The value of Geothermal Energy under different scenario assumptions : the case of the Netherlands

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The value of Geothermal Energy under different scenario assumptions – the case of the Netherlands

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Abstract

Heating covers a large share of total energy use in the Netherlands, and approximately 90% of the total heating demand is currently provided for by natural gas. Although there is a great potential for utilizing geothermal heat in the Netherlands, the application of this technology stagnates. When aiming to increase the share of geothermal heat in the Netherlands, the currently existing barriers should be overcome and the financial benefits of geothermal heat should be made explicit for the most important stakeholder groups: investors, consumers, and governments. In this article, a calculation model is developed with which the potential and feasibility of specific geothermal heat applications can be analyzed under different scenario assumptions. This calculation model, based upon the principles of System Dynamics, is tested on three case studies in Eindhoven, the Netherlands. The main conclusions are that – despite the lack of investor awareness – geothermal heat applications are often very attractive from a financial perspective. The most important considerations when initiating geothermal heat projects are the maximization of the number of geothermal heat consumers and whether it is necessary to develop new heating infrastructures. Additionally, we found that governmental interventions on carbon emission right sales and on heat prices can contribute strongly to the financial feasibility of new geothermal heat projects.

Keywords: Geothermal Heat Implementation, System Dynamics, Scenarios

1. Introduction

Generally, heating covers a large share of the total energy use in the Netherlands. An average Dutch household consumes 76,200 MJ of energy per year, of which 63,500 MJ (83%) is used for heating, and 12,700 MJ (17%) for electricity. On national scale, 3,495 PJ was used in 2010 (CBS Statline, 2011b), of which 38% is used for heating with T > 100^{0}C, 30% for heating and cooling with T < 100^{0}C, 20% for transport, and 12% for electricity; heating and cooling covers 68% of the total Dutch energy use.

A large share of the total Dutch energy demand is supplied by combusting fossil fuels. Of the total energy demand in the Netherlands, 9.1% is generated with coal, 37.2% with oil, and 47.1% with natural gas (CBS Statline, 2011b). Approximately 90% of the total heat demand is provided for by natural gas (AgentschapNL, 2010). The share of renewable energy in the Netherlands is small and hardly increasing. In 2010, renewable energy in the Netherlands accounted for only 3.8% of the national energy demand, a decrease of 0.4% compared to 2009 (CBS Statline, 2011a). In the years before 2009, the renewable energy share grew on average with 0.5% annually. Especially the production of renewable heat stagnates, covering only 2% of the total heat demand; the renewable heat share grew annually with 0.1% in the last five years (CBS Statline, 2011a).

The stagnating introduction of renewable energy in the Netherlands can be explained by the availability of large gas reserves. The Dutch subsurface currently contains approximately 1,400 billion m^3 of natural gas. Yearly, 70 billion m^3 is extracted, of which 40 billion m^3 is used for own purposes. Out of this internally used 40 billion m^3, approximately 25% is used by households, 25% by offices, 20% for electricity power plants, and 35% for industrial activities (CBS Statline, 2011b). Since the natural gas stock will deplete in the near future, the uncertainty of energy supply will increase in the coming years. Additionally, it is likely that gas prices will rise on short term, leading to an increasing value of the gas field reserves but also to increasing heating costs for consumers. The depletion of natural gas resources and the increase in fossil fuel prices will force governments, companies, and consumers to consider the use of alternative energy sources (e.g. Aaheim and Bundschuh, 2002; Henriques and Sadorsky, 2008). Alternatives to fossil fuel should therefore provide financial benefits to consumers and investors.

In the Netherlands, there is a great potential for utilizing indigenous geothermal energy as a cleaner, nearly emissions-free renewable source of heat, of which the characteristics are ideal for local district heating applications (TNO, 2010a; Thorsteinsson and Tester, 2010; IF Technology, 2011). However, high upfront costs, affordable gas and oil supplies, lack of investor awareness, well developed natural gas infrastructures, landlord/tenant incentive splits, and the wealth of Dutch gas resources are major barriers to the deployment of geothermal energy (TNO, 2007; Seyboth *et al.*, 2008; Thorsteinsson and Tester, 2010). The main problem is that investors, operators, consumers, and governments are currently unaware of the possible social and financial benefits of geothermal heat applications in the built environment. In order to successfully introduce geothermal heating as a substitute of natural gas, the benefits of geothermal heat compared to natural gas should be made explicit.

This article discusses the possibilities for geothermal heat to compete with natural gas, based on economic drivers, under different scenarios. More specifically, the aim is to provide insight in the influence of endogenous and exogenous variables on the feasibility of the application of geothermal heat as an alternative to natural gas based heating in the built environment. The benefits of applying geothermal heating in the Netherlands are explored for three main stakeholder groups (investors, consumers, and governments) while incorporating the influence of variables resulting from possible future events. This will be tested on three Dutch cases; all situated within the city of Eindhoven and comprising different geothermal energy characteristics. To achieve the stated aim, System Dynamics modeling is applied.

2. Geothermal energy

In general terms, geothermal energy is the thermal energy stored at accessible depth in the earth's crust (Mock, *et al.*, 1997). Everywhere on earth, the temperature rises along the depth; in the Netherlands the temperature just below surface is around 10°C and temperature rises with 31°C per kilometer. The heat is accessed by drilling and is extracted from a geothermal reservoir. Generally, the earth's heat at a depth of 1.5 kilometers can be applied for direct heating of dwellings and greenhouses.

The earth's enormous geothermal resources have the potential to contribute significantly to sustainable energy use worldwide as well as to help mitigate climate change (Axelsson, 2010). Geothermal energy provides a stable energy source, which may produce a high capacity all year round. For most other renewable energy sources, daily and/or seasonal variations in inflow reduce the yearly utilization of the total capacity. The importance of this property depends on the fluctuations in demand (Aaheim and Bundschuh, 2002). The application of geothermal energy contributes significantly to the reduction of CO_2 emission, it does not entail visual or noise nuisance, the security of supply is high, and the technology is safe and proven, mainly based on extensive experience in oil and gas production (Wong and Lokhorst, 2007).

The theoretic technical potential of geothermal energy in the Netherlands is determined at 90,000 PJ (TNO, 2009). The amount of energy that may eventually be produced successfully, however, depends strongly on location specific reservoir properties. TNO (2010a) estimated the technical and economic recoverable potential up to a depth of four kilometers at 38,000 PJ; 1 PJ corresponds to the annual energy use of approximately 15,000 existing dwellings. Additionally, IF Technology (2011) analyzed the sustainable potential of geothermal energy from locations deeper than four kilometers. The results show a great potential: 22-31% of the final heating consumption can be satisfied by deep geothermal energy (IF Technology, 2011). This large potential is due to the good conditions of the Dutch subsurface (De Mulder *et al.*, 2003; TNO, 2010b). However, the utilization of geothermal energy in the Netherlands lacks behind compared to other countries as Germany and Iceland (Lund *et al.*, 2011); especially the latter has major expertise in utilizing geothermal energy (e.g. Gunnlaugsson *et al.*, 2001; Loftsdottir and Thorarinsddottir, 2006; Thorsteinsson and Tester, 2010).

