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HEAT PROVISION COSTS FROM GEOTHERMAL ENERGY IN COMPARISON TO OTHER SOURCES OF ENERGY

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ABSTRACT

The use of geothermal energy as well as other renewable sources of energy instead of fossil energy to meet the heat demand in Europe can contribute to the reduction of greenhouse gas emissions. Therefore a fast market introduction of such systems is a common demand of politicians throughout Europe. But to increase the use of renewable energies as a source of energy for meeting the given energy demand they must compete economically with the use of fossil fuels. On this background the aim of this paper is it to analyse the costs of the provision of heat from geothermal energy in comparison to the use of other renewable and fossil energies exemplarily for the circumstances given in Germany. The investigations show that the costs of the provision of useful energy from geothermal energy are in most cases higher compared to the costs of a heat provision from fossil energy carrier. But compared to the heat provision from other renewables geothermal energy could be a very promising option.

1. INTRODUCTION

Geothermal energy as well as other renewable sources of energy can contribute to the reduction of greenhouse gas emissions. Therefore it is often claimed by politicians throughout Europe that such sources of energy should contribute much more to meet the given heat demand. To support this claim in some European countries also some market introduction programmes have been introduced in the last years. Such incentives are limited in time and budget. Therefore on the long term a technology for the provision of useful energy can remain on the market only if this option is competitive or only a bit more expensive than other options.

On this background the aim of this paper is it to analyse the costs of heat provision from geothermal energy and other renewable and fossil energy carriers exemplarily under German circumstances. Special focus is put on the costs of a heat provision from geothermal energy.

For covering a given heat demand with renewable and fossil energies a lot of different possibilities are given. These options show very different technical characteristics. Therefore within the following explanations three typical supply cases are analysed (i. e. "Dwelling House", "Small District Heating System", "Large District Heating System") to allow an easy comparison. In particular heat

- from the soil and from groundwater with heat pumps for dwelling houses,
- from hydrothermal resources for large district heating systems,
- from biomass fired boilers for dwelling houses as well as for small and large district heating systems,
- from solar collectors for dwelling houses and for small district heating systems and
- from light oil or natural gas for dwelling houses as well as for small and large district heating systems

is analysed. Therefore first the methodological approach is described. Then the different supply tasks are defined in more detail. Based on this the results of the cost analysis are presented and discussed. At the end some conclusions are drawn.

2. METHOD AND FRAME CONDITIONS

Based on the investment costs (costs i. e. for the different components needed for the plant, for planning and permission, for the contraction) and the costs for operation and maintenance the energy provision costs can be calculated based on the provided useful energy. This will be done in accordance with VDI 2 067. According to this guideline the annulised cost approach is used. This approach is used to calculate the mean depreciation for each year during the technical life time based on the overall investments for the plant. Together with the operation and maintenance costs the overall yearly costs can be calculated. By dividing these overall costs by the provided useful energy the specific heat provision costs are available (Kaltschmitt and Wiese (1997)).

The specific energy provision costs are calculated in a real way; i. e. the monetary value of the year 1999 is taken as a basis and no inflation is taken into consideration. The economy wide discount rate is assumed to be 4 % (i. e. the average real economy wide discount rate in Germany within the last 35 years). The depreciation rate is defined to be the technical life time of the plant (i. e. economy wide real energy provision costs) which could differ between different types of plants. The border of the analysis is the costs of the heat feed into the heat distribution system of the consumer (i. e. heat feed into the heat distribution system).

This approach with constant monetary values (i. e. real calculation) results in lower costs compared to the analysis in nominal value, which is applied in such investigations quite often. But the relation between the different options remain unchanged. The advantage of such a procedure is the fact that the costs are available in real values (i. e. the well known costs of the year 1999).

The cost values outlined below can vary from costs published in other papers or investigations considerably. This is true because different interest rates, varying depreciation periods, other approaches for the calculation of the average costs, different borders for the calculation and the consideration of external effects could change the results significantly. Therefore the costs outlined below can only show the average order of magnitude of costs the whole economy has to pay for in average. The costs given at a certain spot under the site specific conditions can therefore vary considerable from the figures shown below to higher as well as lower values.

3. HEAT FROM RENEWABLE AND FOSSIL ENERGY

For comparing the costs of different possibilities to provide heat, three different supply tasks have been defined because for technical reasons different technologies to use renewables work at very different capacity ranges.

