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A New Countrywide Geothermal Resource Assessment for Iceland

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ABSTRACT

In 1985 a countrywide assessment of the geothermal resources of Iceland was published by the National Energy Authority. It emphasized estimating the thermal energy content (stored heat) of the island's crust. Consequently, the technically harnessable geothermal energy was estimated based on the expectation that hot dry rock technology would soon become feasible. In addition, the heat flow through the crust was estimated (heat conduction and hot springs), reflecting the double nature of geothermal. The proportion of geothermal in the primary energy mix of Iceland is now about 2/3 and it is envisioned that it will continue to increase. The 1985 assessment has therefore been updated based on a vast and comprehensive database compiled during the last 40 years, including exploration data, information on nearly 3000 exploration and production wells as well as monitoring and evaluation data for numerous geothermal systems utilized. The present assessment emphasizes the heat flow aspect even though the stored crustal energy is also estimated. The energy flow is assessed for four energy streams: 1) Crustal heat conduction, 2) natural state flow through hot springs and geysers, 3) estimated capacity of drilled wells and 4) present geothermal energy production. The results confirm a vast resource indicating that geothermal use in Iceland can continue to grow in the future, partly through utilization of unconventional resources (deep drilling, EGS development and ocean floor utilization) but also through more efficient utilization of conventional hydrothermal resources. The present assessment will serve as basis and motivation for public policy, innovation and technological advances needed for future development.

1 INTRODUCTION

Harnessable geothermal resources are widespread and accessible in Iceland due to a unique geological setting, both in terms of volcanism and divergent tectonics (Arnórsson et al., 2008). Geothermal energy is extremely important for Iceland as a nation as it provides about 2/3 of the primary energy utilized on the island (Ragnarsson et al., 2025). Geothermal electricity provides a large part of the country's baseload and direct utilization is varied, providing more than 90% of the energy used for space heating as well as playing a key role in food production, in industry and for tourism. Without geothermal the economic situation and living standards in the country would be completely different.

In contrast to other renewable energy resources geothermal resources are of a double nature, consisting of both heat flow (both heat conduction and fluid flow or convection) and vast stored energy. In addition, geothermal resources consist of the general heat flow through the Earth's crust and the vast thermal energy stored within the Earth, on one hand, and hydrothermal systems where geothermal energy involves fluid-based heat transfer and storage, on the other hand (Axelsson, 2024). The latter are sometime referred to as "conventional geothermal systems", existing where sufficient crustal permeability and heat coexist. The above categorization should be viewed as an important basis for the work presented here.

In 1985 a comprehensive assessment of Iceland's geothermal resources was published (Pálmason et al., 1985), the first of its kind. The emphasis was on estimating the stored heat in the crust down to 3 and 10 km depth, respectively, for six separate regions and the volcanic zone, using the principles of volumetric assessment. The technically harnessable geothermal energy was consequently estimated for the same regions. The results simply indicated enormous potential, given that technology for extracting energy from hot, mostly dry, rock would soon become available (later EGS technology). In 1985 the total heat flow through Iceland's crust was also estimated as well as heat flow through hot springs and fumaroles. It should be mentioned that three years prior to this Bödvarsson (1982) completed a comprehensive study of all aspects of the heat flow through Iceland.

During the 40 years since the assessment above was completed, knowledge on geothermal conditions in the Icelandic crust has increased dramatically. This is mainly because of data collected through numerous boreholes drilled, both for exploration and for utilization. Knowledge has also increased through geoscientific studies and monitoring of the response of geothermal systems to utilization has helped to significantly increase understanding of their nature. Therefore, it was decided to update the 1985 assessment on basis of the new information. An updated assessment will support governmental plans to rely on sustainable geothermal energy utilization to meet rapidly increasing energy demand in Iceland, both for electricity and heat. Iceland is also a suitable case study due to its variable geothermal resources, comprehensive data compilations and small size.

Countrywide assessments based on volumetric estimates of stored heat, comparable to the 1985 one for Iceland, were conducted for a few regions and countries in the late 1970's and in the 1980's (Stefánsson, 2005), e.g. for the USA, Japan, Mexico and Tuscany (Italy). Since then, very few such regional assessments have been completed. A noteworthy exception is the USGS assessment from 2008, which concluded that up to 500,000 MW_e could possibly be generated in the USA, assuming EGS utilization (USGS, 2008).

The current countrywide assessment of the geothermal resources of Iceland follows the general approach of the 1985 assessment, by estimating both heat flow and stored heat. It is, however, based on a much larger and comprehensive database, consisting of data collected and compiled during the last 40 years, including geological, chemical and geophysical exploration data, information on nearly 3000 exploration and production wells, including numerous temperature gradient wells, as well as monitoring and evaluation data for numerous geothermal systems utilized. The present assessment emphasizes the heat flow aspect with the flow assessed for four energy streams: 1) Crustal heat conduction, 2) natural state flow through hot springs and geysers, 3) estimated short-term capacity of drilled wells and 4) present geothermal energy production. The first two streams involve heat flow under natural conditions, undisturbed by utilization, while the latter two are manmade (or forced). It should be noted that even though available data is much more detailed and comprehensive than 40 years ago, there are still major gaps in the knowledge, especially within the volcanic zones of Iceland and in sparsely populated parts of the country where exploration has been minimal.

Following this introduction our paper presents the methodology applied in the current assessment, as well as describing the main datasets. Then the paper presents the results for different aspects of the assessment as well as summarizing its principal results. The paper is concluded by a brief discussion of the future of geothermal development in Iceland, in view of the assessment results. It should be kept in mind that the present brief paper can only give a glimpse into the methodology, data and results. More details can be found in Axelsson et al. (2025).

