

## MASTER

### The value of geothermal energy under scenarios exploring the potential of geothermal energy in Eindhoven

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# THE VALUE OF GEOTHERMAL ENERGY UNDER SCENARIOS

Exploring the Potential of Geothermal Energy in Eindhoven

Graduation Report 'The Value of Geothermal Energy under Scenarios'  
July 14<sup>th</sup> 2011

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## PREFACE

The report in front of you is my graduation thesis for the master Construction Management and Urban Development at the Eindhoven University of Technology. My final research has been performed in the context of KENWIB, a program that has been designed to develop and share knowledge on energy neutral living in Brainport. The goal energy neutral living is in my opinion two-folded, and I think two pathways can be distinguished. One is reducing the energy consumption in the built environment; the other, of which I think is more interesting, is preserving the energy supply. In other words, why should we save energy, if we can generate all energy from renewable and domestic resources? However, it is an interesting discussion whether all energy can be generated from renewable resources. Based on this mind-set, geothermal energy caught my attention, since it is independent to seasonal influences, the potential of this resource is enormous, but mainly because of the fact it is new in the Netherlands. Arcadis gave me the opportunity to research this topic.

Since the moment I started I experienced several challenges, my start was not as I hoped it would be. However, the help and support from my supervisors, family and friends kept me motivated and helped me to finish my MSc. Therefore, I would like to thank some persons in particular.

First, I would like to thank Gerwin Brandsen –my supervisor at Arcadis- for his time and feedback on my research. His thinking along, the discussions with, and the critical comments of Gerwin allowed to solve the problems I encountered during my research. Furthermore, I would like to thank my supervisors at the TU/e, Wim Schaefer and Erik Blokhuis for their guidance, advice and critical comments on my research.

Finally, I want to thank my family and friends for their support. In particular, my little brother Joost and my girlfriend Olga, who helped me to get my mind off during the weekends. But great appreciation goes to my parents, Jos en Aleida, who gave me the possibility to study and live in Eindhoven for almost three years now.

*Erik Alfrink*  
*Eindhoven, July 14<sup>th</sup> 2011*



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**LIST OF ABBREVIATIONS**

Btu	British thermal unit
CBS	Statistics Netherlands (Centraal Bureau voor de Statistiek)
CPB	Netherlands Bureau for Economic Policy Analysis (Centraal Planbureau)
ECN	Energy Research Centre of the Netherlands
EJ	Exajoule = $10^{18}$ Joule
EPC	Energy Performance Coefficient
GE	Global Economy (WLO scenario)
GJ	Gigajoule = $10^9$ Joule
IRR	Internal Rate of Return
KENWIB	Knowledge cluster Energy Neutral Living in Brainport
MNP	Netherlands Environmental Assessment Agency (
NMDA	Consumers will not pay more for heat than they would in the gas-fired situation (Niet Meer Dan Anders)
NPV	Net Present Value
OECD	Organisation for Economic Co-operation and Development
PJ	Petajoule = $10^{15}$ Joule
RPB	National Institute for Spatial Research
SE	Strong Europe (WLO scenario)
WLO	Welfare, prosperity and quality of the living environment (Welvaart en Leefomgeving)







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## 1 INTRODUCTION

### 1.1 *Research Context*

The global population is consuming an enormous amount of energy, and the trend shows this demand for energy will continue to grow in the future. The Netherlands consumes approximately 3.260 PJ of energy per year; 40% of this energy consumption can be addressed to heating. The built environment and industry are the biggest consumers of heat. The energy consumption of households that can be related to heating constitutes the greatest part of the total consumption. Despite the improvement on energy efficiency of buildings, a great part of the consumed energy will still be constituted by space heating and hot water supply. Currently, the energy demand for heating in households is mainly provided by a fossil fuel, natural gas. Only a small part of the generated heat comes from renewable resources. The fact heating constitutes the greatest part in the total energy consumption, it mainly is provided by a fossil fuel, and only a fraction of heat is generated sustainably shows a focus on providing a sustainable alternative to consumers is appropriate.

