How policy, technology and innovation can foster geothermal district heating development

An Icelandic case study

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ABSTRACT

In addition to shedding light on key success factors to geothermal development in Iceland, this paper proposes to bring insight on advantages of district heating.

Iceland is well-known for its exemplary utilization of geothermal resources, having today over 90% of households heated up via utilisation of geothermal resources. What is less known to the general public is the history and the synergies that allowed this to happen. The journey started some 80 years ago in the 1930’s, when visionaries had the idea to use the resources below their feet for space heating in Reykjavík. It did not go without debate and started slowly, house by house, street by street. It was not until the 1960’s that development accelerated when various legislative tools were put into place and the system was enhanced. By then, Icelanders had learned many lessons about geothermal district heating from the Reykjavik system and were able to transfer their knowledge and experience to other parts of the country.

This brings us to an event that took place in the early 1970’s with a volcanic eruption in the Westman Islands. The Island did not have any specific geothermal resources available for direct use but once the eruption had settled, the hot lava was used as a heat exchanger for a new local district heating taking benefits of the knowledge and experience accumulated over the years from the Reykjavík geothermal district heating system. 20 years later, when the heat stored in the lava was exhausted, the local utility sought other sources of energy such as waste energy from fish industry combined with energy from waste incineration, an electrical boiler and now with prospects of a heat pump, showing how flexible such a system can be in the long term.

REYKJAVIK DISTRICT HEATING – FORERUNNER OF GEOTHERMAL UTILISATION IN ICELAND

District heating, as any utility is not easy to develop . Add to this equation the uncertainty related to geothermal resources and it probably explains why so few geothermal district heating systems have been developed so far despite geothermal resources being available in many ideal places, where both climate and population density justify the installation of such a system.

Pioneers and public debate

Iceland is nowadays considered a model for geothermal utilization. Nevertheless, development in this field is fairly recent.

Snorri Sturluson, Icelandic historian, poet and politician in the 13th century, was famous among other things for his pool, Snorralaug, in Reykholt which possibly dates back to the 10th century. Not much was done with this resource that flowed here and there around the country apart maybe for washing clothes like Reykjavík, see Figure 1.

Figure 1: Laundry springs in Reykjavík.

Early in the 20th century, various trials were conducted by farmers and industrials across the country to tame hot springs and use for heating, cooking, and food sterilisation. A farmer in Seltjarnarnes diverted a hot spring to his house for heating purposes in 1908. In 1920, Sigurjón Pétursson used hot water from the Amsterdamhver, a spring nearby Alafoss, close to Reykjavík, not only to heat up his factory and the houses where his staff dwelled, but also in the process for drying the wool, for cooking and to boost the growth of vegetables in his garden. The system piped 70-75°C hot water over about 1,1 km and once used through the system, the run off was 57°C. It is said that this allowed the industrial plant to save about 150 tons of coal annually.

Other pioneers across the country found ingenious ways to use geothermal energy for their businesses or simply to keep their houses warm. The technique was not quite there though and progress in this field was slow for various reasons: equipment and material was expensive and people had to find economic solutions to gather hot water and channel it to the right place with minimal heat losses.

In the early 1930’s, heating up houses in Iceland was still a luxury with its set of side effects on health and safety. Reykjavík and its neighbouring cities had about 33.000 inhabitants. The area was covered with smog from coal burning (Figure 2).

Figure 2: Smog in Reykjavík prior to geothermal utilisation.

Scientists, politicians and visionaries had been stirring the debate on geothermal for a while arguing that geothermal would be a benefit for society but still not finding a consensus on the way to proceed.

During World War I, the society had realised how dependent it was energetically. Coal price had become so high in 1917 that the Parliament discussed possibility to suspend school over the winter.

The price of coal had been steadily increasing becoming in itself an ideal driver for shifting to a new source of energy.

Large public users as a booster

A first step was taken in 1930 with the connection of a relatively large user, the primary school Austurbæjarskóli, a swimming pool and 60 to 70 houses. The system was fed by 14 shallow wells in the vicinity of the laundry springs and produced a total of 14 l/s of 87°C water. The water was piped through a 3 km long pipeline to its end users.

Such an approach of connecting a large public user is very common and quite often practiced to strengthen a geothermal district heating project to make the prices more attractive to other smaller users who cannot be reached by any incentive.

