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The 100-year plan – A long term vision for sustainable resource management in Reykjavik District Heating

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ABSTRACT

Reykjavik Energy (OR) and Veitur Utilities are working on a long-term vision for a sustainable resource management for all thermal production areas. Veitur Utilities distribute hot water to two thirds of Icelandic homes. The project has been defined as a key project with high priority by the OR Board. Overall, the project's mission is to establish a comprehensive appraisal of the status of natural resources owned and operated by the OR Group and establish a long-term strategy for utilization and acquirements of rights for hot water production. While the overall project includes all production areas within the OR-group, the capital area of Reykjavík will be used as a case study. Light will be shed on the development of methodology to establish a vision for long-term strategy; a methodology that included the principles of design thinking and inter-disciplinary teamwork. The methodology includes establishing a model for demand forecast, putting forth a plan for preparing feasible production areas and a plan for acquiring rights for hot water production. The output is a roadmap detailing when an increase in production is required in the long term. The approach to the project was developed over a number of years and the OR/Veitur team has sharpened its focus on long-term strategy for natural resource development and hot water production.

1. INTRODUCTION

Iceland, a country located in the North Atlantic Ocean close to the Arctic Circle, boasts an oceanic climate that is much milder than one might expect given its northerly location. The mean annual temperature in Reykjavik, the country's capital and largest city, is 5°C, with an average temperature of -0.4°C in January and 11.2°C in July, shown in Figure 1-1. Despite the mild climate, heating is necessary all year round due to the country's location.

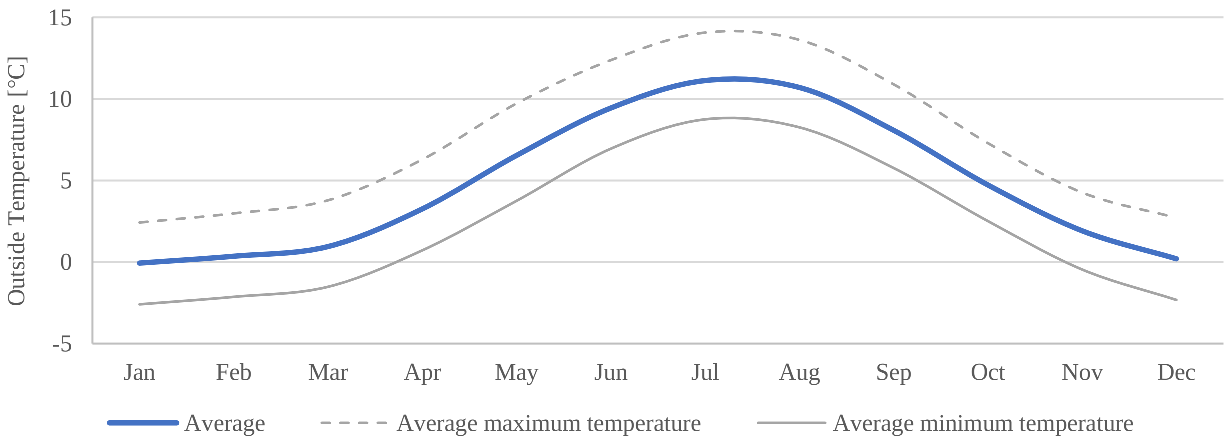

Figure 1-1: Outside temperature in Reykjavík. Data from 1931 to 2022.

Iceland's unique geology plays a major role in its climate and heating needs. The country is located on a continuation of the Mid-Atlantic Ridge, where the American and European tectonic plates are diverging at a rate of approximately 2 centimeters per year. This geological activity has resulted in a large number of hot water springs and geothermal fields throughout the country. In fact, there are over 600 hot water springs in 250 low-temperature fields and 28 potential high-temperature areas have been identified. All the high-temperature fields are located within the volcanic zones while the main low-temperature fields are found on the flanks of the volcanic zones.

Iceland is a world leader in the development of geothermal district heating. Over 90% of the country's total population use geothermal water for space heating (Ragnarson, Steingrimsson, & Thorhallsson, 2021). Most of the geothermal production comes from low-temperature fields (60-130°C), which contain relatively low content of dissolved solids. This water can be used directly for district heating, making it an efficient and cost-effective solution for providing heat to the population.

Additionally, Iceland's geothermal resources have been used for other purposes such as electricity generation and for direct use in industry and agriculture. Iceland's geothermal energy has been considered as a model for sustainable energy development, and it has attracted the attention of many researchers and experts worldwide. The historical development of primary energy use in Iceland is shown in Figure 1-2.