- "Dwelling House". The lower bound of the capacity range could be described by the heat supply for a dwelling house with an installed thermal capacity of 40 kW. The full load hours of this system are assumed to be at 1 800 h/a.
- "Small District Heating System". The medium capacity range is characterised by a small district heating system with an overall installed thermal capacity of 3 000 kW. This system provides heat for a small suburb without industrial users (i. e. 1 800 h/a). The heat losses within the network are 15 %. Due to economic reasons such systems consists mostly of a base load system (i. e. the system to use renewables) and peak load system (i. e. a boiler fired with fossil energy).
- "Large District Heating System". The upper border of thermal capacities installed in heating systems is defined to be a large district heating system (15 % heat losses during the heat distribution) with an overall installed capacity of 10 000 kW. For an easy comparison a heat supply for dwelling houses is assumed only (i. e. 1 800 h/a). Again the distribution losses are 15 %. These systems consist of a base load and peak load system too.

For these different supply tasks the following heat provision systems based on renewable and fossil energy could be applied.

Geothermal Energy from Soil and Groundwater. Due to the low temperature of geothermal energy from soil and groundwater a heat pump driven by electrical energy is needed to cover the given heat demand. With such a device the geothermal energy could be extracted from the soil with horizontal laid earth bound collectors or vertical drilled wells. Additionally the groundwater could be used via a production and injection well. Due to economic reasons such systems are used only for heating relative small units (i. e. "Dwelling House").

Geothermal Energy from Deep Wells. Geothermal energy from the deep underground (i. e. approx. 2 000 to 3 000 m) can be extracted with the help of deep wells. Within such a well a heat transfer medium (i. e. water) is circulated between the well head and the bottom of the hole. Due to the relatively low geothermal heat flow in the underground and the relatively low temperature levels achievable at the well head with such systems a heat pump is needed in most cases to provide heat with temperatures sufficient for meeting the given energy demand. Additionally due to economic reasons such systems provide heat from geothermal energy for covering the base load and from fossil energy for meeting the peak load. The thermal capacity of such systems is typically in the range of a few MW (i. e. "Small District Heating System").

Geothermal Energy from Hydrothermal Resources. Sometimes porous and permeable layers exist in the deep underground, which contain warm or hot water. If such layers could be opened by wells the pore water could be extracted and pumped to the surface. Here based on a heat exchanger the energy could be removed from these geofluids. This energy is then in most cases used to heat the heat transfer medium used within a district heating system. The now cold geofluid is then passed back into the underground with an injection well. Depending on the temperature of the water extracted from the underground a heat pump might be necessary to ensure a temperature level needed to meet the given demand. For economic reasons such plants are only realised with thermal capacities of more than 5 MW (i. e. "Large District Heating System") with a base load (i. e. use of geothermal energy) and a peak load system (i. e. use of fossil energy).

Solar Energy. The solar radiation from the sun could be transformed in solar collectors for the provision of hot water. Due to the anti-correlation between solar radiation and heat demand in Europe such systems provide mostly only sanitary hot water. Therefore a backup system is needed necessarily for covering a given supply task; such backup systems are based in most cases on fossil energy like natural gas or light oil. To increase the use of solar energy for meeting a specific supply task some effort has been made in the past for the development of seasonal heat storage facilities. Such solar thermal systems in combination with a fossil fired heat provision system are used in dwelling houses (i. e. "Dwelling House") and together with a seasonal heat storage system for small district heating systems (i. e. "Small District Heating System").

Biomass. Solid biofuels could be used in combustion plants for the provision of heat. Such systems could cover a broad range of thermal capacities. But for economic reasons for plants above a few 100 kW additionally to the biomass fired base load system a peak load system based on fossil energy is used. Therefore solid biofuels (i. e. residual wood) could be used in different system configurations for all supply tasks investigated here.

Fossil Energy. The use of fossil energy for the provision of heat is state of technology for a very broad range of thermal capacities. Therefore the use of light oil respectively natural gas is possible for all supply tasks analysed here.

4. HEAT PROVISION COSTS FROM GEOTHERMAL ENERGY

For the possibilities to provide heat based on geothermal energy the costs are analysed in detail within the following explanations. For these options first the investment costs are discussed. Based on this and on the operation and maintenance costs the heat provision costs are shown. Additionally the most important parameters influencing these costs are analysed.