Furthermore, natural gas plays a significant role in the energy supply of the Netherlands; it constitutes a 60% share in the energy mix for the generation of electricity, and over 90% of the heating demand by households is provided by burning natural gas. Furthermore, the Netherlands has great natural gas reserves; almost a quarter of the European gas field reserves can be addressed to the reserves in the Netherlands. The domestic natural gas contributes to the Dutch wealth, and is considered as a relatively 'clean' fossil fuel compared to coal and crude oil. However, since it is considered as a finite source it might lead to future challenges such as uncertainty in energy supply as a result of the dependency on countries in possession of these resources. It is likely that gas prices will increase in the future, leading to an increasing value of the gas field reserves but also to increasing costs for consumers. This increase in fossil fuel prices will force governments, companies, and consumers to consider the use of alternative energy sources. Alternatives to fossil fuel should therefore provide financial benefits to consumers and investors.

To introduce geothermal energy for heating as a substitute of natural gas successfully, the financial benefits of geothermal energy compared to natural gas should be made explicit. The research is focused on the problem how geothermal energy will compete with natural gas, based on economic drivers, under different scenarios.

### 1.2 *Problem Definition*

The greatest part of the energy consumption is constituted by heating, which is mainly provided by natural gas while only a fraction is generated from renewable resources. The conservation of the heating supply in the Netherlands reveals there is a great potential for utilizing indigenous geothermal energy as a cleaner, nearly emissions-free renewable source of heat whose characteristics are ideal for local district heating applications. (Thorsteinsson & Tester, 2010) However, high upfront costs, affordable gas and oil supplies, lack of investor awareness, well developed electricity delivery infrastructure, landlord/tenant incentive splits, and the wealth of Dutch gas resources are barriers to the deployment of geothermal energy. (Seyboth et al., 2008) (Thorsteinsson & Tester, 2010)(TNO, 2007)



The identified problem is that investors, operators, consumers, and governments are currently unaware of the social and financial benefits of geothermal energy in the built environment. This leads to the question how these barriers are withdrawn and geothermal energy can be introduced successfully in the Netherlands, so investors, operators, consumers, and governments are aware of, and benefit from geothermal heating?

### 1.3 Research Target

The research provides insight in the effect of exogenous variables on the application of a renewable resource based alternative for meeting the heating demand in the built environment. The first goal of this research is examine the current energy consumption and explore possibilities for geothermal energy in the Netherlands. This should provide insight in the heating demand in the Netherlands and the role geothermal energy could play in the preservation of the heating supply.

The second goal is to explore the financial feasibility of geothermal energy systems in the Netherlands, while incorporating the influence of exogenous variables resulting from future events. This will be tested on different cases, with different geothermal energy characteristics. The generated knowledge should be used to recommend the organization of a local energy company to the municipality.

### 1.4 Research Questions

In order to withdraw the barriers to the deployment of geothermal energy in the Netherlands, research questions have been defined to study possible solutions.

*What are the social, and economic benefits for governments, project developers, and consumers in geothermal energy projects? How do economic and demographic scenarios influence the business case of these renewable energy projects?*

To answer this main question, three sub-questions have been distinguished. Each part of the research is addressed to these questions.

1. *What is the current situation of the energy consumption in the Netherlands, what is the share of renewable energy in the Dutch energy supply, and what are the possibilities for geothermal heat?*
2. *What would be realistic scenarios, and what are possible and realistic geothermal energy solutions for specific cases in Eindhoven? Furthermore, how could System Dynamics integrate these elements?*
3. *What are the costs and benefits for the local energy company and its customers, and what are the effects of scenarios on the business case for particular geothermal energy systems? How do these systems correlate to each other?*

### 1.5 Research Boundaries

The research project is performed within a certain time period, which forced a delineation of the research. The attractiveness of geothermal energy for governments, investors and consumers is expressed in financial and social benefits. Furthermore, geothermal energy can

be applied for the generation of heat, cooling, and electricity. This thesis focuses on providing a renewable alternative for heating to consumers and therefore does not incorporate the other possibilities. The actual power production of an energy plant is dependent on many parameters, which require in practice extensive and expensive research. There is little knowledge of the soil in the southeast of Brabant since there have not been many oil and gas drills in the past. Therefore it is necessary to make assumptions on the geological and technical aspects. However, expert interviews allowed a realistic design of three different geothermal energy solutions. The purpose is not an exact and technical design of a geothermal energy plant, but a study on the potential and feasibility of geothermal energy in the Netherlands.

