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Legal Framework and National Policy for Geothermal Development in Iceland

Jonas Ketilsson, Harpa Th. Petursdottir,
Maria Gudmundsdottir, Jon A. Johannesson, Jon R. Gudmundsson, Anna L. Oddsdottir,
Valdimar Eggertsson, Dilja B. Stefansdottir, Gudni A. Johannesson
Orkustofnun, Grensasvegi 9, IS-108 Reykjavik, Iceland
Corresponding author: jonas.ketilsson@os.is

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ABSTRACT

In this paper, a description is given of the national policy, legal framework, official monitoring and accumulation of geothermal energy statistics in Iceland in a global context. The legal framework and amendments to the energy legal framework since 2015 will be reviewed. In particular the rules regarding preparedness and reactions to seismic hazards due to fluid injection into the ground via boreholes and rules for boreholes. It is the policy of the Government of Iceland to increase the utilization of energy resources and hence governmental support was increased for new geothermal based heat utilities by 50% even though 9 out of 10 households are heated with geothermal energy. The Icelandic National Renewable Energy Action Plan in accordance with Directive 2009/28/EC outlines the energy strategy until 2020 and goals of geothermal utilization. In accordance with the plan, electricity generation from geothermal sources is estimated to reach 5.8 TWh and geothermal heat use to 34 PJ in 2020. In year 2018 6 TWh were generated and 33 PJ of geothermal heat used. Geothermal energy plays an important role in providing the nation with clean and reliable energy and is fundamental to the Icelandic economy as well as Icelandic welfare and independence. Effective policy making and official monitoring of geothermal development for sustaining a renewable energy society in Iceland is crucial for maintaining a long-term lifespan of the resource. A population growth of 36% is expected by 2050 and geothermal utilization is estimated to increase by over 70% to almost 50 PJ by 2050.

1. INTRODUCTION

During the 20th century Iceland emerged from being a nation dependent upon imported oil and coal, to a country where practically all stationary energy, and 86% of primary energy, is derived from domestic renewable sources with near carbon-free electricity production in year 2018. This is the result of an effective policy in making renewable energy a long-term priority in Iceland. Nowhere else does geothermal energy play a greater role in providing a nation's energy supply. In Figure 1 an overview is given of surface manifestations in Iceland based on work by Helgi Torfason for Orkustofnun.

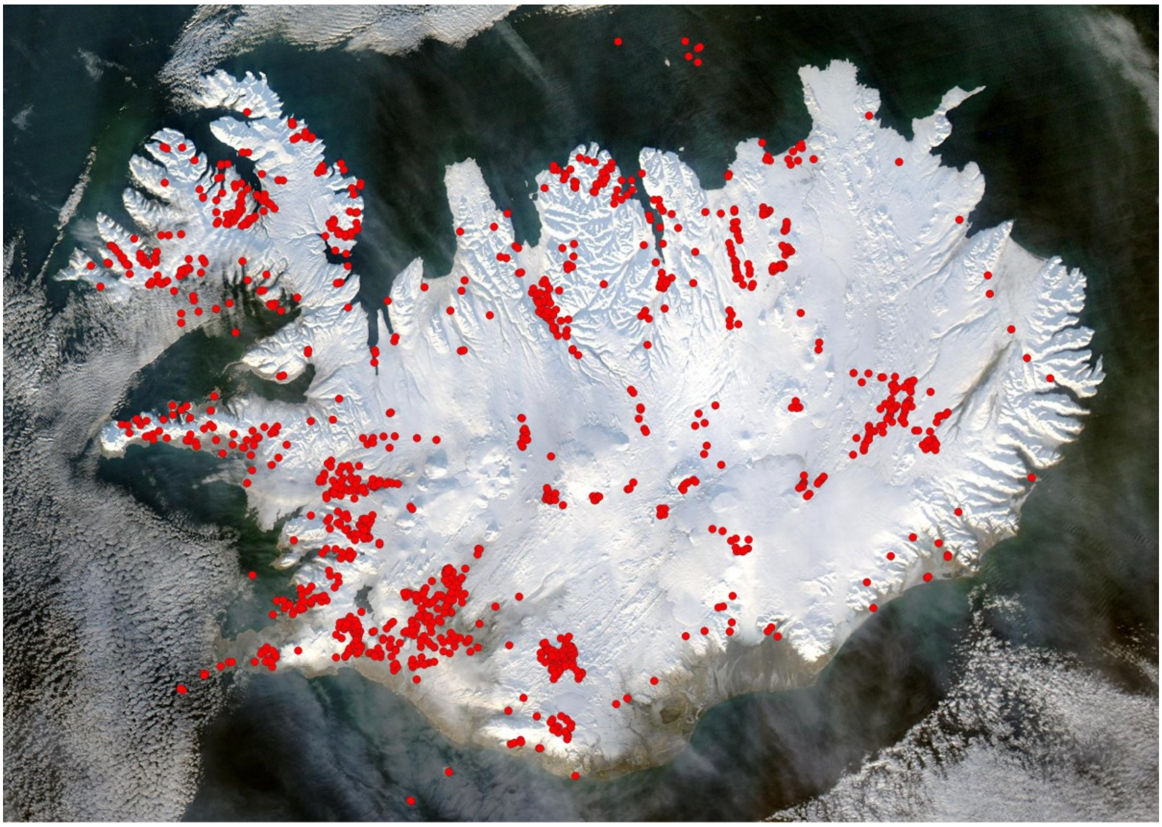

Figure 1: Surface manifestations of geothermal energy. In year 2020 a geoportal will be made publicly available with further details for each marked site.

Already in the 1940s, the State Electricity Authority promoted geothermal development and carried out regional surveys of geothermal areas suitable for space heating and explored promising fields with exploratory drilling. The capital Reykjavik obtained by law a monopoly to operate a geothermal heating service in the town and took the initiative in production drilling and establishment of the first large geothermal district heating system. The State guaranteed loans for the construction of the system. In 1950 about 25% of families in the country enjoyed geothermal heating services, while 40% used coal and 20% oil for heating. The low cost geothermal heating was attractive and intensified the flux of people from rural areas to the capital. To balance that, the Parliament approved an Act in 1953 on geothermal heating services in communities outside Reykjavik which permitted the State to guarantee loans up to 80% of the total drilling and construction cost of heating services. Further, to encourage the development, the State established a Geothermal Fund in 1961. The fund gave grants for surveying and exploratory drilling carried out by the Geothermal Department of the State Electricity Authority and offered loans to communities and farmers for exploratory and appraisal drilling covering up to 60% of the drilling cost. If the drilling was successful the loans were to be paid back at the highest allowed interest rate within 5 years of exploitation commencement. If the drilling failed to yield exploitable hot water, the loan was converted to a grant and not paid back. In this way the fund encouraged exploration and shared the risk. Within the next 10 years many villages used this support and succeeded in finding geothermal water. In 1967 the fund was merged with the Electricity Fund and named the Energy Fund. The Electricity Fund had since the 1940s supported electrification and transmission in rural areas. Over 535 geothermal loans and grants have been issued since the beginning that has led to the widespread use of geothermal across Iceland.

When the oil crisis struck in the early 1970s, fuelled by the Arab-Israeli War, the world market price for crude oil rose by 70%. At about the same time, close to 90,000 people enjoyed geothermal heating in Iceland, or about 43% of the population. Heat from oil served over 50% of the population, the remainder using electricity. In order to reduce the effect of rising oil prices, Iceland began subsidising those who used oil for space heating. The oil crises in 1973 and 1979 (Iranian Revolution) caused Iceland to change its policy, reducing oil use and turning to domestic energy resources; hydropower and geothermal heat. This policy meant exploring for new geothermal resources, and building distribution networks. It also meant constructing transmission pipelines (commonly 10–20 km) from geothermal fields to towns, villages and individual farms, as well as converting household heating systems from electricity or oil to geothermal heat. However, despite the reduction in the use of oil for space heating from 53% to 7% from 1970 to 1982, the share of oil still remained about 50% to 60% of the total heating cost due to rising oil prices. Today about nine out of ten households are heated with geothermal. In Figure 2 areas of various users are shown that either are auto-producers or buy heat from main activity producers. From an economical perspective, the present value of the estimated savings of house heating with geothermal instead of oil between 1914 and 2018, using 2% real interest rate over the cost price index, is estimated at 3,200 billion ISK (123 ISK/US$) (see Figure 4). In 2018 the estimated savings of that year amounted to about 3.5% of the GDP of Iceland or 2,100 US$ per capita only for 2018. Beside the economical impact of high energy security and avoided cost of importing energy to the country, there are also environmental benefits for reducing greenhouse gas emissions by using geothermal energy compared to conventional fossil fuel-based technologies. In 2018, geothermal utilization reduced the anthropogenic release of CO_2 by 4.9 million tonnes for geothermal based electricity generation and 3.7 million tonnes for geothermal based heat use compared to coal. This has also considerably improved air quality in populated areas over the decades since the time Icelanders used to heat their houses with coal and later oil. Total anthropogenic release of CO_2 excluding heavy industries amounts to 2.9 million tonnes in Iceland. Accumulated CO_2 savings amounts to some 174 million tonnes of CO_2 (see figure 5).