The ultimate result of the current assessment does not consist of a single absolute number but of updated numerical results for the different aspects/streams listed above, for different parts of the country. The final result also supports a future vision for Iceland, in which geothermal energy will play an increasingly important role, including on new fronts, as it is clear that the updated geothermal assessment indicates a much larger resource than is reflected in today's utilization. To set the stage it should be noted that geothermal systems in Iceland are fundamentally classified into low-temperature systems (reservoir temperature < 150°C), found outside the island's volcanic zone and mainly utilized as sources of direct heat, and high-temperature systems (reservoir temperature > 200°C), associated with volcanic centers and mostly used for electricity generation (Steingrímsson et al., 2022). Finally, it should be mentioned that the current assessment is based on a reference temperature of 5°C, the average ambient temperature in Iceland. Thus, the numerical results are independent of the mode of utilization, reflecting total energy.

2 APPROACH AND DATA

The following inventory outlines the approach and data types, on which the current assessment is based, for both the energy streams assessed and the crustal energy storage. More details and the main results are, consequently, presented in next chapter:

A. **Energy currents / Heat flow**:
   1) This is firstly based on mapping, including the estimation of flow rate and temperature, of natural hot springs throughout Iceland. This is based on an original compilation from 1985 (Pálmason et al., 1985) and a new update of the corresponding database (Torfason, 2024). This data is used to estimate the thermal power at individual locations, sum it for the regions/zones of the assessment (see below) and the country as a whole. In many cases, the flow has stopped due to pressure decline by geothermal utilization (through boreholes). Therefore, the method provides an estimate of the natural thermal power at each location before utilization began. This energy stream involves

heat advection or convection. Yet, the available information is mostly limited to low-temperature areas, mostly without boiling. The current assessment also estimates the heat flow through high-temperature areas, where direct measurements are limited, as was done in 1985 (subsection 3.3).

2) In addition to this, the heat conduction through the crust of the country as a whole is estimated based on the latest temperature gradient map of the country (subsections 3.1 and 3.2 below) and general knowledge on the temperature state of the crust in the areas where there are gaps in the temperature gradient map. Together, energy streams 1) + 2) give the heat flow through the crust of Iceland in its natural state, before large-scale geothermal exploitation began.
3) Another component of the heat flow, or energy current, consists of the combined power of the country's geothermal wells. This is not constant heat flow, except in part. Rather, it is an estimate of what the respective wells would produce if they were all running simultaneously at full capacity, which can then be summed up for given regions, and the country as a whole. This current is, therefore, different from items 1) and 2) but includes important information about the country's geothermal resources. The relevant information is based on a compilation of data and reports from the National Energy Authority and ÍSOR on the power of wells (Sveinbjörnsson, 2016 & 2018). Information on the capacity of wells in high-temperature areas is mostly missing from this database, as is the case for item 1) as well. It should also be pointed out that the cumulative capacity of wells is much greater than the natural power of hot springs. The capacity is estimated from short well test data, which in most cases is greater than the sustainable production capacity of individual areas.
4) The fourth energy current evaluated is based on yearly production data from geothermal areas in the country, compiled by the Environment and Energy Agency of Iceland (previously by the National Energy Authority/Orkustofnun). The relevant numbers are available for all public geothermal district heating services, high-temperature areas utilized for electricity and heat generation, as well as a number of private geothermal suppliers. This data is slightly incomplete, because of data lacking from some small producers, but these are mostly small. The latest available numbers are for 2023. The data is compiled as water volume and total thermal energy produced annually, relative to a reference temperature of 15°C. In the current assessment the data is converted into average power, or annual average heat flow, based on 5°C reference temperature. In this regard, it is appropriate to refer the reader to an assessment on the status of geothermal heating services in Iceland published by ÍSOR (Iceland GeoSurvey) (Hauksdóttir et al., 2023).
5) The final energy stream examined in the current assessment involves an estimate of the cumulative production capacity of most known high-temperature areas within the volcanic zone of the country. It is estimated according to the methodology of Ketilsson et al. (2009) but updated on basis of new information, where available (subsection 3.3 below).

B. **Stored heat**:

1) First, the energy content down to a certain depth is estimated based on rock temperature and relevant rock properties. The temperature is estimated based on the estimated temperature gradient, see item A. 2) above. The high-temperature areas are considered separately. The stored energy is estimated down to 5 km depth and 10 km depth, respectively. Based on available technology and corresponding economics, 5 km is approximately the practical maximum drilling depth today. It can be assumed, however, that this limit will increase in the coming decades.
2) In the 1985 geothermal assessment, emphasis was placed on estimating how much of the above-mentioned stored energy could be extracted to the surface, by unconventional means, and utilized. Since the technology for this is still in its early stages of development, the same emphasis has not been placed on this in the current assessment, but the order of magnitude involved estimated instead, assuming utilization through e.g. EGS technology.

In the current assessment Iceland is divided into 14 parts or regions, based on geological and geothermal conditions, as shown in Figure 1. The focus of the assessment was, hence, to estimate either the sum or average of a given parameter (see listing above) for each region, the primary outcome of the assessment (see below), as well as relevant statistics. Iceland is 103,000 km^2 in size and the regions vary in size, ranging from 930 to 17,800 km^2. For comparison, the 1985 assessment was based on a division into 7 parts, reflecting the much more limited data available at the time. Table A.1 in the appendix to this paper summarizes the relevant statistics of each region, i.e. area, number of hot springs and wells, as well as the number of district heating systems.