### *1.6 Objectives and Expected Results*

The aim is to develop a model for geothermal energy that simulates the effects of scenarios on the utilization of geothermal energy as a renewable alternative to natural gas. The model will contain parameters that can be changed, which will affect the outcomes. The parameters that can be incorporated can be for instance, the size and composition of the district, the geothermal energy solution. The model will simulate how these parameters will influence the business case for consumers, operators, investors and governments.

The purpose of the model is to present the financial and social benefits of geothermal energy compared to natural gas in the future. A causal loop diagram is underlying the model; it will make the relations between different variables explicit. The stock and flow diagram is the calculation model that will provide future predictions of different geothermal systems under different scenarios. Although, this research is focused on a city district of Eindhoven, it should be applicable for different situations.

The last part will constitute a recommendation to the municipality for an organizational design of a local district heating company.





## 2 RESEARCH DESIGN

The research comprises four phases: the contextual orientation, the model design, findings & results, and the conclusion and discussion of the results.

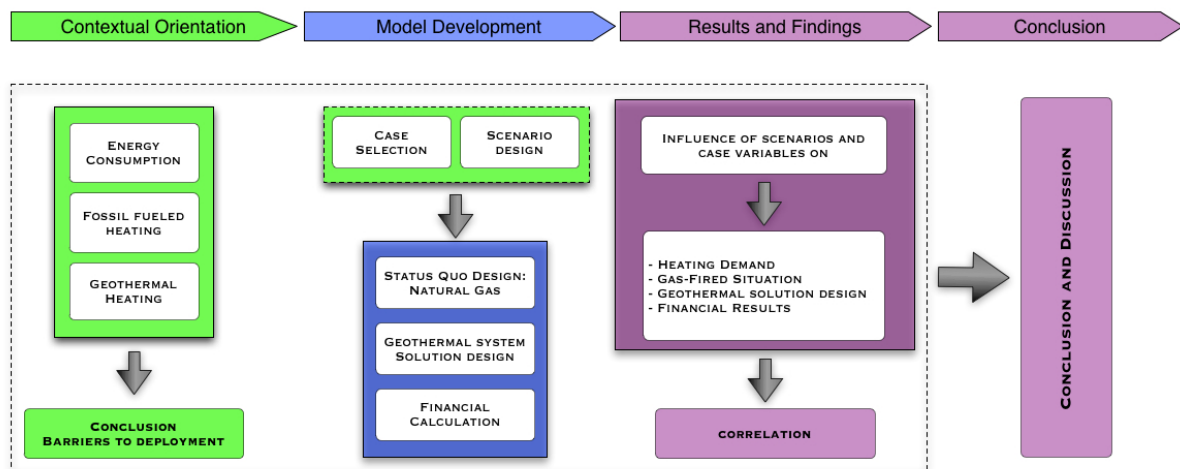


Figure 1: Research Model

- Contextual orientation:** this is considered as the literature phase of the research, and is designed to gain knowledge on the energy consumption, the heating demand and the trends in the heating demand within the Netherlands. Subsequently, I will study the gas-fired generation of heat; what are the benefits and constraints of the utilization of natural gas in the Netherlands? Hence, geothermal energy, an alternative based on renewable resources, will be introduced. What is geothermal energy, what are its advantages and what are the barriers and constraints to its utilization? This will be discussed in part I.
- Model development:** this part comprises the development of a model that should create insight in the influence of scenarios on the particular geothermal system solution. Besides the development of the system dynamics model, this part further comprises the design of realistic geothermal energy solutions, the development of scenarios and the selection of appropriate cases. The system dynamics model contains the calculation on the projects net present value, the heating demand of the area based on the gas-fired situation, and the application of the renewable alternative. These will be subjected to exogenous variables resulting from scenarios, and different geothermal energy system solutions. This will be discussed in Part II of this report.
- Results and findings:** The third part contains applying different input variables, as the different scenarios and geothermal system solutions. The influence of different variables will be made explicit by graphs and will be compared mutually under the status quo-, and the geothermal solution design. This step should allow us to create insight in the answers to questions as, what do consumers currently pay for a gas-fired generation of heat, and what will they pay under different scenarios for the use of gas, and how does this relate to the geothermal energy solution, and what is the correlation between the different systems. Part III will discuss the results and findings.



- **Conclusion and discussion:** The final step of the research constitutes the conclusion and discussion. This comprises a discussion on the value of the findings and results and will subsequently be used for recommendations for an organizational design and further research.