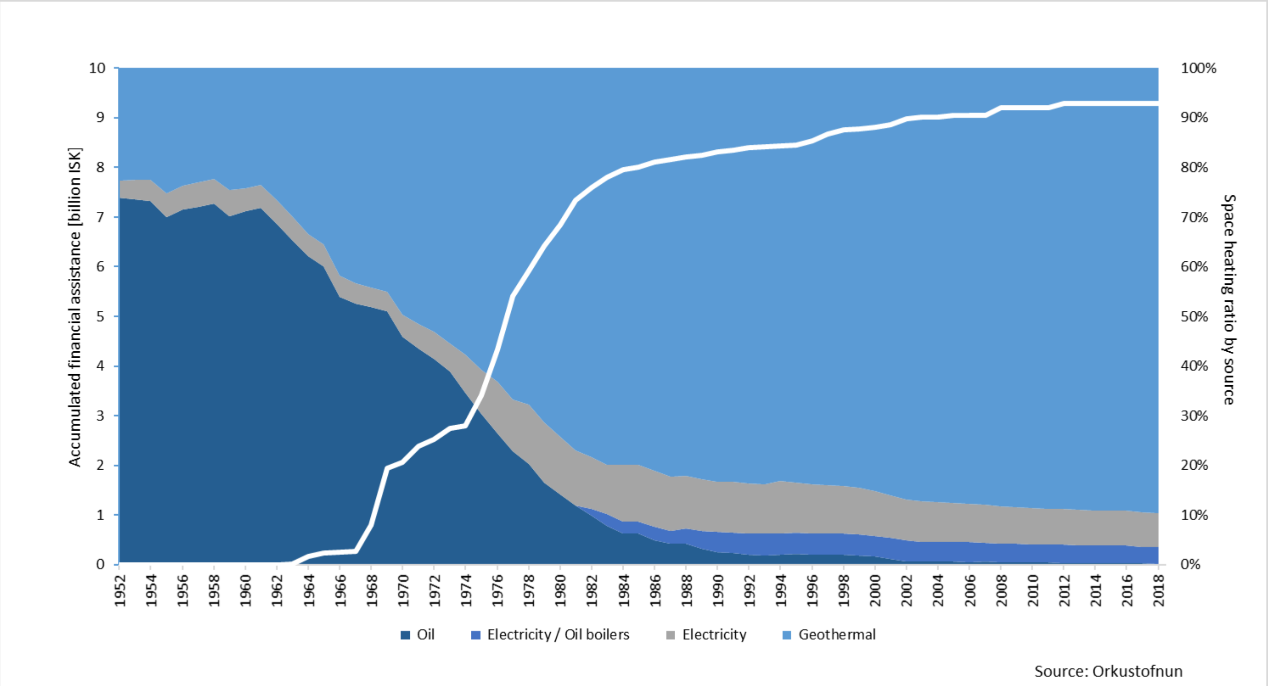

Figure 2: Space heating by source from 1952−2018 with the accumulated financial assistance through the Energy Fund for geothermal, in total 9,2 billion ISK (123 ISK/US$) from 478 geothermal loans and 57 geothermal grants. This excludes financial assistance to district heating services and only refers to financial assistance for finding and exploiting geothermal resources.

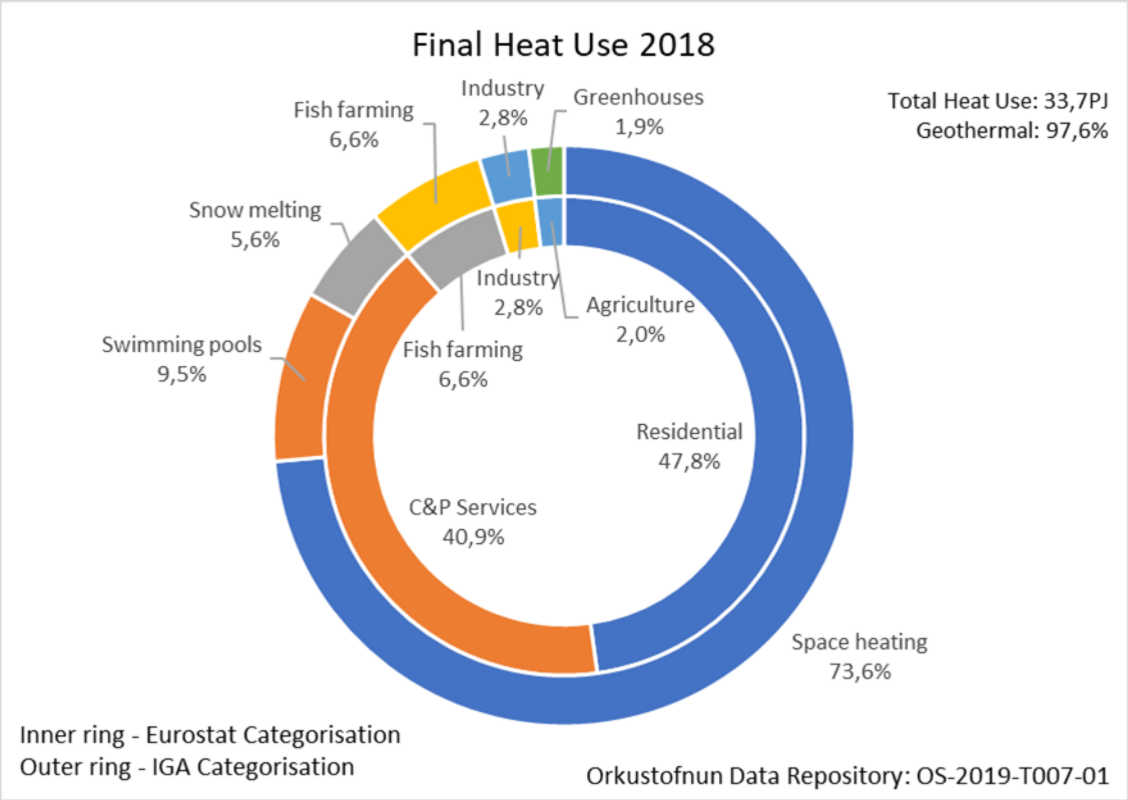

Figure 3: Final heat use in Iceland with geothermal contributing 98%. Heat use in 2018 with IGA categories (outer ring) and IEA categories (inner ring). In total 34 PJ, thereof geothermal 33 PJ.

Geothermal utilization amounted to 33 PJ in 2018 as shown in Figure 3 using both IGA and IEA final use categories. Detailed monitoring of geothermal utilization has been set up in Iceland by Orkustofnun with data from over 53 geothermal based heat utilities (where geothermal energy production is the main business activity) and over 100 auto-producers (where geothermal energy is produced mainly for own use in support of some business) of geothermal energy using a web portal for authentication. The data is accumulated and analysed annually by Orkustofnun with 19 categories of utilization in order to be able to fully disseminate information to the public in accordance with the legal role of the institution and international requirements.

Within the geothermal industry, Orkustofnun participates in several associations and partnerships and collaborates with many others like the Implementation Agreement within the IEA (IEA Geothermal), International Geothermal Association (IGA), European Geothermal Energy Council (EGEC), Geothermal ERA NET and now Geothermica, GeoEnvi and the International Partnership for Geothermal Technologies (IPGT) to name a few.

The information Orkustofnun disseminates is based on the accounting system of the heat utilities after extensive review and collaboration over recent years which still is ongoing to ensure the reliability of the information. For the first time categorization of space heating for residential and commercial and public services is possible. Verification of the information is through comparison of data from Registers Iceland and Iceland Met Office. That being said, the focus of this paper is not to give a detailed account of statistics in Iceland. The point is to examine Icelandic policy in respect of geothermal energy, both research and utilisation, and at the same time observe how official monitoring of both geothermal research and utilisation manifests itself in Icelandic legislation and amendments from a previous review in year 2015 (Ketilsson et al., 2015).

2. NATIONAL POLICY

2.1 National Renewable Energy Action Plan for 2020

The Icelandic National Renewable Energy Action Plan (NREAP) was published in year 2012 in accordance with Directive 2009/28/EC which outlines the strategy for 2020 and goals of geothermal utilization amongst other renewable energy sources. Promotion of the use of energy from renewable sources was further stipulated by changing law no. 30/2008 for promotion of electricity generation with renewable resources taking into consideration Directive 2009/28/EC. The total use of geothermal energy for heating is estimated to increase to 34 PJ in year 2020. Electricity generation from geothermal power plants was expected to increase to 5.8 TWh in year 2020 according to the NREAP but reached 6 TWh in year 2018. The predicted overall share of renewable energy of final energy use in Iceland of 72% as a binding target was already achieved in year 2014.

