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District Heating and Economy of Scale

Ragnar Thorisson, Gabor Molnar, Lilja Tryggvadottir

Urdarhvarf 6, 203 Kopavogur, ICELAND

ragnar.thorisson@mannvit.is

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ABSTRACT

A tendency in the market favors electricity generation from renewable resources. Low and medium enthalpy geothermal resources are thus often modelled for electricity generation before investigating the possibility of direct use. The objective is to investigate and show for reference the economy of scale for Geothermal District Heating Systems (GDHS).

For the purpose of this paper the investigation is framed into four scenarios:

- Well(s) and a distribution system in place
- Well(s) in place but not distribution system
- Distribution system in place but no well(s)
- Neither well(s) nor distribution system in place

There are unutilized geothermal wells that produce geothermal water at temperatures ideal for GDHS. The most common obstacles considered are the lack of a distribution system to customers and a small locally bound market.

This paper presents the minimum requirements for a potential GDHS project investment to become feasible during its lifetime based on market size and population for each scenario mentioned above.

In certain areas grants are available for GDHS development. Furthermore the harnessing of the geothermal energy and the development of the distribution systems can be viewed as separate projects. These projects can be subject to separate grant schemes. The feasibility of the projects will be estimated with and without grants.

1. INTRODUCTION

The first distribution system for geothermal district heating in Iceland was completed and went into operation in Reykjavik in 1930. It was generated from a low enthalpy source and yielded 3.4 MW of thermal power. It served 2-3% of the population in Reykjavik at the time. Before, buildings were heated by burning coal or peat and later oil. Soon it became apparent that the living standard in geothermal heated houses was much higher and expansion of the distribution system became a recurring matter in local government elections (Thordarson and Jonasson, 2006).

The first municipal in Iceland to connect a geothermal district heating distribution system to every household was Ólafsfjörður in 1944. About 700 inhabitants in 150 apartments were connected. The system was initially intended to have a ten year lifetime, the same as the estimated return on investment. A part of it lasted half a century and was renovated in 1997 (Thordarson and Jonasson, 2006).

In 2006 approximately 54% of geothermal energy in Iceland is utilized for district heating. In 2005 the distribution system in Iceland totaled approximately 3,800 km and about nine out of ten people in Iceland are connected (Thordarson and Jonasson, 2006).

Price fluctuations on imported fossil fuel were a large factor in this rapid shift to utilization of locally powered cheap geothermal district heating. Although the capital costs for drilling of wells and construction of distribution system and infrastructure are high the resulting drastic reduction in dependence of imported fossil fuel means that this has since proved to be extremely financially beneficial and the capital costs have long since been paid back (Thordarson and Jonasson, 2006). The savings in 2012 by utilizing geothermal energy compared to heating with oil amounted to approximately 720 million Euros or 22,000 Euros per person. Accumulated net present value of savings from 1914 – 2012 amounts to approximately 15,000 million Euros (National Energy Authority of Iceland, 2013).

But why isn't everybody that is able to utilize geothermal power utilizing it? In the U.S. the economic feasibility of a geothermal district heating system (GDHS) development was identified as the main barrier by local leaders in communities located in geothermal active areas (Thorsteinsson, 2008). Thorsteinsson (2008) concluded that geothermal district heating systems can be developed economically and will provide savings for their users. Thorsteinsson (2008) also identified that financial incentives, such as grants, are important. Another barrier identified by Thorsteinsson (2008) is that geothermal is not well recognized by the general public as an energy source.

The aim of this report is to show that GDHS development is indeed financially viable. This is done by identifying the economy of scale, i.e. what is the necessary market size, which translates to population size, for a GDHS development to become financially viable.

2. SCENARIOS

Throughout the world there are municipalities located in geothermal active areas. A geothermal active area refers to areas that have an underground geothermal source that can be drilled into and harvested. These sources can be classified as high-enthalpy and low-enthalpy sources depending on the temperature and pressure. For the purposes of this paper the focus is on the low-enthalpy sources.

Many municipalities located near a low-enthalpy geothermal source are not utilizing its power for district heating. Buildings in these municipalities are heated with several different methods. The most common methods are local boilers and district heating systems that are e.g. powered with fossil fuel. Municipalities that have district heating systems have got an existing distribution system that can be adapted for a GDHS. Additionally, some municipalities may have access to one or more unutilized geothermal wells that can be used for a GDHS. A schematic drawing of a complete GDHS is shown in Figure 1.

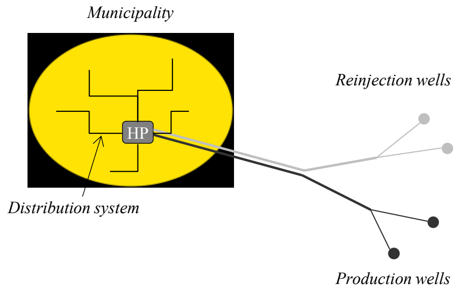

Figure 1: Schematic drawing of a GDHS.

The two most expensive parts of a GDHS are namely the distribution system and geothermal wells. Therefore it is logical for the purpose of this paper to frame the investigation into four scenarios depending on the existence of these two components. The scenarios are summarized in Table 1 and shown schematically in Figures 2 through 5. The scenarios are then expanded upon in the following sections.

Table 1: Scenario numbers.

	Distribution System	No Distribution System
Wells	1	2
No Wells	3	4

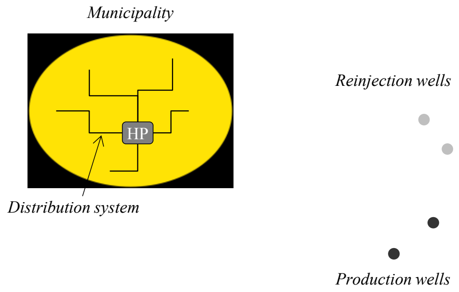

Figure 2: Schematic drawing of scenario 1.