In 1943, a second step was taken with the implementation of the so-called Reykjaveita (Figure 3), fetching 200 l/s of 86°C hot water self-flowing from shallow wells some 17 km away from the main users. About 2850 houses were connected with this new system.

Figure 3: Installation of the new Reykjaveita, 1943.

Political will

Much debate was still ongoing regarding geothermal district heating and a party even advertised itself as pro district heating as part of its campaign (Figure 4). The campaign promised cleaner air and modernised indoor lifestyle.

Figure 4: Vote for geothermal district heating.

Among the measures that were taken to promote district heating, was a recommendation from the city to house owners refurbishing their property or building new houses that everyone connect to the district heating system whenever possible.

After the war – more prosperous conditions

Soon after the war, the population in Reykjavík and neighbouring towns started to grow rapidly with 65.000 inhabitants in 1950. The district heating system had proven its viability and its growth was mainly limited by the pace at which demand could be matched by supply. Never-the-less, hot water shortages were quite common and in 1958, more wells were drilled and deep well pumps were installed to boost the system’s capacity.

Renewal of Reykjaveita pipeline was also undertaken thanks to a loan granted by the World Bank.

Legal steps towards generalisation of geothermal district heating and new technology is available

Between 1961 and 1972, the geothermal district heating in Reykjavik expanded rapidly with new neighbourhoods being developed. In 1972, over 98% of the city was connected to the system. About 108.000 inhabitants were in the area or approximately half of the country’s population.

Various conditions and measures contributed to this achievement. For instance a law was enforced concerning new houses that were to be systematically connected to district heating. Also the capacity of the system was increased and innovation in the field of deep well pumps (Figure 6) and piping insulation paved the path to the expansion of the system.

Oil crisis in 1973-74 then boosted even more the development of geothermal district heating in Iceland.

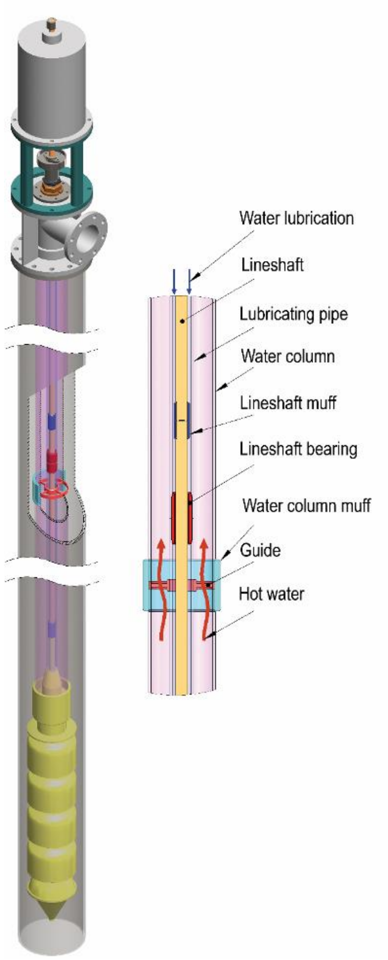

Figure 6: Icelandic geothermal well pump, an innovation making the expansion of district heating possible

Later steps - Cogeneration…

Later on, following the example set in Svartsengi, capacity was added to the Reykjavik district heating system when harnessing of geothermal energy began at the high temperature field at Nesjavellir in the 1990’s and more recently at Hellisheiði.

Today there are six times more people living in the Reykjavik area than in 1930. Geothermal district heating has been installed in other communities around the country. Exponential growth of the city is without a doubt linked to various factors but it is certain that geothermal district heating has played its part in making the city attractive for a quality of life and economical point of view. The example set in Reykjavík has been followed in other places in Iceland as can be seen in Figure x and today over 40 geothermal district heating systems are in use all over the country, Figure 7, with a total installed power of 2,1GW successfully contributing to energy independence of the country.