## 2.1 Research Methodology

During the research different research methods have been applied. The contextual orientation mainly constituted desk research and expert interviews. The review on the literature created insight in the current situation in the provision of heat to consumers, the role of natural gas in the generation of heat, and the opportunity for geothermal energy in the Netherlands. The next paragraphs will introduce the research methodologies scenarios and system dynamics. However, the precise application of the research model is elaborated in part II, modeling business dynamics, scenarios, and cases.

## 2.2 System Dynamics

System dynamics is a methodology and mathematical modelling technique for framing, understanding, and discussing complex issues and problems. It has been developed in 1950 by Jay W. Forrester from the Massachusetts Institute of Technology (MIT). The framework is focused on system thinking, but takes additional steps of constructing and testing of a simulation model. System dynamics simulation is performed to learn about the dynamics of the system behavior that may impact the planning solution by using closed-loop feedback, and to design policies for improving system performance. The main characteristics of this method are the existence of complex systems, the change of system behavior and the existence of the closed-loop feedback to describe the new information about the system. As Sterman (2000) states, the goal of system dynamics is to improve the understanding of the ways in which organizations performance is related to its internal structure and operating policies, including those of customers, competitors, and suppliers and then to use that understanding to design high leverage policies for success.

System Dynamics can always deal with problems that develop over time. The researcher represents the problem situation in a model comprising the variables of interest. The system state at any time is captured by a set of state variables, called stocks. A fundamental idea in System Dynamics modelling is the “principle of accumulation.” This principle says that all dynamic behaviour in the world occurs when flows are accumulated (integrated) in stocks. (Tao, 2010)

System dynamics can be and has been applied to a wide range of problem domains such as strategy and corporate planning, public management and policy, business process development, biological and medical modeling, energy and the environment, theory development in the natural and social sciences, dynamic decision making, complex nonlinear dynamics, software engineering, and supply chain management. (Suryani, Chou, Hartono, & Chen, 2010) System Dynamics is applied in this research to support the decision making process, by forecasting the costs and benefits for concerned parties of a geothermal energy solution under certain scenarios.

### 2.3 Scenarios

Scenarios have been widely applied, and for different purposes. During the past few decades, this way of thinking on dealing with scenarios essentially is spread out from Shell to many other organizations and institutions. (Postma & Liebl, 2005) Scenario development is a prognosis method where the present data is used to develop various possible, often alternative future scenarios. (Reibnitz, 1988) Schwartz (1991) states that scenarios provide a method for articulating the different pathways that might exist for you tomorrow and for finding appropriate movements down each of those possible paths. Furthermore we need to be able to re-perceive, i.e. to question, our assumptions about the way the world works, so that we can see the world more clearly. Schwartz argues the end-result is not an accurate picture of tomorrow, but better decisions about the future. (Schwartz, 1991) (Tao, 2010) The research studies the effect of uncertainties on the application of geothermal energy, and should contribute to making better decisions about investments in the future.

