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Development of Low Temperature Utilization and Resource Monitoring for District Heating Services in Iceland

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ABSTRACT

The majority of the district heating services in Iceland use energy from many of the numerous low-temperature geothermal systems, which are all located outside the volcanic zone. Many district heating services have been in operation for several decades, the oldest ones for more than 90 years and several others for 40 – 70 years. They have experienced a long history of production but have encountered relatively few problems related to the utilization. The long term reservoir monitoring programs and sustainable use of low temperature geothermal systems, is one of the main reasons for the success of the operation of these valuable resources. Through the long history of resource monitoring for different district heating services in Iceland there are many lessons learned and various versions of generic plans made. This requires the operator to collect and have available production data for processing from geothermal fields being utilized while also applying cutting edge exploration techniques for finding new resources. District heating services are facing new challenges in recent years mostly due to increased demand for hot water. This is the result of increased population in some urban areas, a huge increase in number of tourists in Iceland as well as increased demands in using geothermal water from low temperature resources for innovative utilization.

1. INTRODUCTION

This paper will give an overview of the different issues involved in the successful sustainable production of low temperature geothermal fields utilized by district heating services in Iceland. The main focus will be on aspects involved in resource monitoring, how requirements from regulators impacts planning of resource monitoring and also what problems that have been encountered during the long history and solutions applied. Then there are some observations made regarding the changes facing the district heating services and how resource monitoring programs play a key role to continue the sustainable utilization of the geothermal fields along with application of new technologies in exploration for successful drilling new wells for production or reinjection.

The planning of resource monitoring aims for the operations to be sustainable, both for the utilization of the geothermal resource as well financial. Much can be learned from the long operation of district heating services in Iceland, in particular regarding long-term management of low-temperature geothermal resources. This experience also provides valuable input into discussions and studies related to the renewability of geothermal energy and the possible contribution of geothermal energy to sustainable development (Axelsson et al., 2005). Several problems have faced these operations, however, such as overexploitation manifesting itself in excessive pressure draw-down as well as problems related to colder water inflow and sea water incursion. None of the district heating systems have ceased operation and solutions have been found to these problems.

2. UTILIZATION OF LOW TEMPERATURE GEOTHERMAL SYSTEMS

The low-temperature systems, which by definition have a reservoir temperature below 150°C at 1 km depth, are mainly located outside the volcanic zone that passes through Iceland. The largest such systems are located in SW-Iceland on the flanks of the volcanic zone, but smaller systems are found throughout the country. The heat-source for the low temperature activity is believed to be the abnormally hot crust of Iceland, with the geothermal gradient in the range of about 50 – 150°C/km, outside the volcanic zone. Faults and fractures, which, are kept open by continuously ongoing tectonic activity, play an essential role by providing the channels for the water circulating through the system and extracting the heat.

Geothermal energy provides at present about 2/3 of the primary energy supply in Iceland (Figure 1). The principal use of geothermal energy in Iceland is for space heating, but other direct uses and electricity generation are also highly significant. Over 90% of the space heating is currently by geothermal energy. Other uses of geothermal energy in Iceland include direct uses such as for industrial applications, swimming pools, snow melting, greenhouses and fish farming as well as indirect electricity generation (Ragnarsson et al., 2018). Figure 2 gives a breakdown of the utilization of geothermal energy in Iceland for 2017, both for direct uses and for power generation (Orkustofnun, 2018). The 47.6% share of space heating was by far the greatest geothermal use sector while electricity production accounted for 35.2%.

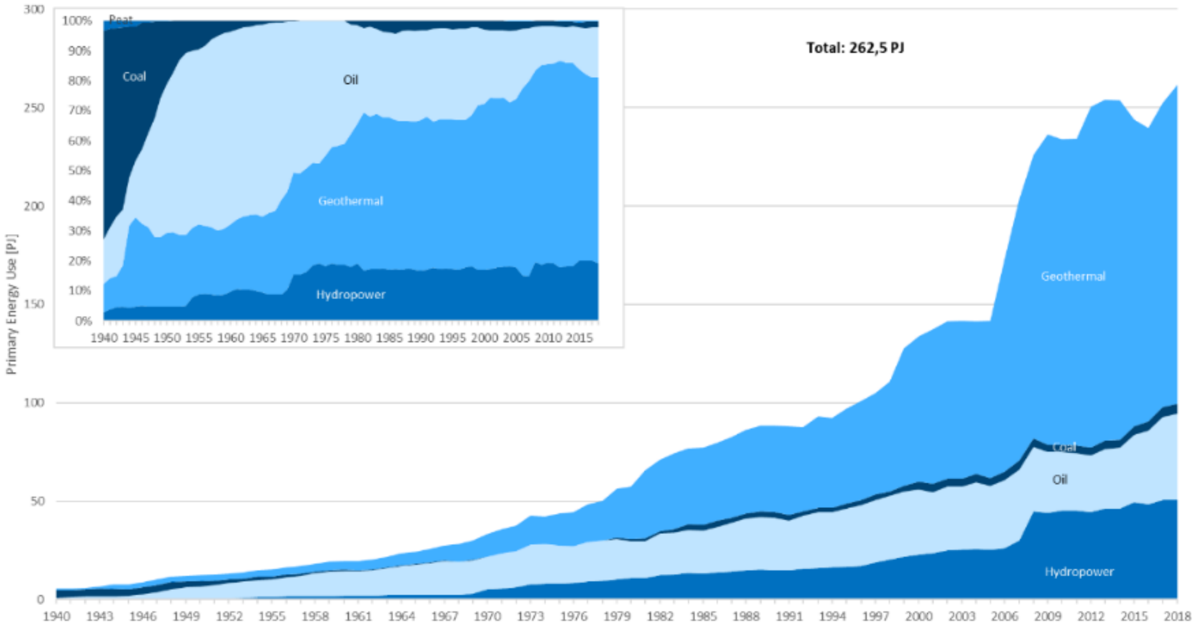
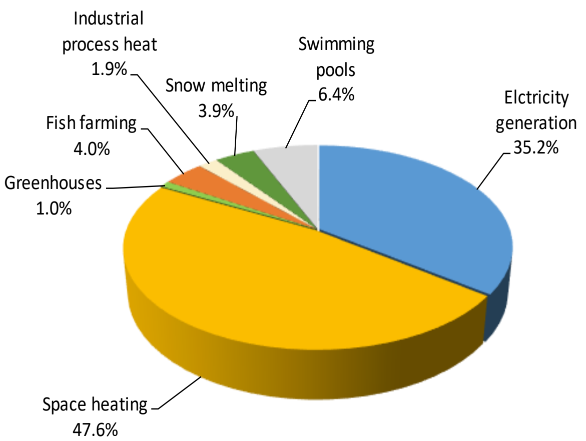