Geothermal Energy from Soil and Groundwater. Table 1 shows the investment costs for different systems to provide heat from soil and groundwater for the supply task "Dwelling House". This indicates that the investment costs for the earth bound collectors are the highest and those for the system based on the use of groundwater are the lowest (Lux and Kaltschmitt (1997), Lux and Kaltschmitt (1998)).

Table 1 shows also the operation and maintenance costs. They are mainly influenced by the costs for the electricity needed to run the heat pump (i. e. operation costs). The maintenance costs are fairly low because such systems are already quite reliable.

Based on this the heat provision costs can be calculated (Table 1) according to the assumptions made in chapter 2. Following this the heat provision costs of a system based on wells to extract the energy from the soil are the lowest with 11.9 €/GJ compared to the other options of removing the geothermal energy from the underground. This is the reason

why such systems are most widely used within Germany compared to the other possibilities shown in Table 1.

The main parameters influencing the heat provision costs of the system based on an earth bound collector (cf. Table 1) is shown in Figure 1. According to this graphic the depreciation period (i. e. the technical life time) as well as the overall investment costs influence the heat provision costs the most. They are influenced less – and in a similar way – by the costs for the electricity needed to run the heat pump and the interest rate. Only the maintenance costs have a significant smaller influence. Therefore a reduction in the investment costs by administrative measures (i. e. grant) could have a significant influence on the heat provision costs.

Geothermal Energy from Deep Wells. Table 2 shows the costs for two systems for the provision of heat from deep wells for the supply task "Small District Heating System". One system is based on a new well. The other system assumes that there is a well already available from the exploration of oil or gas. This existing well could be used for this heat provision system.

The costs for these systems sum up to approx. 2.3 Mio. € for the system based on an existing well and to approx. 2.9 Mio. € for the system with the hole especially drilled for this heat provision system (cf. Table 2).

Table 2 shows also the operation and maintenance costs to provide heat based on this system. Following this table approximately half of the overall costs for the system relate to the energy needed to run the heat pump and the peak load system. The other half of these costs are needed for maintenance and others (like pumping the heat transfer medium through the well as well as the district heating system).

Based on these cost figures the heat provision costs at plant gate and free consumer can be calculated taking the frame conditions discussed in chapter 2 into consideration. Therewith the heat provision costs are between 17.6 and 18.6 €/GJ. The lower border is true for plants using an already existing well and the upper bound for systems based on a newly drilled hole. Figure 2 shows the influence of some of the most important parameters influencing the heat provision costs. According to this the heat provision costs are mainly influenced by the investment costs and the operation and maintenance costs. Compared to these parameters the depreciation period and the interest rate affect the costs for the heat free consumer less but still considerably. Subsidising of the investment costs and/or the energy costs (as part of the operation and maintenance costs) by administrative measures (i. e. market introduction program to support the use of renewable energies) could have therefore a significant influence on the heat provision costs.

Geothermal Energy from Hydrothermal Resources. Table 3 shows the costs for the provision of heat from deep wells by using hydrothermal resources for the supply task "Large District Heating System". According the procedure applied so far again two different system configurations are assumed to show the given range of the costs to be expected. For one system very good conditions of the reservoir are assumed (i. e. 95 °C at 2,000 m depth). Therefore no heat pump is needed. This is not true for the other system showing a significant lower temperature of the water extracted from the deep underground (i. e. 55 °C at 1,500 m depth) (Kayser et al (1998), Kayser (1999)).

According to Table 3 the overall costs sum up to about 9.1 Mio. € for the system based on the deep wells and to ca. 8.4 Mio. € for the heat provision system based on the less deep wells. The later system is cheaper because the drilling of the less deep wells leads to significant cost savings. These savings overcompensate the additional investment costs for the heat pumps necessary for this heat provision system.

Table 3 shows also the operation and maintenance costs of these heat provision systems. Due to the different system configuration (i. e. heat pump is needed for the system based on the 55 °C water) the energy costs vary significantly. Therefore the operation and maintenance costs of the system with a heat pump are approximately double the costs of the other system.