The Icelandic Government has expressed a strong will and supported various research and demonstration programs for the transition from hydrocarbon fuels, e.g. methane collected from waste-deposits, hydrogen generation and recycled carbons. In the NREAP for 2020 a goal of 10% share of renewables in transport is targeted. Currently oil is still needed for 12% of the primary energy demand in the country, about half to operate the fishing fleet and the other half mainly for motor vehicles. All electricity in Iceland is produced from renewable energy sources and 19.8 TWh/a were generated in year 2018, and therefore one of the possibilities of transition from hydrocarbon fuels is electricity as fuel. It is estimated that 0.8 TWh are required to drive private motor vehicles in Iceland (270,000 in total) with 200 Wh/km consumption. The capacity needed is thus about 230 MW assuming 15,000 km/yr per vehicle.

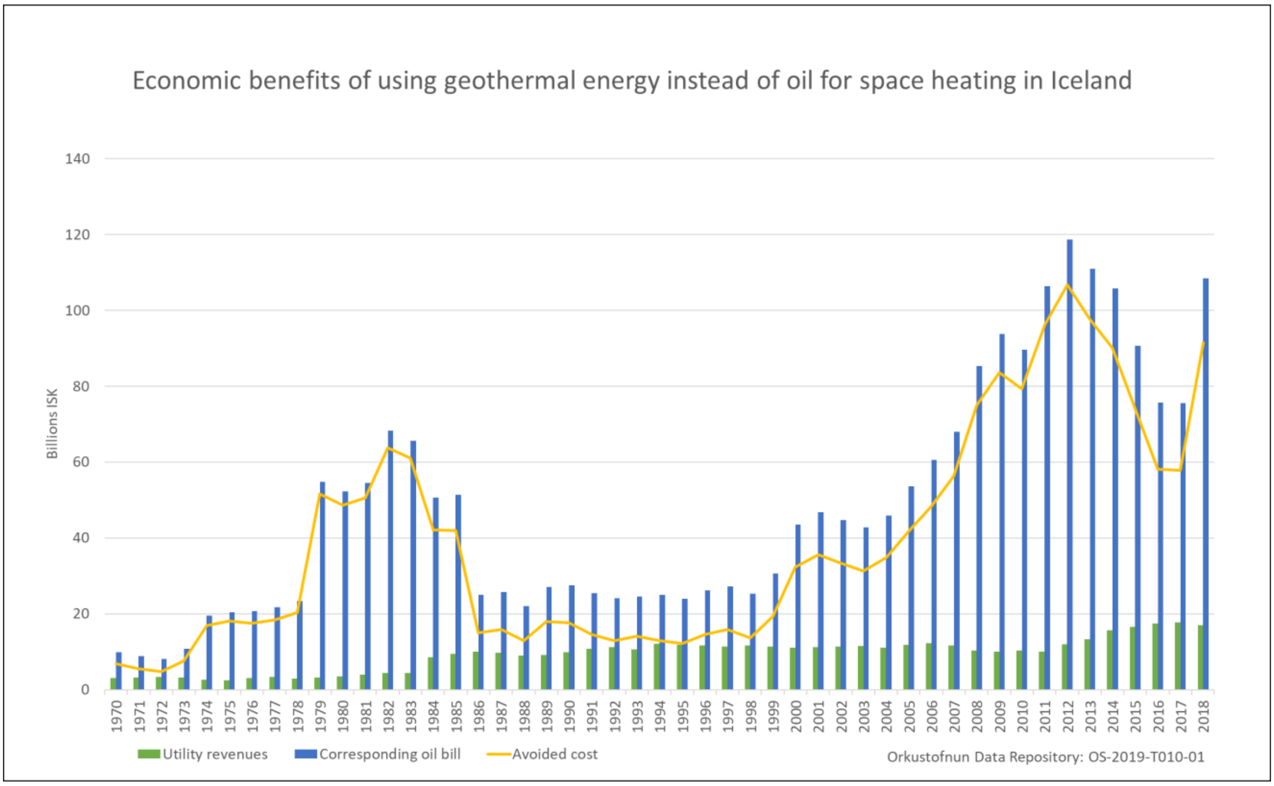

Figure 4: Avoided cost of using geothermal energy instead of oil. The lower columns show actual total utility revenues for hot water but the higher columns the estimated cost with oil, adjusted to a price index (1 US$ = 123 ISK).

Carbon dioxide capturing from geothermal power plants can also be a source for alternative fuel by converting it to methanol, e.g. Carbon Recycling Ltd. is running a plant at Svartsengi power plant for this purpose with promising results. ON Power has successfully illustrated that it is possible to also turn CO_2 and H_2S into rock. Until now, Iceland has been an island not only geographically but also economically to a greater extent than many of its neighbours in Europe (Björnsson, 1995). In recent years another possibility, besides energy intensive industry in Iceland, of increased utilisation of the country's energy resources has been considered with growing seriousness, viz. export of electricity via HVDC submarine cables. The feasibility of interconnecting the country to mainland Europe is under assessment. Not only is there a need for a cable but also for further interconnection of the transmission system on land. Hence the issue is complex and needs thorough investigation in addition to public acceptance.

2.2 Geothermal Energy Forecast until 2050

The Geothermal Working Group, under the Icelandic Energy Forecast Committee, has regularly developed a multi decade forecast for geothermal utilization in Iceland based on assumptions concerning the development of Icelandic society. The base assumptions are stipulated by the Energy Forecast Committee and are common to all energy forecasts for Iceland. Orkustofnun compiles the energy statistics data, which in turn is important for all studies on future geothermal utilization that are used for the forecast. A new geothermal forecast until 2050 is now being developed. It will describe the assumptions used and the predicted effect geothermal utilization will have on the renewable energy sector in Iceland. Statistics Iceland predict a population growth of 36% until 2050 so geothermal utilization, e.g. residential and commercial services, is expected to increase considerably over the next decades. The energy forecast committee has predicted the total cubic meters of heated buildings to increase by 50% until 2050 from the current value of 60 million cubic meters to close to 90 million cubic meters. In total geothermal use is predicted to increase from to 49 PJ in year 2050. Fish farming is expected to increase considerably relative to other sectors.

2.3 Market Development and Stimulation

The government has encouraged exploration for geothermal resources, as well as research into the various ways geothermal energy can be utilised. As stated earlier, this work began in the 1940s at The State Electricity Authority, and was later in the hands of its successor, Orkustofnun, established in 1967. The aim has been to acquire general knowledge about geothermal resources and make the utilization of this resource profitable for the national economy. This work has led to great achievements, especially in finding alternative resources for heating homes. Since the electricity market was liberalized with adaption to EC Directive in year 2003 Orkustofnun only contracts research for exploration of domestic resources.

Geothermal electricity is today competitive with hydro in Iceland and is not subsidised; providing reliable base load, small surface footprint, green energy and favourable prices. Transmission and distribution costs are high in Iceland due to low population density. For cost of residential heating see Figure 6. In recent years geothermal has become cost-competitive for electricity which was not the case a few decades ago (Bjornsson, 1995) when geothermal was not competitive with hydro on a major scale. Wind power is estimated to become cost-competitive within the next years after successful demonstration projects, e.g. Hafið operated by Landsvirkjun.

Space heating of residential buildings is subsidized by the state as shown in Figure 6 for those areas where geothermal based district heating systems are not reachable. Hence to compensate a lump sum of this state subsidization for 12 years has been available to support home owners and instalment of District Heating Services to transform to renewable heating (Act No. 78/2002). This has recently been increased 16 years lump sum.