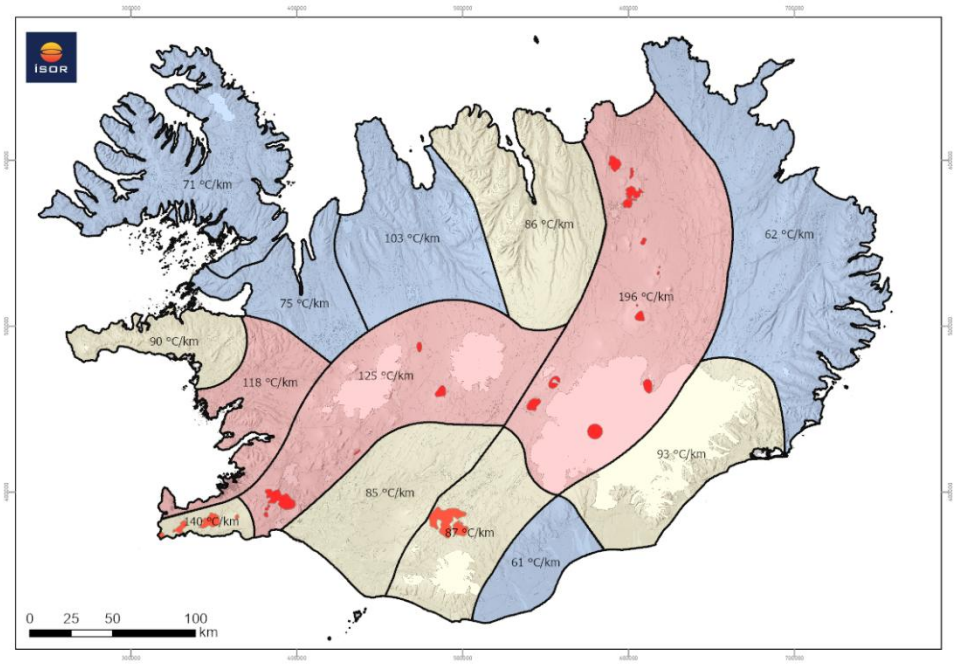


Figure 1. The division of Iceland into regions on which the current assessment is based. Also shown are all known high-temperature areas (in red, see subsection 3.3) as well as weighted average geothermal gradient for the 14 regions.

3 RESULTS FOR ENERGY STREAMS AND STORAGE

This chapter summarizes part of the main results of the 2025 countrywide geothermal assessment for Iceland. Table 1 below and tables A.2 and A.3 in the paper's appendix provide some details, while Table 2 in chapter 4 provides a basic overview. It should be kept in mind, however, that the comprehensive and intricate results can't be done full justice in a short paper like this. For that the full report must be studied (Axelsson et al., 2025).

3.1 Updated Temperature Gradient Map

Logging the temperature of the underground through boreholes of varying depth is one of the tools used to study the Earth's thermal conditions and in geothermal exploration. This has also been the case in Iceland and temperature gradient surveying has played a key role, both for regional studies and local geothermal exploration. The first full-scale temperature gradient map of the country was published in association with the 1985 assessment (Pálmason et al., 1985). Since then, the map has been updated regularly, with the updates by Flóvenz and Saemundsson (1993) and Hopper et al. (2014) most noteworthy. The most recent update was associated with the current assessment, see also Einarsson et al. (2025).

The current map is presented in Figure 2, with details of its development found in either Axelsson et al. (2025) or Einarsson et al. (2025). The great variability in the gradient is noteworthy, i.e. the great contrast between the volcanic zones and SW-Iceland, on one hand, and NW-Iceland and the easternmost part of the island, on the other. This reflects completely different tectonic conditions and volcanic activity.

This temperature gradient data was, consequently, used to estimate average temperature gradient values for the different regions, both simple arithmetic means and averages weighted by area of influence of each value. The data is so unevenly distributed that neither of the averages suffices to determine the average temperature gradient for all the regions. Therefore, the crustal temperature model of Pálmason et al. (1985) was used as further aid in the process. The final results, i.e. the average temperature gradient used for the fourteen regions of Iceland in the 2025 geothermal assessment, is presented in Table A.2 in the Appendix, along with two averages and the gradient used in 1985. The gradient values used now are in general comparable to those used in 1985, except for the volcanic zones. In 1985 it was assumed that the high permeability of the volcanic zones caused great downflow of cold groundwater, suppressing the temperature gradient. The authors of this paper believe that this is just the case locally and only down to a limited depth. Therefore, the general temperature gradient of the volcanic zones is now assumed to be primarily controlled by the volcanic conditions there.