2.1 Barriers to deployment; challenges and opportunities

In spite of the great opportunities and the potential for geothermal energy, there are systemic barriers concerning the utilization of these projects. Seyboth *et al.* (2008) identified that most important barriers are the comparatively high up-front cost of installation, a lack of investor awareness, existing infrastructure constraints, and landlord/tenant incentive splits. Furthermore, Thorsteinsson and Tester (2010) identified the relatively affordable gas and oil supplies, together with the separate, well-developed electricity and fuel delivery infrastructures as main barriers to implement geothermal district heating; this seems also to be the case in the Netherlands. TNO (2007) concludes that the wealth of the Dutch gas resources, the tariff structure imposed on gas for agricultural application, and the lack of subsidiary instruments for the use of green heat are the main factors preventing the development of geothermal applications in the Netherlands.

Additionally, there are some political and legal barriers in introducing geothermal heat in the Netherlands. An important legal constraint, influencing the financial attractiveness of geothermal heat application, is the so-called NMDA principle (Niet Meer Dan Anders; No More Than Usual). This principle – recorded in the Dutch law – ensures that the consumer will not pay more for its heat per GJ when employing geothermal energy than he or she would when using a conventional gas fired generation system. The heat price is linked with the gas price, and is determined each six months; this gives investors certainty on future revenues and prevents the consumers from being exploited in a monopolist situation. However, the principle is generally disadvantageous for heat consumers, since possible savings in development, maintenance and exploitation of the heating system only benefit investors; the linkage to fossil fuel prices only increases the probability of future heat price increases. Another political constraint is the limited possibility for carbon emission trading in the Netherlands. Since reduction of CO_2 emissions helps the Dutch government in satisfying binding agreements with the European Union, it might be interesting to financially remunerate technologies that reduce CO_2 emission. In turn, this contributes to the financial attractiveness of renewable alternatives.

Another main characteristic of geothermal applications influencing the financial attractiveness is that it requires a distribution network. A geothermal district heating system (GDHS) is a system that uses geothermal energy as a heat source and distributes heat through a distribution network connected to five or more buildings. The development of such infrastructure networks is usually very costly; expansion of an existing system's capacity or linking of new users to an existing system is less expensive. When establishing a new network, investors need to make sure a sufficient number of users will connect to it. Concerning GDHS network development, Bloomquist and Lund (2000) identified several potential barriers; the most important barriers are that local authorities are frequently unaware of geothermal energy system benefits and that GDHS are perceived to be complex, high-risk undertakings. Local leaders lack the necessary knowledge to develop GDHS and consequently are often not interested in utilizing geothermal energy (e.g. Gleason, 1993). Moreover, Barbier (2002) concludes that it is still very difficult to convince governments and investors that non-electrical uses of geothermal energy can play a significant role in the saving of high quality fuels. The major constraint in this process is that it takes a long time before gains can be harvested and large investments are required at the beginning of the project.

We can conclude that there are several barriers restricting the application of geothermal heat in the Netherlands. Nevertheless, Lund (2002) states that – given the right environment, and an ongoing dwindling of gas and oil supplies – geothermal energy will provide a competitive, viable and economic alternative source of renewable energy. Furthermore, TNO (2007) concludes that a sharp rise in gas and oil prices would force private enterprises to consider the use of alternative energy sources. As the price of fossil fuels increases, the opportunities for alternative energy will present itself; the value of sustainable alternatives will increase with increasing fossil energy prices. This research aims to translate these barriers, challenges and opportunities into a calculation model with which the potential and feasibility of geothermal energy in the Netherlands can be analyzed under differing scenario assumptions. As the feasibility of the introduction of geothermal energy is characterized by a high number of endogenous and exogenous variables which are complexly interrelated, the calculation model is based upon premises from systems theory.

3. System Dynamics

The field of systems theory has generated a broad array of tools, with which one can graphically depict one's understanding of a particular system's structure and behavior, communicate with others about this understanding, and design high-leverage interventions for problematic system behavior. One modeling method within the field of systems thinking is System Dynamics, a method for understanding the dynamic behavior of complex systems. It originated with the work of Forrester (1961), who developed the initial ideas by applying concepts from feedback control theory to the study of industrial systems.

System Dynamics (SD) models have some characteristics that distinguish them from other simulation methods. For instance, human decisions, behavioral patterns, and other exogenous difficult-to-measure variables hold a very important position in SD, and the emphasis of SD lies on understanding patterns of such variables. Human decisions are often formed by the perceptions of what the current state of the world is, but this is rarely the same as the real state of the world, due to time delays and dynamic complexity (e.g. a high number of involved actors or non-linear relations). Therefore, System Dynamics deals with internal feedback loops, time delays and stocks and flows that affect the behavior of the entire system. These elements help to describe how even seemingly simple systems display strong nonlinearity; the essential viewpoint taken by System Dynamics is that feedback and delay cause the behavior of systems, i.e. that dynamic behavior is a consequence of system structure (Richardson and Pugh, 1981). Furthermore, System Dynamics always deals with problems that develop over time, and the system state at any time is captured by a set of state variables, called stocks, which are fed by flows. This specific model structure is derived from a fundamental idea in System Dynamics modeling, which is the principle of accumulation (Tao, 2010).

4. Stock and flow model

In order to be able to perform computer simulations and calculations on the feasibility of geothermal system solutions, a stock and flow model is developed. The created stock and flow model is divided in three sub-models. The first sub-model comprises the calculation of the consumer costs for geothermal heat, the second model deals with the heating grid connections, and the third model applies the gained data in calculating the financial feasibility of the project.

In this research, three different system solutions are generated, with different subsoil and application characteristics. These solutions – discussed in section 6 – will be simulated and tested on three cases in Eindhoven, using the developed stock and flow model. Different scenario assumptions are incorporated in the model; possible future developments – like changing energy consumption patterns or fossil fuel price increases – can have either a positive or a negative effect on the application of large-scale geothermal heat solutions. The different scenarios are discussed in detail in section 5.

4.1 Sub-model 1: Consumer costs for geothermal heat

The first sub-model (figure 1) calculates the consumer costs for geothermal heat. In this research, we assume that the base heat price lies 15% below the NMDA price; the NMDA price is related to the price of heat when employing gas-fired installations. The annual geothermal heat costs are calculated by multiplying the average gas consumption per house with the price per GJ. The effects of different scenarios are also incorporated in this sub-model; these scenarios contain annual changes in gas prices and in heating demand.