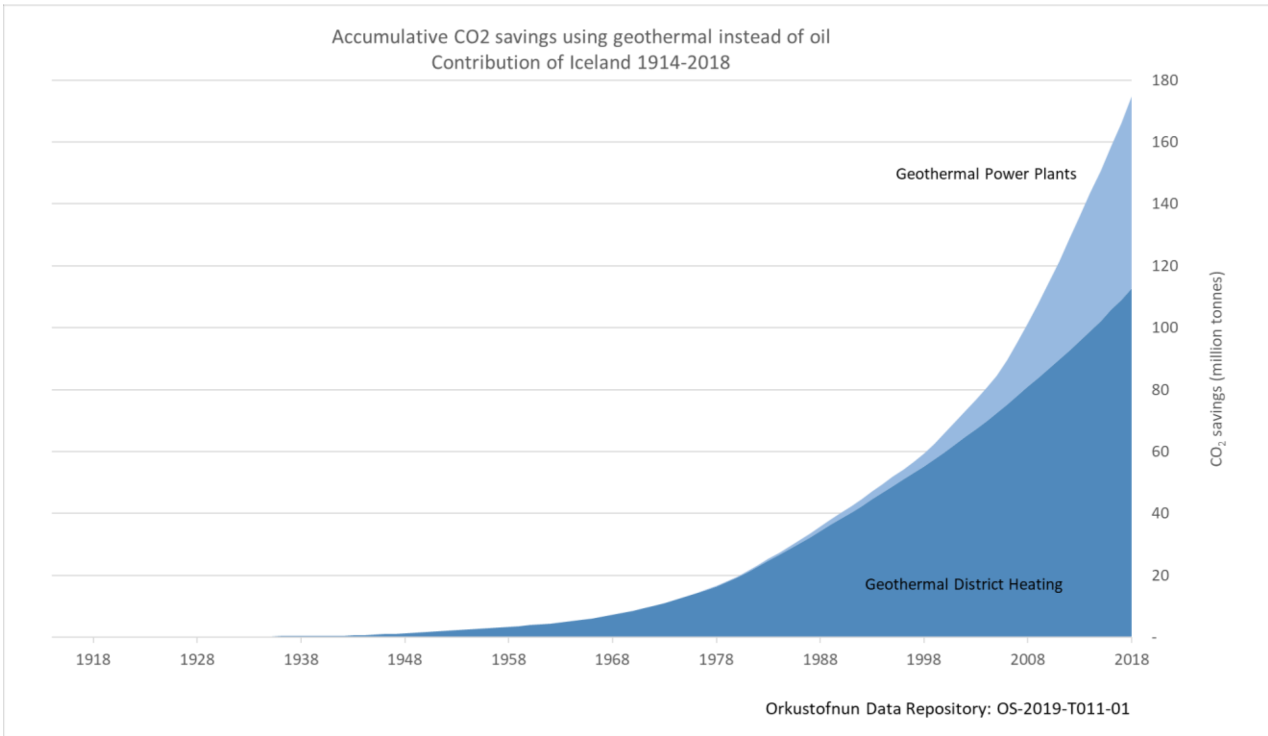

Figure 5: Accumulative CO2 savings using geothermal amounts to about 175 million tons. (Orkustofnun, 2019).

In total for the passed 20 years Orkustofnun has paid 2.6 billion ISK to support installment of new District Heating Services. For individual homes in total 240 million ISK have been supported to about 300 individuals. The need for additional funding for projects which are underway is estimated at 1,8 billion ISK. This is done due to the imbalance that is created by subsidizing the use of fossil fuel or electricity for space heating. The yearly subsidies amount to 1,3 billion ISK per year and over the past 35 years amount to 50 billion ISK.

Interesting recent examples of this is the town Skagaströnd which received a lump sum grant in year 2013. A new district heating system is currently being installed in the town Höfn í Hornafirði which is expected to start using geothermal in year 2020 from the geothermal system near Hoffell. In total RARIK, the operator, has estimated the upfront cost to be 2,8 billion ISK. Orkustofnun supports the project by 0,7 billion ISK through a lump sum support payment. In addition, the Energy Fund supported exploration drilling. After drilling in total 50 shallow wells and five deeper wells enough fluid was harnessed, amounting to 100 l/s of about 80°C hot water which the town needs to convert to geothermal instead of using electricity. Hence a low exergy source, geothermal, is then replacing a high-exergy source to do work which only requires a low exergy source. Thus, the electricity can then be used for some other purposes. Particularly taking into consideration the further need for electricity for various industries and innovation endeavors. Orkustofnun has yet to review the total amount of assistance to installing district heating systems. However, in the period of 1983-1990 in total the state nationalized over 3,2 billion ISK of debt due to extenuating circumstances to prevent them going bank-rupt which could be interesting to analyze further.

New and effective exploration techniques have been developed to discover geothermal resources. This has led to the development of geothermal heating services in regions that were not thought to enjoy suitable geothermal resources. Iceland's geothermal industry is now sufficiently developed for the government to play a more limited role than before. Successful power companies now take the lead in the exploration for geothermal resources; either geothermal fields that are already being utilized, or discovering new fields. The Government supports the Iceland Deep Drilling Project (IDDP) with 342 million ISK. If successful this project could start a new era in geothermal development. The main purpose is to find out if it is economically feasible to extract energy and chemicals out of hydrothermal systems at supercritical conditions. The first well drilled yielded superheated steam after drilling into magma at roughly 2 km depth. The second well was completed in Reykjanes geothermal field in January 2017 when an existing well was

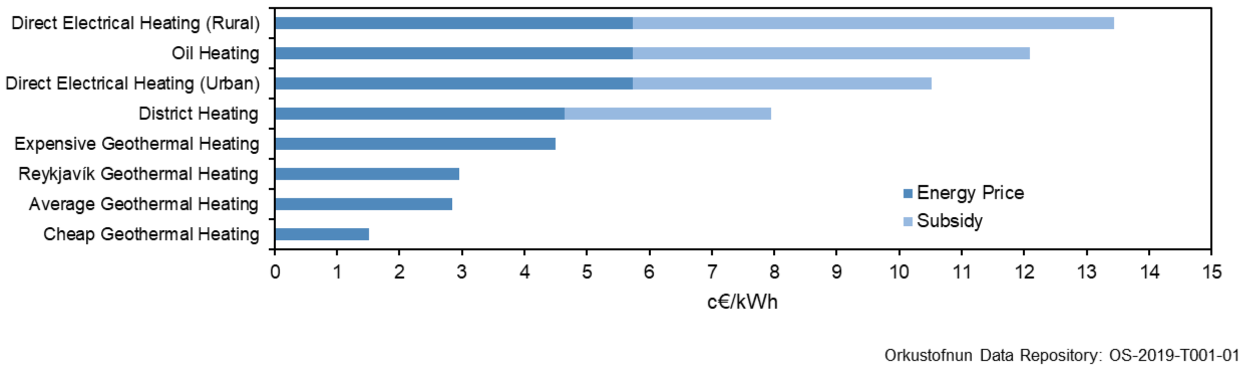

Figure 6: Comparison of energy prices for residential heating in September 2018 in €-cents per kWh of heat.

deepened and reached supercritical conditions at a depth of 4,5 km. Based on measurements the bottom hole temperature is estimated to be about 535°C. Currently flow testing is underway, and plans are for a third well in the Hellisheiði geothermal field.

Drilling success has been on average 74% in Iceland into high temperature systems for electricity generation (Sveinbjörnsson, 2014). In total 105 wells were used in year 2019 to generate electricity and hence the average well is contributing 6.3 MW of electric power and generating 50 GWh of electricity. The average high temperature well is 1866 m deep, cased down to 1585 m. For low temperature systems in total 173 wells are used and 9 hot springs with an average depth of 1055 m, cased down to 223 m (Oddsdóttir and Ketilsson, 2012). For wells drilled for production of hot water for district heating systems, 93% were productive and 88% had a discharge temperature of over 60°C. The average age of production wells currently in use is 33 years, and the oldest well currently in use was drilled in 1946 (Sveinbjörnsson, 2018).

2.5 Geothermal Sustainability Assessment Protocol

As reviewed in more depth in Johannesson et al. (2020) the three largest Icelandic Power Companies and two Governmental Agencies formed a Working Group in year 2016 for the development of an assessment tool to measure geothermal sustainability performance; Geothermal Sustainability Assessment Protocol, GSAP. At the initiative of the International Hydropower Association, IHA, a multi stakeholder Sustainability Assessment Protocol, HSAP, was prepared in the period 2008 to 2010. Representatives from IHA, Governments, Finance Institutions and NGOs prepared the Protocol. HSAP is now applied worldwide, to assess key sustainability factors of projects; social, environmental and economic. The aim is to measure, guide and improve performance for sustainability topics. Iceland actively participated in the preparation of HSAP. The GSAP Working Group took on to transform this widely accepted HSAP tool to geothermal application. As the stakeholders are in principle more or less the same, modifications are kept to a minimum to maintain as possible the existing consensus on HSAP. A Draft GSAP is now prepared and successfully tested for the Preparation Stage of *Theistareykir 90 MWe* and the Operation Stage of *Hellisheidi 300 MWe/130 MWth*.