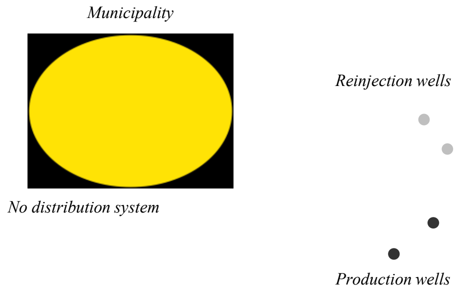

Figure 3: Schematic drawing of scenario 2.

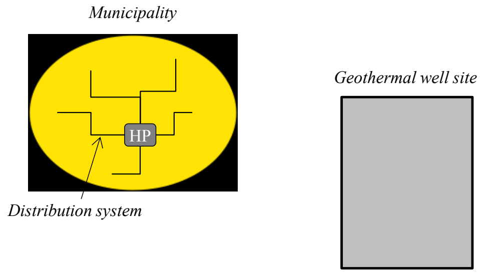

Figure 4: Schematic drawing of scenario 3.

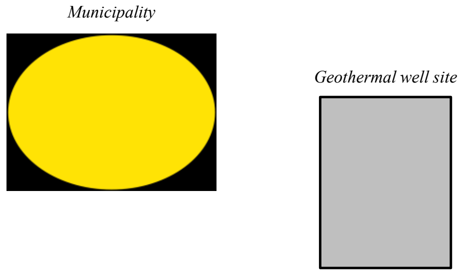

Figure 5: Schematic drawing of scenario 4.

2.1 Well(s) and a Distribution System in Place

Figure 2 shows a schematic drawing of scenario 1. By comparing this to Figure 1 it shows that the project deals with connecting the wells to the existing distribution system via a heat plant. It is assumed that the number of existing geothermal wells is sufficient to meet the total heat demand of the population, i.e. no additional wells need to be drilled. In this scenario the cost of drilling, well sites and distribution system is neglected. Adaptation costs are included.

2.2 Well(s) in Place but no Distribution System

Figure 3 shows a schematic drawing of scenario 2. By comparing this to Figure 1 it shows that the project deals with constructing a distribution system and a heat plant and connecting the existing wells to it. It is assumed that the number of existing geothermal wells is sufficient to meet the total heat demand of the population, i.e. no additional wells need to be drilled. In this scenario the cost of drilling and well sites is neglected. Adaptation costs are included.

2.3 Distribution System in Place but no Well(s)

Figure 4 shows a schematic drawing of scenario 3. By comparing this to Figure 1 it shows that the project is about drilling new geothermal wells and connecting it to the existing distribution system via a heat plant. In this scenario the cost of a distribution system is neglected. Adaptation costs are included.

2.4 Neither Well(s) nor Distribution System in Place

Figure 5 shows a schematic drawing of scenario 4. By comparing this to Figure 1 it shows that the project deals with developing a total GDHS from scratch. Geothermal wells need to be drilled and a distribution system needs to be constructed.

3. ASSUMPTIONS

In order to estimate the cost and financial parameters of a general GDHS several assumptions are made. These assumptions are organized into the following groups:

- Town size and density
- Heat market size
- Construction and operational costs
- Financial assumptions

All of these are based on Mannvit's experiences (Mannvit kft., 2011) and general average data of a town and landscape.

3.1 Town Size and Density

Towns with population from a few thousand people up to 2 million are taken into consideration in the modelling. Town size and density is assumed to be in line with the population, greater population means larger town and greater density at the same time. There are two kinds of density variables used for the calculation. Both are assumed different for downtown and for suburban areas. Density values have an effect on the installation cost within the town and on the heat market size as well. The density variables used in the model are:

- Building density
- Utility density

Building density reflects on the size of the buildings (number of flats per building) and the available free space between them. Smaller villages and suburban areas of small cities usually consist of family houses with large gardens, while the downtown areas of cities are highly built up with larger residential and commercial buildings.

Utility density is similar to building density. It reflects on the number of existing utilities needed to be taken care of during construction, ratio of the concrete or asphalt paved surfaces and green areas, etc. This has considerable effect on the pipeline installation and design cost.

According to experience, building density in downtown areas is assumed to be 100% (maximum value) when population reaches 100,000, while suburban density is always half of it. Utility density reaches its maximum value, 100%, at population value of 30,000, which is assumed to be an average size "small city".

Town size also has direct effect on the pipeline installation cost. Larger town results in longer pipelines because distance between the resource and the consumer is greater.

3.2 Heat Market Size

Heating capacity demand is one of the main determining parameters of a geothermal system. The required capacity value is calculated from the estimated number of flats in the town (1 flat for every 2.48 inhabitant - KSH data sheet, 2012), number of commercial and industrial buildings (based on experience and statistical data) and the average heat demand of different consumer types (based on standard values). These values are summarized in Table 2.

Table 2: Heat capacity demand.

	Yearly heat amount ($MJ/m^2/year$)		Heat capacity demand ($W/1,000\ m^2$)		Average	
	Newly built	Old, badly insulated	Newly built	Old, badly insulated	Capacity (W/m^2)	Size (m^2)
Block of flats	540	756	60	70	0.068	50
Family houses	630	900	85	100	0.097	100
Office building	504	684	75	85	0.083	3,000
School	540	684	70	80	0.078	1,500
Industrial	666	990	90	105	0.102	1,000

Total heat demand of the town can be calculated using the numbers and assumptions presented above. District heating system size is determined using the following assumptions. District heated flats are usually located in downtown areas and the DH system heat demand in most cases is maximum at approximately 1/3 of the town's total heat demand. Therefore, to estimate the real heat demand it is calculated from the total heat demand divided by 3 and multiplied by the density.