Based on the investment costs as well as the operation and maintenance costs the heat provision costs can be calculated according to the definitions made in chapter 2. Following this the costs for the heat provision to the consumer (i. e. free consumer) varies between 16 and 21 €/GJ. The upper bound of this cost span results from the system based on the lower temperature of the extracted water due the energy costs for running the heat pump (i. e. the much lower share of geothermal energy at the overall provided energy free consumer) and – to a minor degree – the fuel costs for the peak load system. The lower bound results from the system with the higher temperature of the water from the hydrothermal resource. Here the costs for running the plant are fairly low which results in lower specific heat provision costs.

Some of the parameters influencing the heat provision costs of this system are analysed in Figure 3. According to this the heat provision costs are mainly influenced by the investment costs and the depreciation period. Operation and maintenance costs as well as the interest rate does not influence the costs to this extend. There by subsidising the investment costs within the framework of administrative measures to support the use of renewable energies the heat provision costs could be reduced substantially.

5. COMPARISON

The costs analysed in chapter 4 have to compete with the costs for heat provision from other renewable energies and from fossil energy. Therefore within the following explanations the outlined heat provision costs will be compared to the costs for systems for the heat provision from solar energy, from biomass and from light oil as well as natural gas (cf. chapter 3). Table 4 (Kaltschmitt et al 1999)) shows the heat provision costs for the different supply tasks calculated according the explanations made in chapter 2. The costs shown in this table are directly comparable by each other because they are calculated on the same basis and refer to the same system boundaries.

"Dwelling House". A heat provision for this supply task is possible with systems based on solar energy, on biomass, on geothermal energy extracted from soil and groundwater as well as on fossil energy. Table 4 indicated that from all these options the use of fossil energy for providing heat shows the lowest costs. But on average only a bit more expensive are the costs for heat provision based on heat pump systems using geothermal energy from soil and groundwater. This is true because the investment costs of heat pumps have fallen significantly within the last years at least in Germany. Therefore this option is more or less competitive to the use of fossil energy if the prices for the electrical energy to run the heat pump are relatively low (i. e. depending on the utility). Compared to this the heat provision from biomass is slightly and from solar energy clearly more expensive. The high costs

of solar energy based systems are caused by the fact that due to the varying solar energy supply a backup system based on fossil energy is needed with the full thermal capacity to fulfil the given supply task. The higher costs from the biomass option is true because the investment costs are much higher for combustion plants based on solid fuels (like pieces of wood) than based on liquid or gaseous fuels (like light oil or natural gas) by nearly the same costs for the fuel free plant.

To sum up, the use of geothermal energy from soils and groundwater with heat pump based systems are a promising option, which is more or less in the same costs range as systems based on the use of fossil energy. Compared to other possibilities to provide heat in the capacity range needed by dwelling houses the use of geothermal energy is clearly the cheapest possibility at the moment in Germany.

"Small District Heating System". A heat provision for this supply task could be realised with systems using solar energy, using biomass, using geothermal energy based on deep wells and using fossil energy carrier. According to Table 4 the heat provision costs of these different options vary significantly. The provision of heat with systems based on the use of fossil energy is the cheapest option. Noticeably more expensive is the heat provision from biomass and geothermal energy extracted from the deep underground by deep wells. This is true because for the system using geothermal energy very high investment costs are needed (cf. chapter 4). For a biomass based heat provision system in this capacity range a highly sophisticated combustion technology is used in most cases to meet the legal environmental standards. Additionally a person is needed to run the plant. Fairly high costs are the result. They could only be reduced if the biomass feedstock is available at very low costs. Compared to such systems the heat provision from solar energy via solar thermal collectors and a seasonal heat storage system are much more expensive due to the reasons outlined above (i. e. need for a backup system with the full thermal capacity, expensive seasonal storage system).

To sum up for supply tasks with the characteristics underlying the "Small District Heating System" the use of fossil energy is the most promising taken only economic aspects into consideration. Compared to this the heat provision from renewable energy is much more expensive. But if only systems based on renewable energies for heat provision are compared to each other the use of geothermal energy can easily compete with the use of other renewables.