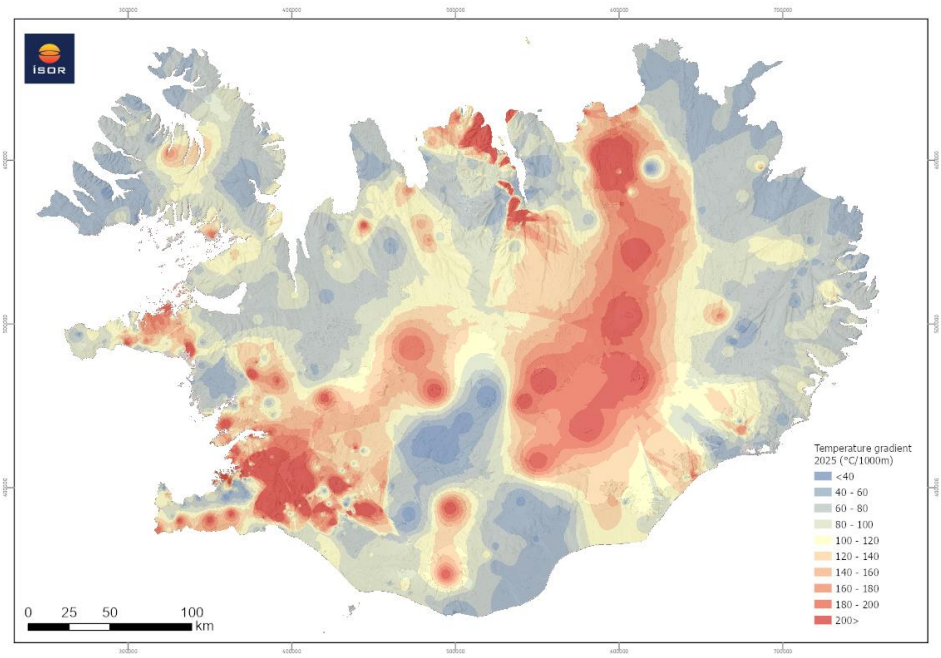


Figure 2. Temperature gradient map of Iceland updated as part of the present resource assessment. Based on data from approximately 1800 boreholes, a large part shallow, slim temperature exploration wells. There are large gaps in the underlying dataset (see Table A.1), especially within the volcanic zones, where points are added in the known high-temperature areas (see Figure 1 for their locations) assuming a 220°C/km gradient to supplement the map.

3.2 The Four Low Temperature Energy Streams

The first energy stream comprises flow through hot springs, in the natural state prior to any production. The inventory of hot springs in Iceland dates back to the early 1900's and a thoroughly updated one was published as part of the 1985 assessment (Pálmason et al., 1985). Since then, more detail has been added to the inventory, even though the bulk of the hot springs was already listed in 1985. The inventory lists flow (L/s) and temperature (°C), where that information is available. In the present work the thermal power is calculated based on a reference temperature of 5°C. The results are presented in Table 1 at the end of this subsection, as a sum for each region. Now the total flow is estimated to be 4100 kg/s while in 1985 it was only 1800 kg/s, as little emphasis was on the lowest temperature resources back then. These don't add much to the total thermal power, which is now estimated to be 640 MW_{th}, slightly more than the approximately 600 MW_{th} estimated in 1985.

Figure 3 shows how both the hot spring flow and thermal power varies with temperature. It is noteworthy that the greatest power is associated with the highest temperature while the most voluminous flow is around 10°C.

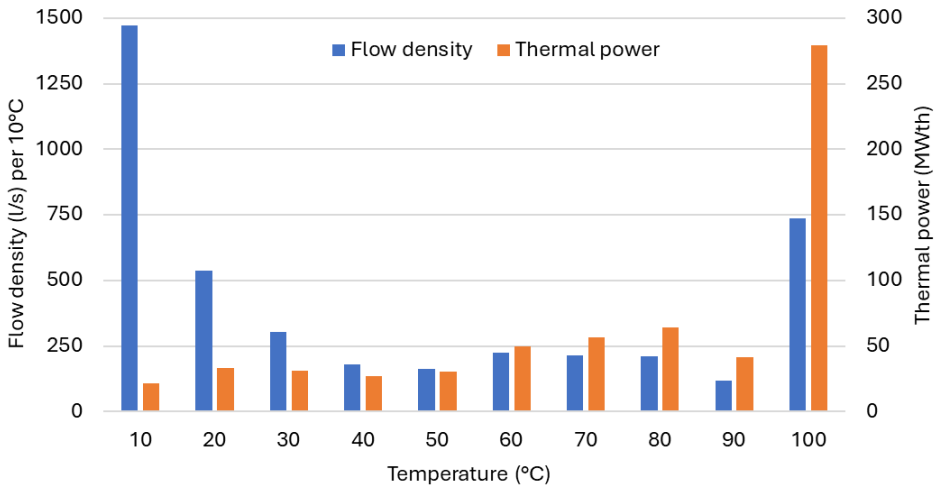


Figure 3. Cumulative flow and thermal power of hot springs in Iceland for 10°C intervals centered on the temperature values on the horizontal axis.

It should be noted that the hot spring inventory doesn't include fumaroles or hot springs in high-temperature areas, as these are more difficult to quantify. The natural heat flow through these areas, including both heat conduction and fluid advection/convection is estimated approximately, see subsection 3.3 and tables 3 and A.3.

The second energy stream assessed involves heat conduction to the surface through Iceland's crust. This is based on the temperature gradient estimated for the country's different regions (Table A.1, marked 2025) and an average thermal conductivity of 1.7 J/(m°C). The results are again presented in Table 1.

The third energy stream involves the sum of the short-term production capacity of geothermal production wells in different regions. This does not constitute thermal power that's constantly available, but rather maximum short-term capacity, as discussed above. The database used does not include data from the high-temperature areas utilized, as the necessary data is either not available or not accessible. The results are presented in Table 1.

The fourth energy stream involves the average yearly production of all geothermal heating services, as described above. The cumulative numbers for Iceland's regions are presented as average thermal power in Table 1, while the actual production varies greatly within the year. Electricity and heat production in high-temperature areas is excluded but presented in the following.

The fifth energy stream involves the estimated production capacity of all high temperature areas in Iceland, excluding a few unexplored below glaciers, 19 in total. This energy stream is discussed in subsection 3.3, following this one.

Table 1. Present assessment of the four main energy streams through Iceland, both natural and man-made. High-temperature areas are excluded here but presented in the following subsection.