Each well is assumed to yield on average 30 l/s at 90°C. These values are chosen according to Mannvit's experience on low-enthalpy geothermal areas (Mannvit kft., 2011). However, the forward and return temperature of the district heating system is assumed to be 100°C and 70°C respectively during the peak heat demand on the coldest months. This creates an excess heat demand. Figure 6 shows this excess demand in the case of a municipality with 20,000 inhabitants. This demand is assumed to be fulfilled with gas boilers.

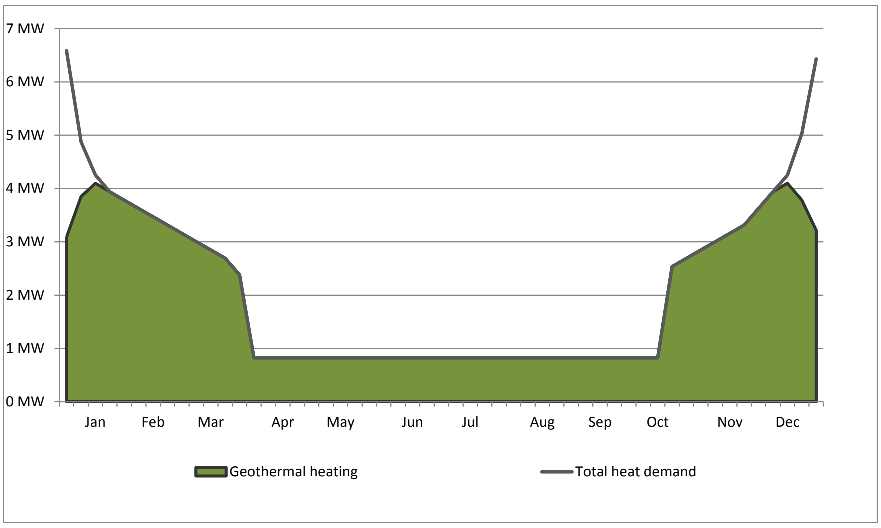

Figure 6. Heat demand curve.

3.3 Construction and Operational Costs

One of the largest cost elements of a geothermal system is the drilling of wells. The number of production wells is determined from the heat demand (using the exploitable amount of energy from one well).

It is assumed in the model that the number of production wells is never more than 6, which limits the size of the DH system. This limit is used because large number of wells requires huge investment and a long time to drill. This is not realistic when the present investment environment is taken into consideration. Large number of wells also has serious licensing effect; high level utilization of the water base is very risky from a licensing point of view.

The number of reinjection wells is assumed to be the same as the production wells.

Another large cost element of the DH system is the geothermal and distribution system pipeline. Its length is defined based on the town size and the pipeline diameter is calculated according to the number of production wells (harvested flow rate).

Drilling cost and pipeline installation costs is calculated based on industrial standards by estimating the necessary material and installation costs. Costs of the mechanical and electrical equipment are defined according to the GDHS size in MW.

Operation cost is calculated based on experience as the ratio between the installation cost of the different equipment and facilities of the GDHS.

3.4 Financial Assumptions

It is expected that the project financing will be a mixture of the following sources:

- Investor
- Non-refundable grant
- Bank financing

Financial and/or technical investor shall put equity into the project. According to experience at least 30% equity is needed to start the investment.

There are non-refundable grants available to support renewable energy projects. Intensity is usually between 40% and 80% of the capital expenditure. This depends on the applicant, the project and the grant scheme. The maximum amount can be applied for one project is usually 3-3.5 million Euros. For the purposes of this investigation the maximum intensity is assumed to be 50% and the maximum grant amount at 3.1 million Euros.

4. CALCULATIONS

The calculations are made with a GDHS project cost model built in-house by Mannvit. This model and its assumptions are described in section 0. The model calculates the following financial values:

- Capital Expenditure (CAPEX)
- Operational Expenditure (OPEX)
- Net Present Value at Weighted Average Cost of Capital (NPV @ WACC)
- Internal Rate of Return (IRR)
- Payback period

The WACC is calculated according to the following equation:

$$WACC = \frac{E}{V} R_e + \frac{D}{V} R_d (1 - T_c) \qquad (1)$$

Where:

- E/V = Equity ratio (30%)
- R_e = Equity return (20%)
- D/V = Debt ratio (70%)
- R_d = Loan interest (8.5%)
- T_c = Average tax rate (calculated for each scenario)

The calculations are made with the population size as a variable to determine at which values the NPV of the investment is positive.

4.1 Scenario 1 (Well(s) and Distribution System in Place)

Scenario 1 considers a municipality that has one or more unutilized geothermal wells in its vicinity that conform to the assumptions discussed in section 0. Additionally this municipality has a functioning distribution system connected to a heat plant currently powered by fossil fuel. The project for this scenario is therefore to connect the existing wells to the existing heat plant, adapting it to the existing distribution system and thereby replacing fossil fuel with geothermal power.

Figure 7 shows the NPV of a DH project. Theoretically, a GDHS project for this scenario is feasible with population sizes up to well over 1.5 million. However, in order to serve the heat demand of a city with a population of 1.5 million 96 production wells are needed. As explained in section 0 this is not a realistic value for a single project. A more realistic value is limiting the number of production wells at 6 which will serve a population of approximately 100,000. Figure 8 shows the NPV for this range.

