Geothermal Energy Use, Country Update for Iceland

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ABSTRACT

The geothermal resources play a major role in the energy supply of Iceland. They are utilized both for electricity generation and direct heat application. The share of geothermal energy in the nation´s primary energy supply is 66%. Space heating is the most important direct utilization of geothermal energy in Iceland, covering 90% of all energy used for house heating in the country. Other sectors of direct use are swimming pools, snow melting, industry, greenhouses and aquaculture. The total direct use of geothermal energy in 2015 is estimated to be 7,676 GWh_{th} (27,634 TJ). Generation of electricity by geothermal energy has been increasing during the past two decades, mainly due to increased demand in the energy intensive industry. The total installed capacity is now 663 MW_e and the total generation in 2015 was 5,003 GWh_e, which is 26.6% of the total produced in the country.

1. INTRODUCTION

Iceland has a huge geothermal potential based on the location of the country on the Mid-Atlantic Ridge. The country is mountainous and volcanic, with much precipitation, making hydropower resources abundant. The population of Iceland is 333,000, of which almost two third live in the capital area. During the course of the 20th century, Iceland went from what was one of Europe's poorest countries, dependent upon peat and imported coal for its energy, to a country with a high standard of living where practically all stationary energy, and roughly 85% of the primary energy comes from indigenous renewable sources (66% geothermal, 19% hydropower). The rest comes from imported fossil fuel used for the transport sector and fishing fleet. Iceland´s energy use per capita is among the highest in the world and the proportion provided by renewable energy sources exceeds most other countries.

The geothermal resources in Iceland are used to a great extend for both electricity generation and direct uses. In the high-temperature (>200°C) fields geothermal steam is utilized for electricity generation and to an increasing extend also for hot water production in so-called co-generation plants. Thus, the energy efficiency is improved considerably. The low-temperature (<150°C) fields are used mainly to supply hot water for district heating. The current utilization of geothermal energy for heating and other direct uses is considered to be only a small fraction of what this resource can provide. A master plan assessing the economic feasibility and the environmental impact of proposed power development projects has been adopted by the Icelandic Parliament.

It has been the policy of the government of Iceland to increase the utilization of renewable energy resources even further for the power intensive industry, direct use and the transport sector. A broad consensus on conservation of valuable natural areas has been influenced by increased environmental awareness. Thus, there has been opposition against large hydropower and some geothermal projects. The ownership of energy resources in Iceland is based on the ownership of land. However, exploration and utilization is subject to licensing.

2. OVERVIEW OF THE GEOTHERMAL UTILIZATION

Table 1 and Figure 1 give a breakdown of the estimated utilization of geothermal energy in Iceland for 2014 (Ragnarsson, 2015). Direct use of geothermal energy that year, i.e. for heating, was in total about 26,700 terajoules (TJ), which corresponds to 7,417 GWh_{th} of used energy. This is based on estimated inlet and outlet water temperature for each category (e.g. 35°C outlet temperature for space heating). In addition, electricity production by geothermal amounted to 5,245 GWh_e in 2014. The 42.6% share of space heating was by far the greatest direct use sector while electricity production accounted for 41.4%.

Table 1: Geothermal utilization in Iceland 2014.

	Installed power	Energy consumption	
	MW	TJ/year	GWh/year
Space heating	1,550	19,400	5,389
Greenhouses	45	660	183
Fish farming	85	2,230	619
Industrial process heat	70	910	253
Snow melting	195	1,900	528
Swimming pools	90	1,600	444
Direct uses total	2,035	26,700	7,417
Elctricity generation	663	18,882	5,245
Geothermal utilization total	2,698	45,582	12,662

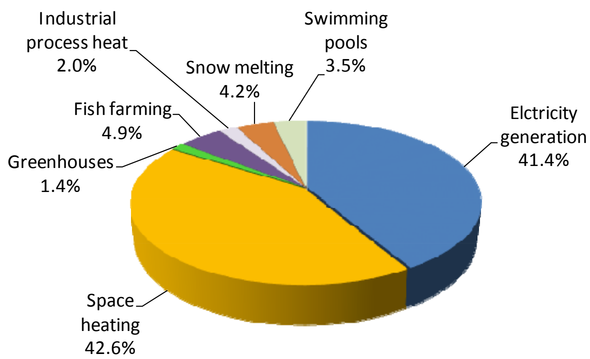

Figure 1: Sectoral share of geothermal utilization in Iceland 2014.

3. GELOGICAL BACKGROUND

Iceland is a geologically young country located in the North Atlantic astride the Mid-Atlantic Ridge, which is the boundary between the North American and Eurasian tectonic plates. The two plates are moving apart at a rate of about 2 cm every year. Due to this position geological and tectonic processes are extraordinary rapid and easily observed in Iceland. Some 20-30 volcanic eruptions occur every century on average, producing lava in the order of 45 km^3 every 1000 year. Some 400 km are exposed of the Mid-Atlantic ridge which makes it possible to observe a variety of tectonic processes such as volcanism and associated features. A large number of volcanoes and hot springs are found in the country and earthquakes are frequent. The volcanic zone is running from the southwest to the northeast. More than 200 volcanoes are located within this zone and at least 30 of them have erupted since the country was settles over 1100 years ago. Associated with the volcanoes are numerous geothermal systems, ranging from freshwater to saline in composition and from warm to supercritical temperatures. At least 20 high-temperature areas exist within the volcanic zone with temperatures reaching 200°C within 1000 m depth. About 250 separate low-temperature areas with temperatures not exceeding 150°C in the uppermost 1000 m are mostly in the areas flanking the active volcanic zone. Over 600 hot spring areas (temperature over 20°C) have been located (Figure 2).