Additionally, Wikipedia states that scenario planning may involve aspects of system thinking, specifically the recognition that many factors may combine in complex ways to create sometime surprising futures (due to non-linear feedback loops). The method also allows the inclusion of factors that are difficult to formalize, such as novel insights about the future, deep shifts in values, unprecedented regulations or inventions. Systems thinking used in conjunction with scenario planning leads to plausible scenario story lines because the causal relationship between factors can be demonstrated. In these cases, when scenario planning is integrated with a systems thinking approach to scenario development, it is sometimes referred as structural dynamics.

This will be incorporated in this research; the designed system dynamics model will be subjected to the parameter scenarios. The scenarios will be introduced in chapter 8.

### 2.4 Validation and Verification

Giannanasi et al. (2001) have defined validation as the process of determining the simulation model based on an acceptably accurate representation of reality. Validation deals with the assessment of the comparison between sufficiently accurate computational results from the simulation and the actual/hypothetical data from the system. (Martis, 2006) There are three steps in determining if a simulation is an accurate representation of the actual system considered, namely, verification, validation and credibility. (Garzia & Garzia, 1990) Suryani et al. (2010) has elaborated the steps of validation, verification and credibility:

- Validation: is the process of determining whether the theories and assumptions underlying the conceptual model are correct and reasonable for the intended purpose of the model.
- Verification is the process of determining whether the model implementation accurately represents the developer's conceptual description of the model and the solution to the model (AIAA, 1998)
- Credibility or operational validation is defined as determining whether the behavior of the model output has sufficient accuracy for the model's intended purpose over the domain of the model's intended applicability (Sargent, 2003)



The model will be verified with experts on system dynamics modeling, and validated if the right data has been applied with experts on geothermal energy systems; If Technology, Arcadis, Platform Geothermie. Experts from Arcadis will perform the operational validation and credibility. Although, the purpose of the model is not focused on incorporating precise and exact numbers, it should represent realistic and possible outcomes.

## *2.5 Reading Guide*

This research is organized as follows. The first part comprises a literature review on the energy consumption, the use of natural gas in the Netherlands, and the introduction of geothermal energy. Subsequently, part II introduces the system dynamics model, the applied scenarios and the designed system solution for geothermal energy. Furthermore in this section the designed System Dynamics model is applied on a case study in Eindhoven. Part III presents the results and findings, and the conclusion and discussion on the results. Finally recommendations for an organizational design, and further research will be presented in part III.

## **PART I: CONTEXTUAL ORIENTATION**



### 3 Energy Consumption

#### 3.1 Global and National Energy Consumption

The global population is consuming an enormous amount of energy, and the trend shows this demand for energy will continue to grow in the future. The factsheet of the World Energy Outlook shows that based on a reference scenario, which assumes no change in government policies, the primary energy demand in 2035 will be 49% higher than in 2007. Especially non-OECD contribute to this increase, they account for over 90% of the increase in energy demand. (International Energy Agency, 2009)

The global energy consumption in 2007 was approximately 500 exajoule (EJ) of primary energy. Of the 500 EJ that is consumed yearly, the Netherlands accounts for 3,26 EJ in the total energy consumption. (CBS, 2010) Crude oil, coal, natural gas, and renewable resources are utilized for meeting this annual energy demand of 3.260 petajoule in the Netherlands. This primary energy consumption in the Netherlands is further distinguished in the energy use for transport, raw materials, and for producing electricity and warmth. Especially the last case, heat represents the greatest part of the total energy consumption in the Netherlands; it accounts for 40% of the total energy consumption, producing electricity constitutes 24% of the total primary energy consumption while transportation and the production of raw materials both can be addressed for 18% of the total energy demand. (Agentschap NL, 2010)

According to Agentschap NL (2010), the Netherlands consumes approximately 1224 PJ of energy that is related to heating. The energy consumed for heating can be accounted for 48% to the industry, 45% can be addressed to the built environment, and a 7% is consumed by agriculture. This means that approximately 584 PJ of primary energy is consumed in the industry, the built environment consumes 555 PJ, and agriculture 84 PJ.