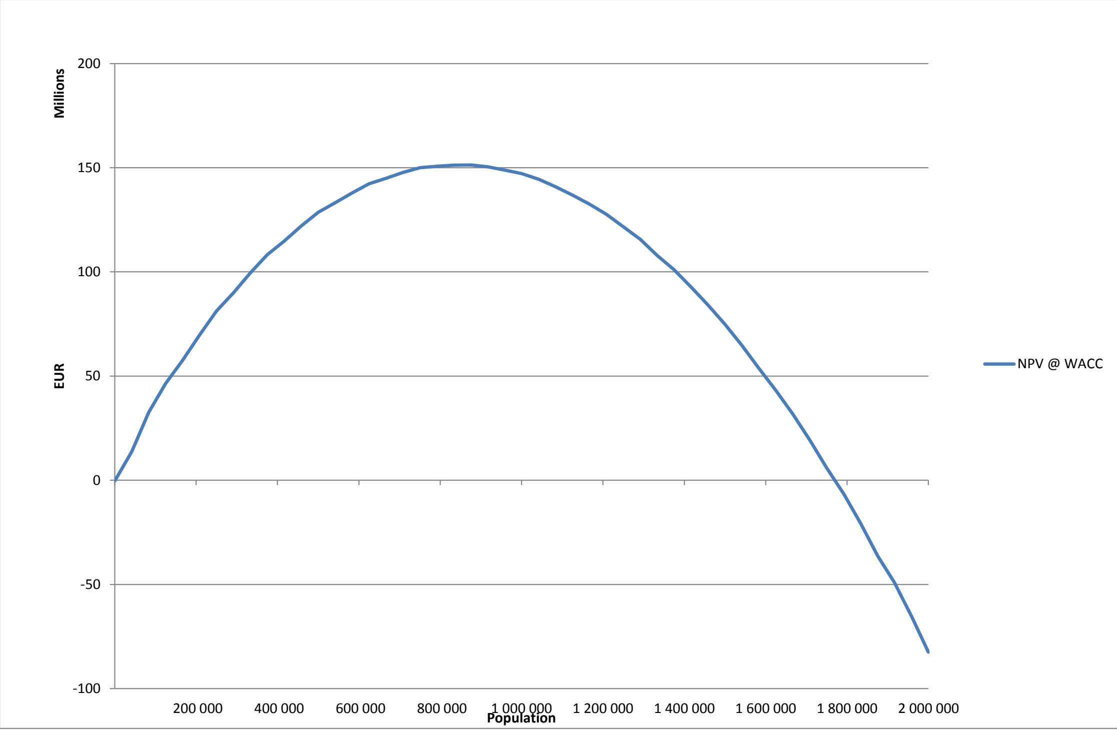

Figure 7: Net Present value of a GDHS project with respect to population size, scenario 1.

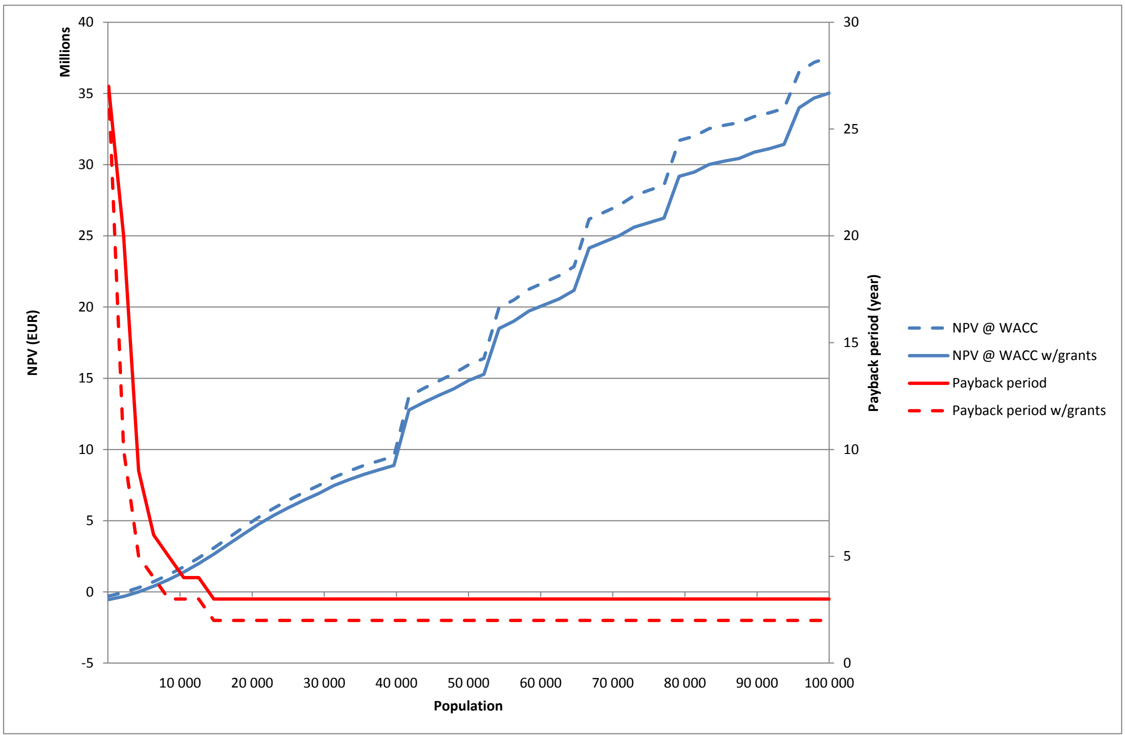

Figure 8: Net present value and payback period of a GDHS project for population size less than 100,000, scenario 1

Figure 8 shows that if one or more wells and a distribution system is in place the feasibility of a project connecting the wells to a distribution system via a heat plant is very considerable. The payback period decreases rapidly with population size and reaches five years for population sizes well under 10,000. Therefore, it is obvious that a GDHS development in this scenario, with or without grants, is highly feasible.