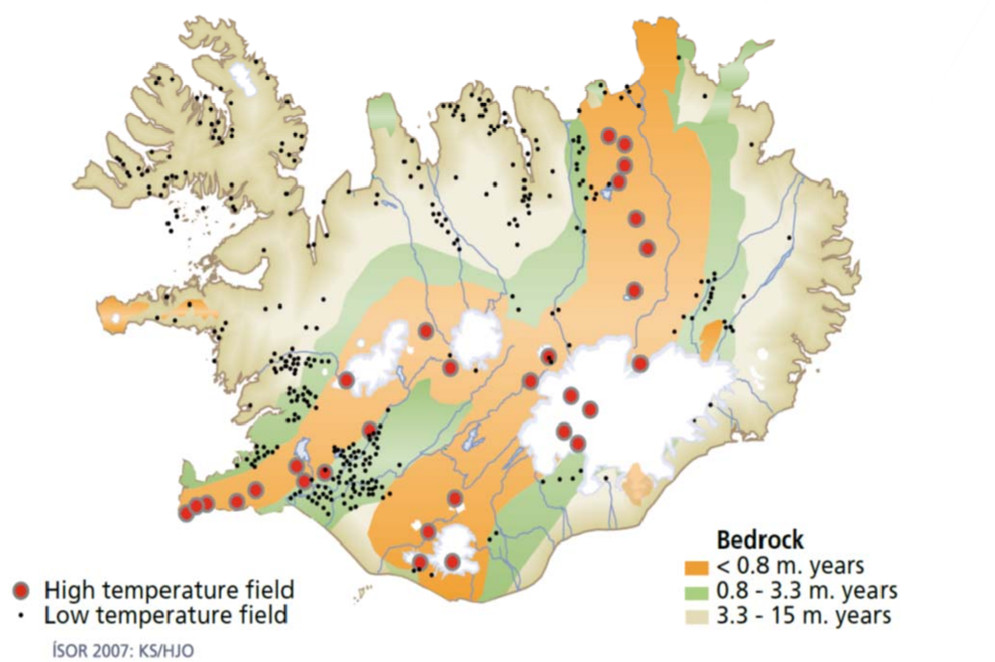

Figure 2: Volcanic zones and geothermal areas in Iceland.

4. SPACE HEATING

Direct uses and especially space heating play a predominant role in the geothermal utilization in Iceland. The pioneer was a farmer at Sudur-Reykir in the vicinity of Reykjavík who started using geothermal water for heating his house in 1908 by transporting water from a hot spring through a pipeline over a distance of about 500 m. Utilization of geothermal energy for space heating on a large scale began with the laying of a 3 km long hot water pipeline from the hot springs of Laugardalur in Reykjavík in 1930. The formal operations of Reykjavík District Heating (now Reykjavík Energy) began in 1946. Following the oil price hikes of the 1970s, the government took the initiative in expanding district heating, with the result that the share of geothermal energy increased from 43% in 1970 to the current level of about 90%. This development is illustrated in Figure 3. About 30 separate geothermal district heating systems are operated in towns and villages in the country and additionally some 200 small systems in rural areas. These smaller systems supply hot water to individual farms or a group of farms as well as summerhouses, greenhouses and other users. Geothermal space heating has enabled Iceland to import less fossil fuel, and has resulted in a very low heating cost compared to most other countries. Using geothermal energy, which is classified as a renewable energy source, for space heating has also benefited the environment. Although most of the towns and villages in Iceland with the possibility of geothermal heating have already such a system in operation, exploration activities are ongoing with the aim to develop geothermal heating in new areas.

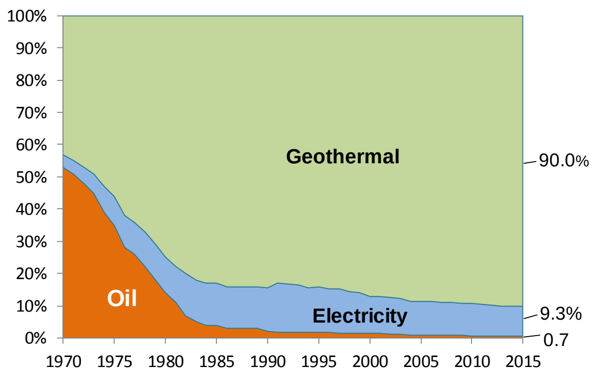

Figure 3: Energy sources used for space heating in Iceland 1970-2015.

4.1 District heating in Reykjavík

Reykjavík Energy (Orkuveita Reykjavíkur) is a public utility responsible for distribution and sale of both hot water and electricity as well as the city's waterworks and sewage system. The total number of employees is about 450 and the turnover in 2015 was about 40,000 million ISK (273 million € based on the average 2015 exchange rate). Reykjavík Energy is by far the largest geothermal district heating utility in Iceland. It serves in total over 200,000 people or about two third of the Icelandic population, the entire population of Reykjavík, plus neighboring communities as well as some additional villages by separate smaller systems.