Figure 1: Primary energy use in Iceland in 1940 to 2018 (Orkustofnun, 2019).

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 for the remaining villages and rural areas (Ragnarsson et al., 2018).



	Installed power	Energy consumption	
	MW	TJ/year	GWh/year
Space heating	2,000	25,204	7,001
Greenhouses	37	518	144
Fish farming	85	2,135	593
Industrial process heat	80	1,012	281
Snow melting	218	2,065	574
Swimming pools	194	3,367	935
Direct uses total	2,614	34,300	9,528
Elctricity generation	708	18,611	5,170
Geothermal utilization total	3,322	52,911	14,697

Figure 2: Sectoral share of geothermal utilization in Iceland 2017 (Orkustofnun, 2018).

3. DISTRICT HEATING SERVICES

The low-temperature geothermal systems in Iceland that are utilized for district heating services have been studied extensively during the last half a century or so. First through resource exploration and later reservoir engineering studies, resource assessment and monitoring. Axelsson and Gunnlaugsson (2000) and Axelsson et al. (2005) reviewed the associated research and experience. Axelsson (2008) discusses the factors that control the production capacity of geothermal systems and presents Icelandic as well as worldwide examples. Axelsson et al. (2010a, 2010b) furthermore discuss a method of lumped parameter modelling which has been used successfully to simulate the pressure changes in the Icelandic low-temperature geothermal systems during production.

In Iceland there are 64 major district heating services that utilize over 100 well fields in 33 districts (Figure 3, Table 1). In recent years larger energy companies have been established and they have taken over the operations of many smaller heating services, e.g. Veitur (Reykjavík Energy) operates licensed geothermal heating services in the Reykjavík area as well as several in West and South Iceland. The same has been ongoing for Norðurorka at Akureyri which have overtaken many of smaller district heating services in Eyjafjörður and Northern part of Iceland.

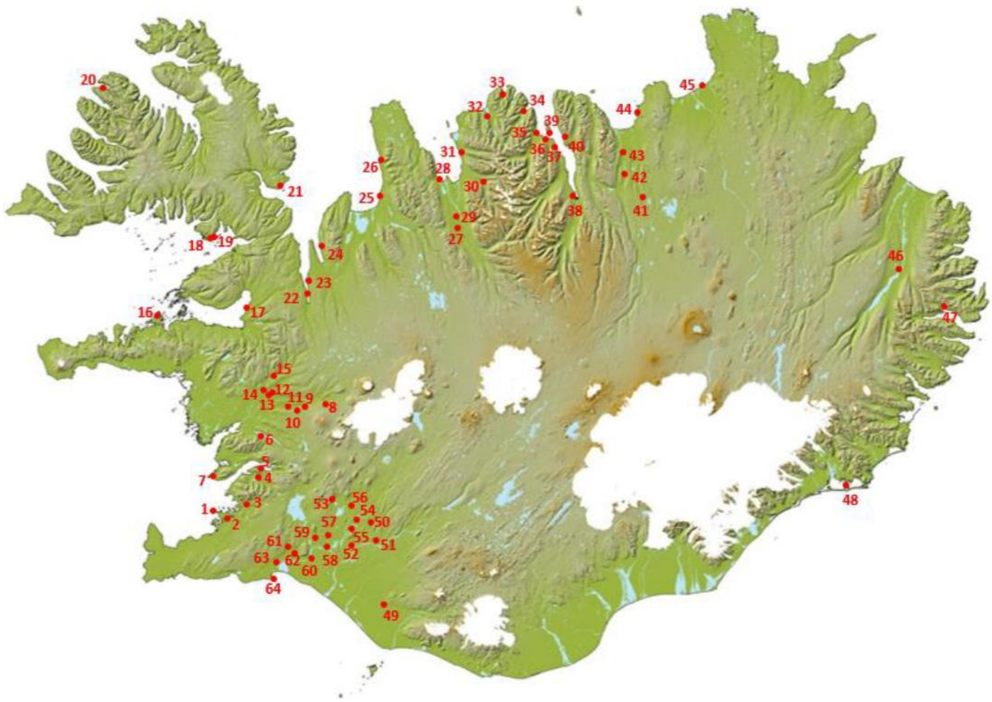


Figure 3. Location of the major district heating services in Iceland. Numbers in red relate to list of names and operator of district heating services listed in Table 1 (Sveinbjörnsson, B.M., 2018).