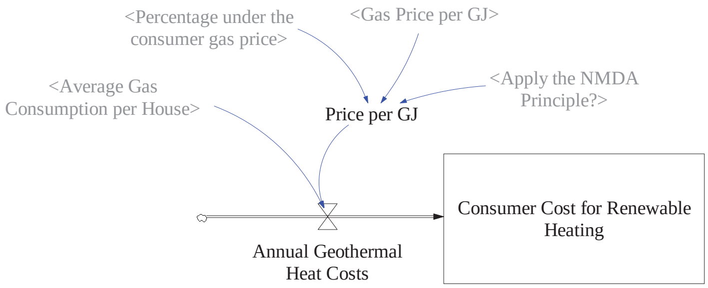

Figure 1: Consumer costs for geothermal heat

4.2 Sub-model 2: Heating grid connections

In the second sub-model, the geothermal heat switching rate and the costs for the development of the heating grid development are calculated. Both aspects are important, since having sufficient heat consumption at the start of the project is one of the greatest challenges in developing a geothermal energy plant; each discrepancy between the heating production and heating demand results in an expensive loss. However, it cannot be assumed that all consumers switch instantly after developing a geothermal energy plant; alternative heating facilities and infrastructures are often already available in existing urban areas. Based upon the product diffusion model of Rogers (1962), we assume that after eight years all consumers have switched to the renewable alternative (figure 2). The related second sub-model is represented in figure 3.

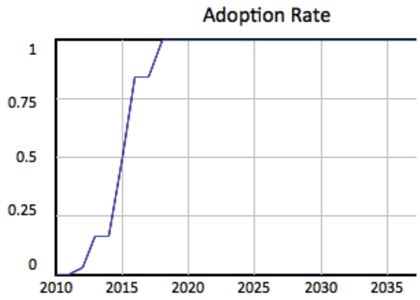

Figure 2: Assumed Adoption Rate

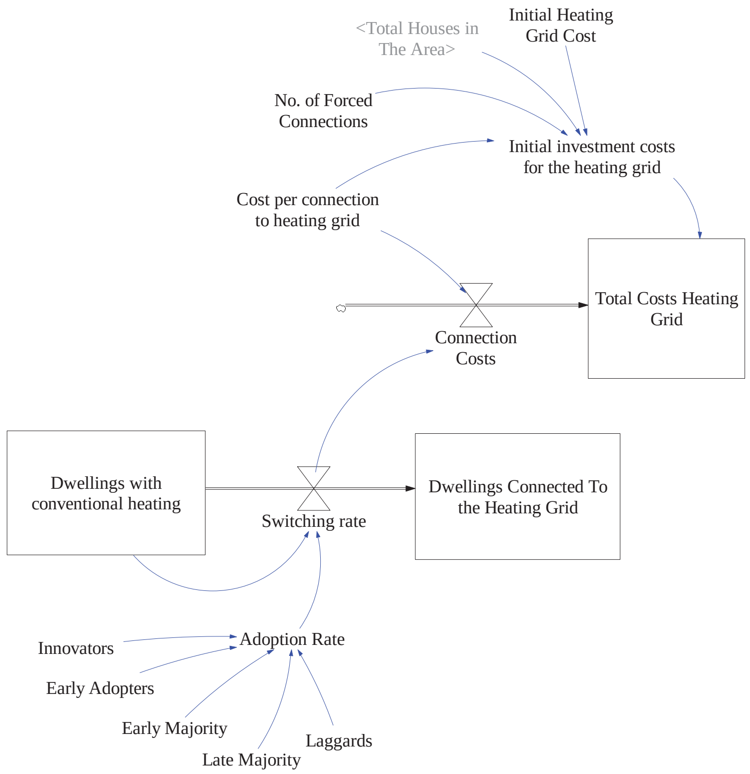

Figure 3: Heating Grid Connections

Figure 3 shows when and how many connections are established per year, together with the annual heating grid investments. Below, the formulas underlying the second sub-model are represented.

Switching rate =

*Adoption Rate * Dwellings with conventional heating*

Connection costs =

*Switching rate * Cost per connection to heating grid*

Initial investment costs for the heating grid =

*No. of Forced Connections * Cost per connection to heating grid +*
*Initial Heating Grid Cost * Total Houses in the Area*

Total Costs Heating Grid =

INTEG (Connection Costs, Initial investment costs for the heating grid)

4.3 Sub-model 3: Financial calculations

The Net Present Value (NPV) method is used to calculate the financial feasibility of geothermal heat projects. The NPV is calculated by discounting the annual cash flow, and summarizing this for the estimated duration of the project. Therefore, the calculation of the cash flow stands central in this sub-model (see figure 4). The annual cash flow is calculated by subtracting the Costs Rate from the Cash in Rate.

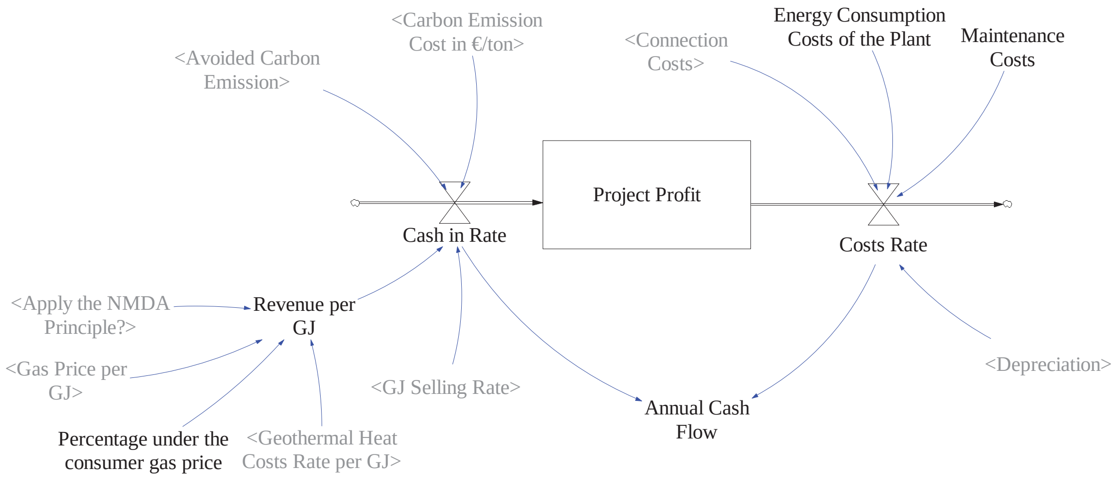

Figure 4: Cash flow Calculation

An important variable in determining the Cash in Rate is the Revenue per GJ. This revenue is calculated by subtracting the geothermal heat costs rate per GJ from the selling price of geothermal heat. The Cash in Rate is determined by multiplying the GJ selling rate with the revenue per GJ, and adding possible sales of carbon emission rights. Together with the Costs Rate, the Cash in Rate determines the annual cash flow.