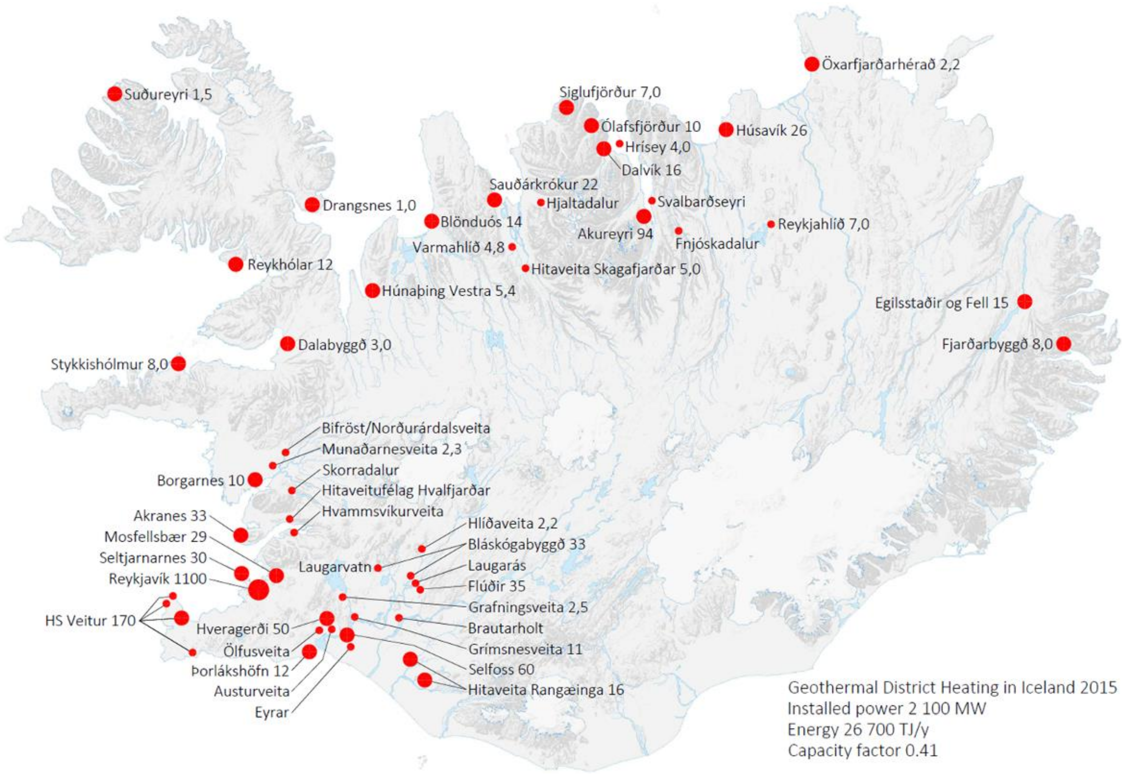

Figure 7: Geothermal district heating in Iceland in 2016.

THE WESTMAN ISLANDS CASE

This brings us to the Westman islands case in the early 1970s. Not all the communities in Iceland are blessed with cheap and easily accessible geothermal resources. The Westman Islands used to be a tough place to live. Located only a few kilometres off the south shore of Iceland, fresh water resources are very limited there and no specific geothermal resources are to be found on the island despite the presence of a volcano.

In January 1973, a sudden eruption took the inhabitants of the man island Heimaey by surprise. About 5.300 inhabitants lived in the island by that time, They had to flee overnight not to return until a few months later.

The eruption was not considered to be a big one compared to prior eruptions in Iceland although about 250 million cubic meters of lava had been expelled. The lava’s special composition made very viscous when it started to cool and it accumulated in piles along a path that lay northeast of the crater. The eruption engulfed many houses and nearly blocked the harbour that was and remains the only connection point to the main island, a vital element for the economic activities of the island. Seawater was sprayed on the lava during the eruption and successfully stopped the inflow of lava from completely blocking the harbour, Figure 8. When the eruption was over, the area of the island had increased from 11,2 km^2 to 13,44 km^2 and the lava field was about 100-130 m thick.