3.1 Drilling success in geothermal fields utilized by major district heating services in Iceland

The success of the development and operation of the district heating services in Iceland is not only resulting from effective monitoring of the production and framework for license and regulations, but also advances that have been made in both exploration and drilling techniques leading to further successful in drilling. In a recent report on drilling success in geothermal fields utilized by major district heating services in Iceland there are reported the results of 446 production wells drilled in the years of 1928 to 2017 (Sveinbjörnsson, B.M., 2018).

The dataset on which the report is based has been collected from the National Well Registry of boreholes at Orkustofnun and available reports. About 93% of the drilled wells were productive, i.e. encountered feeders that could yield a flow from the well. Of the productive wells 164 were still in use, with an average production capacity of 31.7 l/s at 90.3°C. The main reasons for productive wells not in use are: a) drawdown of reservoir pressure, b) replaced by better wells or c) idle but could produce. About 49% of the main feeders are shallower than 500 m, 76% are shallower than 1,000 m and 95% are shallower than 1,600 m.

About 88% of the 446 drilled production wells fulfilled the minimum criterion set for space heating of a discharge temperature of 60°C and 65% fulfilled the criterion of 80°C discharge temperature. The far largest low enthalpy geothermal field, Reykir in Mosfellsbær, has a present production capacity equivalent to 1.800 l/s of 85.4°C hot water or a thermal power potential of 367 MWth above 35°C. The largest well fields, Æsustaðir and Suður-Reykir, in the Reykir field have a thermal power potential above 35°C of 139.7 and 96.7 MWth respectively. The total thermal power potential of all the geothermal fields exploited by the 64 major district heating services is equivalent to 1,770 MWth above 35°C (Sveinbjörnsson, B.M., 2018).

Table 1: List of the major district heating services and owners/operators in Iceland as presented in Figure 3 (Sveinbjörnsson, B.M., 2018).

Districts	District Heating Services (Owner)	
Seltjarnarnes	1	Seltjarnarnes District Heating
Reykjavík	2	Reykjavík District Heating (Veitur)
Mosfellsbær	3	Mosfellsbær District Heating (Veitur)
Kjósarhreppur	4	Kjós District Heating
-	5	Hvammsvík District Heating (Veitur)
Skorradalshreppur	6	Skorradalur District Heating (Veitur)
Borgarbyggð	7	Akranes/Borgarfjörður District Heating (Veitur)
-	8	Húsafell District Heating
-	9	Reykholt District Heating
-	10	Kleppjárnsreykir District Heating
-	11	Brúarreykir District Heating
-	12	Varmaland District Heating
-	13	Stafholtstungur District Heating
-	14	Munaðarnes District Heating (Veitur)
-	15	Norðurárdalur District Heating (Veitur)
Helgafellssveit	16	Stykkishólmur District Heating (Veitur)
Dalabyggð	17	Dalabyggð District Heating (RARIK)
Reykhólahreppur	18	Reykhólar District Heating (OV)
Reykhólahreppur	19	Thorverk District Heating
Ísafjörður	20	Suðureyri District Heating (OV)
Kaldrananeshreppur	21	Drangsnes District Heating
Húnaþing vestra	22	Borðeyri District Heating (HÚV)
	23	Reykir District Heating (HÚV)
	24	Hvammstangi/Laugarbakki District Heating (HÚV)
Húnavatnshreppur	25	Blönduós District Heating (RARIK)
-	26	Skagaströnd District Heating (RARIK)
Skagafjörður	27	Steinsstaðir District Heating (SKV)
-	28	Sauðárkrókur District Heating (SKV)
-	29	Varmahlíð District Heating (SKV)
-	30	Hólar District Heating (SKV)
-	31	Hofsós District Heating (SKV)
-	32	Sólgarðar/Langhús District Heating (SKV)
Fjallabyggð	33	Siglufjörður District Heating (RARIK)
-	34	Ólafsfjörður District Heating (NO)
Dalvík	35	Dalvík District Heating
-	36	Árskógsströnd District Heating
-	37	Ytrivík District Heating (NO)
Hörgársveit	38	Akureyri District Heating (NO)
Akureyrarkaupstaður	38	Akureyri District Heating (NO)
-	39	Hrísey District Heating (NO)
Eyjafjarðarsveit	38	Akureyri District Heating (NO)
Þingeyjarsveit	40	Reykir District Heating (NO)
-	41	Reykjadalur District Heating
	42	Aðaldalur/Kinn District Heating (OH)
-	43	Hafralækur District Heating (OH)
Norðurþing	44	Húsavík District Heating (OH)
-	45	Öxarfjörður District Heating (OH)
Fljótsdalshérað	46	Egilsstaðir/Fell District Heating
Fjarðabyggð	47	Fjarðabyggð District Heating
Hornafjörður	48	Höfn District Heating (RARIK)
Rangárþing ytra	49	Rangá District Heating (Veitur)
Hrunamannahreppur	50	Flúðir District Heating
Skeiða- og Gnúpverjahreppur	51	Gnúpverjar District Heating
-	52	Brautarholt District Heating
Bláskógabyggð	53	Laugarvatn District Heating
-	54	Reykholt District Heating
-	55	Laugarás District Heating
-	56	Hlíða District Heating (Veitur)
Grímsnes- og Grafningshreppur	57	Grímsnes/Grafningur District Heating
-	58	Vaðnes District Heating
-	59	Grímsnes District Heating (Veitur)
Flóahreppur	60	Selfoss District Heating
Árborg	60	Selfoss District Heating
Hveragerði	61	Hveragerði District Heating (Veitur)
Ölfus	62	Austur District Heating (Veitur)
-	63	Ölfus District Heating (Veitur)
-	64	Þorlákshöfn District Heating (Veitur)

4. RESOURCE MONITORING OF DISTRICT HEATING SERVICES

The main purposes of applying an effective resource monitoring program for district heating systems involves:

- Sustainable utilization of a geothermal fields
- Secure the operational basis of district heating services
- Secure the access of the public to hot water
- Strengthen the knowledge of the type and characteristics of the geothermal systems
- Source of data and information to make resource assessments and predictions of utilization

The requirements of a monitoring program for the district heating services originate both from regulatory bodies (legal) and developers through geoscientific/resource engineering consultants. Where these requirements are defined and applied to support each other as well as being well managed, the operations of the district heating services are more likely to be successful.