District heating in Reykjavík began in 1930 when some official buildings and about 70 private houses received hot water from geothermal wells, located close to the old thermal springs in Reykjavík. In 1943 delivery of hot water from the Reykir field, 18 km from the city, started. The district heating system was expanded gradually over the years to the whole greater Reykjavik area. Today Reykjavík Energy utilizes low-temperature areas within and in the vicinity of Reykjavík as well as the high-temperature fields at Nesjavellir, about 27 km away, since 1990 and Hellisheidi since 2010. At Nesjavellir and Hellisheiði fresh water is heated in co-generation power plants, producing both electricity and hot water. In the past Reykjavík Energy has taken over several district heating systems in operation outside the capital area. Some are small systems in rural areas, but others are among the largest geothermal district heating systems in the country. The total installed capacity of Reykjavik Energy district heating system is about 1,150 MW_{th} and the total annual hot water production is over 80 million m^3 per year.

On 1 January 2014 the provision of the Icelandic Electricity Act dealing with electric energy market restructuring came into effect that obliges companies to segregate the licensed part from the competitive market operations. Then the company Our Nature (ON, Orka náttúrunnar) began operating on the competitive electricity market as a subsidiary, wholly-owned by Reykjavik Energy. Our Nature is responsible for the competitive part of the operation, which is generation and sale of electricity, while distribution of electricity and operation of the waterworks and sewage system as well as the district heating systems, which are licensed activities, is the responsibility of another subsidiary of Reykjavik Energy called Veitur Utilities.

4.2 HS Orka and HS Veitur

The privately owned company HS Orka is responsible for production and sale of electricity and heat in the Reykjanes Peninsula. They are the only energy company in Iceland that has been fully privatized. HS Orka was previously a part of Hitaveita Sudurnesja (Sudurnes Regional Heating) which at the time of privatization was split in 2008 into HS Orka for generation and HS Veitur for distribution. Hitaveita Sudurnesja was a pioneer in building the co-generation power plant at Svartsengi in 1977. It is located about 50 km SW of Reykjavík. The plant utilizes 240°C geothermal brine from the Svartsengi field to heat fresh water for district heating (190 MW_{th}), and to generate electricity (74 MW_e). HS Orka has a 100 MW_e geothermal plant on Reykjanes that was commissioned in 2006 for electricity generation only. The company HS Veitur, which has a majority public ownership, takes care of the non-competitive distribution of energy from HS Orka. They serve four communities on the Reykjanes peninsula with totally about 20,000 inhabitants with hot water, electricity and water. They also serve about 30,000 inhabitants in Hafnarfjordur and neighboring communities with electricity.

4.2 Nordurorka – District heating in Akureyri

Akureyri is a town of 18,000 inhabitants located in the central N-Iceland. It has been heated by geothermal energy since the end of the seventies. Hot water is pumped to Akureyri from five different geothermal fields. In addition to this, two 1.9 MW_{th} heat pumps have supplied a small part of the annual energy production most of the time since 1984, but their contribution has been insignificant for the last decade or so. During the last few years several small district heating systems in neighboring communities have merged with Nordurorka. Thus, the total number of people served is now about 23,000. The total installed capacity is 103 MW_{th} and the annual hot water consumption about 8.7 million m^3.

5. OTHER DIRECT UTILIZATION

5.1 Swimming and bathing

For centuries natural hot springs were mainly used for bathing in Iceland, but since early in the last century outdoor swimming pools as we know them today have been gaining popularity and they are today a part of the daily life of a large part of the nation. There are about 165 recreational swimming centers in the country, 140 of which use geothermal heat to keep the water temperature at 28-30°C year round. The combined surface area of the geothermally heated pools is about 34,000 m^2. Most of the swimming pools are open to the public throughout the year. They serve for recreational purposes and are also used for swimming lessons, which are compulsory in schools. Swimming is very popular in Iceland and swimming pool attendance has increased in recent years. In the greater Reykjavík area alone there are fourteen public outdoor pools and a few indoor ones. The largest of these is Laugardalslaug with 1,500 m^2 outdoor pools, 1,250 m^2 indoor pool and five hot tubs where the tub temperature ranges from 35 to 42°C. Other health uses for geothermal energy are the Blue Lagoon, the bathing facility at Bjarnarflag close to Lake Mývatn and the Health Facility in Hveragerdi, comprising geothermal clay baths and water treatments. Typically, about 220 m^3 of water or 40,000 MJ of energy is needed annually for heating one m^2 of pool surface area. This means that a new, mid-sized outdoor swimming pool uses as much hot water as heating 80-100 single-family dwellings. The total geothermal energy used for heating swimming pools in Iceland is estimated to be 1,600 TJ per year.

The Blue Lagoon mentioned above is a 5,000 m^2 surface pond that receives effluent brine from the Svartsengi power plant (42 l/s). At the start of operations of the power plant in 1977 the effluent water was discharged into the surrounding lava field, which was to absorb the water due to its high permeability. People started bathing in the pond and psoriasis patients discovered that the water had a beneficial effect on their skin. Later, showering facilities were added and in 1999 a man-made lagoon with a temperature of 37-39°C was created along with improved facilities for visitors. The Blue Lagoon contains about 6 million liters of brine and the hydraulic retention time is about 40 hours. The salt content is 2.5%, close to 70% of sea water. (Haraldsson and Cordero, 2014). In addition to the bathing facilities there are other important activities of the Blue Lagoon company. They operate a clinic for psoriasis patients that takes advantage of the therapeutic effects of the geothermal brine and produce skin care products that contain unique natural ingredients, silica, minerals and algae. The number of Blue Lagoon visitors has increased rapidly during the past years and has now reached about 1 million per year, making it one of Iceland’s most popular tourist attractions.