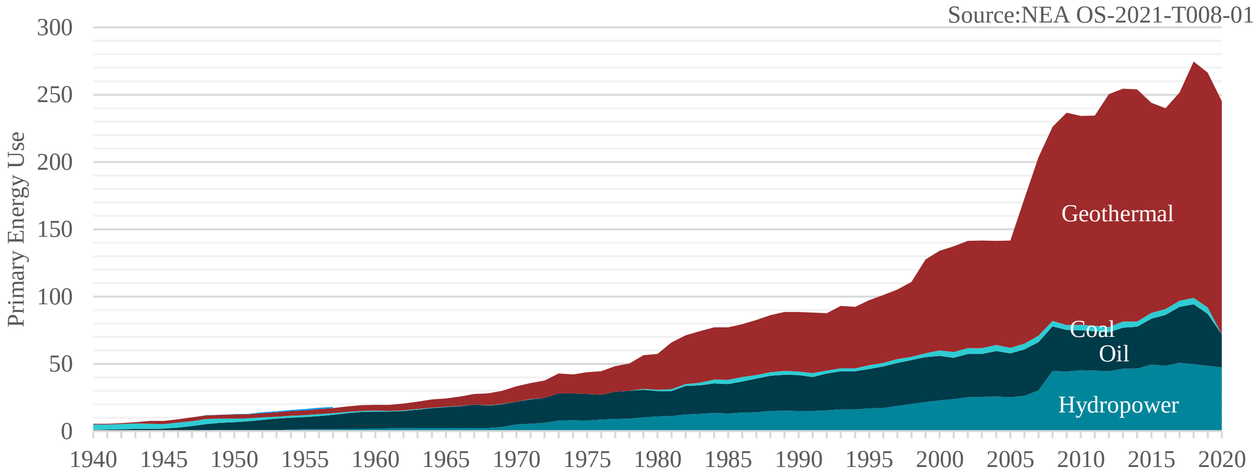

Figure 1-2: The historical development of primary energy use in Iceland (Source: Orkustofnun Data Repository OS-2021-T008-01).

Veitur, a subsidiary of Reykjavik Energy, runs the district heating network in the Capital area of Iceland. The peak-load in December 2022 for the network was close to 1100 MW_{th}. The network utilizes six geothermal resources; four low-enthalpy geothermal fields that are used directly and two geothermal power plants that utilize high-enthalpy geothermal fields to produce electricity and to heat up groundwater.

The Laugarnes field was first exploited for geothermal water in the late 1920s and early 1930s, with the drilling of 14 shallow wells near the Thvottalaugar thermal springs. The wells were 246 m deep and produced 14 l/s of water at 87°C, which was used for heating buildings such as schoolhouses, hospitals, and swimming pools, as well as around 70 homes. In 1958, drilling in the Laugarnes area resumed with a new type of rotary drilling rig that allowed for deeper and wider wells, resulting in a yield of 330 l/s of water at 125-130°C. Currently, the field has 10 production wells, covers 0.28 km^2, and is located at the junction of a caldera and a fault-scarp. The temperature ranges from 110-125°C at depths of 400-500 m and increases with depth, with the highest measured temperature being 163°C at 2,700 m. The main aquifers are located at depths of 1,000-2,000 m.

The Ellidaardalur field had limited surface activity before drilling, with temperatures reaching 25°C. After drilling began in 1967, aquifers with temperatures of 85-110°C were discovered. The exploitation area covers 0.08 km^2, but the surface manifestations cover 8-10 km^2. The water from this field contains oxygen and has a quick drawdown compared to the other fields. There are 8 production wells in the Ellidaardalur field. The Ellidaardalur can produce, when all wells and pumps are healthy, around 250 l/s.

The Reykir-Reykjahlid fields had an estimated artesian flow of 120 l/s of water at 70-83°C before drilling. After drilling, the water was piped to Reykjavik, and by 1943, 200 l/s of 86°C water was available for heating homes in Reykjavik. In the 1970s, deep rotary drilling and the installation of pumps led to an increase in yield to 2,000 l/s of 85-100°C water. The Reykir-Reykjahlid field is 5.5 km^2 in size, is divided into the sub-areas Reykir and Reykjahlid, and is located between two calderas. The field contains 34 exploitation wells and the temperature ranges from 65 to 100°C.

The power plant at Nesjavellir was constructed in the beginning of the 1990s and uses high temperature geothermal resources to produce electricity and to heat up cold groundwater via heat exchangers. The Nesjavellir power plant can produce 350 MW_{th} of thermal power and 120 MW_e of electricity.

The power plant at Hellisheidi was constructed in the beginning of the 2010s and is constructed similar as the Nesjavellir power plant. The Hellisheidi power plant can produce 210 MW_{th} of thermal power and 303 MW_e of electricity.

Figure 1-3 shows the yearly production growth from the six resources. The district heating network's capacity grew rapidly from the 1960s to 1980, then continued to steadily increase in most years after that period. This is evident both from the history described above and the figure.