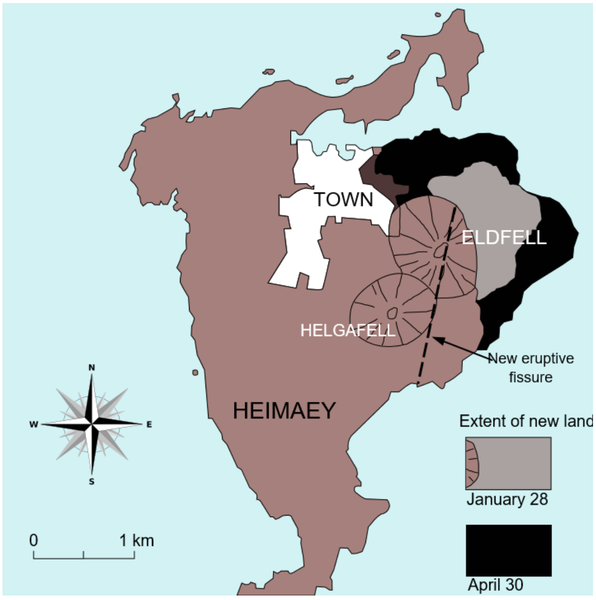

Figure 8: Heimaey after the eruption.

It is considered that the eruption brought along about 250 million megawatt hours of energy.

When people were allowed to return to their house, a giant cleaning and rebuilding effort had to take place and the idea of using the heat stored in the lava started to take form.

It is important to understand that district heating was by that time broadly accepted by people. The technology was considered mature and geothermal district heating systems were under consideration or being developed all around the country. There was no question about the benefit of such system. However, for the inhabitants of the Westman islands, the source of energy was to be either a conventional fossil fuel or with a little innovation, this unusual source of heat. In the end, district heating was implemented and it was inaugurated in the spring of 1975. It was connected to a temporary heating plant and was to be later connected to a boiler using electricity and oil as a backup. However, these plans were soon changed and the lava was used as a source of heat instead.

A letter was written soon after the eruption ended, arguing that this source of free heat should be taken advantage of. Here is an extract from this letter:

"*Lava heat in Heimaey*

It can be compared with that, The inhabitants of the Westmann islands have just acquired a tank full of oil – million tons – that would last for house heating over the coming 15 to 20 years, whether it is used or not.

One of the drawbacks is that the tank is full of small holes and that the source of heat seeps away with every day that passes. No-one can do anything about it. There is no other advice to use this precious power than to begin immediately, and hurry up as if capelin was coming from the north sea. It is impossible to transfer the lava heat in another storage or sell it abroad like pumice or cod from the sea. The inhabitants of the Westman islands should use it themselves immediately for space heating instead of buying oil from Middle East. One fifteenth of it disappears in the "weather and wind" each year that goes by without action. And the lost comfort and cosiness will never be recovered.

Is this an interesting case for the baks of the country or a project for "Sparisjóð Vestmannaeyja" [local Westman fund]?"

So, it was urgent to investigate this idea and geoscientists and engineers began to try out various setups.

An innovative experiment

A total of seven boreholes were drilled soon after the eruption in the new lava to monitor the gases and cooling of the field. Another well that had been drilled prior to the eruption for fresh water was also used. It was pointed out that an interesting heat source was there and that it could be harvested.

To start with, a six meter long spiral heat exchanger was manufactured by Ofnasmiðjan under the guidance of Sveinbjörn Jónsson and Hlöðver Johnsen and installed in one of the boreholes. Water was then circulated in the loop. Results were satisfying and in January 1974, the first house was connected to the system. The system was not very stable and a few months later it stopped working. Another trial was conducted with a longer heat exchanger followed by other trials but it was not satisfying. Many challenges were encountered such as corrosion and unstable systems. Liquid lava was still to be found in the middle of the field and it was difficult to get a fair model of the system in order to predict the cooling effect from below and from above with enough certainty. The project was taken to another level and Raunvísindastofnun Háskólans (the Icelandic Science Institute) got to investigate the matter further with special funds dedicated to the project.

Finally the idea of spraying water on the lava and collecting it underground once it had been heated up was investigated. A so-called steam gathering system was installed, consisting of a water spraying system, a steam well aimed at gathering the steam below and a house equipped with a heat exchanger.