5.2 Snow melting

Geothermal water has for a long time been used in Iceland to heat sidewalks and pavements to melt snow during the winter. These uses have been gradually increasing and today almost all new buildings in areas with geothermal heating have snow melting systems. Iceland´s total area of snow melting systems is around 1,200,000 m^2, mostly in the capital area. Spent water from the houses, at about 35°C, is thus used for de-icing sidewalks and parking spaces. Most of the larger systems have the possibility to mix spent water from the houses with hot supply water from the district heating system (80°C) when the load is high. The main purpose is often to prevent icing or to make removal of the snow easier, rather than directly melt the snow. In downtown Reykjavík, a snow-melting system has been installed under most sidewalks and some streets, covering an area of 70,000 m^2. This system is designed for a maximum heat output of 180 W/m^2 surface area and the annual energy consumption is estimated to be 430 kWh/m^2. About two thirds of that energy comes from spent water from the space heating systems and one third directly from hot supply water. The total geothermal energy used for snow melting in Iceland is estimated to be 1,900 TJ per year.

5.3 Industrial uses

The largest industrial user of geothermal energy in Iceland is the seaweed drying plant Thorverk, located at Reykhólar in West Iceland. It uses geothermal heat directly in its production. The company harvests seaweed found in the shallow waters of Breidafjordur bay using specially designed harvester crafts. Once landed, the seaweed is chopped and dried on a belt dryer that uses large quantities of air heated to 85°C by geothermal water. The plant has been in operation since 1975, and produces about 4,000 tonnes of rockweed and kelp meal annually using 36 l/s of 112°C water for the drying process. The 70°C hot return water from the seaweed drying plant is now utilized by a new table-salt factory, Nordursalt.

Since 1986, a facility at Haedarendi in Grímsnes, South Iceland, has produced commercial liquid carbon dioxide (CO_2) derived from the geothermal fluid of two gas rich wells. The Heidarendi geothermal field has an intermediate temperature (160°C) and a very high gas content (1.4% by weight). The gas discharged by the wells is nearly pure carbon dioxide with a hydrogen sulphide concentration of only about 300 ppm. Upon flashing, the fluid from the Haedarendi well would produce large amounts of calcium carbonate scaling. Scaling in the well is avoided by a 250 long downhole heat exchanger made of two coaxial steel pipes. Cold water is pumped down through the inner pipe and back up the annulus. Through this process, the geothermal fluid is cooled to arrest boiling and rapid degassing and the solubility of calcium carbonate is increased sufficiently to prevent scaling (reverse solubility). The plant uses approximately 6 l/s of fluid and produces some 3,000 tonnes CO_2 annually, which is a large share of the Icelandic gas market. The production is used in greenhouses to enrich the atmosphere, for manufacturing carbonated beverages and in other food industries.

Geothermal energy has been used in Iceland for drying fish for about 35 years. The main application has been the drying of salted fish, cod heads, small fish, stockfish and other products. Cod heads were traditionally dried by hanging them on outdoor stock racks. Because of Iceland´s variable weather conditions, indoor drying is preferred. Hot air is blown over the fish in batch dryers. Today about 10 companies dry cod heads indoors and all of them use geothermal hot water. The annual export of dried cod heads is about 10-12,000 tonnes. The product is shipped mainly to Nigeria where it is used for human consumption. Among the largest Icelandic producers of dried cod heads is the company Haustak. They buy about 1.3 kg/s of steam at 18 bar (220°C) from the nearby Reykjanes power plant to produce annually 2,500 tonnes of dried product from 12,000 tonnes of raw material. The steam is used to heat water up to 70°C for the drying process.

The Icelandic-American company Carbon Recycling International (CRI) has since 2012 operated a plant that uses CO_2 emissions of the Svartsengi geothermal power plant of HS Orka to produce methanol to blend with gasoline to fuel cars. Hydrogen used in the process is produced locally by electrolysis of water. The current production capacity is 1.7 million liters of methanol per year. Output from the plant is currently used directly as a blend component for standard petrol or as a feedstock for biodiesel from esterified vegetable oil or animal fats. CRI and HS Orka have signed an expanded Power Purchase agreement which guarantees the availability of sufficient power for CRI to expand the annual fuel production plant up to 5 million liters per year from about 6,000 tonnes CO_2.

Two salt factories that utilize geothermal energy in their production have been established in Iceland in recent years. The focus is on producing “gourmet” table salt. One of them is Nordursalt that has been in operation since 2013. They use 30 l/s of 70°C hot waste water from the nearby Thorverk seaweed plant, which was until then discharged to the sea. This water, together with 115°C water from a geothermal well that is useful for regulating the heat, is used for the evaporation process and to dry the salt. The other salt factory is Saltverk at Reykjanes in Northwestern Iceland. They started operation in 2011 and utilize about 10 l/s of 90-95°C hot water from a geothermal well that is cooled down to 70°C in the salt production process. The annual production is 70-80 tonnes of salt.

Several other industrial processes utilizing geothermal energy have been operated in Iceland in the past. Among them is the Kisilidjan diatomite plant at Lake Mývatn, which was among the largest industrial users of geothermal steam in the word until the plant was closed down in 2004 after almost 40 years of operation. Examples of other industrial applications that have been realized but are no longer in operation are a salt production plant on the Reykjanes peninsula utilizing geothermal brine and seawater, drying of imported hardwood in Húsavík by geothermal water, retreading of car tires and wool washing in Hveragerdi. Among smaller ongoing activities using geothermal energy are laundry processes and steam baking of bread at several locations and a concrete block plant with steam heated autoclaves. The total geothermal energy used as process heat in industry in Iceland is estimated to be 910 TJ per year.