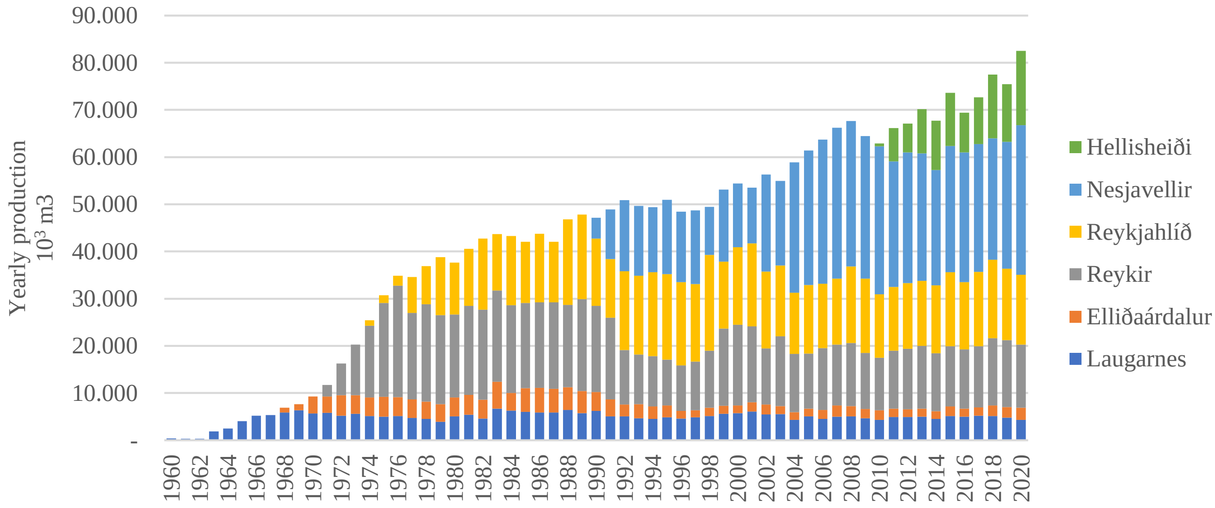

Figure 1-3: Yearly production for the district heating network from the 6 geothermal resources.

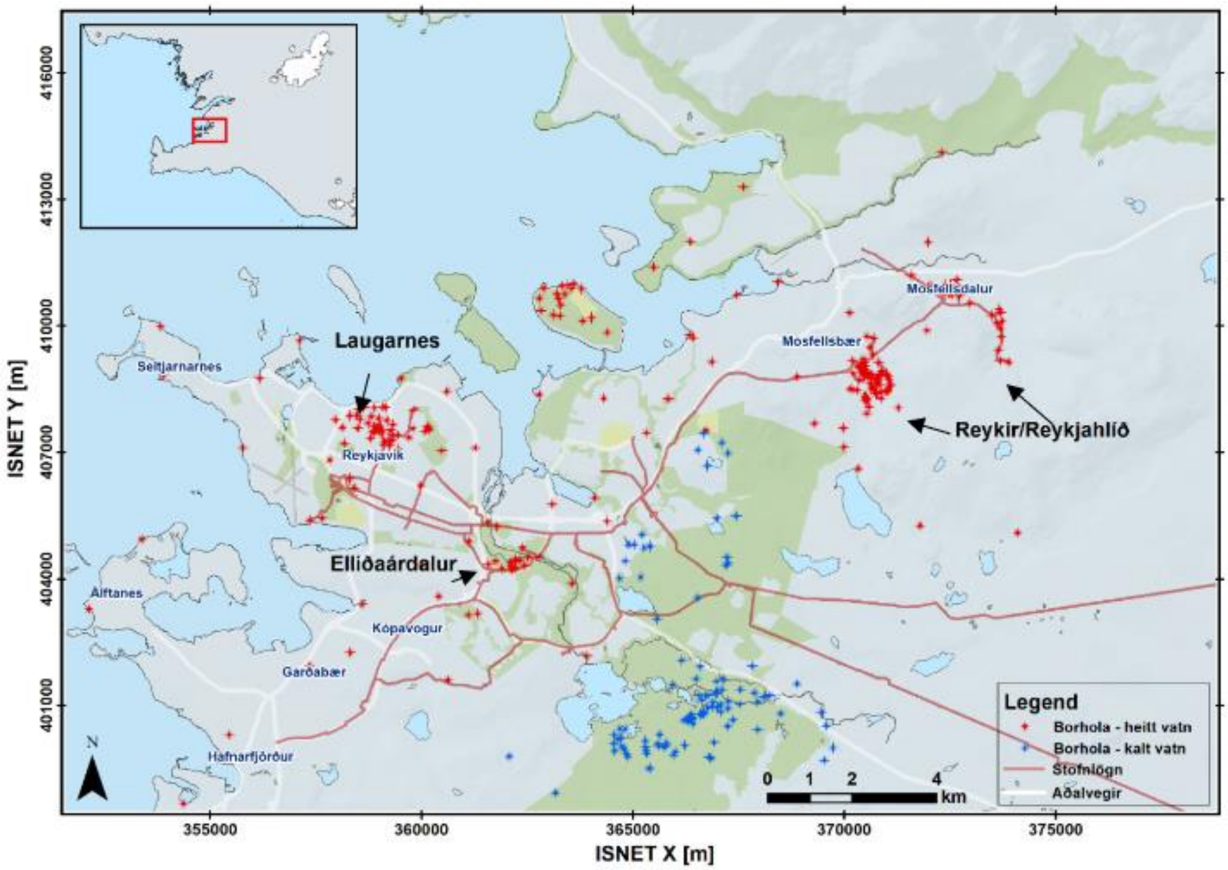

Figure 1-4: Main transmission pipelines for the district heating network in the capital area and the four low temperature geothermal resources.

Veitur Utilities has a mandate to provide sufficient hot water for the heating of Reykjavik and the surrounding municipalities in a cost-effective way. The population in the capital area has grown continuously for more than a century and continued growth is foreseen. This has resulted in a sustained pressure on the district heating system to continue its expansion. The next increase in installed capacity for the network will be expanding operations in Hellisheidi power plant, as well as increasing production from the current low-enthalpy geothermal fields. After that addition, the current geothermal resources are at their limit. Based on the historical and the projected demand forecast, Veitur and Orkuveita Reykjavíkur made a long-term strategy for utilization and the acquirements of rights for hot water production. The project was conducted in 2022. The output was a long-term roadmap to assess the availability of possible new resources. This roadmap will then be updated periodically every three years.