Revenue per GJ =
IF THEN ELSE (“Apply the NMDA Principle?” = 0,
Geothermal Heat Costs Rate per GJ,
*Gas Price per GJ * (1 – Percentage under the consumer gas price))*

Cash in Rate =
*(Avoided Carbon Emission * Carbon Emission Cost in € / ton) +*
*(GJ Selling Rate * Revenue per GJ)*

Costs Rate =
Connection Costs + Energy Consumption Costs of the Plant +
Depreciation + Maintenance Costs

The maintenance costs are assumed to amount to 1.5% of the investment costs (Lako *et al.*, 2011). Furthermore, the energy consumption costs of the plant are determined by the efficiency of the plant, the capacity of the system, the operational hours, and the price per GJ.

5. Scenarios

Scenarios are applied to study the effects of exogenous variables on the feasibility of geothermal energy. In order to study these effects, the general economic scenarios from Janssen *et al.* (2006) and the more specific energy scenarios from ECN (2006; 2009) are employed. All three references distinguish four scenarios that outline possible political, economic and environmental developments for the Netherlands until 2040. The four developed scenarios can be represented in a matrix with two axes: level of international cooperation on the vertical axis and level of public/private responsibilities on the horizontal axis (table 1).

Table 1: Characteristics of WLO energy scenarios (Janssen *et al.*, 2006; ECN, 2006; 2009)

	Public Responsibilities	**Private Responsibilities**
International development	**Strong Europe (SE)** - High population growth - Moderate economic growth - Global trade, environmental restrictions - Effective international climate policy	**Global Economy (GE)** - High population growth - High economic growth - Global trade, no environmental restrictions - No climate policy
National development	**Regional Communities (RC)** - Low population growth - Low economic growth - Trading blocs keep sustained - Effective national climate policy	**Transatlantic Market (TM)** - Moderate population growth - High economic growth - Trading blocs keep sustained - No effective environmental policy

Janssen *et al.* (2006) and ECN (2009) have assumed policy trends in each scenario on for instance carbon emission trading, energy consumption in the built environment, and renewable energy. The policy for both energy saving and climate change remains unchanged in all scenarios until 2020; thereafter it will lapse in the scenarios Global Economy and Transatlantic market (ECN, 2006; 2009). After 2020, each scenario will present other parameter outcomes that influence the application of renewable energy. Since geothermal heat is presented as a renewable alternative to natural gas and it is mandatory to have a sufficient heat demand in a particular area, the most influencing factors for the feasibility of these systems are considered to be the gas prices and the heating demand; the higher the gas price and the higher the heating demand, the greater the feasibility of the geothermal heating plant. Financial support such as subsidies on renewable energy from the government, the possibility to sell carbon emission rights, and increasing gas prices will increase the feasibility of a large-scale energy solution.

All four scenarios have different approaches in supporting and favoring the application of renewable energy. The two scenarios with the largest contrasts are Strong Europe – favoring the application of renewable energy – and Global Economy, the scenario in which little attention is paid to the environment. Table 2 shows the scenario parameters that will be incorporated in the model; it seems that Strong Europe has favorable characteristics for small energy solutions, while the Global Economy characteristics might favor the application of large-scale energy solutions.

Table 2: Assumed policy in WLO scenarios (ECN, 2006; 2009)

	Strong Europe	**Global Economy**
Renewable energy	Continue on current policy, although lower subsidy prices	Same to SE, although policy will be cancelled after 2020
Carbon Trading before 2020	2 €/ ton (2005) 7 €/ ton (2010) 35 €/ ton (2020)	Same to SE
Carbon Trading after 2020	58 €/ton (2030) 84 €/ton (2040)	Carbon Trading system will be terminated

Built Environment	Energy Performance Buildings (EPBD) is introduced	Same to SE, after 2020 EPBD will be cancelled
Household gas consumption	340 PJ (2006) 230 PJ (2040) annual decline 1%	340 PJ (2006) 305 PJ (2040) annual decline 0.3%
Gas Price	annual increase 0.4%	annual increase 0.8%

6. System Solutions for Geothermal Energy Applications

This section will discuss possible and feasible geothermal energy system solutions, varying in thermal capacity and investment costs. These energy solutions will be tested on three different cases and subjected to different scenarios. The inputs and parameters for the different solutions are based on index numbers, since actual numbers change per application, drilling depth, and location. However, it is possible to give realistic indications on the heat production and the related costs of specific solutions. The index numbers are used for the increase of temperature per kilometer, the cost per kilometer drilling, the flow rate of the water, and the operational hours of the geothermal energy plant.

6.1 Geothermal Energy Plant Capacity

The following general formula shows that the thermal power production of the energy plant is based on the characteristics of the aquifer in the subsoil:

$$W_{th} = Q * \rho * cv * \Delta T$$

in which *Q* represents the flow rate of the water in the aquifer in m^3 per hour, $\rho * cv$ represents the heat capacity per volume of water in Joule per m^3K, and ΔT is the difference between inflow and return temperatures. The variables *Q*, ρ, and cv represent aquifer characteristics; expert interviews allowed a realistic assumption on the flow rate (150 m^3/hr) and thermal capacity of the aquifer water in Eindhoven (4.19 m^3K). These values are also adopted in Lako *et al.* (2011).

6.2 Geothermal energy plant and heating grid costs

The mentioned factors also relate to the investment costs of the geothermal energy plant; the deeper the drill, the higher the investment costs for the energy plant. In this research, we assume that drilling costs amount to €2,000,000 per km when drilling less than 3 kilometers deep, and to €3,500,000 per km when drilling deeper than 3 kilometers. These index numbers are derived from expert interviews; ENGINE (2007) supports these assumptions to a large extent.

Excluded in the final system solution designs are the costs for the heating grid, because not all cases require the construction of a new heating grid. However, as the heating grid development costs are a substantial part of the total project costs, the influence of grid development costs will be discussed in the results and sensitivity analyses. In case it is necessary to develop a new heating grid, the costs for the construction of the heating grid cover approximately 75% of the total project investment. Based upon expert interviews, the costs for a heating grid are assessed at €4,000 per dwelling; these costs can be divided in costs for the main heating grid (€1,000 per dwelling) and connection costs to the dwelling (€3,000 per dwelling).

6.3 Three geothermal energy solutions

In table 3, the designed system solutions are summarized. The different solutions vary in drilling depth, geothermal plant costs, capacity, and costs per Gigajoule. Furthermore, all geothermal solutions will provide 70% of the total heating demand in the area; 30% of the heating demand will be supplied by the using peak boilers that are situated at the geothermal plant site.

Table 3: Geothermal Energy Plant Specifications

	System solution 1	**System solution 2**	**System solution 3**
Depth (meters)	2,000	3,000	4,000
Costs of the plant (€)	8,000,000	12,000,000	28,000,000
Flow rate (m^3/hr)	150	150	150
Heating capacity (m^3K)	4.19	4.19	4.19
T inflow (^{o}C)	72	103	134
T return (^{o}C)	45	70	45
ΔT (^{o}C)	27	33	89
Capacity (MW_{th})	4.7	5.8	15.5
Operation hours	4,000	5,000	5,000
Energy production (MWh/yr)	18,855	28,806	77,690
Energy production (GJ/yr)	67,878	103,703	279,683
Production cost at source (€/GJ)	7.86	7.71	6.67

Although the investment costs and drilling costs for solution 3 are incrementally higher, the costs for producing one GJ seem to decline when the drilling depth increases. Each geothermal energy solution will be applied on a particular case with different specifications. System solution one will be tested on a newly built area, system solution two will be applied on an urban area with an already existing building stock, and the third system solution is a cascade connection between a new housing area and the existing building stock. The specifications of the cases will be discussed in the subsequent section.