5.4 Greenhouse heating

Heating of greenhouses is one of the oldest and most important uses of geothermal energy in Iceland after space heating. Naturally warm soil had been used for outdoor growing of potatoes and other vegetables for a long time when geothermal heating of greenhouses started in Iceland in 1924. The majority of the greenhouses are located in the south, and most are enclosed in glass. The heating installations are of unfinned steel pipes hung on the walls and over the plants. Under table or floor heating is also common. It is also common to use inert growing media (volcanic scoria, rhyolite) on concrete floors with individual plant watering. By using electric lighting the growing season is extended to year round, which improves the utilization of the greenhouses and increases the annual production per square meter of greenhouse area. Artificial lighting, which also produces heat, has contributed to a diminishing demand for hot water supply to greenhouses. As a consequence of the lengthening of the growing season the need for new constructions is less than before. CO_2 enrichment in greenhouses is common, primarily by using CO_2 produced in the geothermal plant at Haedarendi (see Chapter 5.3). Outdoor growing at several locations is enhanced by soil heating with geothermal water, especially during early spring.

The total surface area of greenhouses in Iceland was about 194,000 m^2 in 2012 including plastic tunnels for bedding and forest plants. Of this area, 50% is used for growing vegetables (tomatoes, cucumbers, paprika etc.) and the rest mainly for growing cut flowers and potted plants. The total production of vegetables in 2011 was about 18,000 tonnes. The share of domestic production in the total consumption of tomatoes in Iceland is about 75% and for cucumbers about 90%.

Most of the greenhouses in Iceland have automatic control of the indoor climate and thus, for example, the temperature can be adjusted to the optimum temperature for different kinds of crops, ranging from 10-15°C in nurseries up to 20-25°C for roses. Also, the temperature is commonly adjusted to follow the optimum daily variations. The main parameters that influence the heat loss from greenhouses and thereby the heating demand are the outdoor temperature, wind speed, greenhouse cover material, indoor temperature, artificial lighting, heating system arrangement and opening of the windows. A study made on energy consumption for heating a group of typical greenhouses in Iceland resulted in an average energy consumption of 3.67 GJ/m^2 in greenhouses with artificial lighting and 5.76 GJ/m^2 in greenhouses without artificial lighting (Haraldsson and Ketilsson, 2010). The total geothermal energy used in Icelandic greenhouses is estimated to be 660 TJ per year.

5.5 Aquaculture

Fish farming has been a slowly growing sector in Iceland for a number of years. After a rapid growth from 2002 the total production reached about 10,000 tonnes in 2006, mainly salmon. The dominating species are now salmon and arctic char followed by trout. There are about 60 fish farms in Iceland and the total production was about 8,300 tonnes in 2015. Of these fish farms between 15 and 20 utilize geothermal water. Initially, Iceland's fish farming was mainly in shore-based plants. Geothermal water, commonly 20-50°C, is used to heat fresh water, either in heat exchangers or by direct mixing, typically from 5 to 12°C for juvenile production. The main use of geothermal energy in the fish farming sector in Iceland is for juvenile's production (char and salmon). In land-based char production geothermal energy is also used for post-smolt rearing. Geothermal utilization in the fish farming sector is expected to increase in the coming years. The total geothermal energy used in the fish farming sector in Iceland is estimated to be 2,230 TJ per year.

A fish farming plant owned by the company Stolt Sea Farm started breeding warm-water Senegalese sole at Reykjanes peninsula, Iceland, in 2013. It is the first stage of a large indoor land-based plant that is planned. The 22,500 m^2 plant is located close to a 100 MW$_e$ geothermal power plant owned by the energy company HS Orka. The power plant uses a large amount of sea water for the tubular power plant condensers which is at the outlet at a temperature of 35°C, flows by gravity to the sea and a part of it goes to the fish farm. There it is mixed with sea water that is pumped from wells and used in the rearing tanks at about 21°C, which is the optimum temperature for the fish. The water temperature can be kept constant throughout the year without any influences from the environment. In mid-2014 there were about 1.2 million juveniles in the plant and that number is increasing. They are grown to about 400 g before the Senegalese sole is slaughtered and transported fresh to markets in Europe. The production capacity of the first stage is 500 tonnes per year, but the planned production after reaching the final stage is 2,000 tonnes per year. In mid-2014 the number of employees was 14 and it is expected to increase to 60-70 in the final stage.

6. ELECTRIC POWER GENERATION

Geothermal power accounts for a significant share of the electricity generation in Iceland which mainly results from a relatively rapid development during the past 15 years. Table 2 gives an overview of the individual plants and Figure 4 shows how the generation has developed during the period 1970-2015. The total installed capacity of geothermal generating plants is now 663 MW$_e$. The total production in 2015 was 5,003 GWh$_e$, which is 26.6% of the total electricity production in the country (Orkustofnun, 2016).

6.1 Bjarnarflag

The oldest geothermal power plant in Iceland is in Bjarnarflag where a 3 MW$_e$ back pressure unit started operation in 1969. The turbine installed was bought second hand from a sugar refinery, but it was later refurbished. The plant is using steam from a well in the Namafjall geothermal field within the lake Mývatn area in North Iceland. The same well has been used to supply heat for industrial applications, district heating and a geothermal spa. The power plant has been operated successfully ever since the beginning except for three years in 1985-1987 when the plant was closed, partly due to volcanic activity in the area. Exploration drilling has been performed in preparation of further development of the Namafjall field by a new 90 MW$_e$ power plant in two stages.