Regions	Area (km^2)	Hot springs and fumaroles (MW_{th})[1)]	Geothermal production wells (MW_{th})[2)]	Thermal power production 2023 (MW_{th})[3)]	Heat conduction (MW_{th})
SW Iceland	4,237	239	1,072	441	720
Snæfellsnes	2,719	2.4	42.9	8.3	370
Westfjords	9,230	103	20.5	5.8	940
NW Iceland	4,100	8.7	22.8	9.4	490
Skagafjördur	7,442	38.5	101	57.2	1,010
Eyjafjördur	8,412	39.1	214	130	1,140
NE Iceland	14,423	6.7	47.8	25.2	1,590
Vatnajökull South	7,398	1.6	29.0	9.0	1,130
SE Iceland	2,851	0.1	-	-	390
S Iceland	6,373	95.9	224	95.1	920
Reykjanes Volcanic zone	926	-	-	-	240
W Volcanic zone	11,365	55.2	800	136	2,900
SE Volcanic zone	5,488	3.8	-	-	1,490
NE Volcanic zone	17,755	41.6	102	48.2	5,130
Total		**635**	**2,676**	**964**	**18,460**

1) Thermal power of hot springs based on flow and temperature catalogued (Torfason, 2024)
2) Cumulative production capacity of geothermal production wells (Sveinbjörnsson, 2016 & 2018)
3) Average yearly hot water production presented as average power (Orkustofnun, 2024)

The present heat flow and energy current results both reveal a general picture and various intricate aspects, that can't be done full justice in such a short paper (see Axelsson et al., 2025). A few things stand out, however: Firstly, the great variability between different regions of Iceland, despite how small the country is. Secondly, the fact that present geothermal production is only about 50% more than the flow through hot springs in the natural state, hinting that at present the production is generally close to being sustainable. Yet, the cumulative short-term capacity of geothermal wells is almost 3x greater than present production. This reflects the fact that available wells should be able to meet peak demand during winter and also confirm that reinjection should, generally, help increase production capacity. Finally, it should be noted that heat conduction through Iceland's crust is about 20x current production.

3.3 Estimated Production Capacity of High-Temperature Systems

The production potential of known high-temperature geothermal systems has been evaluated based on the volumetric method, where reservoir extent and thermal conditions and properties are used to estimate heat in place and probable power output. The method is often applied in early development, following surface exploration and in some cases exploration drilling. ÍSOR has applied the method to most of the Icelandic high-temperature systems being utilized, however for the present study, the fields in NE-Iceland, Námafjall, Krafla and Theistareykir were used as calibration studies (Halldórsdóttir and Björnsson, 2009; Mortensen et al., 2009; Gudmundsson et al., 2008).

Lateral extent of the majority of the systems is constrained by resistivity surveys, typically using the high-resistivity core at 800–1000 m depth as an indicator of reservoir boundaries (Árnason and Karlsdóttir, 2006). Temperatures within this zone are generally assumed to exceed 230°C (Árnason et al., 2000), which is sufficient for electricity generation. In cases where no high-resistivity core is observed, the maximum extent of the low-resistivity cap, associated with temperatures above ~150–160°C, is used instead. This applies to two systems, Geysir and Hveravellir.

Volumetric assessments combined with Monte Carlo simulations have been carried out for Námafjall, Krafla, and Þeistareykir, as already mentioned. These studies incorporated uncertainties in reservoir volume (lateral extent and thickness), and temperature, by assigning probability distributions to key parameters and applying Monte Carlo calculations. The resulting 90% confidence intervals for electrical power potential are: 50–170 MW_e for Námafjall, 120–350 MW_e for Krafla and 115–370 MW_e for Þeistareykir (Halldórsdóttir and Björnsson, 2009; Mortensen et al., 2009; Gudmundsson et al., 2008).

These correspond to average power densities of 2-7 MW_e/km^2 (90% confidence intervals) for the areas (Axelsson et al., 2025). These results are comparable to the earlier national assessment conducted by the National Energy Authority and ÍSOR in 2009, which reported a range of 3–9 MW_e/km^2 (Ketilsson et al., 2009). Differences in estimated reservoir extent between assessments, particularly for Námafjall and Krafla, partly explain the variation between the two studies.

Based on these power densities and the mapped extent of all high-temperature systems in Iceland (Figure 1), the total generation potential is estimated at 1900–6500 MW_e (Table A.3). The wide range reflects the uncertainty associated with early-stage geothermal evaluation, particularly in systems that lack drilling data. Reservoir extent, temperatures and production behavior have been confirmed by drilling for only a minority of the systems.

In addition, Table A.3 presents a rough estimate of the heat output (heat conduction and advection/convection) of all the areas assuming a natural heat output of 10 – 25 W/m^2, partly calibrated by data associated with the subglacial Grímsvötn system (Reynolds et al., 2018; Björnsson et al., 1982). See Axelsson et al. (2025) for more detail. The table also presents the annual energy production in the 5 areas currently utilized, both electricity and total heat.

3.4 Stored Heat in Iceland's Crust

The stored heat in Iceland's crust was estimated using the volumetric method, in which the heat in place for each area identified (Figure 1) was calculated based on the average temperature gradient within the respective area. The crust is divided into depth intervals that reflect changes in porosity and the heat capacity of the rock and water. This approach is identical to the one used for the assessment in 1985 but incorporates updated crustal temperature conditions, porosity and thermal properties.

In the uppermost 3 km, the average porosity is taken as 5%, with pore space filled by water. The volumetric heat capacity in this interval therefore reflects the properties of both rock and water. In the assessment, the values used are: 900 J/(kg·°C) for rock heat capacity, 3000 kg/m^3 for rock density, and 4500 J/(kg·°C) and 870 kg/m^3 for water heat capacity and density, respectively. Below 3 km depth, lithostatic pressure is assumed to close all pore space, reducing porosity to 0% and leaving the thermal properties governed by the rock.