2.5 Master Plan for New Projects

Earlier energy developments in Iceland were focused on meeting the basic energy needs of the society for space heating and electricity for the general market. Through the years it has become more and more evident that utilisation of energy resources (as other development) must consider not only the energy needs and the economic aspects of the development, but also a range of other interests as well. This includes other land use and the impact of development on the environment and the cultural heritage. The first step towards such an evaluation was undertaken by a collaboration committee of specialists from the Ministry of Industry, the National Power Company, Orkustofnun and the Nature Conservation Council. This committee was active during the 1970’s to the 1990’s. It discussed plans for various electrical power plants with special emphasis on the natural conservation aspects of the projects. A general view on the energy policy and the nature conservation policy was needed for the country. This became even more important by 1994 when the Parliament of Iceland passed the first *Act on Environmental Impact Assessment*. The Icelandic Government published a white paper on sustainability in the Icelandic society in 1997. There the need of the development of a long-term Master Plan for energy use in Iceland was once again stressed. All proposed projects, with installed capacity above 10 MWe or 50 MWth, should be evaluated and categorized on the basis of energy efficiency and economics, as well as, on the basis of the impact that the power developments would have on the environment.

A Master Plan of this kind is comparable to the planning of land use and land protection in a strategic environmental assessment (SEA) process. It is not supposed to go into the details required for environmental impact assessment (EIA). The vision is to prepare an overview of the various potential energy projects in hydro and geothermal and to evaluate and rank these based on their energy and economic potential, feasibility, national economy and the estimated impact that each project would have on nature, environment, cultural heritage and the society, as well as the potential for other uses of the areas in question. The Master Plan should be based on the best available scientific information and conclusions should be transparent and reproducible and made available to the public. It was considered of vital importance to establish public confidence in the evaluation process.

The Master Plan aims to identify power projects that rank high from an economical point of view, have a minimum negative impact on the environment, and a positive impact on the society. Such a score card for the energy projects helps decision makers to filter out which of the proposed projects are likely to become controversial and disputed and which ones not. It also directs attention to those project areas that might have protection value and should be left untouched by human development.

A method for evaluating and ranking energy alternatives based on impact upon the natural environment and cultural heritage was developed as part of the first phase of the Master Plan for the use of hydropower and geothermal energy in 1999 to 2003. The three-step procedure involved assessing i) site values, ii) development impacts within a multi-criteria analysis, and iii) ranking the alternatives from worst to best choice from an environmental–cultural heritage point of view. The natural environment was treated as four main classes (landscape+wilderness, geology+hydrology, species, and ecosystem/habitat types+soils), while cultural heritage constituted one class. Values and impacts were assessed within a common matrix of 6 agglomerated attributes: 1) diversity, richness, 2) rarity, 3) size (area), completeness, pristineness, 4) information (epistemological, typological, scientific and educational) and symbolic value, 5) international responsibility, and 6) scenic value.

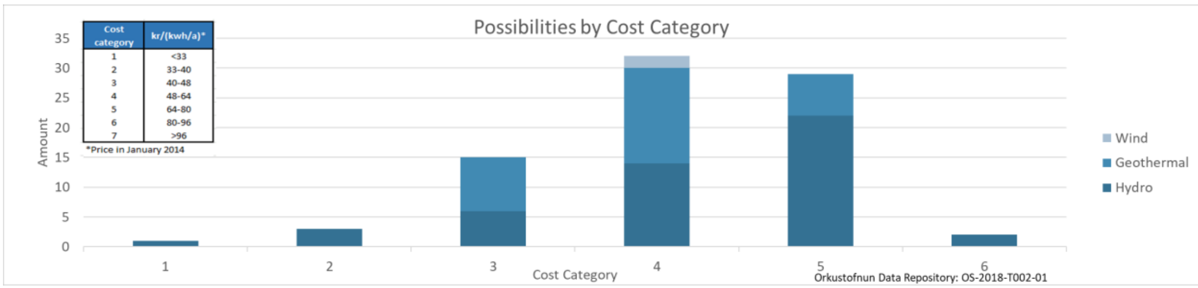

Figure 7: Possibilities by cost category for wind, geothermal and hydro. Costs have increased by 14% in year 2019 from the values presented in year 2014. The graph reveals cost competitiveness of geothermal compared to wind and hydro.

The Government decided to use the work on the Master Plan to establish a permanent planning tool, with regular re-evaluation phases followed by subsequent confirmation of the Master Plan by Parliament. For that purpose, a new *Act on a Master Plan for Protection and Development of Energy Resources* (Master Plan) was passed in Parliament in May 2011. According to the Act the Minister for the Environment, shall in co-operation with the Minister of Industry, at least every four years, propose a Master Plan to the Parliament. The Master Plan shall divide the different projects in three categories, projects for utilisation, projects awaiting further research or projects in areas appropriate for protection. A total number of 84 potential power projects were evaluated during the second phase in 2011 and a Master Plan ranking 28 hydropower projects and 38 geothermal projects approved by the Parliament in 2012. See figure 7 for cost categories which reveals the cost competitiveness of geothermal energy.

Possible electricity production of proposed power development sites by part of country in the third phase of the Master Plan is shown in Figure 7, which is currently under consideration by the parliament. As can be seen the majority of the proposed production is in the South, Southwestern and Northern part of Iceland, the regions which currently have the most power production. Meanwhile, regions such as the Western fjords that need further electricity infrastructure, do not have much proposed production, further highlighting their need. Figure 8 shows proposed sites of power plant development. After the steering committee has decided that resources in a designated area should be harnessed, protected or further studied, the projects themselves can be re-evaluated and hence subject to review again by the Master Plan until the municipalities have adjusted their regional plans. The municipalities could also take the initiative to designate a certain area for protection and another area for re-evaluation. This process of re-evaluation is necessary because with increased understanding on the effects of these projects and with technological advancements, assumptions can change. This re-evaluation is relative until either the area has been formally protected or licenses for the power plant have been issued. Administrative bodies can grant licenses relating to projects that are categorized for utilisation and all research that does not require licensing can be carried out. Administrative bodies cannot grant licenses for projects that await further research if the intended work requires assessment of environmental impact. Research that does not require licensing can be carried out in these areas with the same restriction. Administrative bodies cannot grant any licenses for projects that are in areas categorized for protection except for a limited research license for prospecting on surface without affecting the environment. The projects in question are approved by Orkustofnun before submittal to the Steering Committee and can both be state owned and privately owned. Before presenting the proposal to Parliament the Steering Committee of the Master Plan must ask for both written comments and publicise the draft proposal. After the confirmation of the Parliament, the Master Plan is valid and binding for all parties for up to four years, unless the Parliament changes its resolution. The municipalities are required to adjust their regional plans accordingly within 15 years from the decision of the Parliament. The Master Plan only covers projects that have the potential of at least 10 MW electric or at least a thermal potential of 50 MW. The plan is binding for all municipalities and is to be included in their general land use plans. Currently the 4th phase of the master plan is underway even though the 3rd phase has yet to have passed through the parliament.