6.2 Krafla

The Krafla power plant is located near the lake Mývatn in North Iceland (about 10 km from the Bjarnarflag plant) and has been operating since 1977. Two 30 MW$_e$ double flash condensing turbine units were purchased when the plant started, but due to unexpected difficulties with steam supply the plant was run with only one installed turbine for the first 20 years. The shortfall of steam was due to volcanic activity that injected volcanic gases into the most productive part of the geothermal reservoir. Volcanic eruptions occurred only about two kilometers away from the power plant, posing a serious threat to its existence. Initially the power generation was 8 MW$_e$, but reached 30 MW$_e$ in 1982. The capacity of the Krafla power plant was expanded in 1997 from 30 to 60 MW$_e$ by commissioning the second turbine, and further expansion is being considered. Totally, 33 wells have been drilled in the area, including 17 high pressure and 5 low-pressure production wells. The plant uses 110 kg/s of 7.7 bar saturated high-pressure steam and 36 kg/s of 2.2 bar saturated low-pressure steam.

Table 2: Geothermal power plants in Iceland.

Plant name	Plant size MW	Year	Unit size MW	No of units	Type	Temp. °C	Press. bar	Flow rate t/h	Estimated production GWh/yr
Krafla	60	1978	30	1	DF	172/122	7.2/1.1	400/130	480
		1997	30	1	DF				
Svartsengi	74.4	1977	1	2	SF	159	5	166	611
		1981	6	1	SF	155	4.5		
		1989-1993	1.2	7	B	103	0.12	131	
		1999	30	1	SF	163	5.5	275	
		2007	30	1	DS	198	15	288	
Bjarnarflag	3.2	1969	3.2	1	SF	182	9.5	45	26
Nesjavellir	120	1998	30	2	SF	188	12	432	960
		2001	30	1	SF	192	12	198	
		2005	30	1	SF	192	12	198	
Húsavík	2	2000	2	1	B	122		324	16
Reykjanes	100	2006	50	2	SF	210	18	288	800
Hellisheiði	303	2006	45	2	SF	178	8.5	600	2400
		2007	33	1	SF	124	1.05	315	
		2008	45	2	SF	178	8,5	600	
		2011	45	2	SF	178	8,5	600	
Total	662.6			29				4,460	5,293

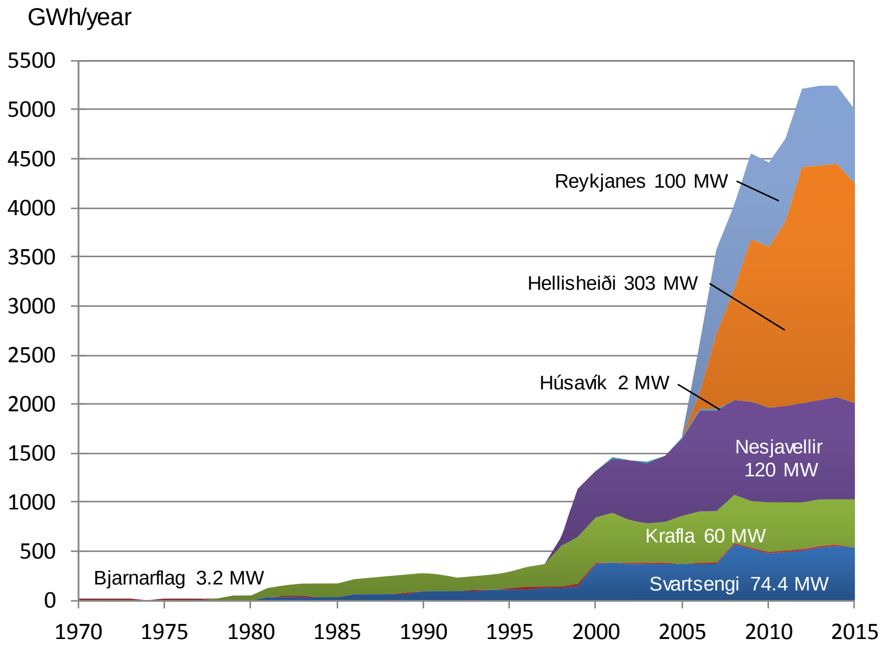

Figure 4: Electricity generation by geothermal energy in Iceland 1970-2015.

6.3 Svartsengi

The Svartsengi co-generation power plant of HS Orka has been producing both hot water and electricity since it started operation in 1977. It is located on the Reykjanes peninsula, about 40 km from Reykjavík, and serves about 20,000 people. The reservoir fluid is a brine at 240°C and with a salinity of about two thirds of sea water. The total production from the reservoir is about 400 kg/s. Of that between 50 and 75% is reinjected. Geothermal heat is transferred to freshwater in several heat exchangers. After expanding the plant in several steps the total installed capacity in Svartsengi is now 190 MW_{th} for hot water production and 74 MW_e for electricity generation. Of that 8.4 MW_e come from Ormat binary units using low-pressure waste steam. A part of the effluent brine from Svartsengi (40 l/s) goes the Blue Lagoon (see Chapter 5.1).

6.4 Reykjanes

HS Orka started operation of a new 100 MW_e geothermal power plant at Reykjanes in May 2006 (two 50 MW_e steam turbines with sea cooled condensers). An expansion of the plant has been under preparation for some time, totally by 80 MW_e of which 30 MW_e are planned to be produced by using brine from high pressure separators. These plans are now being reconsidered.