2. DEMAND FORECAST

A demand forecast is one of two key-components in the long-term vision for the Reykjavik district heating system. The peak demand for hot water is controlled mainly by two variables; the weather and the volume of the buildings that are connected to the district heating network. Two different approaches were used for the low and high forecast. The high forecast is based on the master plans from all the municipalities in capital area and discussions with planning officers in the municipalities. This information, regarding the volume of new buildings that is planned, is transformed into peak demand of hot water that will be added each year. The low forecast is based on historical data for peak demand and the forecast for development of population in the Capital region.

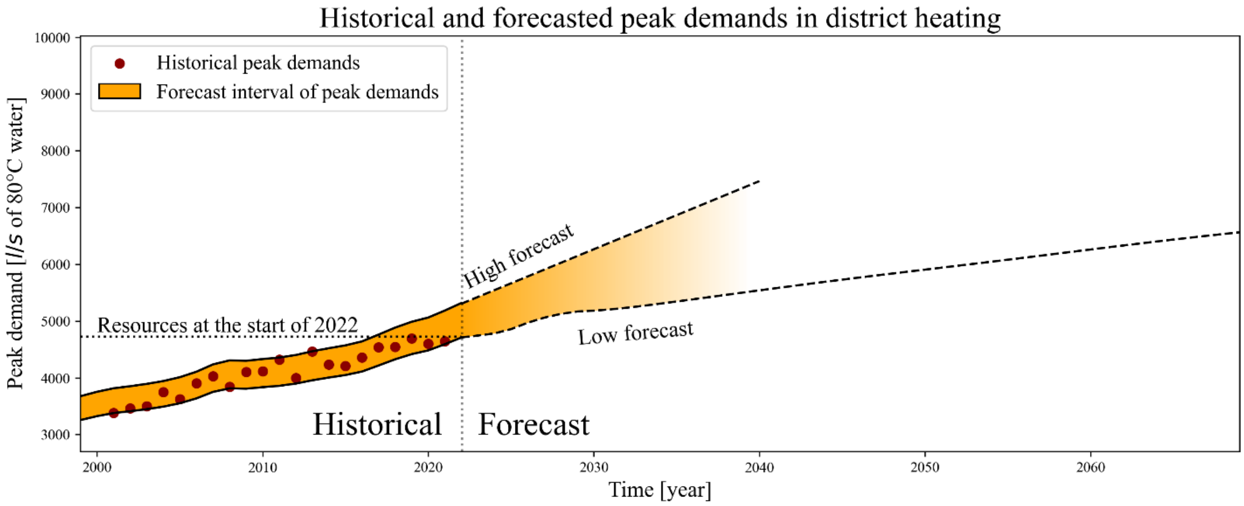

Figure 2-1: Historical peak demand for the district heating network along with the high and low forecasts for the peak demand.

3. AVAILABLE RESOURCES

The second key-component of the long-term vision for the Reykjavik district heating system (RDHS) is the mapping of potential heat resources in the vicinity of capital area that can be tapped into in the short, medium, and long term. This effort focused on identifying potential resources, identifying their location, and assessing their heat production capacity. The different options were compared and ranked by way of a high-level cost analysis and an Analytical Hierarchy Process (AHP) that considered specific non-cost attributes of different options.

3.1 Portfolio of potential resources

More than 50 options for additional capacity for the RDHS were assessed (see Figure 3-1). These options can be classified into six categories. Four of these are along the lines of current activities, i.e., expansion of existing operations and new operations in low-enthalpy geothermal fields and high-enthalpy fields (LE - Expansions, LE - New operations, HE - Expansions, and HE - New operation). The other two are the use of waste heat from industry (Industry – Waste heat) and the use of heat pumps to extract the heat from the return water in the RDHS (Return Water – Heat pumps).