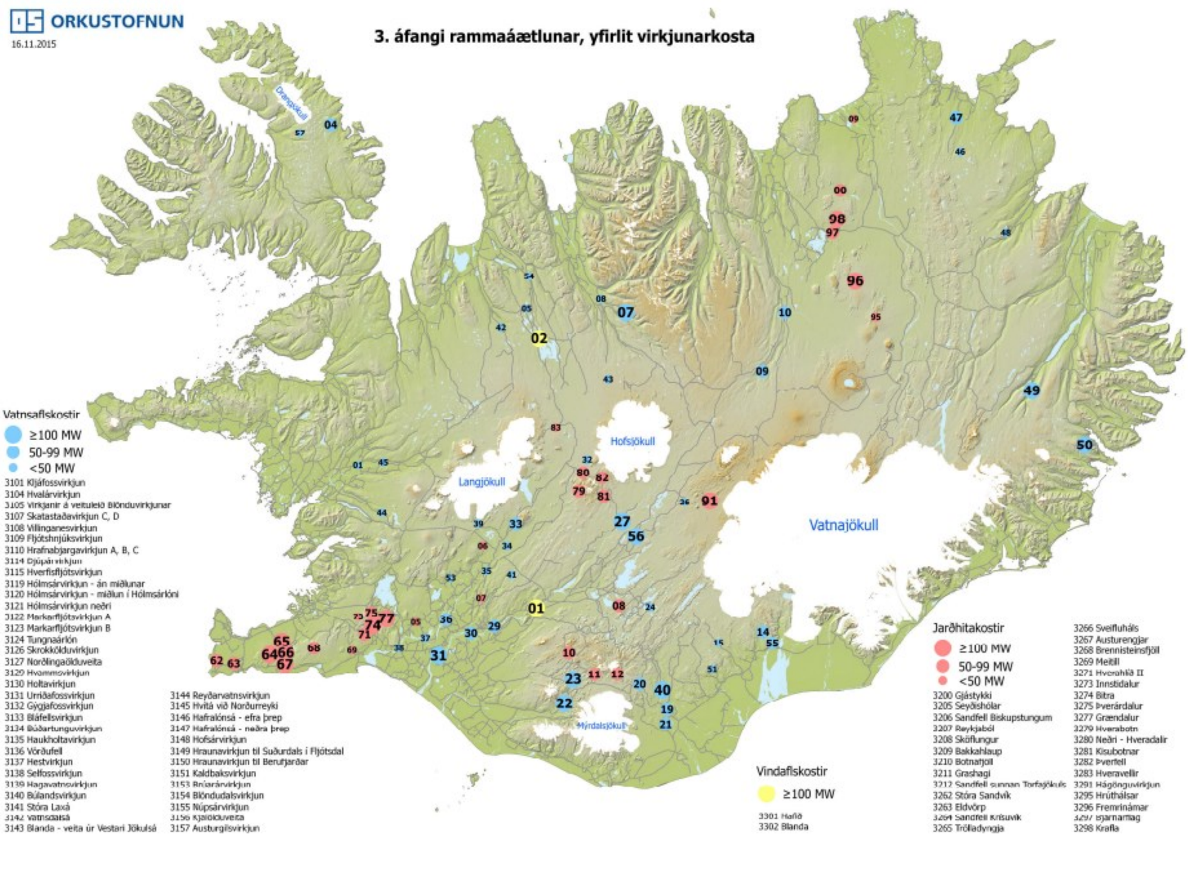

Figure 8: Proposed hydro (blue), geothermal (red) and wind (yellow) areas by Orkustofnun for consideration for the next Master Plan phase. The table above shows possibilities by cost category.

3. LEGAL FRAMEWORK

The ownership of resources in the ground is associated to the ownership of private land, while on public land resources in the ground have to remain in public ownership, unless others can prove their right of ownership. Even though the ownership of resources is based on the ownership of land, research and utilisation is subject to licensing according to the *Act on Survey and Utilisation of Ground Resources*, No. 57/1998 (*Resource Act*) and the *Electricity Act*, No. 65/2003. Survey, utilisation and other development pursuant to these Acts are also subject to the *Nature Conservation Act, Planning and Building Act, Environmental Impact Assessment Act* and other Acts relating to the survey and utilisation of land and land benefits.

The Ministry of Industries and Innovation is the head organisation of energy matters in Iceland. The Ministry has today two ministers, Minister of Industry and Commerce and Minister of Fisheries and Agriculture. The Ministry has authority of the *Resource Act* and the *Electricity Act* which are the two main legal acts that geothermal energy exploration and utilisation is based on in Iceland.

Orkustofnun is a government agency under the Ministry of Industries and Innovation. Orkustofnun works on the basis of the *Act on Orkustofnun* no. 87/2003. The main responsibilities have been to advise the government of Iceland on energy issues and related topics, promote energy research and administer development and exploitation of the energy resources. Orkustofnun is also responsible for gathering, guarding and mediating information on energy resources and their exploitation. It has been responsible for the regulation of the fore mentioned Acts, among other Acts such as the *Act on Prospecting, Exploration and Production of Hydrocarbons*, the *Water Act*, No. 15/1923 and the *Act on the Ownership of the Icelandic State of the Resources of the Sea Floor, No. 73/1990*. More recently Orkustofnun has received the responsibility of granting licenses for exploration and exploitation of natural resources as well as all licenses according to the *Electricity Act*, thus acquiring full independence regarding the granting of licenses based on the Acts regulated by Orkustofnun. Figure 8 gives an overview of the role of Orkustofnun and the two ruling committees that decisions of Orkustofnun can be appealed to.

In 2008 the Parliament decided to prevent any further sale of water resources, including geothermal energy, to private entities. As of that same year, all-natural resources that were not privately owned were guaranteed to remain in the possession of the State or municipalities or entities owned by them. As described previously the State can grant licenses for utilisation, for up to 65 years, according to the *Resource Act*. As of that same year Parliament also decided to implement into the Act a clause stating that the Minister of Industry could delegate the power to grant licenses to Orkustofnun. Prior to that time, the Minister granted such licenses. The decisions made by Orkustofnun, derived from the newly granted power, could be appealed to the Ministry for revision. In that way, civilians had the possibility to have a decision revised in the administrative sector, without having to turn to the courts. Another amendment that same year dictates that combined heating and power plants are obliged to keep separate accounts for heat and power production to prevent cross subsidisation of electricity. Producers of electricity compete in an open market in Iceland whereas the heat is sold based on a natural monopoly license to sell heat within a certain area, hence, it is necessary to keep financial records separate in relation to e.g. the *Administrative Act*, No. 37/1993 as well as Art. 65 of the *Icelandic Constitution*. Later, or in 2012, Parliament decided to move that same license granting power to Orkustofnun by amending the law, making Orkustofnun fully independent in its decision making. Such decisions can today be appealed to the *Appeals Committee for Environmental and Resource Matters* as previously mentioned (see Figure 8).

3. 1. Licensing

Orkustofnun has been working towards making applications for licences easy and accessible. A template has been made as a guide for utilisation licence applications for geothermal energy. The template can be accessed on the Orkustofnun website to make applications more attainable. In addition, an internal procedure has been setup to evaluate systematically applications divided into five phases

In the first phase a specialist begins by reviewing the application and making sure the information is sufficient. In the second phase a lawyer will look over the application from a legal point of view. Formal requirements are examined according to the Resource Act. In the third phase the application is sent to legal entities and individuals for review and the feedback is taken into consideration in phase four and five after receiving a response from the applicant which includes the final stages of the licencing process. After an overview of the application and with input from geothermal energy specialists the application is either granted or rejected. The decision of Orkustofnun can be appealed to the Appeals Committee for Environmental and Resource Matters, cf. Act. No. 130/2011 on the appeals committee.

Licences granted by Orkustofnun can be found in the OS Licensing Registry which is a search engine of licences issued by Orkustofnun from the year 2008. In total 46 licenses issued since 2008 of which 25 are utilisation licences, 15 research licences and 5 power plant licences. In Ketilsson and Bromley (2020) these licenses are further reviewed and in total 12 dilemmas defined that were encountered during the licensing procedure. The tools developed to overcome these barriers are described and analysed based on new governance approach further described in the paper. In addition, leadership roles applicable to these dilemmas are suggested and the Principal Challenge for Iceland identified as being the Transition Challenge (Ketilsson and Bromley, 2020).

3.2 Resource Act

The *Resource Act* covers resources in the ground, at the bottom of rivers and lakes and at the bottom of the sea within netting limits. The Act also covers surveys of hydropower for the generation of electricity. The term resource applies to any element, compound and energy that can be extracted from the earth, whether in solid, liquid or gaseous form, regardless of the temperature at which they may be found.

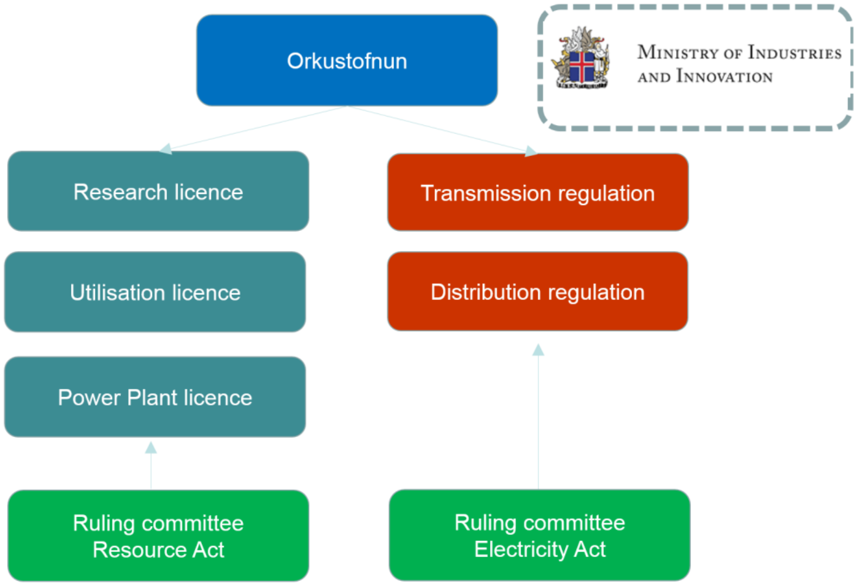

Figure 9: Role of Orkustofnun as a licensing authority and the two ruling committees that can be appealed to.

According to the Act, Orkustofnun is permitted to take the initiative in and/or give instructions on surveying and prospecting for resources in the ground anywhere in the country, regardless of whether the owner of the land has himself or herself begun such surveying or prospecting or permitted others such surveying or prospecting, unless the party in question holds a valid prospecting licence pursuant to the Act. In the same way, Orkustofnun may permit others to survey or prospect, in which case a prospecting licence shall be issued to them. A prospecting licence confers the right to search for the resource in question within a specific area during the term of the licence, survey extent, quantity and potential yield and to observe in other respects the terms which are laid down in the Act and which Orkustofnun considers necessary.