6.5 Nesjavellir

Reykjavík Energy has been operating a co-generation power plant at Nesjavellir high temperature field north of the Hengill volcano since 1990. A mixture of steam and geothermal brine is transported from the wells to a central separator station at 200°C and 14 bars. The primary purpose of the plant is to provide hot water for the Reykjavík area, 27 km away. Freshwater is heated by geothermal steam and hot water in heat exchangers, first by preheating within the turbine condensers and thereafter by utilizing the heat from the liquid brine from the separators. After deaeration a small amount of geothermal steam containing hydrogen sulfide is injected into the water to remove any remaining oxygen and thereby preventing corrosion and scaling. The hot water is pumped to a large storage tank at an elevation of 400 m from where it flows by gravity to smaller tanks in Reykjavík. The capacity of the plant is about 300 MW_{th} which corresponds to 1,800 l/s of district heating water at 83°C. The power plant started generating electricity in 1998 when two 30 MW_e steam turbines were put into operation. In 2001, a third turbine was installed and the plant enlarged to a capacity of 90 MW_e, and finally to 120 MW_e in 2005.

6.6 Hellisheidi

Reykjavík Energy started operation of a new 90 MW_e geothermal power plant at Hellisheidi in the southern part of the Hengill area in October 2006. It was expanded by a 33 MW_e low pressure unit in 2007 and further by installing two 45 MW_e units in late 2008 and additionally two 45 MW_e units in 2011, increasing the total installed capacity of the plant to 303 MW_e. Hot water production for district heating in Reykjavík started at Hellisheidi in 2010. Due to increased demand for steam, additional wells drilled in 2007 and 2008 have recently been connected to the plant. Originally these wells were planned for a new power plant that was expected to be built (Hverahlid), but it was decided to transport the steam over a distance of 5 km to the Hellisheidi plant.

6.7 Húsavík

At Húsavík, in Northeast Iceland, the generation of electricity using geothermal energy began in 2000 when a 2 MW_e binary-fluid power plant, based on Kalina cycle technology, was put into service. Due to operational problems the plant has not been in operation since January 2008. It was one of the first of its kind in the world. The plant utilized about 90 kg/s of 120°C hot geothermal water from wells located about 20 km south of Husavík. This water was used as an energy source to heat a mixture of water and ammonia, which in closes circuit acts as a working fluid for the heat exchangers and a turbine. The Kalina cycle gains efficiency by the ability of the working fluid to closely parallel the temperature of the heat source and the heat sink. Part of the hot water leaving the generating plant at 80°C was used for the town´s district heating, as well as the local swimming pool and other direct uses.

7. CONCLUSIONS

During the last century Iceland has developed the indigenous energy resources, hydropower and geothermal energy, to increase the standard of living and make the country less dependent upon imported fossil fuel. There is a large potential for increased utilization of geothermal energy.

New geothermal developments did slow down considerably after the financial crisis in 2008 which resulted in delays in projects that were planned. This situation has now changed. The most developed project is in the Theistareykir geothermal field in North Iceland, not far from the Krafla geothermal field, where Landsvirkjun (The National Power Company) is building a 90 MW_e power plant. Twelve deep wells have already been drilled in the area and the plant is planned to be commissioned in two phases in 2017 and 2018. The power will go to a planned production plant for silicon metal in the nearby town Húsavík.

After the financial crisis in 2008 there was a drastic reduction in the geothermal drilling activity in Iceland from a high of 28 high-temperature wells drilled in 2008 to no high-temperature well drilled in 2014. The drilling activity has now increased again with 8-10 high-temperature geothermal wells drilled in the country in 2016. One of them is a part of the IDDP project (Iceland Deep Drilling Project) where a 2.5 km deep production well at Reykjanes will be deepened to 5 km. The drilling of IDDP-2 started in August 2016.

The use of heat pumps for space heating in areas of Iceland where geothermal heating is not available (about 10% of the total) has been very limited. However, during the last few years several geothermal heat pumps, mainly of horizontal ground loop type, have been installed with financial support from the government.

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Table A: Present and planned geothermal power plants, total numbers

	Geothermal Power Plants		Total Electric Power in the country		Share of geothermal in total electric power generation	
	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (MW_e)	Production (GWh_e/yr)	Capacity (%)	Production (%)
In operation end of 2015	661	5,003	2,769	18,798	23.9	26.6
Under construction end of 2015	90	738	190	1,038	47,3	71,1
Total projected by 2018	751	5,741	2,959	19,836	25,4	28,9
Total expected by 2020	781	6,000	3,000	20,186	26.0	29.7
In case information on geothermal licenses is available in your country, please specify here the number of licenses in force in 2015 (indicate exploration/exploitation, if applicable):						

Table B: Existing geothermal power plants, individual sites

Locality	Plant Name	Year commis-sioned	No of units *	Status	Type	Total capacity installed (MW_e)	Total capacity running (MW_e)	2015 pro-duction (GWh_e/y)
Bjarnarflag	Bjarnarflag	1969	1	O	1F	3.2	3.2	10.1
Krafla	Krafla	1978/97	2 (RI)	O	2F	60	60	487.4
Svartsengi	Svartsengi	1977/07	10 (RI)	O	1F/B/D	74.4	74.4	531.7
Nesjavellir	Nesjavellir	1998/05	4 (RI)	O	1F	120	120	984.0
Húsavík	Húsavík	2000	1	N	B	2	0	0
Hellisheidi	Hellisheidi	2006/11	7 (RI)	O	1F	303	303	2,227.4
Reykjanes	Reykjanes	2006	2 (RI)	O	1F	100	100	762.4
Total						662.6	660.6	5,003