The temperature structure within high-temperature systems is different from the background thermal gradient in the crust. Elevated permeability, caused by open fractures, and intrusions lead to enhanced convective heat transfer. To capture these conditions, an average porosity of 15% is assumed within the known high-temperature systems (Figure 1). Furthermore, the temperature–depth profile is approximated as 80% of the boiling-point curve for water, reflecting typical thermal structures within the known high-temperature systems.

Representative temperature profiles for each region are shown schematically in Figure 4. In the volcanic zones, temperatures are assumed to reach 1200°C at approximately 7–8 km depth, consistent with brittle-ductile

transition within the crust. Thermal energy was then estimated by integrating the temperature, and appropriate rock/water properties, over depth and multiplying by the surface area of each region. Two depth intervals were evaluated: 0–5 km, representing the approximate limit of modern drilling technology, and 0–10 km, representing the upper crustal volume relevant for long-term assessments.

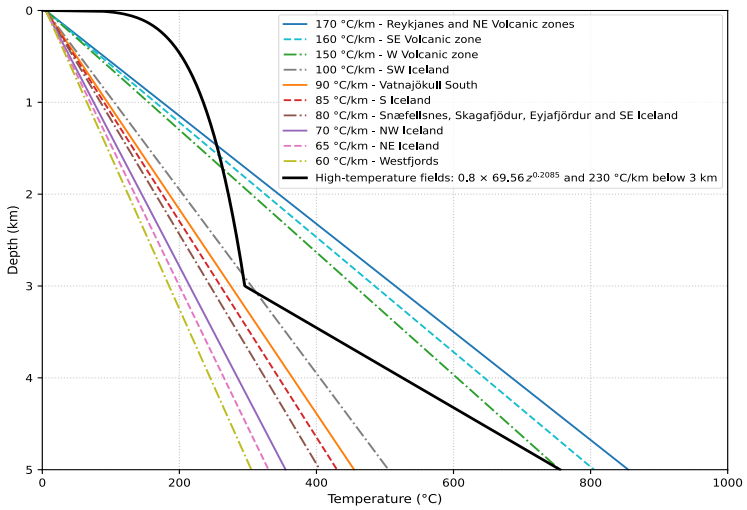


Figure 4. Temperature conditions for different regions of the top 5 km of Iceland's crust, assumed in the present assessment.

The results indicate that slightly more than half of the total heat content is confined to the volcanic zones, mostly due to their elevated temperature gradients (see Table 2). The total heat stored within these zones is estimated to be approximately 2.0×10^{23} J (200,000 EJ) within the uppermost 5 km and thereof 0.0036×10^{21} J (3,600 EJ) within the high-temperature systems. The total heat stored in the Icelandic crust is estimated at 3.8×10^{23} J (380,000 EJ) to 5 km depth and 1.4×10^{24} J (1,400,000 EJ) to 10 km depth. These values exceed the earlier assessment somewhat, primarily due to updated geothermal gradients, particularly within the volcanic zones outside the high-temperature systems. Furthermore, the present results confirm that Iceland's crust contains an extremely large thermal resource, and recovery of even a small fraction would represent a significant long-term energy potential.

4 SUMMARIZED RESULTS

The results of the updated countrywide geothermal assessment for Iceland are comprehensive and detailed and can't be presented in detail in a short paper like the present one. The results are, however, summarized simply in Table 2 below. The authors consider the following the principal conclusions:

- The natural heat flow (heat conduction and water/steam flow) is estimated to be about 37,000 MW_{th} for all of Iceland.
- For comparison, the average heat flow through other parts of the Earth comparable in size to Iceland can be estimated to be just under 8,000 MW_{th}[1].
- Another comparison is Iceland's geothermal energy consumption, which can be estimated to correspond to approximately 5,500 MW_{th} at present.
- Heat flow by hot water and steam through 19 high-temperature areas is estimated at almost 18,000 MW_{th}. As emphasized already, this is based on very rough estimates for all the areas. Furthermore, little-known areas under glaciers are not included (except Grímsvötn and Kverkfjöll).
- The heat flow by water and steam through the high-temperature areas is estimated to be about 30 times greater than the heat flow through hot springs in other parts of the country.
- An updated estimate of the combined electrical generating capacity of the high-temperature areas in the country is in the range of 2000-7000 MW_e. This can be compared with the combined average generated power of the seven areas currently in use, which was 690 MW_e in 2023 (installed

[1] Based on the author's estimate of the weighted average oceanic and continental heat flux according to several recent references, 0.075 W/m².

capacity 790 MW_e). Their combined average thermal power (total thermal power) was, furthermore, 4500 MW_{th} the same year.

- The stored heat in the country's crust is estimated to be enormous, or about 1.2 million EJ down to a depth of 10 km. For comparison, it can be estimated that the total energy consumption (primary energy) of Icelanders from 1940 to 2022 (for 83 years) was about 8 EJ, which is equivalent to only 0.0007% of the stored heat.
- There is a clear correlation between the production of geothermal district heating services and the thermal power of hot springs in different parts of the country. However, the Westfjords stand out as the utilization there is much lower than the correlation suggests should be possible.
- A basic evaluation of accessible results from 15 low-temperature areas used for district heating shows that their average production in 2023 corresponds to about 65% of their production capacity according to model predictions. This gives an indication, but the sample is not considered significant enough to transfer the result to the entire country.

Table 2. Summarized principal results of the updated countrywide geothermal resource assessment for Iceland. The table reflects the double nature of geothermal energy, i.e. heat flow vs. stored heat.