The question that remains is the following. What is the minimum population size for a project to become feasible?

Figure 9 shows where the NVP lines become positive. The continuous lines show the NPV without grants while the dashed lines show the NPV with 50% grants max. The figure shows that, accounting for grants, a municipality with a population larger than approximately 2,400 with one or more existing geothermal well in its vicinity and an existing distribution system should seriously consider initiating a GDHS development. Without grants a municipality with a population larger than approximately 4,300 should make similar considerations.

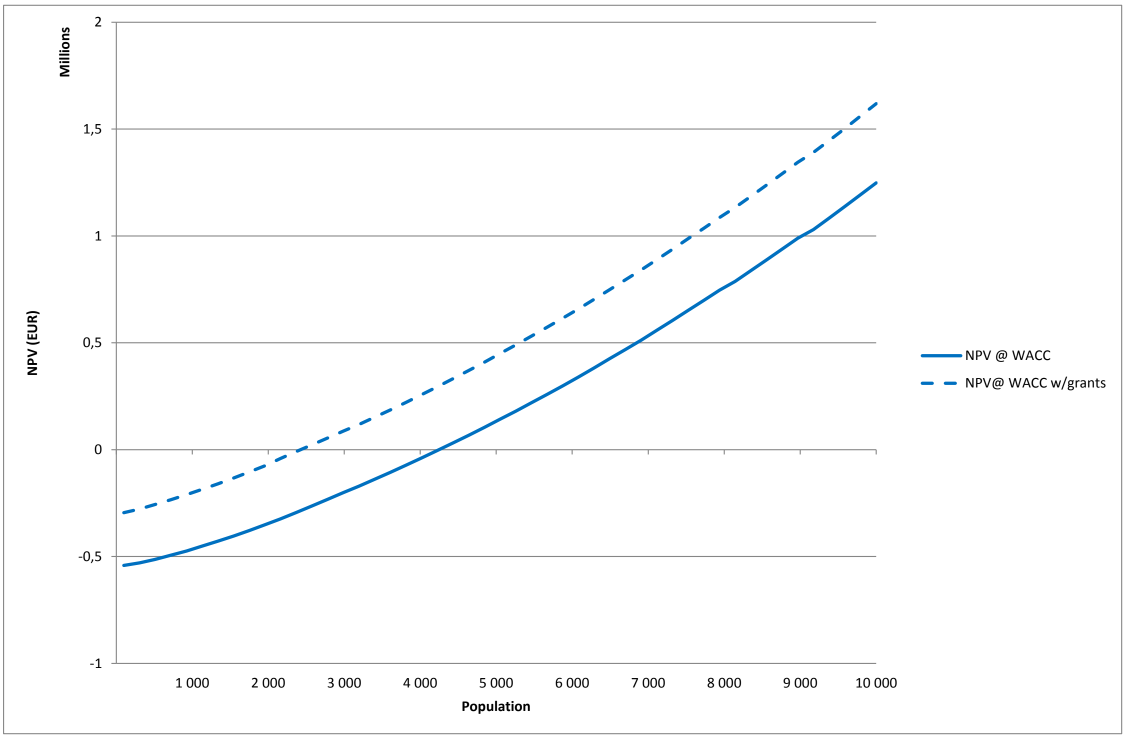

Figure 9: Net Present value of a GDHS project with population size less than 10,000, scenario 1.

4.2 Scenario 2 (Well(s) in Place but no Distribution System)

Scenario 2 considers a municipality that has one or more unutilized geothermal wells in its vicinity that conforms to the assumptions discussed in section 0. However, unlike in scenario 1 there is no distribution system in place and buildings are heated locally. The project in this scenario is then to construct a distribution system and connect it to the geothermal wells via one or more heat plants.

Figure 10 shows the results from NPV calculations for this project. The continuous lines show the NPV calculations without grants while the dashed ones show them with max 50% grants. The calculations shows that municipalities with population up to 90,000 that have geothermal wells in its vicinity should seriously consider applying for grants and constructing a district heating distribution system. This applies to municipalities with population as small as 3,400 as well.

On the other hand without grants such a project can still be feasible with population sizes ranging from approximately 7,300 to 83,000.

Again, the figure shows how rapidly the payback period decreases with increasing population. A GDHS development is highly feasible for municipalities of the above mentioned populations.

4.3 Scenario 3 (Distribution System in Place but no Well(s))

Scenario 3 considers a municipality that has a district heating system powered with e.g. fossil fuels. This municipality is located in a geothermal active area. The project in this scenario is to drill geothermal wells and connect them to the existing heat plant replacing the current power source with geothermal power.

Figure 11 shows that similar to scenario 1 such a project is theoretically feasible for large population sizes or up to approximately 900,000. However, as explained in section 0 the number of wells needed to fulfil such a heat demand exceeds what is considered a realistic number of wells for one project. Therefore, like in scenario 1, the population size is limited to 100,000. Figure 12 shows the calculation results.

Figure 12 shows that for a municipality located in a geothermal active area with a population larger than approximately 16,000 that has an existing distribution system should seriously consider drilling geothermal wells and connect them. With max 50% grants taken into account the population size decreases to approximately 10,000. The figure also shows that the payback period can be as low as 3 years.

The calculations indicate GDHS development for municipalities larger than 10,000 that conform to this scenario is highly feasible.