Key for status:		Key for type:			
O	Operating	D	Dry Steam	B-ORC	Binary (ORC)
N	Not operating (temporarily)	1F	Single Flash	B-Kal	Binary (Kalina)
R	Retired	2F	Double Flash	O	Other

* In case the plant applies re-injection, it is indicated with (RI) after number of power generation units

Table C: Present and planned geothermal district heating (DH) plants and other direct uses, total numbers

	Geothermal DH plants		Geothermal heat in agriculture and industry		Geothermal heat for individual buildings		Geothermal heat in balneology and other	
	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)	Capacity (MW_{th})	Production (GWh_{th}/yr)
In operation end of 2015	1,890	6,651	60	228	109	377	72	420
Under constru-ction end 2015								
Total projected by 2018	2,006	7,058	63	238	116	400	76	446
Total expected by 2020	2,087	7,343	65	246	120	416	79	464

Table D1: Existing geothermal district heating (DH) plants, individual sites

Locality	Plant Name	Year commis-sioned	CHP	Cooling *	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2015 produc-tion (GW_{th}/y)	Geoth. share in total prod. (%)
Reykjavík	Orkuveita	1930	Yes, partly	No (RI)	1,150	1,150	4,170	100
Seltjarnarnes		1971	No	No	30	30	96	100
Mosfellsbær		1929	No	No	30	30	135	100
Sudurnes	HS Veitur	1976	Yes	No (RI)	170	170	670	100
Akranes and Borgarfj.		1981	No	No	7	7	20	100
Akranes		1980	No	No	33	33	100	100
Borgarnes		1980	No	No	10	10	40	100
Stykkishólmur		1998	No	No (RI)	8	8	30	100
Dalabyggd		1999	No	No	3	3	13	100
Reykhólar		1954	No	No	4	4	7	100
Sudureyri		1977	No	No	3	3	13	100
Drangsnes		1999	No	No	1	1	2	100
Hvammstangi		1972	No	No	5	5	17	100
Blönduós		1977	No	No	7	7	27	100
Skagafjördur		1953	No	No	30	30	122	100

Siglufjördur		1975	No	No	7	7	23	100
Ólafsfjördur		1944	No	No	10	10	38	100
Dalvík		1969	No	No	16	16	45	100
Hrísey		1973	No	No	4	4	13	100
Akureyri	Nordurorka	1977	No	No (RI)	100	100	290	100
Húsavík		1970	No	No	26	26	90	100
Reykjahlíd		1971	No	No	7	7	25	100
Eskifjördur		2005	No	No	8	8	15	100
Egilsstadir		1979	No	No	15	15	37	100
Rangæinga		1982	No	No (RI)	16	16	48	100
Flúdir		1929	No	No	35	35	90	100
Bláskógabyggd		1923	No	No	33	33	155	100
Selfoss		1948	No	No	60	60	155	100
Hveragerdi		1947	No	No	50	50	110	100
Thorlákshöfn		1979	No	No	12	12	55	100
Total					1,890	1,890	6,651	100

* In case the plant applies re-injection, it is indicated with (RI) in this column after Y or N.

Table D2: Existing geothermal direct use other than DH

Locality	Plant Name	Year commis-sioned	Cooling	Geoth. capacity installed (MW_{th})	Total capacity installed (MW_{th})	2015 produc-tion (GWh_{th}/y)	Geoth. share in total prod. (%)
Different direct uses at many individual sites				241		1,025	
Total				241		1,025	

Table E: Shallow geothermal energy, ground source heat pumps (GSHP)

	Geothermal Heat Pumps (GSHP), total			New (additional) GSHP in 2015		
	Number	Capacity (MW_{th})	Production (GWh_{th}/yr)	Number	Capacity (MW_{th})	Share in new constr. (%)
In operation end of 2015 *	70	1	5			
Projected total by 2018						

Table F: Investment and Employment in geothermal energy

	in 2015		Expected in 2018	
	Expenditures * (million €)	Personnel ** (number)	Expenditures * (million €)	Personnel ** (number)
Geothermal electric power	76	300	39	200
Geothermal direct uses	17	80	12	80
Shallow geothermal	0	0	0	0
total	**93**	**380**	**51**	**280**

* Expenditures in installation, operation and maintenance, decommissioning

** Personnel, only direct jobs: Direct jobs – associated with core activities of the geothermal industry – include "jobs created in the manufacturing, delivery, construction, installation, project management and operation and maintenance of the different components of the technology, or power plant, under consideration". For instance, in the geothermal sector, employment created to manufacture or operate turbines is measured as direct jobs.

Table G: Incentives, Information, Education

	Geothermal el. power	Geothermal direct uses	Shallow geothermal
Financial Incentives – R&D			
Financial Incentives – Investment		RC	RC
Financial Incentives – Operation/Production		DIS	DIS
Information activities – promotion for the public	Yes	Yes	No
Information activities – geological information	Yes	Yes	No
Education/Training – Academic	Yes	Yes	Yes
Education/Training – Vocational	Yes	Yes	Yes

Key for financial incentives:

DIS	Direct investment support	FIT	Feed-in tariff	-A	Add to FIT or FIP on case the amount is determined by auctioning
LIL	Low-interest loans	FIP	Feed-in premium		
RC	Risk coverage	REQ	Renewable Energy Quota	O	Other (please explain)