Component	Part of country	Subcomponent	Present assessment
Heat flow/ average power (MW_{th})	Volcanic zone	Heat conduction	9,800
		Water and steam	17,900
		Well capacity	(info. not available)
		Utilization	4,500
	Outside volcanic zone	Heat conduction	8,700
		Water and steam	640
		Well capacity	2,700
		Utilization	960
Stored heat (EJ[2)])	Volcanic zone	0 – 5 km depth	202,000
		0 – 10 km	733,000
	Outside Volcanic zone	0 – 5 km depth	174,000
		0 – 10 km	693,000

1) Numbers for 2023
2) 1 EJ = 10^{18}J

Comparing the above results with those from 1985 the following are the main differences: Firstly, heat conduction within the country's volcanic belt is now estimated to be much greater, because the current authors believe it was significantly underestimated 40 years ago. Heat flow through the high-temperature areas by water and steam is now comparable to the 1985 estimate, however. Secondly, the current estimate of the stored crustal heat is about 18% higher than in 1985, mainly due to higher estimates for the volcanic belts.

It is important, however, to keep in mind that part of the numerical results presented in the 2025 assessment are quite uncertain whilst others are much more accurate, as mentioned earlier. Great uncertainty is e.g. associated with temperature conditions in the volcanic zones, which cover about 34% of the country, and hence heat conduction through the zone. This is mainly because wells have only been drilled in 5 volcanic high-temperature areas, which only cover about 0.9% of the volcanic zones' area.

The total natural heat flow (heat conduction and advection by water and steam) through Iceland is estimated to be around 37,000 MW_{th}, while the average heat flow through the Earth's inactive regions of comparable size is around 8,000 MW_{th}. The excess heat flow is thus estimated to be around 29,000 MW_{th}. This excess flow is basically due to magma flowing up into the country's crust, from the mantle below. A large part of the magma remains underground, mostly as huge dykes filling the underground volumes created by the divergence of the plate boundaries transecting the country. Bödvarsson (1982) proposed estimating the associated heat flow based on the spreading rate of the volcanic belts (~2 cm/year) and the energy content of basaltic magma. Building on Bödvarsson's basic assumption, assuming a 600 km volcanic belt, we obtain an estimate of

18,000 MW_{th}. This leaves about 11,000 MW_{th} of the estimated excess heat flow still unexplained. Part of this is probably associated with various magma intrusions and chambers other than the magma dikes of the spreading zones, such as in the various central volcanoes. Part of this flow can undoubtedly also be explained by magma flow associated with the hot spot that is thought to be under Iceland, directly and indirectly. However, one must keep in mind that the heat flow through the volcanic zones and high-temperature areas may have been overestimated to some extent in the present work, due to lacking data.

It is clear from the current results that Iceland's geothermal resources are enormous with comparable areas on Earth being rare. The geological conditions differ from most other places in the world because of the exceptional interaction of a mantle hot spot and a divergent plate boundary. Other areas with powerful geothermal resources are, for example, the East Africa rift zone, New Zealand and Indonesia. The geothermal resources in Iceland are even more powerful than previously concluded, although this is subject to uncertainty due to a lack of data and research on some aspects. Three things can be mentioned that demonstrate this:

- About 25% of the natural heat flow would fulfill all primary energy consumption in Iceland, as it is today, for the entire future.
- About 1% of the stored heat down to a depth of 5 km in the country's crust would fulfill all primary energy consumption in Iceland, as it is today, for approximately 15,000 years.
- About 1% of the stored heat down to a depth of 10 km in the country's crust would fulfill all primary energy consumption in Iceland, as it is today, for approximately 57,000 years.

5 FUTURE OF GEOTHERMAL DEVELOPMENT IN ICELAND

The present geothermal assessment for Iceland indicates a strong potential for continued and expanded geothermal utilization, if knowledge development, technological innovation, and sustainable management are maintained.

Globally, geothermal energy is emerging as a key component of the green energy transition. Technological advances, such as enhanced geothermal systems (EGS), deep drilling, and improved efficiency in energy extraction and utilization, are expanding the boundaries of geothermal utilization. Increasingly, oil and gas companies are transferring their expertise into geothermal development, accelerating innovation and investment. However, alongside technological challenges, environmental regulations, permitting processes, and public awareness must be effectively addressed to ensure sustainable progress (IEA 2024).

Deep drilling and supercritical geothermal systems represent major future prospects. Very high temperature gradients within volcanic systems suggest that supercritical conditions may be widespread. Emerging drilling technologies offer potential to access these deep, high-enthalpy resources, though challenges related to high temperature, pressure, and material durability remain significant. Icelandic research organizations, such as ÍSOR, have contributed to innovations in borehole design and materials suited to extreme geothermal conditions (Skulason et al., 2024).

In Iceland, current production is mainly limited to active hydrothermal systems, which places limits on long-term growth. Updated research/information on crustal conditions suggests large, underexplored thermal resources within Iceland’s volcanic zones, outside known high-temperature systems. We, therefore, propose a national strategy that prioritizes greatly increased research in these zones, systematic data collection, and open access to geothermal data. Artificial intelligence and machine learning are, furthermore, expected to play an increasing role in geothermal data analysis and resource modelling (Algaiar et al., 2024). It is also our hope that EGS-technology will mature further than it has already done, enabling utilization of the vast thermal energy stored in Iceland’s crust outside hydrothermal systems in the not-too-distant future.

For low-temperature systems, which are central to Iceland’s district heating, sustainability depends on optimized production management, reinjection practices, and multi-use applications. Existing modelling software (e.g. LUMPFIT, TOUGH2) are being developed further to enhance prediction capabilities, to strengthen management of geothermal resources during utilization (Halldórsdóttir et al., 2025; Axelsson, 2022). More diverse and cascaded utilization – including heating, cooling, energy storage, food production, and industrial applications – will further strengthen sustainable utilization of these systems. Ground-source heat pumps, which in effect involve utilization of the general heat conduction through Iceland’s crust, represent an underused opportunity, with potential e.g. in regions previously assumed lacking the potential for traditional geothermal heating. In addition, offshore geothermal systems – particularly along oceanic ridges within Iceland’s jurisdiction – represent a long-term frontier for exploration, though technical, regulatory, and financial barriers remain (Hjartarson et al., 2021; Bolton et al., 2024).