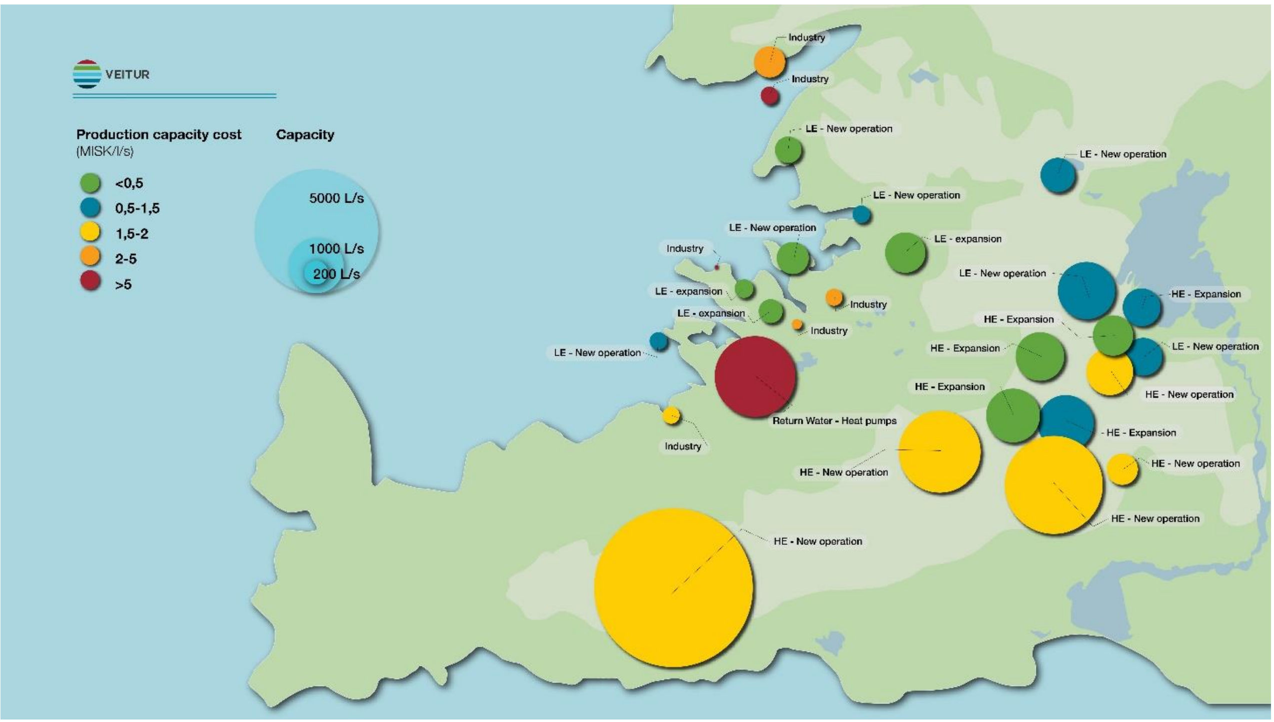

Figure 3-1: Hot water production options for the RDHS. Symbol size indicates estimated production capacity and colour production capacity cost. Note that in some cases several options are pooled into one symbol for clarity.

3.2 Cost and AHP analyses

The different hot water production capacity options were analysed with respect several factors. The most important ones are the estimated production capacity and the estimated annual production capacity cost. Other factors (resource risk, resource management, operational risk management, planning and permissions, improved resource utilization, and environmental impact) were also assessed for each option and pulled together a single AHP score.

3.2.1 Cost analysis

The cost of different options is compared on the basis of annual production capacity cost. The scaling of the capacity of the system is based on maximum demand even though most resource options are only utilized at maximum capacity for a few days every year. The annual production capacity cost is calculated as the CAPEX of full development divided by the lifetime of each component. OPEX over the project lifetime was generally assumed to be 4.3% of the CAPEX except for heating capacity options that involved heat pumps. For options involving heat pumps a 50% up-time was assumed. Experience and best estimates were used to assess the cost and lifetime of different components. Different components were included in the CAPEX for different heating options. The list of components included in the CAPEX includes the cost of exploration, drilling, installation of pumps, connection to the grid and associated pumping stations, construction of thermal plants, facilities for producing cold water for heating, buildings and large-scale heat pumps. The objective of the cost analysis was more focused on internal consistency rather than precision as it is primarily intended to be used for ranking the options.

3.2.2 AHP ranking

An Analytical Hierarchy Process was used to compare non-cost attributes of the different options for additional heat input for the RDHS. The attributes considered were 1) resource risk, 2) resource management, 3) operational risk management, 4) planning and permitting, 5) improved resource utilization, and 6) environmental impact. Table 3-1 lists the attributes and shows their weight as well the definition for the scores for the different attributes. The AHP was conducted in one single group of the different experts involved in the project.

Table 3-1: AHP weights and scores.

Weight	Attribute	Score				
		1	**3**	**5**	**7**	**9**
6	**Resource Risk**	High	Considerable	Moderate	Small	Insignificant
4	**Resource Management**	External management		Resource managed by ON[1]. Hot water production not a primary business	Managed in part by ON[1] and in part by Veitur	Resource managed by Veitur
2	**Operational risk management**	Activity increases production from a resource that supplies more than 20% of total	High partner risk, e.g. when primary goal of partner is not hot water production	Activity involves development in volcanically active area or considerable partner risk	Activity in part in a volcanically active area	Activity outside volcanically active areas or activities to increase production from current installations
6	**Planning and permitting**	Activity needs to be adopted to Master Plan[2]	EIAP required and not completed	Considerable modification to municipal plans needed	Minor changes to municipal plans needed. Activity does not fall under EIAP Act	Planning and permissions not an obstacle
8	**Improved resource utilization**	Production of more heat than needed or considerable amount of electricity needed to produce hot water	Pure thermal plant in a high temperature field. No excess hot water production		Activity involves utilization of all heat produced down to 30°C	Improved utilization of current fluid production
6	**Environmental impact**	Significant negative impact over the lifetime of the project in an undisturbed area.	Significant negative impact over the lifetime of the project in an already disturbed area.	Minor negative impact	Insignificant and reversible impact	Negligible or positive impact

[1] an OR subsidiary. 2 The Master Plan for Nature Protection and Energy Utilization a local Icelandic process

Resource risk: The lowest scores for resource risk (1) were given to new geothermal fields that do not have any surface manifestations and the highest scores (9) were given to options utilizing waste heat from industry and return water as well as the planned expansions of the Hellisheidi power plant.

Resource management: This attribute reflects the risk resulting from entities other than Veitur managing the heat resources. The lowest scores for this attribute were given to resources managed by entities outside the Reykjavik Energy Group (OR), such as the waste heat from industry and high enthalpy fields managed by other power companies. The highest scores were given to options managed by Veitur. Scores of 5 and 7 were given to options managed by ON Power (an OR subsidiary) and ON Power and Veitur together, respectively.