4.1 Regulatory Framework - Submission of Data

The utilization of geothermal resources in Iceland is according to law subject to a license from Orkustofnun (National Energy Authority) (The Act on Survey and Utilization of Ground Resources, No. 57/1998). Orkustofnun is required to have available at any time an overview of the potential geothermal energy resources in Iceland as well as the utilization. A part of the terms of an issued geothermal utilization license are requirements that the developer needs to meet, involve the submission of data to the regulator (Ketilsson, J. and Oddsdóttir, A.L., 2012). Every district heating service that is producing and selling hot water is instructed to submit these data on a yearly basis or otherwise be subject to the license being revoked. The following list shows the requirements as described in the utilization permit issued, and all developers of geothermal fields, including district heating services, need to fulfill:

- Amount of water sold, in value and amount of energy.
- Monthly amount of hot water produced from the resource (kg) as well as annually.
- Monthly amount of hot water produced from each well at the geothermal field (kg).
- Monthly amount of fluid that is reinjected into the resource (kg) as well as annually.
- Monthly mean temperature of water being reinjected into the resource (°C),
- Monthly reading of water level in all wells within the geothermal field and are available (m).
- Measurements of pressure or drawdown in the geothermal resource (Mpa/bar).
- Enthalpy measurements from all wells within the geothermal field and subsequent information to support (kJ/kg).
- Primary geothermal energy from the geothermal resource (PJ/a).
- Primary geothermal energy from the geothermal resource where the energy of reinjected fluid is subtracted (PJ/a).
- Temperature and pressure well logging results.
- Chemical analysis of geothermal fluid from wells.
- Chemical analysis of groundwater in vicinity to reinjection wells.
- Results of lumped and numerical modelling
- Results of measurements made in the effort of monitoring the geothermal resource.
- Information on drilling.
- Results on geological settings of the geothermal resource acquired with drilling

The data collected by Orkustofnun is used for monitoring purposes at the institute as well making subsets of the data available to the public. This involves a web portal (www.map.is/os) and a OS Well registry where the geothermal wells repository is accessible with information on e.g. well location, purpose of drilling and available drilling reports.

On-line data submission platform is being developed at Orkustofnun and guidelines and standards of submitted data aim to fulfill obligations for international commitments, such as IEA and Eurostat. These are described in further detail in an EraNet report where producers of geothermal energy are defined as Principal activity producer, Main activity producer and Auto producer.

4.2 Problems and solutions in operation

For the last decades the operations of district heating services have faced some problems mostly at the start of their operations and generally these problems have been solved. Today it can be stated that most of the bigger district heating services throughout the country have not been subject to serious problems that have impacted the service of hot water to the district. This good record is the result of sensible planning, starting with smaller systems and expanding according to experience and coherent exploration of further production areas, as well as the chemical composition of geothermal water in Iceland is favorable for direct utilization.

Monitoring plans of the district heating services were developed 1985-1990 but have since adjusted to changes in the needs and requirements from both the developers and the resource itself as well as the regulatory body, Orkustofnun. The aim of monitoring plans is sustainable utilization of the geothermal resource which is also the economical and has the least environmental and social risks involved.
The most common problems involving geothermal utilization of district heating services are (Axelsson, et al., 2010b):

- Overexploitation resulting in excessive pressure draw-down.
- Inflow of colder water resulting in temperature decrease and/or changes in chemical composition.
- Inflow and mixing of sea water resulting in temperature decrease and changes in chemical composition.
- Changes in reservoir conditions due to earthquake activity .
- Corrosion and scaling.
- Technical problems associated with wells (casings), pumps, etc.

Some district heating services have not encountered any of these problems and some many but solutions have been found mitigate and solve these problems, and no service has ceased operation as yet.
The solutions include:

- Improving the energy efficiency of the associated heating systems.
- Deeper and more focused drilling (e.g., directional drilling).
- Improved exploration techniques to develop new drilling targets or new drilling areas.
- Injection of return water from the district heating.
- Use of scaling and corrosion inhibitors.
- Technical solutions to surface hardware problems.

It has been with these problems and solutions in mind that a successful resource management programs have been developed for individual district heating services in Iceland.

4.3 Monitoring plans for district heating services

Any resource monitoring plan that is developed for district heating service needs to take into account the above mentioned requirements as well as the general purpose and conditions involved from the developer and often the public. Through the long history of such monitoring for different district heating services there are many lessons learned and various versions of generic plans made. The basis for any district heating service that are at the beginning of operations, the following items are listed as the main types of data to be collected:

- Amount of water produced, pumped or artesian flow, from each production well.
- Amount of water reinjected into each reinjection well.
- Water temperature, preferably on-line continuous monitoring at well head of each production well.
- Amount of energy produced from geothermal field.
- Pressure, water level or well head pressure, preferably on-line continuous monitoring at well head of each production well.
- Chemical composition of water from each production well.