"Large District Heating System". Heat for this supply task could be provided with systems based on biomass, on geothermal energy from hydrothermal resources and on fossil energy. Following Table 4 the corresponding heat provision costs cover a wide range. Again systems based on fossil energy for providing heat are the cheapest option. Heat from biomass and heat from hydrothermal resources are in the same order of magnitude. But compared to the use of fossil energy these options are significantly more expensive. The relatively high costs of a heat provision from geothermal energy extracted from hydrothermal resources results from the high costs for drilling the production and injection well as well as from the geothermal heating plant itself (cf. chapter 4). The costs of system based on the use of biomass are justified due to the reasons discussed above (see "Small District Heating System").

To sum up, the use of renewables for the heat provision for systems like the "Large District Heating System" is significantly more expensive than with fossil energy. But if the options to provide heat from renewable energies are compared to each other the use of geothermal energy costs approximately as much as the use of biomass in the multi MW range.

6. CONCLUSIONS

The specific costs for the provision of energy are one of the main parameters, which determine the use of a certain technology based on a specific energy carrier within the liberalised energy market in Europe. On this background the aim of this paper is an analysis of the costs for the provision of heat from renewable and fossil energy exemplarily for the circumstances given within Germany. A special focus has been put on the possibilities to provide heat from geothermal energy based on different technologies.

By comparing the costs of the different systems for the provision of heat analysed within this paper the following statements could be made.

- The use of renewables in general and geothermal energy in particular for the provision of heat is more expensive than the use of fossil energy throughout the overall range of thermal capacities. The only exception is the use of geothermal energy from the soil and groundwater; here the costs are similar compared to the use of fossil energy due to significant reductions of the investment costs of heat pumps in the last years.
- The heat provision costs of systems using geothermal energy in particular and renewable energies in general are very strongly dependent on the investment costs for the plant. Only if a heat pump is needed (i. e. some options to use geothermal energy) or an expensive fuel is used (like for biomass) the operation costs have a certain influence on the heat provision costs. This is the reason why most of the administrative measures to support the use of geothermal energy as well as other renewable energy give a grant to the investment costs.
- The use of renewable energies for providing heat depends strongly on the site specific circumstances and frame conditions given at a certain spot. Therefore the heat provision costs vary significantly according to the local conditions. If the site specific circumstances are very promising relatively low heat provision costs might be possible. Therefore the economic evaluation of options to provide heat from geothermal energy in particular and renewables in general for a specific project should be done only site specific based on the local frame conditions.

To sum up the use of geothermal energy for covering a given heat demand could compete easily with other renewable energy sources and under certain circumstances also with the use of fossil energy. But in most cases the use of geothermal energy for the provision of heat in Germany and in most places in Europe is more expensive than the use of oil and gas. If therefore such options should be used due to environmental and other reasons administrative and/or legal measures have to be applied to make these options economically feasible. This could be a grant to the investment costs as well as an eco-tax.

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Table 1 Costs for a heat provision from soil and groundwater

	Soil Earth Collector	Well	Ground -water
Investment Costs in €/kW$_{th}$			
Heat Source	450	400	300
Heat Pump	350	350	250
Installation, Others	40	40	35
Sum	840	790	585
O & M Costs in €/GJ			
Energy Costs	4,3	4,3	3,9
Maintenance	0,7	0,7	1,0
Sum	5,0	5,0	4,9
Heat Provision Costs			
in €/GJ	12,5	11,9	13,1
in €-Cent/kWh	4,5	4,3	4,7

Table 2 Costs for a heat provision with deep wells

	New Well	Exist. Well
Share of geothermal energy in %	71	71
Investment Costs in 1,000 €		
Heat Source	1,800	1,250
Heat Pump	200	200
Peak Load System	220	220
Building, Others	220	200
District Heating System	450	450
Sum	2,890	2,320
O & M Costs in 1,000 €		
Energy Costs	80	80
Maintenance, Others	90	90
Sum	170	170
Heat Provision Costs (at plant gate / at the consumer)		
in €/GJ	16.0 / 18.6	15.5 / 17.6
in €-Cent/kWh	5.8 / 6.7	5.4 / 6.4

Table 3 Costs for a heat provision from hydrothermal resources

	95 °C	55 °C
Share of geothermal energy in %	97	41
Investment Costs in 1,000 €		
Heat Source	4,800	3,900
Heat Pump		190
Peak Load System	200	200
Building, Others	2,300	2,300
District Heating System	1,800	1,800
Sum	9,100	8,390
O & M Costs in 1,000 €		
Energy Costs	60	380
Maintenance, Others	220	220
Sum	280	600
Heat Prov. Costs (at plant plant gate / at the consumer)		
in €/GJ	11.0 / 16.0	15.6 / 20.7
in €-Cent/kWh	4.0 / 5.8	5.6 / 7.5