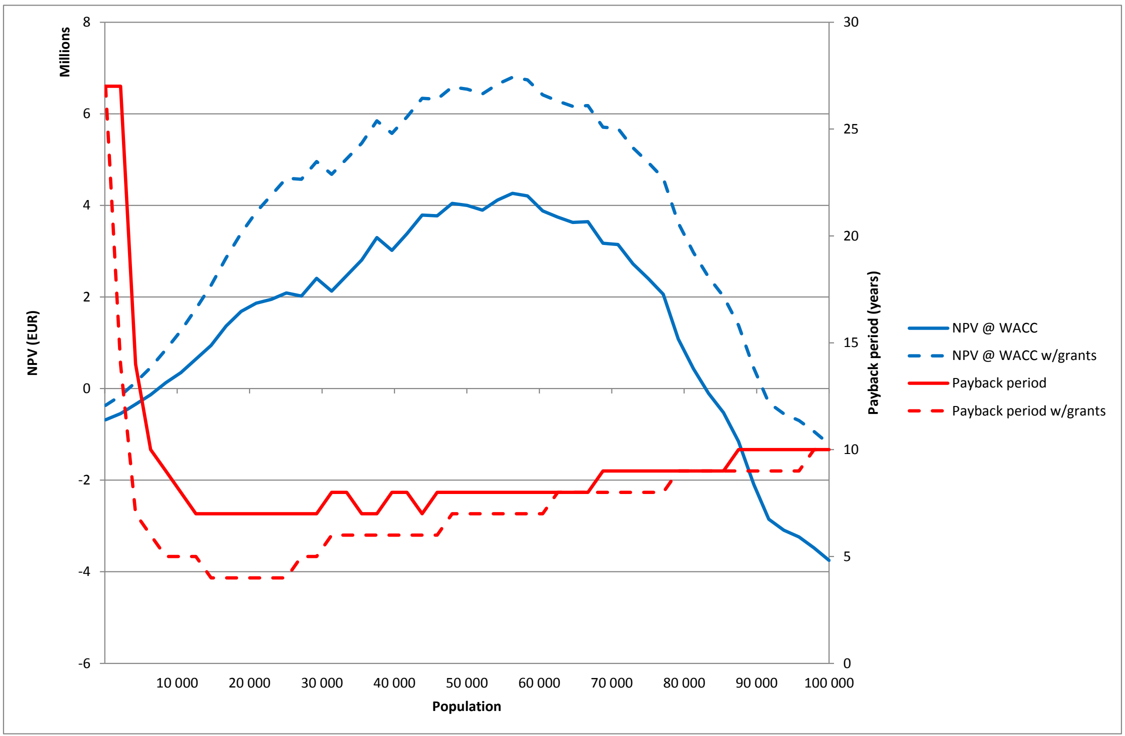

Figure 10: Net Present value of a GDHS project with respect to population size, scenario 2.

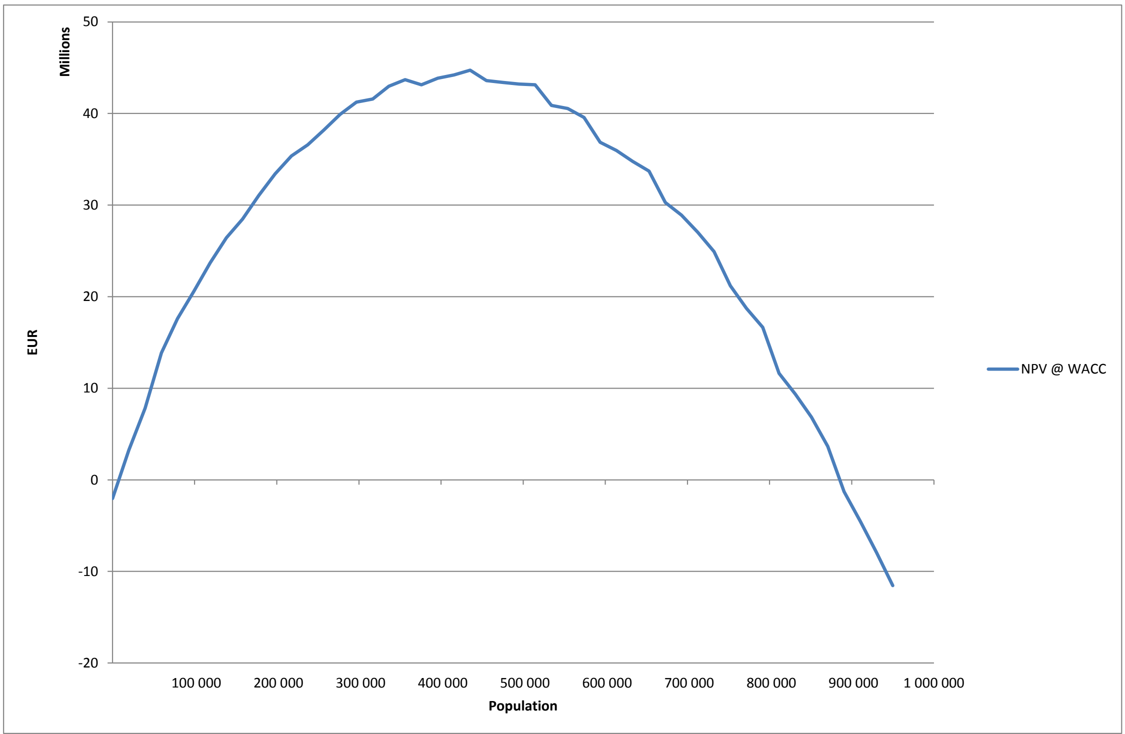

Figure 11: Net Present value of a GDHS project with respect to population size, scenario 3.