In addition there are data that aim to strengthen modelling and assessments of the geothermal resource as well as supporting the geoscientific consultation for future utilization. Lumped parameter models are updated intermittently (every 3-5 years) which has proven to be a very effective resource management tool. The datasets include:

- Temperature logs from wells.
- Scaling and corrosion monitoring in pipes and wells.
- Inspection of well casings.
- Previous resource assessments and predictions
- Seismic monitoring, before and during drilling as well as monitoring production
- Tracer testing and recovery calculations

A list of the minimum types of measurements made for each well, production or reinjection, and suggested frequency to secure that the data will give sufficient information on short and long term changes in geothermal systems is presented in Table 2.

Table 2: Suggested types and frequency of basic measurements for resource management for district heating services in Iceland (Hauksdóttir, S. and Axelsson, G., 2018).

Parameter	Frequency for monitoring annual changes	Frequency for long term changes
Water production	Weekly/Monthly	1-2 x Year with continuous production
Reinjection	Monthly	1-2 x Year with continuous production
Water temperature	Monthly	1-2 x Year with continuous production
Pressure	Monthly	1-4 x Year with continuous production
Chemical content	Yearly/ 6 Months	1-2 x Year with continuous production

The type and frequency should in each case be adjusted according to the production history for each geothermal field but this list represents what is considered a minimum according to the decades of experience in resource monitoring in Iceland. Subsequently if data is intended to determine the connection between reinjection and seismic activity, the frequency of measurements for monitoring the reinjection wells needs to be substantially higher than listed in Table 2.

4.4 Successful resource monitoring – Case study Norðurorka District Heating of Akureyri

Akureyri is a town of about 19,000 inhabitants located in the north of Iceland. It has been heated by geothermal energy since the end of the 1970's. Hot water is pumped to Akureyri from six different geothermal fields. In addition to this, two 1.9 MWth heat pumps supplied a small part of the annual energy production after their installation in 1984, but their contribution has been insignificant for the last decade or so. During the last few years, several small geothermal district heating systems in neighboring communities have merged with Norðurorka. Thus, the total number of people served is now about 24,000. The total installed capacity is 103 MWth and the annual hot water consumption about 9 million m3 (Ragnarsson, Á. et al., 2018).

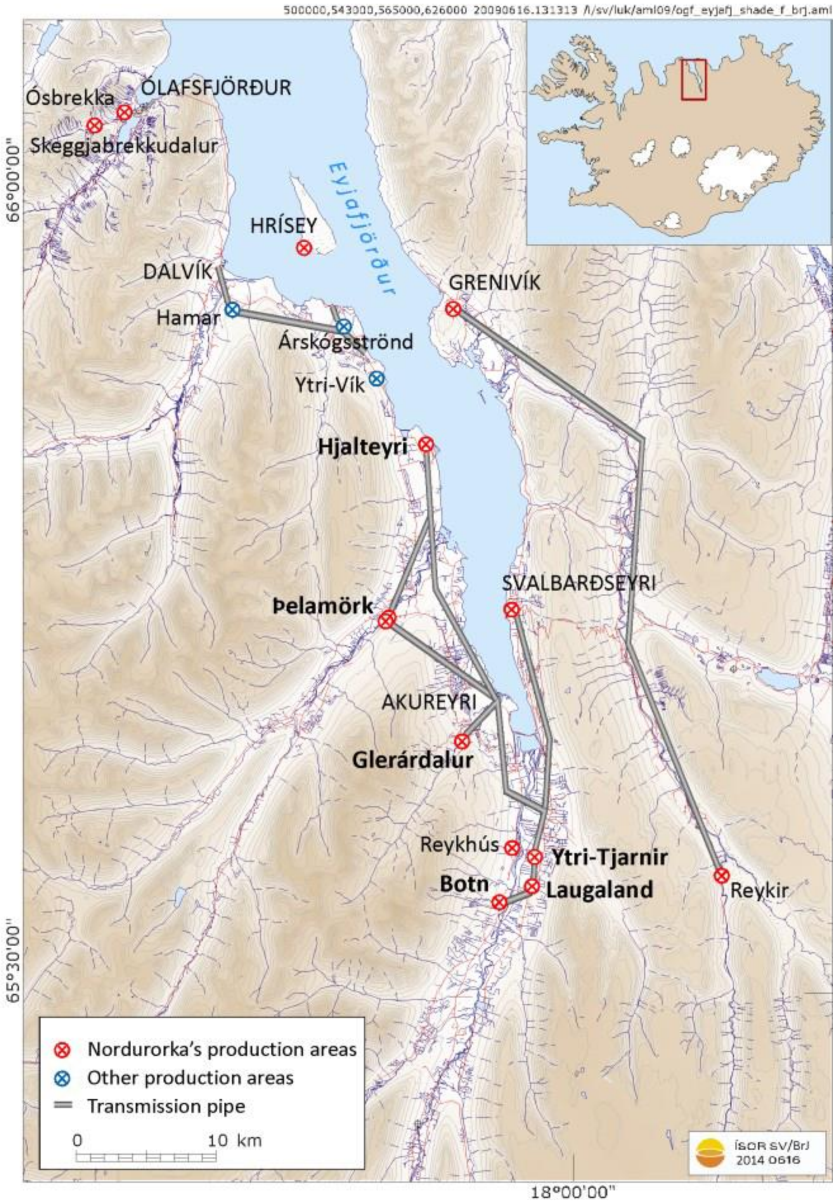


Figure 4: A map of the Eyjafjördur region showing the geothermal production areas of Norðurorka and the main hot water transmission pipes (Gautason, B. et al., 2019)