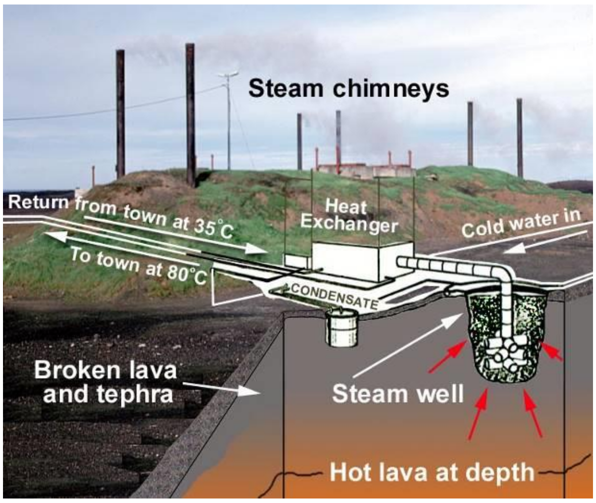

Figure 9: Principle of the steam gathering system.

From 1979 on, this principle was implemented successfully. Meanwhile the district heating system in town was enlarged and a double pipe distribution system installed. It was designed for 80-35°C supply-return water, Figure 9.

Figure 10: The town seen from one of the production areas.

In total, four steam harnessing areas were implemented with one fourth, or 60 x 70 metre, used at once. Each area was connected to nine steam wells and equipped with six heat exchangers. The system was able to produce about 20 MW in total and each harnessing area was expected to last for two to three years, Figure 10 and 11.

Figure 11: A steam well installed.

Nevertheless, by 1989, the system was only able to supply 50°C to the district heating. Since this was foreseeable, a committee had already been appointed by 1986 in order to plan for a suitable alternative to the lava heating system. Fortunately, the district heating system provided for flexibility and it was mainly a matter of finding a new source of energy

Switch over to new sources of energy

Various solutions were available ranging from standard fossil fuels such as coal, oil or gas to the use of waste heat from incineration or fish industry or even more interestingly heat pumps. The situation of the islands is peculiar in that sense that electricity is produced on the mainland and distributed to the island via a sub-marine cable. Iceland’s electricity was in the late 1980’s already mostly produced with renewable sources of energy, hydropower and geothermal, an advantageous solution. A deal was cut in 1988 with Landsvirkjun and Rafmangsveitur Ríkisins, the state production and transmission companies, to supply so-called surplus electricity to the Westman islands at beneficial cost. The lava district heating was now supplied with energy from an electrical boiler.

But the story is not over, district heating systems being rather flexible, the idea previously investigated of using waste heat from incineration was later on taken up and implemented, in 1998. Also, waste heat from fishing industry was taken advantage of.

Today, the heat central is part of the Westman Island´s district heating system. Primary energy is electricity from hydropower and geothermal power stations on the mainland. This is used to produce steam in an electrode boiler for heating of secondary district heating water circulated in a closed-loop distribution network. Heating energy from other sources is also utilised, among these is waste heat from a refuse burning plant and two fish processing factories. For reserve heating and emergency back-up, three heavy fuel oil boilers have been installed.

Newest development

Today’s system has a total installed power of 20 MW and the current maximum demand is 15 MW. About 4.300 inhabitants live on the island. The distribution system is a traditional two pipe system. All pipes are pre- steel pipes insulated with polyurethane in polyethylene casing pipe. The annual energy consumption is 67 GWh, 81% of which comes from electricity, 9% from waste, 6% from fish processing factories and 4 % from oil.

A feasibility study has been carried out for installation of a 3 – 9 MW heat pump that would provide the base load for the heating system. The system will most likely be upgraded in 2017.

3. CONCLUSIONS

The story of how geothermal district heating has been developed in Iceland is an interesting case that could be used as an interesting example to follow in many places around the world.

As a matter of fact district heating is a mature technology that can easily be implemented in new neighbourhoods as well as in retrofitted areas. One could argue that Iceland is blessed with geothermal resources and that using them for district heating is indeed common sense but the story told here shows that it took quite a few steps to bring it to the level of utilisation at which it is today. The Reykjavík geothermal district heating will hopefully be a source of inspiration for other cities as it was at times in Iceland.

What the Westman Islands story tells us in addition to that is that a district heating system is a valuable facility, flexible and easy to adapt to any changes in the direct environment: the city has been able over 40 years to use waste heat from several sources to serve its heating load including lava, an electric boiler, waste heat from incineration and the fish industry and is currently planning on installing a seawater heat pump.

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Figure 8 By Eldfell_eruption.svg: Ejkum derivative work: Cmglee - This file was derived from Eldfell eruption.svg:, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=24095230