7. Case selection

The cases are selected on available technical, social and financial parameters. The main technical parameter is the heating temperature requirement of the dwellings. The social parameters are related to the selection of the dwelling types that will be provided with geothermal energy. The existing building stock holds great potential in the preservation of its energy consumption; newly built dwellings are far more efficient in their energy consumption. The financial parameters address the effect of the heating grid on the feasibility of the project.

In case of geothermal plants with a drilling depth of 2 kilometers, it is required to connect to an area with newly built dwellings, since the inflow temperature from the aquifer is too low for heating existing dwellings. For this, we selected a new housing development project in Eindhoven called Meerhoven, in which a heating grid is already present. The second system solution allows providing the existing building stock with geothermal heat, because the inflow temperature is high enough for high temperature systems. An existing housing stock in the neighborhood Rapenland & Kronehoef has been selected. This area requires the construction of a heating grid, which will have a strong influence on the feasibility of the project. The third case (Flight Forum, Meerhoven and Strijp) has been selected because of its cascade connection between commercial buildings, existing dwellings and new dwellings.

The case should include these characteristics and have a sufficient size of scale, since this system solution has a large capacity output. In figure 5, the cases are positioned within the city map of Eindhoven; the case details are summarized in table 4.

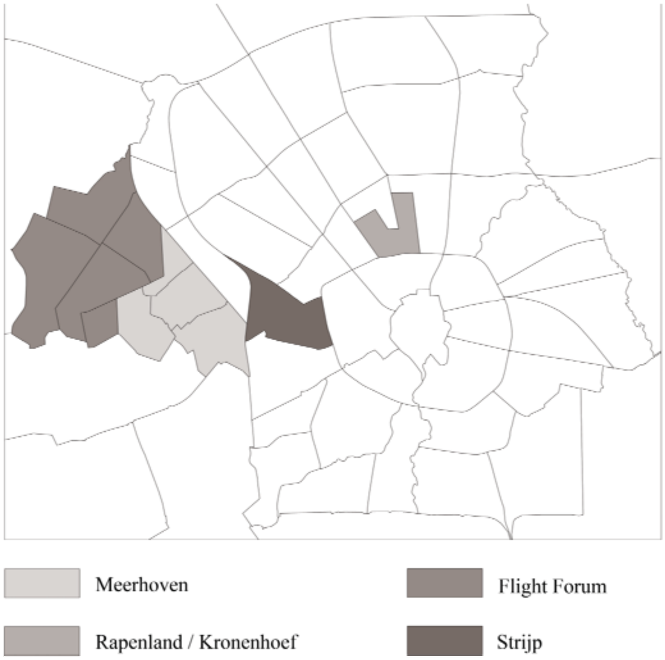

Figure 5: Selected cases in Eindhoven (case 1 = Meerhoven; case 2 = Rapenland / Kronehoef; case 3 = Flight Forum, Meerhoven, and Strijp)

7.1 Case 1: Meerhoven

Meerhoven is a new housing development project, situated in the western part of Eindhoven. It is the most recent and largest city expansion of Eindhoven. The development project comprises the development and construction of 5,800 dwellings. Since the heating in this area is serviced by a biomass power station, a heating grid is already present in this area. The dwellings are designed with a low temperature heating system, and although there is no exact information available on the energy demand of the households in this area, it is assumed that a newly built dwelling consumes 20 GJ for heating and 8 GJ for hot water supply per year. Given this assumption, it is possible to provide 3,463 dwellings with geothermal heat when applying geothermal system solution one.

7.2 Case 2: Rapenland & Kronehoef

The second case concerns an area with an existing building stock. This case is interesting because the existing building stock holds great potential in the preservation of the energy supply. Additional advantages are the high density of the building stock and the relative low energetic quality of these dwellings. However, an important constraint is the heating grid, which is generally not present in such existing areas. Since these costs could comprise four times the costs of the geothermal heating plant, it is interesting to study the effect of the development of a heating grid on the geothermal business case. The actual case is situated in Woensel-Zuid, which is located north to the centre of Eindhoven. In total 3,144 dwellings are situated in the neighborhoods Rapenland and Kronehoef, of which 1,255 dwellings

(42%) are in ownership of housing associations. The dwellings in this area are designed with high temperature heating systems, which results in a small difference between the inflow and return temperature of the geothermal heating system. The average heating demand per household is based on available gas consumption data; the averaged heating demand per dwelling is 49 GJ per year.

7.3 Case 3: Flight Forum, Meerhoven and Strijp

The third case is a cascade connection between commercial buildings, the existing building stock, and a new housing development project, resulting in a combination of high temperature and low temperature heating systems. This asks for a high thermal capacity due to the large difference between the inflow and return temperature. This case is interesting because of its cascade connection and its scale of utilization; it is possible to connect over 8,000 existing buildings with a considerable heating demand. This case contains new dwellings in Meerhoven, commercial buildings in the Flight Forum area, and existing buildings in the areas Het Ven and Lievendaal in Strijp. The city districts Meerhoven, Het Ven and Lievendaal contain 9,261 dwellings. Based on actual gas consumption data, the commercial buildings consume 83,501 GJ annually, the new dwellings use approximately 28 GJ per year, and the existing dwellings consume 49 GJ annually. As discussed in the first case, a heating grid is already constructed in Meerhoven. However, the city district Strijp has no heating grid; the existing building stock is connected to a gas infrastructure, requiring the development of a heating grid in this particular area.

Table 4: Case details

	Case 1	**Case 2**	**Case 3**
Heating system	Low temperature (70/40 °C)	High temperature (90/70 °C)	High & low temperature (90/40 °C)
Average heating demands of households (GJ/yr)	28	49	28
Commercial heating demand (GJ/yr)	-	-	83.501
Share of geothermal heating in total heating demand (%)	70	70	70
Number of dwellings provided with geothermal heat	3,463	3,023	5,811 (new dwellings) 3,129 (existing dwellings)
Heating grid connections (housing association)	Available	1,255	7,509
Percentage forced to switch (% of total)	100	41.5	84
Percentage of existing stock (%)	-	-	54
Discount rate (%)	5	5	5
Depreciation period (years)	25	25	25
Gas price (€/m^3)	0.55	0.55	0.55
kWh price (€/kWh)	0.065	0.065	0.065
Connection cost per house (€/house)	3000	3000	3000
Main heating grid costs (€/house)	1000	1000	1000
Carbon emission gas (kg/m^3)	1.78	1.78	1.78
Carbon emission electricity (kg/kWh)	0.608	0.608	0.608
Coefficient of performance	20	20	20

8. Results

8.1 The feasibility of geothermal heat under different scenario assumptions

Several barriers – like the high up-front costs and the lack of investor awareness – relate to the financial outcomes of the geothermal energy applications. Considering these specific barriers, each geothermal system solution will be analyzed on the internal rate of return (IRR) of the project and its net present value (NPV). The internal rate of return is the discount rate at which the net present value is zero; the higher the rate on return, the more desirable it is to undertake the project. The internal rate of return should be high to attract investors; in this research, a business case is considered to be feasible with an IRR of eight percent or higher. In table 5, the NPV and IRR of the three geothermal system solutions are represented. Figures 6 and 7 represent the detailed development of the NPV in time, both under GE and SE scenario assumptions.