Iceland's geothermal future depends on effective integrated policy, intensified and comprehensive further research, as well as innovation. Data access, interdisciplinary collaboration, and adoption of emerging technologies, will also be essential to support Iceland's national strategy for sustainable geothermal energy utilization and development.

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APPENDIX: TABLES PRESENTING SELECTED RESULTS OF THE 2025 ICELAND GEOTHERMAL ASSESSMENT

Table A.1. Information on the 14 regions used in the 2025 geothermal assessment of Iceland; area, number of hot springs, geothermal production wells, geothermal gradient wells, and the number of district heating systems.

Regions	Area (km^2)	Geothermal gradient - average[1)]	Geothermal gradient - weighted average[2)]	Geothermal gradient 1985 (°C/km)	Geothermal gradient 2025 (°C/km)
SW Iceland	4,237	194	118	90	100
Snæfellsnes	2,719	121	90	90	80
Westfjords	9,230	84	71	60	60
NW Iceland	4,100	76	75	70	70
Skagafjördur	7,442	80	103	70	80
Eyjafjördur	8,412	141	86	70	80
NE Iceland	14,423	79	62	60	65
Vatnajökull South	7,398	124	93	60	90
SE Iceland	2,851	55	61	60	80
S Iceland	6,373	121	85	90	85
Reykjanes Volcanic zone	926	120	140	60	170
W Volcanic zone	11,365	169	125	60	150
SE Volcanic zone	5,488	102	87	60	160
NE Volcanic zone	17,755	165	196	60	170

1) Number of hot spring areas (w. 500 m radius) according to Torfason (2024)
2) Geothermal boreholes according to ÍSOR/UOS databases, drilled as production well.
3) Geothermal exploration boreholes according to ÍSOR/UOS databases, drilled and/or used as gradient wells
4) Number of district heating systems registered at UOS, both public and private

Table A.2. Estimated temperature gradients for regions of the country.

Regions	Area (km^2)	Hot springs and fumaroles (MW_{th})[1)]	Geothermal production wells (MW_{th})[2)]	Thermal power production 2023 (MW_{th})[3)]	Heat conduction (MW_{th})
SW Iceland	4,237	239	1,072	441	720
Snæfellsnes	2,719	2.4	42.9	8.3	370
Westfjords	9,230	103	20.5	5.8	940
NW Iceland	4,100	8.7	22.8	9.4	490
Skagafjördur	7,442	38.5	101	57.2	1,010
Eyjafjördur	8,412	39.1	214	130	1,140
NE Iceland	14,423	6.7	47.8	25.2	1,590
Vatnajökull South	7,398	1.6	29.0	9.0	1,130
SE Iceland	2,851	0.1	-	-	390
S Iceland	6,373	95.9	224	95.1	920
Reykjanes Volcanic zone	926	-	-	-	240
W Volcanic zone	11,365	55.2	800	136	2,900
SE Volcanic zone	5,488	3.8	-	-	1,490
NE Volcanic zone	17,755	41.6	102	48.2	5,130
Total		**635**	**2,676**	**964**	**18,460**

1) Average geothermal gradient of wells in ÍSOR database, excluding wells w. values above 500°C/km.
2) Average geothermal gradient weighted by the area of influence of each well.

Table A.3. Assessment results of high-temperature areas in Iceland; estimated surface area, natural heat flow, power generation based on areal capacity of 2 to 7 MW_e/km^2, 2009 assessment results, along with average yearly power generation and total thermal power, for the 5 areas utilized.

Regions	Area (km^2)	Natural heat flow (MW_{th})	2025 assessment of generation capacity (MW_e)	2009 assessment of generation capacity (MW_e)[1)]	Average power output 2023 (MW_e)[2)]	Thermal power output 2023 (MW_{th})[2)]
Reykjanes[3)]	9	135	20-60	30-80	80	577
Svartsengi	32	320	60-230	90-270	65	547
Krýsuvík	72	1,080	140-500	270-800		
Brennisteinsfjöll	5	50	10-40	15-45		
Hengill	142	2,130	270-950	430-1,280	398	2,440
Geysir[3)]	5	125	10-40	15-45		
Kerlingarfjöll	32	800	60-220	120-350		
Hveravellir[3)]	14	210	30-100	40-130		
Torfajökull	269	6,725	540-1,880	760-2,280		
Grímsvötn[4)]	65	1,800	130-460	-		
Hágöngur	43	430	90-300	130-390		
Vonarskard	29	725	60-200	90-260		
Kverkfjöll[5)]	34	1,200	70-240	90-280		
Askja[5)]	27	540	50-190	80-240		
Hrúthálsar[5)]	3	30	10-20	10-40		
Fremrinámar	10	100	20-70	30-90		
Krafla-Námafjall	81	1,215	160-560	190-560	57	530
Gjástykki	11	110	20-80	30-100		
Theistareykir	48	720	100-340	140-430	86	444
Total	**931**	**18,445**	**1,860 - 6,520**	**2,560 - 7,670**	**686**	**4,538**

1) According to Ketilsson et al. (2009).

2) National Energy Authority statistics (2024).

3) Estimated from resistivity measurements.

4) Reynolds et al. (2018) and Björnsson et al. (1982).

5) Estimated on basis of surface manifestations.