4.4 Scenario 4 (Neither Well(s) nor Distribution System in Place)

Scenario 4 considers a municipality located in a geothermal active area. In this municipality there are neither geothermal wells available and nor is there an existing distribution system. The project in this scenario is to drill geothermal wells as well as constructing a heat plant and a distribution system.

This scenario is, as expected, the least likely to become feasible. First of all, as can be seen in Figure 13, a GDHS development in this scenario is not feasible without grants. However, when grants are taken into account a project in this scenario may become feasible for a municipality with population sizes between approximately 12,000 and 38,000. This may be referred to as this scenario's "Goldilocks' zone". A municipality within this population range should seriously consider applying for grants to drill one geothermal production well and for constructing a distribution system. The payback period for such a development is less than 10 years.

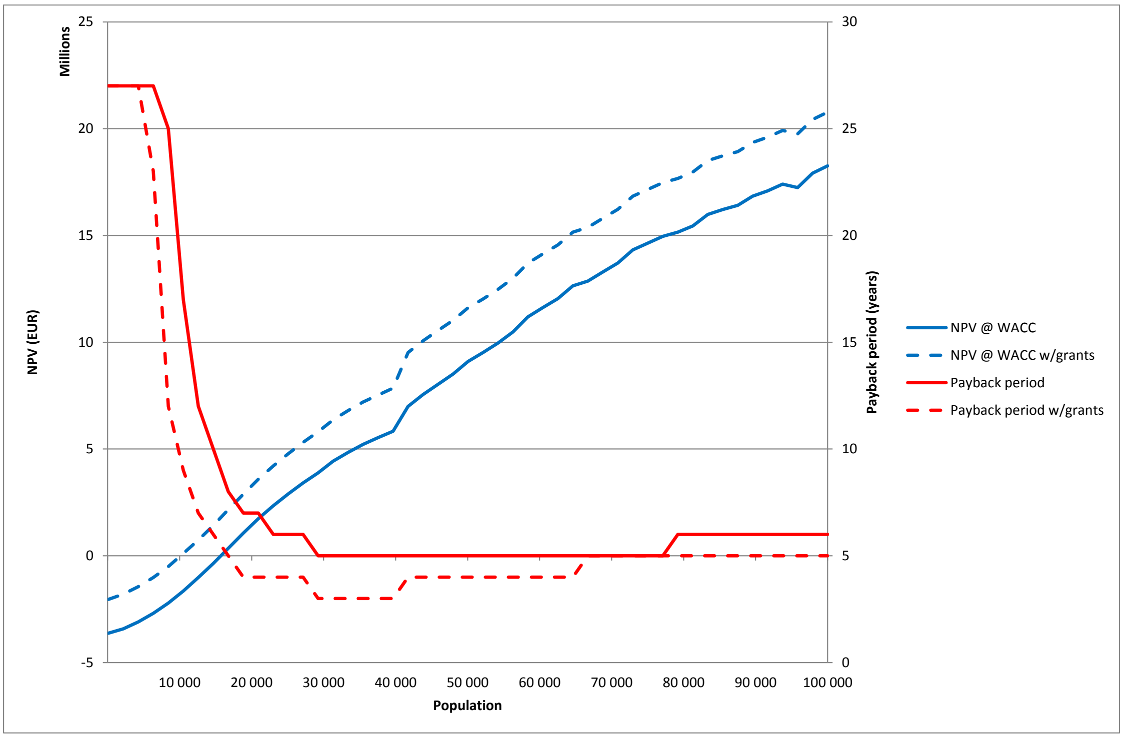

Figure 12: Net present value and payback period of a GDHS project with population size less than 100,000, scenario 3.