Five of the six systems (Botn, Laugaland, Ytri-Tjarnir, Glerárdalur and Thelamörk) are of low productivity because of their size and geological setting while the sixth system, Hjalteyri, is much more productive (Figure 4). This blend of several systems of different capacity, along with the fact that production from many of the systems was often uncomfortably close to their capacity before Hjalteyri came on line, has required intricate resource management to be practiced. It has mainly included maintaining reservoir pressure above a certain level in each system and at the same time meeting the demand of the district heating system. The lumped parameter models have been updated intermittently since they were first set up in 1988 (Axelsson, et al., 2015). The repeated modelling has proven to be a very effective resource management tool. Firstly by indicating how to limit production from the less productive systems and secondly by suggesting how much the other systems can additionally contribute. During the history of repeated modelling the capacity estimates for the different systems have either remained relatively unchanged or they have declined somewhat with time. In the case of Hjalteyri, however, the first model revision resulted in a capacity estimate that is 25% higher than the earlier one (Axelsson, G. et al., 2015).

Table 3 provides basic information on all the low-temperature geothermal systems utilized by Norðurorka, including their estimated capacity. The blend of several systems of different capacity, along with the fact that production from many of the systems was often uncomfortably close to their capacity before Hjalteyri came on line, has required intricate resource management to be practiced. It has mainly included maintaining reservoir pressure above a certain level in each system and at the same time meeting the demand of the district heating system. Lumped parameter modelling of the pressure changes in all the geothermal systems, with associated future reservoir pressure predictions, has played a key role in this management.

Table 3: Information on geothermal fields utilized by Norðurorka (Axelsson, G. et al., 2015).

System	Initial whp[1] (bar)	Max. pump depth (m)	Temperature (°C)	Production capacity[5] (l/s)	Thermal power capacity[7] (MW_{th})
Botn	17.0	250	85	31	6.9
Laugaland	20.5	250	95	39[6]	10[6]
Ytri-Tjarnir	5.7	400[3]	80	27	5.5
Glerárdalur	5.8	250	60	15	1.9
Thelamörk	1.9	250	100	17	5.8
Hjalteyri	0.8	250	90	250	61
Hrísey	–[2]	ff[4]	80	(15)	(3.1)
Ósbrekka	5.8	100	70	30	4.9
Skeggjabrekkudalur	–	ff	55	28	2.9
Reykir	~0	100	90	50	12

1) Estimated well-head pressure, usually not measured directly.
2) Unknown.
3) A submergible down-hole motor pump.
4) Artesian flow / free flow.
5) Mainly based on the results of lumped parameter modelling (see later).
6) With 10 L/s average reinjection.
7) Based on a 30°C reference temperature.

5. NEW CHALLENGES FOR MANY DISTRICT HEATING SERVICES IN ICELAND AND PROSPECTS FOR THE FUTURE

The emphasis on production monitoring has been increasing through the decades of utilization of district heating services as it has proven to be a key factor in a successful sustainable geothermal utilization. During this time different issues regarding the operations of the district heating systems have influenced the development of monitoring plans for the individual district heating services, e.g.:

- Larger energy companies have taken over smaller companies.
- Long history of resource management during decades of production.
- Problems of scaling or corrosion have encountered and solutions applied.
- Are wells being pumped or is there artesian flow from wells.
- Mixing of water from two or more geothermal fields.
- Increased demand due to population growth or number of tourists.
- Increased demands of geothermal water for innovative utilization.

5.1 Impact of increasing population - Case study of Selfossveitur, S-Iceland

In the last 20 years the population of the town Árborg (previously Selfoss) has doubled, from about 4000 to 8000 inhabitants (Figure 5). This has resulted in the need for expansion of the district heating system, operated by Selfossveitur, which has been answered with efforts for further exploration. The geothermal fields that have sustained the area for hot water, Þorleifskot/Laugardælir, have been utilized since 1948, could not support this expansion and in the year 2000 the first well was drilled in a new production field, Ósabotnar located north of Árborg (Figure 6). The resource monitoring data has been collected from the start of production from well ÓS-1 as well as for the following wells drilled, ÓS-2 in 2010 and ÓS-3 in 2016 (Tulinius, H. et al., 2016).

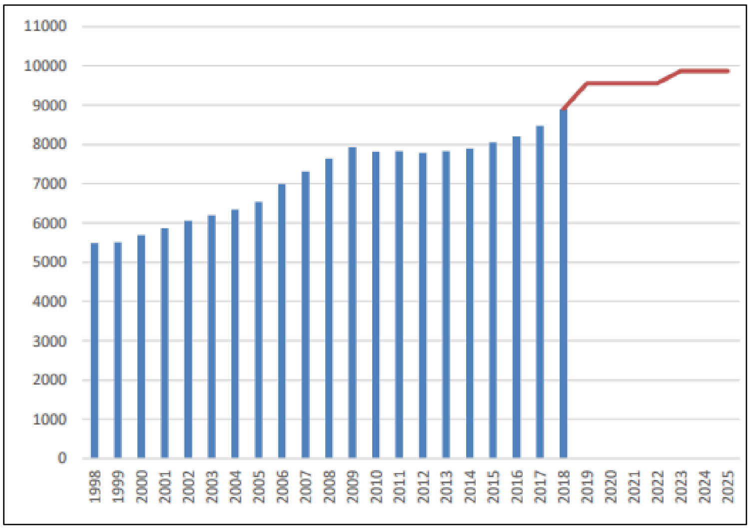


Figure 5: Population of urban nuclei Selfoss/Árborg (Statistics Iceland, 2019/Árborg urban development, 2018).