Operational risk management: This attribute captures several components, including relying too heavily on heat from a single resource (applies to expansions of the Hellisheidi and Nesjavellir Power plants), risk of disruptions by volcanic activity (applies to development of other high-enthalpy resources in volcanic settings), and the risk incurred by relying on heat from operators that do not have heat production as their primary business (waste heat from industry). Other options generally got full score for this attribute.

Planning and permitting: This attribute captures the effort and time needed to clear planning and permitting hurdles and the lowest scores were given to options that involve development of new high-enthalpy fields, particularly for fields that are not already in the utilization category of the National Master Plan for Nature Protection and Energy Utilization. The highest score was given to options based on expansions of existing heat production options.

Improved resource utilization: The lowest scores were given to options that do not utilize all the heat that is produced (combined heat and power plants) and options that require significant electric power input (heat pumps). The highest scores go to options that utilize heat that is currently produced but not used, including waste heat from industry and expansions of the Hellisheidi power plant.

Environmental impact: The lowest scores are given to options that involve development of pristine geothermal fields and the highest score is given to options that involve expansions of current resources that generally do not require new wells or pipelines in undisturbed areas.

3.3 Comparison of available options

The results of the cost and AHP analyses are summarized in Table 3-2 and Figure 3-2. The table shows that the estimated annual cost per l/s ranges by more than one and half order of magnitude or from 0.14 million ISK to 8,2 million ISK. The most economically feasible options are the expansions of current activities in low- and high-enthalpy fields. The most expensive options are small operations involving waste heat from industry that require heat pumps and the option of using heat pumps on return water. The table also shows that there is a considerable overlap of the costs of new low-enthalpy operations and expansions of current activities. New high-enthalpy options are, however, in all cases more expensive than expansions of existing activities.

Expansions of current activities generally also receive favourable AHP scores. Options involving waste heat from industry and heat pumps on return water also get fairly high AHP scores. The lowest AHP scores are given to new high-enthalpy options and some new low-enthalpy options.

Table 3-2. Cost estimates and AHP results for the heating options considered.

Option	Number	Estimated capacity	Cost estimate (MISK/l/s/year)		AHP results[1]	
		l/s @80°c	Weighted average	Range	Weighted average	Range
LE – New operations	7	450 – 2,650	0,73	0,4 – 1,2	4.9	3.2.-7.0
LE - Expansions	16	850	0,39	0,2 – 4,9	8.5	7.9-8.6
HE – New operations	15	4,000-13.800	1,75	1,65 – 1,8	2.2	1.2-3.4
HE - Expansions	7	3,700	0,32	0,14 - 1,3	6.6	5.2-8.0
Industry - Waste heat	8	650	3,4	1,7 - 8,2	7.0	5.6-7.6
Return water – Heat pumps	1	1,950	7,45	na	6.6	na

[1] see Table 3-1 for AHP score definitions.

Figure 3-2 shows cost estimates and AHP results for individual options. The most feasible options cluster in the lower left-hand corner of the figure. These options are mostly expansions of current operations in low- and high-enthalpy fields and new low-enthalpy fields. The figure also highlights how options involving the return water and many of the options using heat from industry are two to eight times more expensive than the most feasible options. Finally, the figure shows how the new high-enthalpy options, and some new low-enthalpy options tend to have much lower AHP scores and are slightly less economically feasible than the most feasible options.