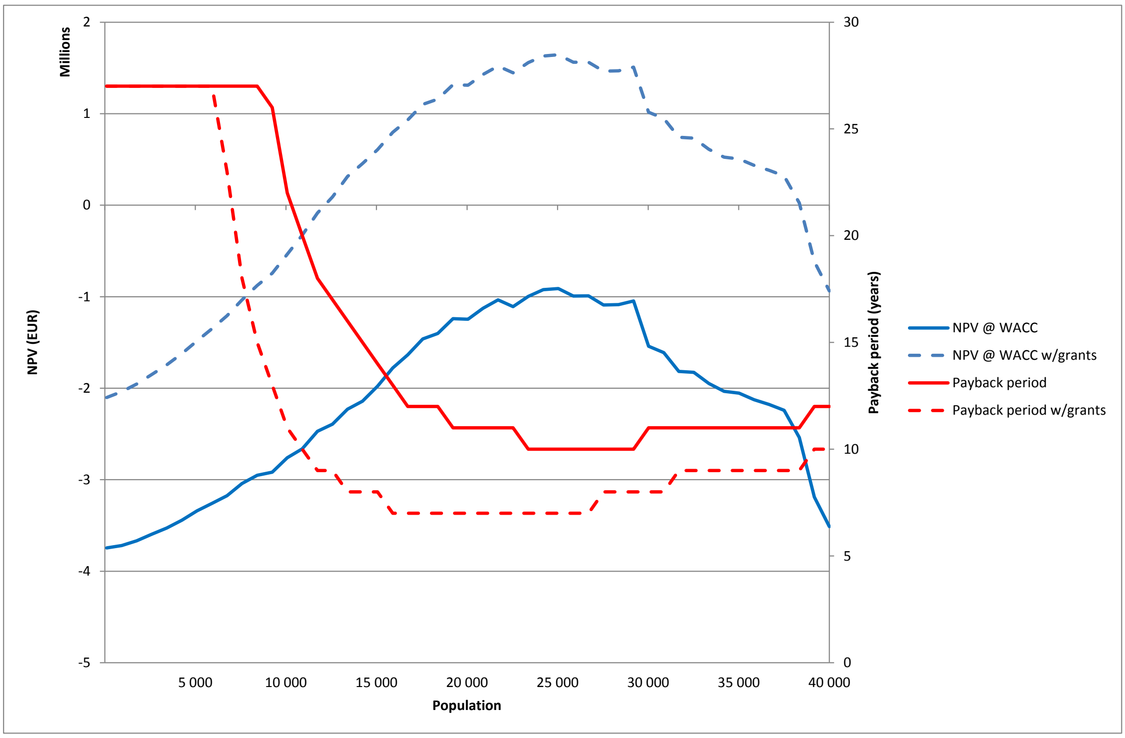

Figure 13: Net Present value of a GDHS project with respect to population size, scenario 4.

5. CONCLUSIONS

The population sizes needed for a GDHS development project to be feasible are summarized by scenario in Tables 3 and 4 along with its financial values. The calculations in the previous section show a stark contrast between the scenarios that include distribution system and the ones that do not. The cost of constructing a distribution system within the boundaries of a municipality increases exponentially with population size. This is because the model assumes that with larger municipalities the more densely populated it becomes. This means complicated installation work and thus more expensive. Therefore the population size range is narrower for the scenarios with no distribution system (scenarios 2 and 4). The limiting factor for the other scenarios that do include a distribution system is the realistic number of wells for one project as explained in section 0. The upper population limit for those scenarios are therefore set at 100,000.

Table 3: Population size limits by scenario, with grants.

Scenario	Population		No. of wells	CAPEX (kEUR)	OPEX (kEUR)	Grants (kEUR)	NPV (kEUR)	Payback project (years)	IRR project
1	Lower	2,400	1	680	15	340	0	9	11.4%
	Upper	100,000	6	9,150	820	3,100	37,500	2	83.1%
2	Lower	3,400	1	1,070	17	540	0	9	11.4%
	Upper	90,500	5	54,500	720	3,100	0	9	11.2%
3	Lower	10,100	1	4,500	120	2,100	0	9	11.4%
	Upper	100,000	6	28,500	1,320	3,100	20,800	5	23.1%
4	Lower	12,200	1	5,850	120	2,900	0	9	11.4%
	Upper	38,400	1	15,250	230	3,100	0	9	11.3%

Table 4: Population size limits by scenario, without grants.

Scenario	Population		No. of wells	CAPEX (kEUR)	OPEX (kEUR)	Grants (kEUR)	NPV (kEUR)	Payback project (years)	IRR project
1	Lower	4,300	1	730	18	0	0	9	11.4%
	Upper	100,000	6	9,150	820	0	35,000	3	58.7%
2	Lower	7,300	1	1,560	23	0	0	9	11.4%
	Upper	83,000	5	48,000	630	0	0	9	11.1%
3	Lower	15,700	1	4,500	130	0	0	9	11.4%
	Upper	100,000	6	28,500	1,320	0	18,300	6	20.6%
4	Lower	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A
	Upper	N/A	N/A	N/A	N/A	0	N/A	N/A	N/A

It must be kept in mind that the calculations made in this paper are based on a fictional municipality conforming to the assumptions described in section 0. The population sizes like those given in Tables 3 and 4 are therefore not absolute values but rather indicators. Every municipality has its own unique scenario but each should be able to identify within the four discussed in this paper.

Although there is an upper limit of 100,000 on the population size, larger towns can utilize this information as well. Towns can be divided into separate smaller sections. The sections can range from being inner-city areas, suburban areas to new urban developments. Tables 3 and 4 can then be used as indicators on section sizes for a GDHS development to become feasible.

This paper agrees with the conclusions made in Thorsteinsson (2008) that geothermal district heating systems can be developed economically and will provide savings for their users. Thorsteinsson (2008) also identified that financial incentives are important. While being important this paper shows they are not necessary for a feasible project in some scenarios as shown in this paper.

This paper provides a basis for identifying and targeting municipalities that have potential for a GDHS development. Once identified the local leaders can then be educated on the possibilities and benefits of such a system and instructed on how and where to apply for grants. It is recommended that GDHS development projects should be divided into two separate projects, drilling of wells and construction of a distribution system. Grants can then be applied separately to increase the likelihood of acceptance.

The GDHS development in Iceland conforms to scenario 4 in this paper. There were no wells nor were there any distribution systems. By developing small sections at a time the result was a highly financially viable project as discussed in the 1. Introduction. The circumstances as it was in Iceland at the time are somewhat similar to what is widely experienced throughout the world today. Fluctuating prices on imported fossil fuel and on occasion unpredictable delivery. Local geothermal power is therefore a very attractive proposition that local leaders should consider harnessing. In order to achieve that goal more education on GDHS is needed. With this paper it has become possible to strategically identify who to educate.

REFERENCES

Thordarson, S., and Jonasson, T.: Um hitaveitur á Íslandi, *Samorka*, (2006).

National Energy Authority of Iceland: Annual report (2013) Retrieved 25/05/2014 from www.samorka.is/doc/1713.

Thorsteinsson, H.: U.S. Geothermal District Heating: Barriers and Enablers, *Massachusetts Institute of Technology*, (2008).

Hungarian Central Statistical Office: Hungarian Town's Population data sheet (2012), www.ksh.hu/docs/hun/hnk/hnk_2013.pdf

Mannvit kft.: MV1-PGS-014-F3-A17-00000-0001_(Prototype Geothermal System - Cost Estimation), *Mannvit* (2011).