The resource estimate for the Ósabotnar geothermal field was updated 2016 based on the production history, data on production/yield, pressure and temperature from the production wells and nearby monitoring well (HT-24). The results based on relatively high permeability (40-46 mDarcy) gave positive results on increasing the production from the field from 45 L/s to 80 L/s (Tulinius et al., 2016). In 2018 an additional production well (ÓS-4) was drilled in the area and recently further exploration efforts are taking place in areas around Árborg (Ingimarsson H., et al., 2018b). These include the areas west of the river Ölfusá, Árbær field, and Hrefnutangi, Oddgeirshólar to the east of Árborg as well as continuous exploration at Ósabotnar and Stóra-Ármót to the north (Ingimarsson, H. et al., 2018a; Ingimarsson, H. and Hafstað, Th.H., 2018c). In addition a new well was drilled in Thorleifskot for maintaining the production from the field (Hafstað, Th.H. et al., 2018).

Selfossveitur have taken on the demanding task of increasing the production capacity for the district heating service rapidly and maintaining a sustainable utilization. This requires the operator to have available production data for processing from fields being utilized while also applying cutting edge exploration techniques for finding new resources. Recent study of televiewer logging from wells in Hrefnutangi of Árborg, west of Ölfusá, show interesting results where changes of the dominated direction of fractures with depth, will be a valuable information in future plans and siting for successful production drilling (Erlendsson, Ö., 2018).

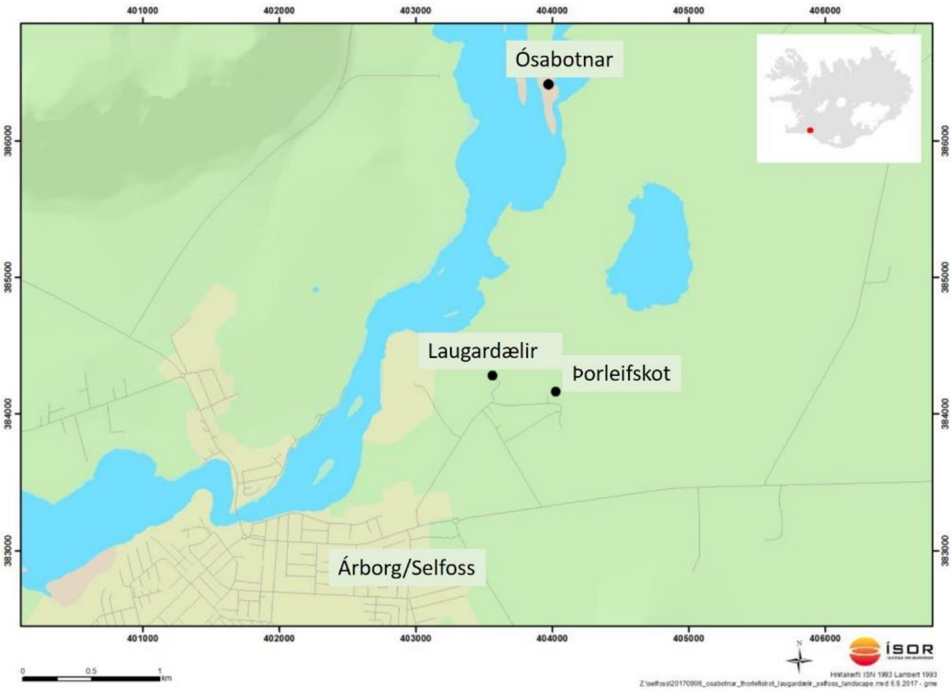


Figure 6: Overview of the current production fields of Selfossveitur, district heating service of Árborg and vicinity (modified from Tulinius, H. et al., 2016).

5.2 Impact of increasing number of tourists - Case study of Hitaveita Egilsstaða and Fella, E-Iceland

In recent years the number of tourists visiting Iceland, with population of 350,000 inhabitants, have increased dramatically. In the year of 1998 Iceland received about 230,000 visitors arriving with airlines or commercial cruiser ships (Iceland Tourist Board, 2019). Twenty years later, in 2018, there were 10 times more tourists visiting or 2,300,000 (Figure 7). This new reality has added to the demanding task of district heating services all across Iceland to provide hot water services, as some of the most popular tourist attractions include balneology, swimming and many other forms requiring increase of geothermal hot water production.

	2011	2012	2013	2014	2015	2016	2017	2018
Keflavík Airport	540.824	646.921	781.016	969.181	1.261.938	1.767.726	2.195.271	2.315.925
Other airports	12.282	13.072	9.696	10.048	8.661	4.539	6.979	7.158
Seydisfjörður Seaport	12.505	12.780	16.637	18.115	18.540	19.795	22.353	20.690
Total	**565.611**	**672.773**	**807.349**	**997.344**	**1.289.139**	**1.792.060**	**2.224.603**	**2.343.773**

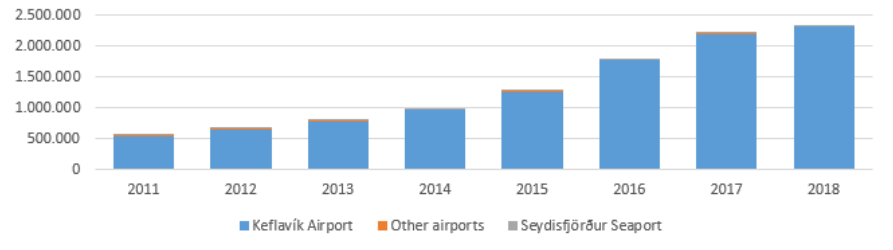


Figure 7. International visitors by the point of entry into Iceland in 2011 to 2018 (Icelandic Tourist Board, 2019).