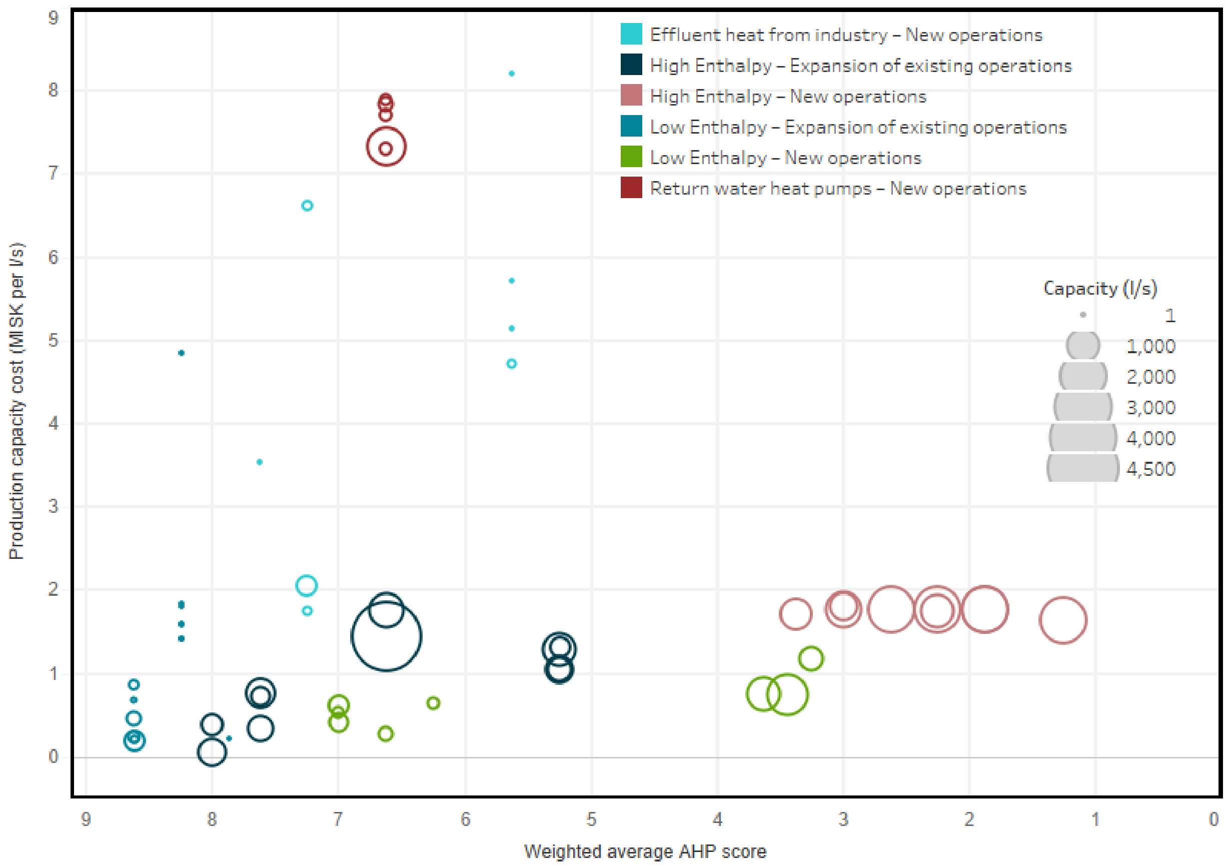

Figure 3-2: Annual production cost of 80°C hot water as a function of weighted AHP score for the options considered in this study.

4. ROADMAP

The ultimate output of this project is a roadmap of how Veitur can meet its mandate of providing sufficient heat to meet the heating needs of the capital area in a cost-effective way for 100 years. Figure 4-1 shows the high-level results. The red curve represents the upper limit of the demand forecast and the blue circles represent new resources connected to the system. The resources were added in the order of economic feasibility, starting with the most economically feasible options first.

The project team is cognizant of the plethora of uncertainties regarding the demand forecast and the capacity estimates of unexplored geothermal fields and by ignoring potential developments towards increased energy efficiency of buildings. The figure, nevertheless, shows that even if the aggressive demand forecast is realized there are sufficient resources to meet the demand growth for the next century. This can be done by implementing the planned expansions of the production capacity of the existing low- and high-enthalpy options, developing the known new low-enthalpy fields near the capital and some of the high-enthalpy resources in the vicinity of the capital area.

Figure 4-2 shows the cumulative capital investment cost for the development and connection of new heating resources for the Reykjavík District Heating. The increasing slope of the cumulative investment cost curve reflects that new resources are added in the order of decreasing economic feasibility.

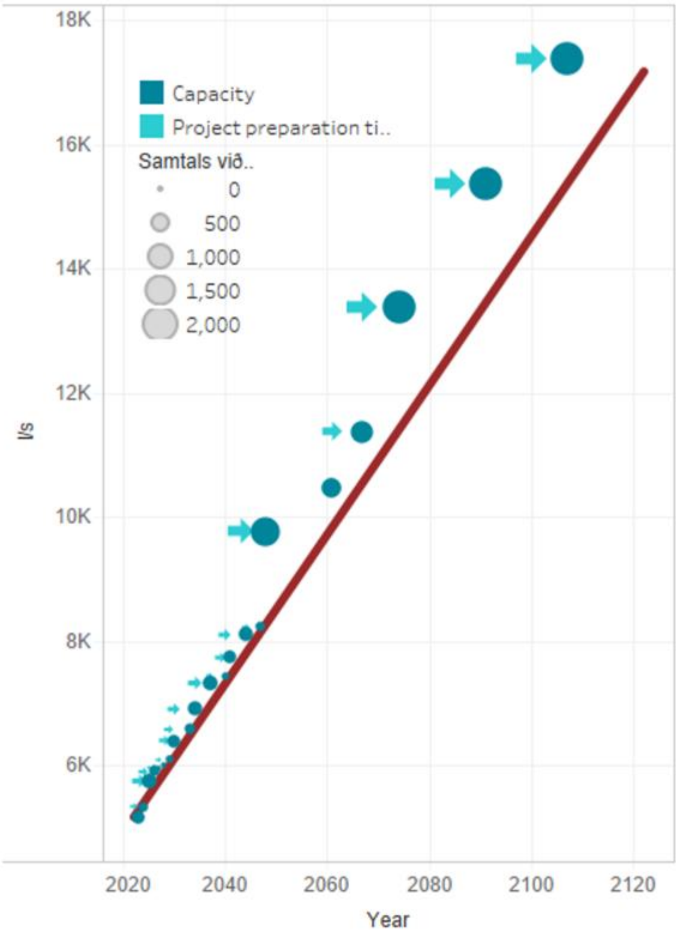

Figure 4-1: 100-year roadmap for the Reykjavík District Heating system. The figure shows how new heating resources need to be added to the system in order to keep the production capacity above the long-term demand forecast (red curve).