The utilisation of resources in the ground is subject to a licence from Orkustofnun, whether it involves utilisation on private land or public land, with the exceptions provided for in the Act. A landowner does not have priority to a utilisation licence for resources on his or her land, unless such an owner has previously been issued a prospecting licence. A utilisation licence permits the licence holder to extract and use the resource in question during the term of the licence to the extent and on the terms laid down in the Act and regarded necessary by Orkustofnun. Before the holder of a utilisation licence begins extraction on private land the holder needs to reach an agreement with the landowner on compensation for the resource or obtain permission for expropriation and request assessment. In the event that neither an agreement is made on compensation nor expropriation requested within 60 days immediately following the date of issue of a utilisation licence, the licence shall be cancelled. The same applies if utilisation on the basis of the licence has not started within three years of the issuance of the licence. This also applies to the utilisation of resources on public land.

Orkustofnun may revoke the above licences if their conditions are not fulfilled. If a licence holder does not comply with the conditions established in the licence or contracts relating to the licence, Orkustofnun shall issue a written warning and provide time limits for rectification. Should the licence holder not comply with such a warning, the licence shall be revoked.

3.3 Electricity Act

According to the *Electricity Act* a licence issued by Orkustofnun is required to construct and operate a power plant. However, such a licence is not required for power plants with a rated capacity of less than 1 MW, unless the energy produced is delivered into the distribution system of a distribution system operator or into the national transmission grid. Power plants with installed capacity less than 100 kW are exempt from this requirement. The owners of power plants with a rated capacity of 30–1000 kW shall submit technical details of the plant to Orkustofnun. Also, Orkustofnun shall be informed annually of the total generation of power plants with a rated capacity of over 100 kW.

3.4 Recent rules and regulations

3.4.1 Rules regarding preparedness and reactions to seismic hazards due to fluid injection into the ground via boreholes

Geothermal areas are geologically active and such areas are likely to experience seismic activity. Fluid withdrawal and fluid injection into the ground accompanying geothermal utilization causes changes in the stress field of the Earth's. Research on fluid injection into the ground in geothermal areas has shown that in active geothermal areas in Iceland it may stimulate some microearthquake activity. On the one hand there are microearthquakes as a response to this change in the stress, but on the other hand it may bring forward earthquakes that would inevitably take place later. The most common reason is change in injection rate, e.g. if injection is for some reason temporarily stopped, the probability of microearthquake activity is increased. In general, these earthquakes are not felt at the surface but in specific cases there is a considerable probability that increased fluid pressure due to release has triggered larger earthquakes.

The injection of geothermal fluids into the ground is an important part of the utilization of geothermal energy on the one hand to dispose of fluids, but on the other to counteract pressure decline in geothermal systems. In some cases, injection is mandatory in accordance with a utilisation licence and/or an operation licence according to Act No. 7/1998 on hygiene and pollution control, and is practiced from the start of operations. In other cases, it has been initiated after some time of operation. Geothermal energy is however widely harnessed without injection into the ground.

The extent of fluid injection into the ground with the utilization of geothermal energy is steadily increasing. With reference to the risks described here Orkustofnun issued rules on the preparation and execution of fluid injection into the ground via boreholes (OS-2016-R01-01) the rules were issued on January 21st of 2016. The objective of the rules is to minimize the risk of bodily harm, damage to man-made structures and inconvenience due to earthquakes in connection with fluid injection to the ground via boreholes. Furthermore, they are intended to restrict and explain duties, roles and involvement of the licence holder, Orkustofnun and other parties as applicable in each instance, and to promote the proper emphasis during the preparation and execution of the injection.

The chief objective is to provide information to applicants for production licences according to the Electricity Act and utilization licences according to the Resource Act, due to power production or other utilization of geothermal energy, regarding the requirements considered upon the publication and revision of these licences with reference to the provisos of Item 7, Article 18 of the Resources Act and Item 4, Paragraph 1, Article 6 of the Electricity Act.

3.4.2 Rules for boreholes

Orkustofnun and its predecessors have kept a registry of the boreholes drilled in Iceland for many decades. At the start of 2019 the registry had over 14.000 boreholes, with the oldest dating back to 1904. Just over 4.500 of these are related to geothermal activity, either research or production boreholes. Each borehole has an ID number by which information about it is identified. This includes the location of the borehole, its depth, casing depth, when it was drilled, purpose of drilling, the drilling contractor in charge and what drill rig was used. In recent years, considerable improvements have been made to the registry, such as assigning every well in the registry a location, scanning older drilling reports and making them available online and developing a new web portal for Orkustofnun where the registry can be accessed more easily (www.map.is/OS). By law, Orkustofnun shall be notified when a borehole is drilled and receive a report once drilling is concluded. However, this is often not the case leading to boreholes not being reported and therefore not included in the registry. Another problem that has emerged is the uncertainty regarding the ownership and responsibility of a number of boreholes, leading to some unused boreholes becoming hazardous due to low maintenance and inadequate closure.

In order to improve this, Orkustofnun has developed rules on the registration, design and permanent closure of boreholes, and the submission of information on boreholes to Orkustofnun. The purpose is to clarify the obligations placed on those who drill boreholes and the intended result will be increased regulating and more complete data on boreholes. During the development of these rules stakeholders were consulted, resulting in valuable feedback and dialogue. The rules outline the relevant articles of the Resource Act regarding boreholes, and what is required of Orkustofnun as well as owners of boreholes and other stakeholders by law. In order to streamline the data collection, three forms have been made for borehole owners to fill out and send to Orkustofnun. One is to be filled out before drilling, fulfilling the legal requirement of notifying Orkustofnun of drilling activities; the second form is to be filled out after drilling, describing the drilling process, the borehole depth, casings, geology etc.; and a third to be filled out when a borehole has been permanently closed. Additionally, guidelines will also be published to explain the purpose and execution of the borehole rules to stakeholders.

The desired outcome of the implementation of these rules is an organized and systematic data collection, resulting in a complete borehole registry that is available to the public on an accessible online portal which is valuable to drilling contractors and other entities that are considering drilling, as well as professionals, academics, students and the general public. This is in line with Orkustofnun's policy of public data dissemination which has been valuable for the geothermal development in Iceland for the last few decades. Another outcome of the implementation of these rules would be to clarify the ownership of boreholes, which increases the security of the general public and tourists traveling in Iceland.

5. OFFICIAL MONITORING

In June 1999 the Icelandic Parliament passed *Act on Official Monitoring* no. 27/1999 in order to promote efficient yet beneficial monitoring practice. The objective of this act is to ensure that official monitoring is conducted in the most economic way possible, both for the State and for those the monitoring is aimed at. The official monitoring rules have to be effective in order for it to serve its aims. According to Art. 2, the objective of the Act is also to ensure that official monitoring rules promote the welfare of the Nation, safety and public health, safety of property, environmental protection, normal business practices and consumer protection. The *Official Monitoring Act* requires authorities to conduct an economic evaluation before new monitoring rules are passed as law, to ensure that the extent of the monitoring is reasonable in proportion to the objectives aimed for. The monitoring should not be more extensive or more complex in execution than is required to achieve the distinctive objectives.

The official monitoring of utilisation of geothermal resources in Iceland is rather extensive and is the responsibility of different public authorities, as will later be addressed. The objective of the monitoring for each sector is different, respectively: to protect the environment, to prevent overexploitation of the resource, and to secure occupational safety and safety of delivery at the power plants as outlined in the following sections.

5.1 Environmental monitoring

The objective of official monitoring of the environment surrounding geothermal projects in Iceland is reflected in the stated aims of Art. 1 of the *Nature Protection Act* no. 60/2013. The objective is to regulate the interaction of man with his environment so that it harms neither the biosphere nor the geosphere, nor pollutes the air, sea or water. The ultimate aim is to ensure that the Icelandic ecosystem can develop according to its own laws and to ensure the conservation of its exceptional or historical aspects. An important pillar in environmental protection according to Icelandic legislation is *Act on Environmental Impact Assessment* no. 106/2000 (*EIA*) as previously mentioned. The objective of the EIA is to gauge the effects a project may have on the environment and to minimize as far as possible the negative environmental impact of projects. Furthermore, when resource utilisation and power plant licenses are issued, environmental factors should be taken into consideration. Surveying, utilisation and power plant licenses may be bound by specific conditions in order to safeguard environmental requirements, according to the *Resources Act*, Art. 17 and the *Electricity Act*, Art. 5. With the *Strategic Environmental Assessment Act* no. 105/2006 (*SEA*), Iceland adopted Directive 2001/42/EC from the European Parliament and the Council as previously mentioned. The objective of the Directive is to protect the environment and to encourage sustainable development by conducting an environmental assessment of plans which are likely to have an impact on the environment. In the Directive it is assumed that the impact of plans and programmes on the environment are assessed before they are passed and executed.