The district heating service of Egilsstaðir and Fell has been in service since 1980 utilizing the geothermal area at Urriðavatn, East Iceland. This is a fracture controlled geothermal field in tertiary basaltic bedrock, outside the neovolcanic zone. Production started from only one well being in operation, well UV-4, which produced 12 L/s of 64°C water, mainly from a shallow aquifer. In 1982 three wells were in operation and six wells had been drilled in the area. Raping development during the first two years of production resulted in severe cooling of the water as the water temperature decreased to about 55°C (Haddadin G., 1995). Following this four wells have been drilled where UV-8 and UV-10b are currently the production wells for the district heating service, producing about 55 L/s from both wells. In the most recent report on the resource monitoring for the Urriðavatn geothermal field the average temperature measurements show some indications of cooling as the production has increased (Figure 8) (Tryggvason and Harðardóttir, 2017).

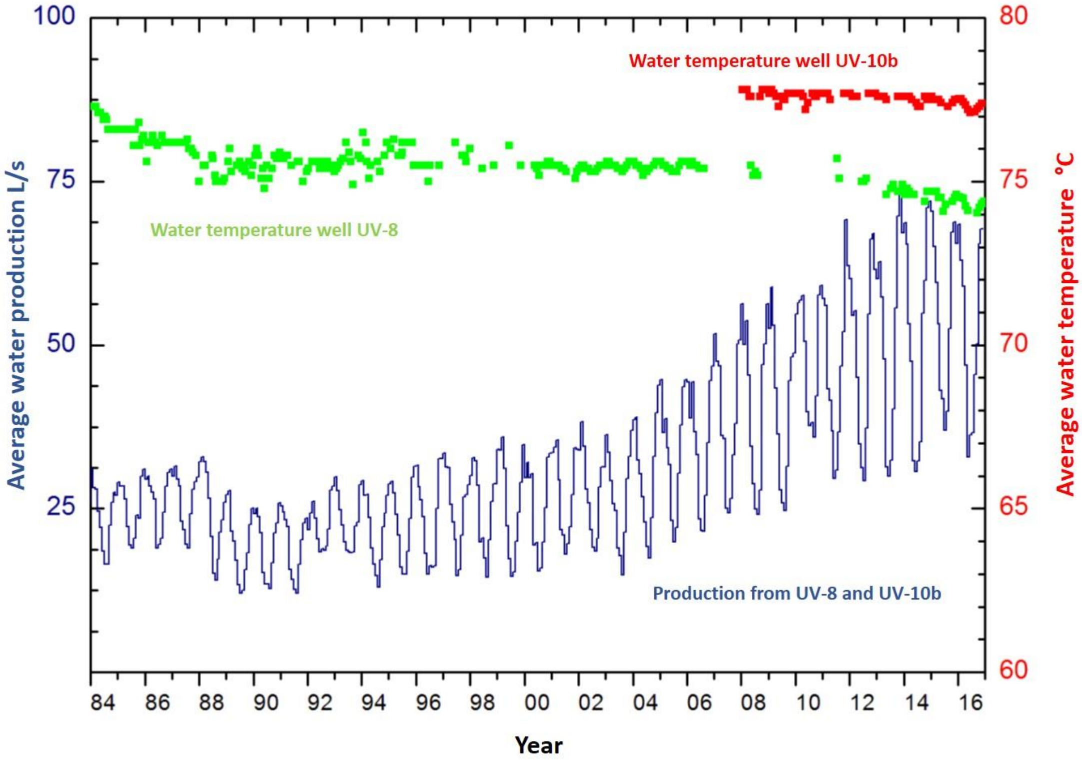


Figure 8. Average water temperature and well production measurements from the geothermal field at Urriðavatn (modified from Tryggvason H. and Harðardóttir, V., 2017).

The operation of the district heating service has mainly involved production of hot water for house heating in Egilsstaðir and Fellahreppur but has also supplied a few local businesses hot water for e.g. fish drying. New challenges are facing the district heating service as Vök Baths, a geothermal pool and spa, will be opening at Urriðavatn in summer 2019. This facility is located at Urriðavatn and will use hot water from the production wells that are located at the lake, increasing the demand substantially. An updated resource assessment is currently in preparation in order to estimate the need for additional hot water and with the history of the production from Urriðavatn geothermal field in mind this will probably call for further geothermal exploration and siting of new production wells.

6. CONCLUSONS

The long-term reservoir monitoring programs and sustainable use of low temperature geothermal systems, is one of the main reasons for the success of the operation of these valuable resources. An ongoing „Second phase“ for many district heating services in Iceland and prospects for the future and district heating services are facing new challenges. These challenges are mostly due to increased demand for hot water, as a result of increased population in some urban areas, a huge increase in number of tourists in Iceland as well as increased demands in using geothermal water from low temperature resources for innovative utilization methods.

The requirements of a monitoring program for the district heating services originate both from regulatory bodies (legal) and developers through geoscientific/resource engineering consultants. Where these requirements are defined and applied to support each other as well as being well managed, the operations of the district heating services are more likely to be successful. Any resource monitoring plan that is developed for district heating service needs to take into account the requirements as well as the general purpose and conditions involved from the developer and often the public. Through the long history of such monitoring for different district heating services there are many lessons learned and various versions of generic plans made. This requires the operator to collect and have available production data for geoscientific processing from geothermal fields being utilized while also applying cutting edge exploration techniques for finding new resources.

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