that problems because of H_2S is very unlikely and as the area is considerably windy, the risk of accumulation should be low.

The attention was also drawn to the radioactivity measured in deposits from wellheads in Reykjanes power plant and that it is worth to have such measurements as a part of the monitoring program at the Assal-Fiale geothermal area.