The Health Committees of municipalities are responsible for official monitoring of the operation license. These committees derive their power from the *Hygienic & Pollution Act* no. 7/1998. The Act divides Iceland into ten regulatory zones and each zone has one committee. The operation licenses for power plants are issued by these health committees. The objective of these licenses is to prevent pollution from e.g. run-off water and to promote a clean environment. The operation license is equipped with conditions and the health committees oversee that these conditions are met. Failure to do so can result in official warnings, daily penalties and termination of the license.

5.2 Resource monitoring

Another objective of official monitoring of utilisation of geothermal resources is to ensure that the most efficient exploitation of the resource is adopted in the long run and that extraction of geothermal fluid does not exceed levels deemed necessary, according to Art. 25 of the *Resource Act*. One way to ensure this is to have effective official monitoring of the utilisation taking place at every geothermal project. Besides efficient monitoring it is also important that relevant institutions, municipalities and developers are aware of the fact that utilisation of geothermal energy in Iceland is to be conducted as stipulated in Art. 25 of the *Resource Act*. Some natural resources are exhaustible; therefore, it has been considered necessary to apply rules to manage their utilisation, in order to ensure natural resources are protected and maintained for future generations.

Orkustofnun has the responsibility to monitor geothermal areas being researched or utilised, according to the *Resource Act*. Orkustofnun is also responsible for the official monitoring stipulated in the *Electricity Act*.

Appendices within utilization licenses and power plant licenses stipulate what detailed information a developer shall present annually to Orkustofnun. The information required is as follows:

- The amount of fluid extracted or reinjected into each well in the geothermal field, each month.
- The temperature of the water reinjected into the geothermal reservoir each month.
- Results of water level measurements in wells where the water level can be measured and are within the geothermal field.
- The pressure changes or drawdown determined in the geothermal reservoir.
- The results of measurements of the enthalpy of the fluid from every production well in the geothermal field.
- Chemical analysis of the geothermal water (and steam, if appropriate).
- Results from simulations of the geothermal reservoir.
- Results of measurements made to monitor changes in the geothermal reservoir.
- Information on drilling in the industrial area.
- A resume of improved understanding of the physical characteristics of the geothermal reservoir based on the results of latest drilling.

The abovementioned items should provide all the necessary information for the monitoring authority to monitor the utilisation of the resource. Furthermore, Orkustofnun has stipulated certain limits on drawdown within the geothermal systems of the last three utilisation licenses for geothermal power plants. This is done to maintain long term balance of water in place, in order to secure the possibility of continuing carrying heat in place to the surface using water as the carrier. An example is given in Figure 9 for actual drawdown limitations stipulated in a utilisation license issued in year 2015 of the Hellisheiði Geothermal Power Plant proposed by ON Power to be built in the next years. In addition to limitation of drawdown there are also limitations in terms of annual reduction in steam supply to be no more than 3%. If those limits are reached ON Power is required to take the necessary steps in mitigating the effects by calibrating the reservoir model and predicting again whether the geothermal system can sustain enough yield through the lifetime of the power plant. The prediction is given with a calculated probability margin taking uncertainty into account. If the drawdown goes beyond the error margin the license holder needs to re-evaluate the reservoir model, change the extraction levels within the area or increase reinjection into the same geological formation to maintain long-term water balance.

5.3 Safety and management

The objective of monitoring utilisation of geothermal energy does not only entail monitoring of the surrounding environment and the resource. The third objective of monitoring of geothermal projects is to ensure the safe and responsible management of power plants which generate electricity from geothermal energy. Monitoring of a power plant starts before construction of the plant begins. First, the municipal authority in the area where the power plant is to be built issues a development license or a building license, according to the *Planning and Building Act* no. 73/1997. According to Paragr. 2 in Art. 38 it is the local authority's responsibility to monitor power plant development and its surroundings, according to the terms of the development or building license that it has issued for the power plant. The council is to make sure that all buildings are built according to the development plan, rules and regulations. Second, a power plant license is required in order to build and operate a power plant, according to Art. 4 of the *Electricity Act*. Orkustofnun is responsible for official monitoring of the conditions stipulated in the relevant license. The objective of monitoring after generation of electricity at the power plant has begun is to ensure that operations are conducted according to the requirements of the Act. On-site monitoring at the power plant, quality of electricity, security of supply of electricity and accounting should be as stipulated in the *Electricity Act.*

5.4 Reaching the objectives

According to the *Official Monitoring Act* the objective is to ensure that official monitoring rules promote the welfare of the Nation, safety and public health, safety of property, environmental protection, normal business practices and consumer protection. In para. 4 of Art. 9 of the derivative Regulation of the *Official Monitoring Act* it is stipulated that the requirements of individual official monitoring authorities are to be harmonised and the monitoring implemented by one and the same party to the greatest possible extent.

The objectives formulated in the legislation concerning the arrangements for official monitoring of utilisation are in general being reached, especially with regard to the preparation phase for utilisation, environmental protection and the construction phase.

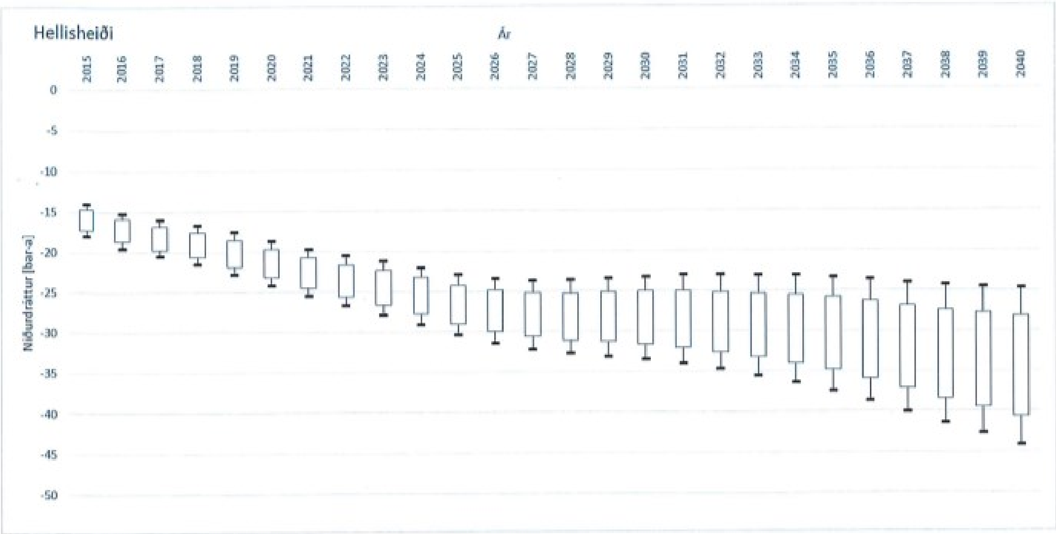

Figure 10: Limitations of drawdown to ensure long-term utilisation of the resource. The vertical scale shows pressure drawdown from natural state in bars. The horizontal scale is in years of operation with an uncertainty margin (Orkustofnun, 2015).

6. CONCLUSION

This paper gives a short overview of the national policy, legal framework and official monitoring of geothermal resources in Iceland. Utilisation of geothermal resources has expanded rapidly during the last decade. Electricity generation was estimated to increase to 5.8 TWh in year 2020 in the National Renewable Energy Action Plan but has reached 6 TWh in year 2018. Heating has been estimated in the Action Plan to reach 34 PJ in year 2020 and was 33 PJ in year 2018. Iceland's long-term objective is to ensure long term utilisation of its resources and the legal amendments mentioned earlier, as well as the future implementation of the Master Plan for hydro and geothermal energy resources in Iceland are steps in maintaining and sustaining this objective. Iceland has developed a great deal of know-how and experience in harnessing of geothermal resources, both for space heating and electricity generation.

A few minor amendments have recently been made with two rules regarding preparedness and reactions to seismic hazards due to fluid injection into the ground via boreholes and rules for boreholes. Geothermal energy plays an important role in providing the nation with clean and reliable energy and is fundamental to the Icelandic economy as well as Icelandic welfare and independence. The rules and procedures of official monitoring in Iceland have been explained in this article in a concise manner. The legal framework itself is extensive and counting derivative regulations, the law on the matter is vast. Some of the legislation is recent while other branches are long-standing. Effective policy making and official monitoring of geothermal development for sustaining a renewable energy society in Iceland is crucial for sustaining a long-term lifespan of the resource.

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