Table 5: Financial results of three cases under different scenario assumptions

Case	Calculation	Global Economy	Strong Europe	Difference GE-SE
1	NPV (after 30 years)	€ 8,568,852	€ 6,658,718	+28.7%
	Internal Rate of Return	12%	11%	+1%
2	NPV (after 30 years)	€ -2,026,945	€ -4,817,175	+57.9%
	Internal Rate of Return	5%	4%	+1%
3	NPV (after 30 years)	€ 16,274,561	€ 9,656,921	+68.5%
	Internal Rate of Return	8%	7%	+1%

Considering the financial output under the GE scenario, the first case and the third case are interesting. Based on the IRR, the first case is far more desirable. We can conclude that case two is not interesting for investors, since it reaches break even after 2045 and has an internal rate of return of only 5%. This illustrates that the construction of a heating grid has a strong influence on the projects feasibility. The IRR values under SE scenario assumptions are little lower, but show the same pattern. Comparing the results of figures 6 and 7 shows how these scenarios influence the NPV and the IRR; the GE scenario has an earlier break-even moment for all cases and the generated value at 2045 is remarkably higher than in the SE scenarios. Furthermore, the difference between case one and three in the annual discounted income under the GE scenario is greater than in the SE scenario, respectively 3.35 million and 2.54 million Euros. This suggest that under the SE scenario the first case is more desirable, while under the reference scenario (GE) the third case is more interesting, considering the annual internal rate of return. Overall, the reference scenario seems to be more desirable than the SE scenario.

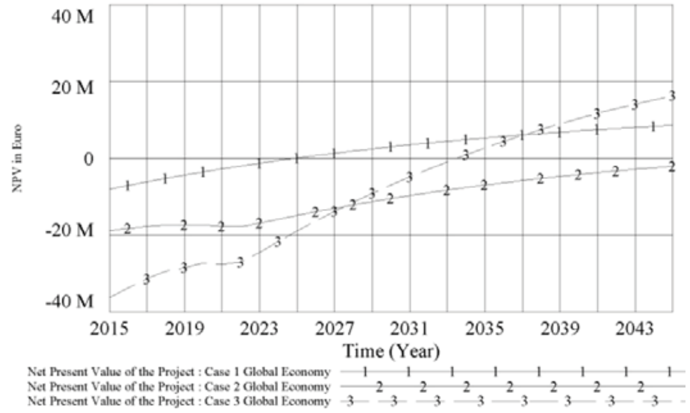

Figure 6: Net Present Value under Global Economy scenario

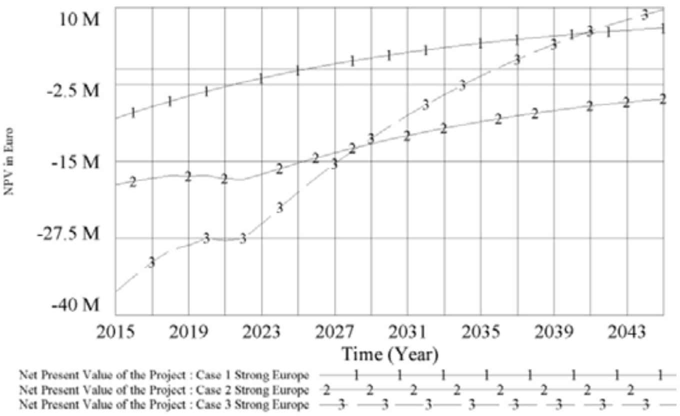

Figure 7: Net Present Value under Strong Europe scenario

The larger the energy solution in terms of investments, the more advantageous the Global Economy scenario becomes. The SE scenario favors smaller energy solutions like case one. This means that the decline in energy consumption has a stronger negative effect on the financial result than the increasing fossil fuel prices, since it decreases the annual amount of energy sold to consumers. However, when the discrepancy between the energy demand and generation of energy is large enough, it could be interesting to expand the heating grid and connect additional dwellings. This increases the energy demand, ensuring that the yearly income will be on its initial level.

8.2 Avoided carbon emission under scenarios

Governments are interested in renewable energy because it decreases the dependency on fossil fuels from political instable countries, and it decreases the annual carbon emission. The latter is important since the Dutch government agreed upon an international protocol to reduce its yearly carbon emission. This means that besides financial reasons, a main governmental incentive for applying geothermal energy is the annually avoided carbon emission. Table 6 illustrates the results on the annual avoided emission of carbon.

Table 6: Cumulative avoided carbon emission

Case	Avoided Carbon Emissions (tons)	Global Economy	Strong Europe	Difference GE-SE
1	After 15 years	17,053	14,669	+16.3%
	After 30 years	31,886	22,618	+40.9%
2	After 15 years	45,941	42,618	+7.8%
	After 30 years	106,408	92,570	+14.9%
3	After 15 years	143,152	135,916	+5.3%
	After 30 years	309,130	279,462	+6.2%

The rate of avoided carbon emission is the highest in the third case, while the first case avoids the least carbon emission. The avoided carbon emissions are relatively low in case 1 since the existing biomass plant emits little carbon dioxide compared to gas-fired heating. The fact that the second and third cases have an increase during the first years can be addressed to the fact that the maximum of connections to the heating grid is reached after eight years. After these years the maximum of potential avoided carbon has been achieved.

8.3 Consumer Costs for Geothermal Heat under Scenarios

The consumer costs per GJ for geothermal heat depends on the geothermal energy plant capacity, the number of connections to the heating grid, and the gas price (e.g. whether the NMDA principle is applied). During the first operational year of the geothermal energy plant, consumers pay between 370 Euros (case 1) and 650 Euros (case 2) per year for their heating, depending on the geothermal energy solution. Since the heating demand per dwelling is highest in case 2, figure 8 illustrates how the geothermal costs are distributed over the years for this case.