Table 4 Comparison of the costs

	"Dwelling House"	"Small District Heating System"	"Large District Heating System"
		in €/GJ	
Solar Energy	21.0	28.0	
Biomass	14.4	18.2	17.8
Geothermal Energy			
Soil & Groundwater	11.9 – 13.1		
Deep Wells		17.6 – 18.6	
Hydroth. Resources			16.0 – 20.7
Fossil Energy	12.0 – 12.5	13.6 – 14.3	12.1 – 12.8

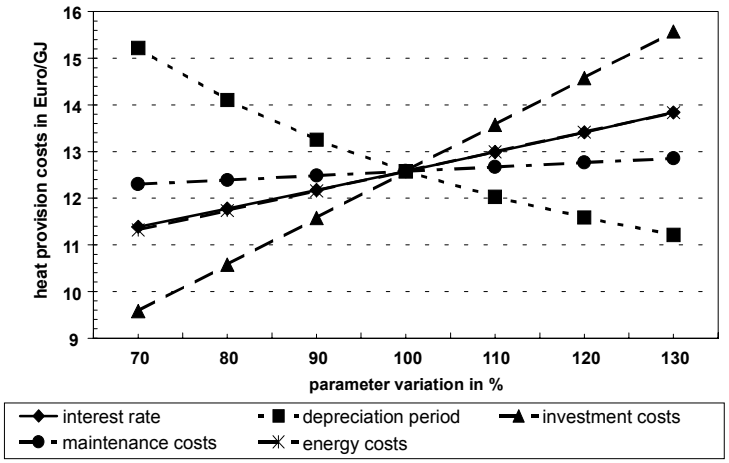


Figure 1 Parameter variation of a system based on an earth bound collector

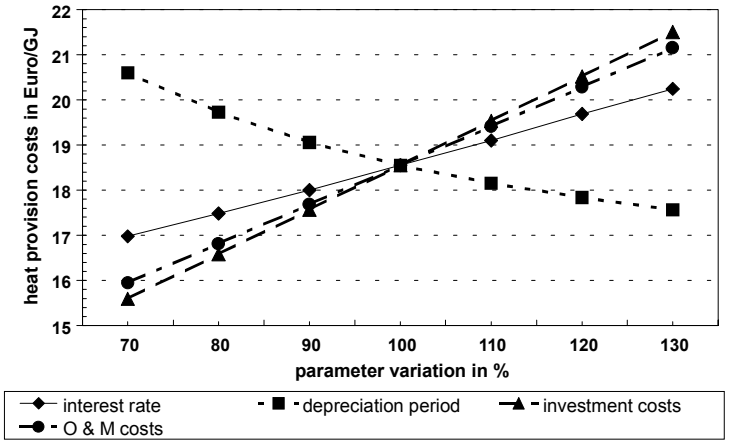


Figure 2 Parameter variation of a system based on a deep well (i. e. new well)

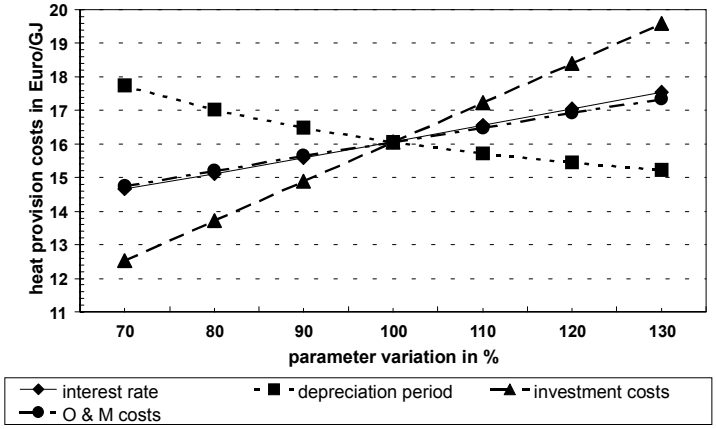


Figure 3 Parameter variation of a system based on a hydrothermal energy (i. e. 95 °C)