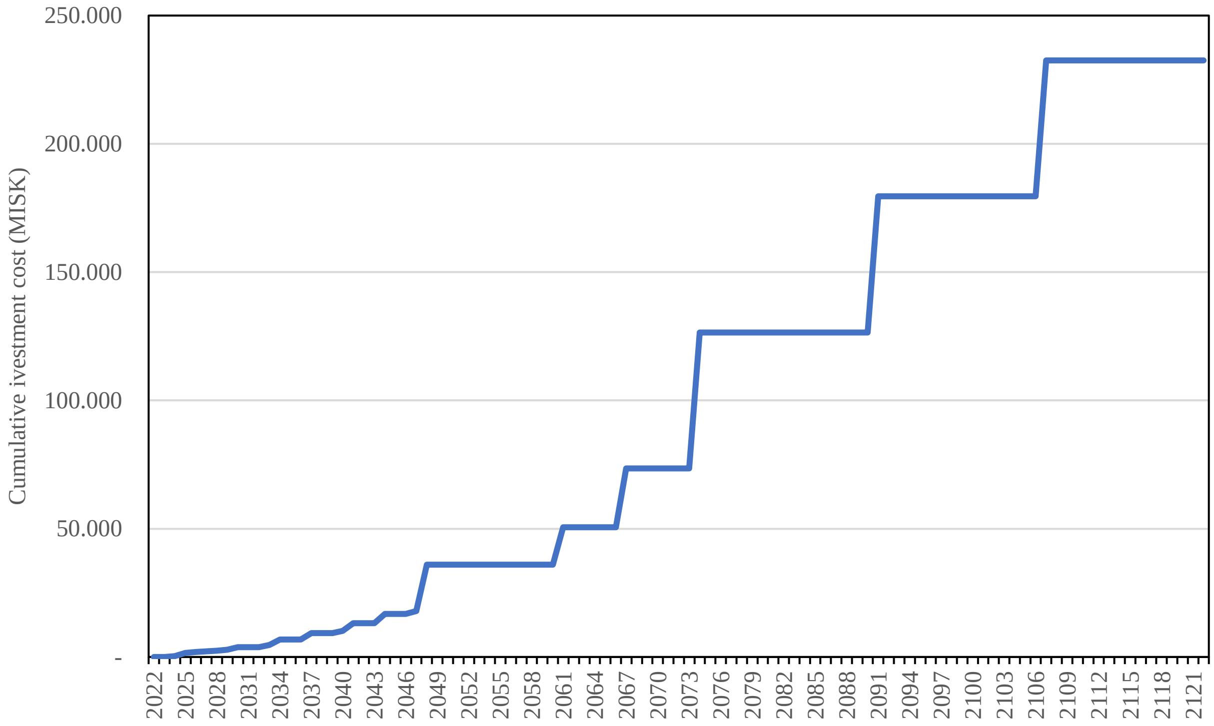

Figure 4-2: Cumulative investment cost for the development of new resources for the Reykjavík District Heating over the next 100 years based on the roadmap for resource development for the Reykjavík District Heating.

5. KEY LESSONS

The current 6 geothermal resources are close to the limit during the district heating network's current peak demand. The roadmap, created in this project, delivers the next steps in gathering new resources that are both cost beneficial and have high AHP scores. The project confirmed that an expansion of the current resources is both beneficial as well as receiving a high AHP score.

A key lesson derived from this work is the feasibility and high AHP score of new low-enthalpy geothermal fields. Veitur Utilities and OR-Reykjavik Energy have not developed a new low-enthalpy area since 1967 when Ellidaardalur area was taken into production. Even though exploration in new areas has been conducted, funding and resources have not been prioritized. This was an important finding, as the project results shifted focus from looking at power plants in new high-enthalpy geothermal fields to realizing that a combined system of feasible low-enthalpy areas as well as new power plants will ensure a more sustainable and cost-effective source of hot water for the Capital region. The reality is that power plants in high-enthalpy geothermal areas can provide a greater volume of water, this however does not exclude exploring the low-enthalpy areas. When located close to urban areas, low-enthalpy areas can reduce cost of transmission pipes from power plants, creating a more sustainable geothermal district heating system, and reduces operational risk by increasing the number of resources that the district heating network utilizes.

Another lesson is the high cost of utilizing waste heat from industry that require heat pumps and the option of using heat pumps on return water. These options have been on the radar of Veitur Utilities for some time; however, the project results show that direct use of geothermal energy is a more feasible and sustainable option, under the current circumstances. There are still relatively low hanging fruits available before Veitur Utilities would be advised to explore more expensive resources.

An important finding in the project was a reminder of the gestation period of low-enthalpy geothermal areas. Even though new possible areas have been identified and researched to some extent, there are risks in terms of cost, time and magnitude when drilling in geothermal fields. Further exploration and planning also need to be taken into consideration, which is time consuming. Additionally, potential production capacity of the field will not be fully understood until production has begun. This has pushed Veitur to start exploring new low temperature geothermal fields in a more structured manner, parallel to exploring other options and years before full expected utilization is needed.

When the methodological approach of the project was reviewed, the group identified a risk of social comparison bias in the AHP analysis. To mitigate this risk in the next update, or in other similar projects, it would be recommended to conduct the AHP in smaller groups and compare the results afterwards. Another risk lies in the difference in available data of the options that were explored, which affects the cost-analysis. This is addressed in the AHP analysis; however, it is vital to carefully mitigate this risk when putting the roadmap to use. This can be done by exploring several resource options simultaneously, not ruling out or choosing options until detailed information has been gathered and reviewed.

It is also important to note that Veitur is continuously evaluating and analysing new technologies and resources that are available in the market to ensure that they are utilizing the most cost-effective and efficient options. By continuously staying up to date with the latest technologies and resources, Veitur can ensure that they are providing a reliable and sustainable source of energy to their customers.

6. REFERENCES

Ragnarson, A., Steingrimsson, B., & Thorhallsson, S. (2021). Geothermal Development in Iceland 2015-2019. *World Geothermal Congress 2020+1*. Reykjavik.