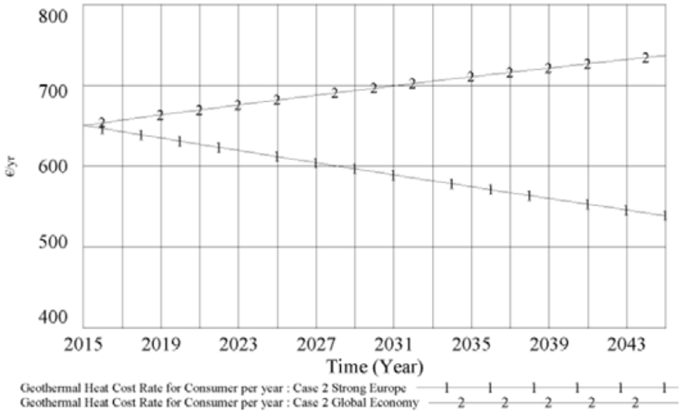

Figure 8: The Geothermal Heating Costs for Consumers for case 2

Figure 8 also illustrates the effect of the scenarios. The SE scenario implies a decrease in energy consumption and lower increase in fossil fuel prices than the GE scenario. As the figure illustrates, the heating costs will increase in the GE scenario while the costs for heating decrease in the SE scenario; the decline in energy consumption has a stronger influence than the gas price increase. We can conclude that the SE scenario has more favorable characteristics for consumers than the GE scenario; this is opposite to the case for investors.

9. Sensitivity Analysis

The developed model contains some approximations and assumptions, which makes it mandatory to examine the sensitivity of the results to plausible alternative structural assumptions, including changes in the model boundary. A sensitivity analysis is executed to discuss the credibility of the results, and to test the robustness of the model and the results. Only case two is subjected to a sensitivity analysis, since this case is characterized by an absence of a suitable heating grid. This is the case in many urban areas in the Netherlands. However, the sensitivity patterns also count for the other two cases.

9.1 Connection Rates

First, we examine how changes in the number of initial switchers will affect the feasibility of the project. Figure 9 illustrates the effect of the connection rate on the feasibility of the second case. Line 1 shows the results when no user will connect initially; line 3 illustrates the case in which all energy users will initially connect. As the figure illustrates, the initial project investments increase with the number of initial connections. Furthermore, a lower income in the first eight years has an incremental influence on the project; while the case with 100% initial connections will turn break even in 2043, the case with no initial switchers will not reach break even within 30 years. A certain number of initial connections are required to get at least a positive net present value over the project period.

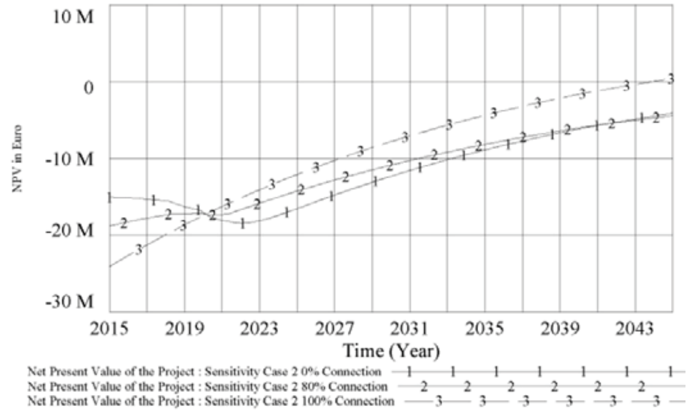

Figure 9: Sensitivity analysis – Connection Rates (Case 2, GE scenario)

Furthermore, we tested the influence of a lowering of the total number of connections in an area. In the base calculations, we assumed that 100% of all inhabitants will connect, either directly or within 8 years. Line 2 in figure 9 represents the NPV of case 2 when only 80% of the inhabitants in the urban area will connect. It shows that such a connection limit reduces the financial feasibility strongly; break even is not reached in 2045.

9.2 NMDA Price

The NMDA principle has been applied to sell heat to consumers conform market prices, but also to create financial benefits for the consumers. In the base results, we assumed that each GJ of geothermal heat will be sold 15% below the heat price a consumer would pay with a gas-fired connection. It is interesting to study how a change in this percentage influences the financial results. The most desired percentage under the gas price could be derived in order to create an interesting financial environment for both consumers and investors. Furthermore, an additional assumption has been tested to examine at what price geothermal heat should be sold. This could provide information to governments regarding subsidizing geothermal heat. Figure 10 shows the sensitivity analysis results.

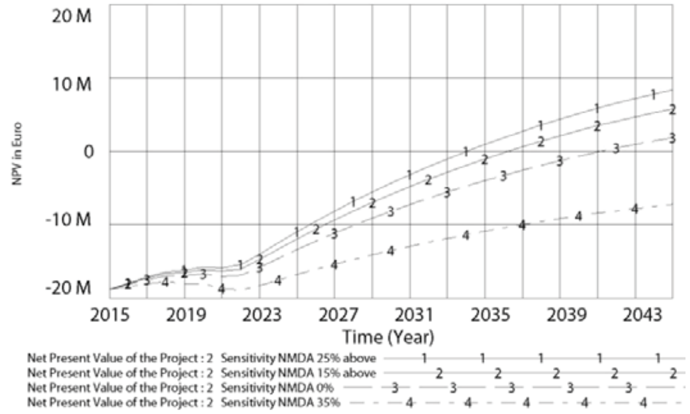

Figure 10: Sensitivity analysis – NMDA Rates (Case 2)

Generally, the second case is not feasible, since the IRR is considered too low. However, as figure 10 illustrates, selling it against gas price does not strongly improve the feasibility of the case; the resulting IRR is 5%. Therefore, a governmental subsidy is necessary to attract investors, but also to offer the desired financial benefits to consumers. A subsidy of at least 15% above the current gas price is required; this will increase the project's IRR to 9%. To attract investors for this project, even higher yields on the financial investments are desired. If the government will subsidize 25%, the project will have an IRR of 11%.

9.3 Heating Grid Costs

The costs related to the heating grid can differ greatly; it is more expensive to construct a heating grid in a high-density neighborhood than in a new housing development project. The complexity of the project and the size of the heating grid mainly determine the costs of the heating grid. It is assumed that the costs are approximately €4.000 per dwelling; this section examines the effect of increasing or decreasing costs of the heating grid on the projects feasibility. In this analysis, the costs of a connection to heating grid were increased by 10%, and decreased by 10% and 20%. In table 7, the results are presented.

Table 7: Sensitivity analysis – Heating grid costs

Case	Financial results	Base Case	10% increase	10% decrease	20% decrease
2	NPV (after 30 years)	€ -2,026,945	€ -3,010,102	€ -1,043,785	€ -60,624
	IRR	5%	3.8%	5.6%	6.3%

In both analyses with lower connection costs, the resulting IRR lies around 6%, a minor increase compared to the base calculations. The analysis with higher connection costs results in an IRR of 3.8%. We can conclude that decreasing connection costs do not withdraw the barrier regarding the feasibility of the project.

9.4 Selling Carbon Rights

In case an organization would be erected for realizing the geothermal energy project and its additional heating grid, this local energy company can be allowed to sell carbon rights because it avoids the emission of carbon. The effects of the selling of carbon rights are illustrated in figure 11.

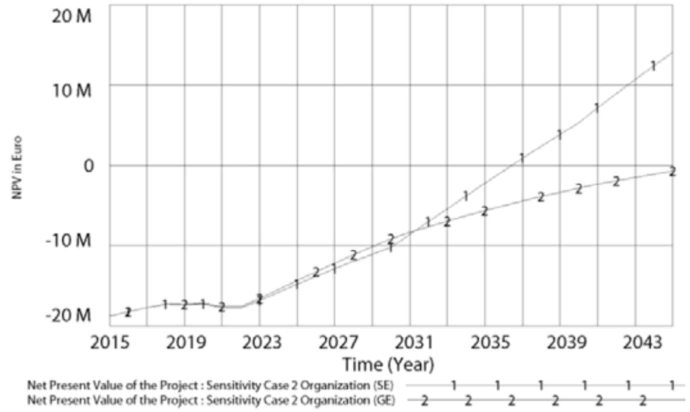

Figure 11: Sensitivity analysis – Selling carbon emission rights (Case 2)

The resulting internal rates of return are 4.6% in case of GE, and 8.1% in case of SE. This shows that – especially under SE scenario assumptions – selling carbon emission rights can contribute strongly to the financial feasibility of geothermal heat projects. The GE scenario has a lower decrease in energy consumption but a higher increase in fossil fuel prices compared to the SE scenario. The project is most successful under the conditions of SE. This can be addressed to the fact that – in case of GE – the carbon emission trading mechanism will be terminated after 2020, and no additional revenues will be generated. The additional revenues in the SE scenario are expected to be €58 per ton CO_2 by 2030, and €84 per ton CO_2 in 2040.

10. Conclusions

Geothermal heat offers great potential in renewably satisfying the future Dutch heating demand. Currently, heating is mainly provided for by natural gas. In spite of the extensive Dutch natural gas resources, these reserves will deplete eventually, requiring involved stakeholders to already look for alternatives. Additionally, combusting natural gas emits carbon dioxide, and gas is subject to price fluctuations; as supplies dwindle, it is likely that prices will increase. This introduces the opportunity for utilizing geothermal heat. TNO (2010a) has estimated the technically and economically recoverable potential up to a depth of four kilometers at 38.000 PJ. However, to date, the introduction of geothermal heat applications stagnates; several barriers hinder the application of this renewable heat technique. These barriers should be overcome; the benefits of geothermal heat should be made explicit for the most important stakeholder groups (governments, consumers, and investors). Below, the main conclusions concerning these benefits are summarized per user group.

10.1 Benefits for governments

One of the greatest benefits of geothermal heat is its independence of seasonal influences, and the high security of supply. It can provide a stable energy supply to consumers all year long, depending on the operational hours of the energy system. Furthermore, it has a substantial energy capacity, which allows connecting a large number of consumers to renewable energy. This decreases the use of fossil fuels, the emission of carbon, and increases the share of renewable energy in the Netherlands.

Based on our assumptions, application of geothermal heating plants can reduce the fossil fuel consumption for heating in the case study areas with 70 percent. In the extreme condition, 30% of the peak demand is provided by geothermal heat. Furthermore, governments and municipalities benefit from applying geothermal energy since it avoids the emission of carbon. Depending on the case and system solution, it is possible to avoid an annual emission of between 2,800 and 13,000 tons of CO_2 per geothermal heat application. This amount can be higher since peak boilers, situated at the geothermal plant site, utilize fossil fuels. When providing the peak demand with renewable energy, the annually avoided carbon emission increases with between 30% and 70%. From a governmental perspective, these measures contribute strongly to achieving the binding agreements with the European Union on increasing the share of renewable energy and reducing the emission of carbon dioxide.

10.2 Benefits for consumers

Generally, the NMDA principle is disadvantageous for heat consumers, since possible savings in development, maintenance and exploitation of the heating system mainly benefit investors; the linkage to fossil fuel prices only increases the probability of future heat price increases. Therefore, we assumed a geothermal heat price that is always 15% below the price for heat in a gas-fired situation. The baseline calculations showed that geothermal heat projects can be profitable, even under this lower heat price assumption. For larger price discount percentages on geothermal heat, additional governmental subsidies are necessary.

Besides possibilities for reducing heat prices for consumers – which present financial benefits to the consumers – geothermal heat systems often deliver a high level of indoor comfort. Consumers experience heating and cooling with geothermal systems as more comfortable than high-temperature natural gas heating or cooling with air from air condition systems. This is caused by the more evenly spreading of heat through spaces, and by the decrease of air flows and draught.

10.3 Benefits for investors

Despite the current lack of investor awareness, geothermal heat applications show to be financially attractive in several circumstances. Still, in many situations, the internal rate of return remains too low to attract investors. The most important considerations when investing in geothermal heat projects are the maximization of the number of geothermal heat consumers, the availability of suitable heating infrastructures, and the heat prices. The sensitivity analysis on switching rates shows that the NPV and IRR of geothermal heat projects are extremely influenced by the percentage of residents that switch to geothermal heat, and to the duration of the period in which they decide to switch. Furthermore, as the case studies illustrate, the availability of a heating grid has an incremental positive influence on the feasibility of the project. However, it is considered not very realistic since it probably will mean that the geothermal heat plant has to compete with the current energy plant. It is more realistic that, along with the development of the geothermal energy plant, a heating grid has to be constructed in the specific area. This means that additional costs have to be made. Finally, the NMDA principle limits the possibilities for investors to vary their heat prices; the sensitivity analysis shows that increasing heat prices strongly improves the business case.

Although the internal rate of return is regularly too little to attract investors, geothermal heat projects generally have numerous benefits. Once the plant is operating, it has a stable and guaranteed production of energy and it is insensitive to seasonal influences. The offset of heat is only dependent on the demand for heat in the area. If the risks can be reduced by for instance a guarantee on the drill, a geothermal project gains investment attractiveness.

10.4 System interventions

In order to overcome some of the final barriers in executing geothermal heat projects, we can distinguish two governmental interventions that strongly contribute to the financial feasibility of new geothermal heat projects. First, subsidies on geothermal heat or an increase in the price of natural gas are possible governmental interventions to increase the investment attractiveness. The sensitivity analysis shows that heat price levels of between 15 and 25 percent above the current gas price are sufficient to firmly attract commercial parties. Second, when the social benefit for governments – e.g. carbon emission avoidance – is financially remunerated, the attractiveness of geothermal heat projects increase for investors. The avoided emission of carbon will generate so-called carbon emission rights, which can be traded for money; the higher the avoidance of carbon emission, the greater the project revenues. Sensitivity analyses show that the NPV and IRR of geothermal heat projects increase significantly when incorporating emission right sales. Generally, this favors large-scale geothermal energy projects, since larger carbon emission right revenues can be generated.

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