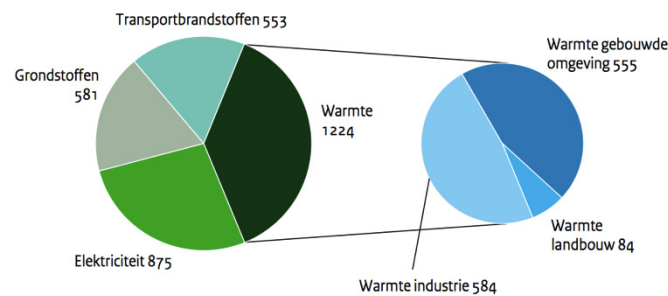
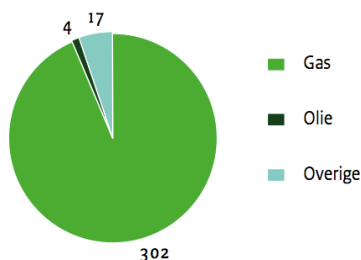


Figure 2: Energy Consumption Netherlands (Agentschap NL, 2010)

The heating demand in the built environment and agriculture mainly comprises space heating below 100 °C. Of the 555 PJ that is yearly used for heating, an amount of 323 PJ can be accounted to heating by households, while commercial buildings have a heating demand of 232 PJ. The energy consumption related to heating by the industry cannot be compared with those of households or commercial buildings. The heating demand in the built environment is primary related to space heating, while the industry demands heat for its production processes, of which the greatest part is represented by temperatures between 250- 500°C and above 1000°C. The main consumers of this heat are the chemical industry, refineries, and the metal industry. (Agentschap NL, 2010) Currently, 60% of the total heating demand in the Netherlands is below 100°C. (CE Delft, 2010) The greatest part of the heating below 100°C can be addressed to the built environment.



As mentioned previously, the built environment can be accounted for 555 PJ of energy, and is distinguished in residential and commercial buildings. The commercial building sector comprises for instance functions as, offices, hospitals, and shops. The commercial sector consumes yearly 232 PJ of energy related to heating, while the residential sector represents 323 PJ of the energy provided for heating. Currently, the energy for heating in the residential sector is mainly provided by burning natural gas; crude oil and other resources represent a small part in the energy supply for heating. As the figure below illustrates, over 90% of the energy consumed for heating is provided by natural gas. (Agentschap NL, 2010)



**Figure 3:** Heating demand of households per resource (Agentschap NL, 2010)

As Figure 3 illustrates, the heating demand of households is mainly provided by burning natural gas. Natural gas is a fossil fuel, which will deplete eventually. The fact this heating demand is provided by fossil fuels reveals a great potential in improving the sustainability of heat supply to households and some particular industries.

### 3.2 Energy Use of Households

The preceding text clarified the greatest part of our energy consumption in the Netherlands is related to heating. Within the different sectors heating related energy consumption can mainly be distinguished into space heating and process heating; where space heating mainly is addressed to the built environment and process heating is related to the industrial sector. The fact 60% of the total heating demand comprises temperatures below 100°C, and since this heating demand can be addressed for 75 % to the built environment shows a focus on improving the sustainability of heating the built environment is appropriate.

The energy consumption of households has changed on different aspects; legislation improved the energy performance of houses (EPC), and households are using more electronic devices; however electronic and gas-fired devices became more efficient. This resulted in a decline in the consumption of natural gas with 300 m<sup>3</sup> over ten years, to a final natural gas consumption of 1.608 m<sup>3</sup> per year in 2009 and 2010. Of course, variables such as the length of winters influence the gas consumption. The consumption of electricity increased until 2008, it subsequently decreased and remained in equilibrium at an average consumption of 3.430 kWh per year.

	Average gas consumption per household [m <sup>3</sup> ]	Average electricity consumption per household [kWh]
2000	1,965	3,230
2001	1,875	3,255
2002	1,812	3,275
2003	1,759	3,296
2004	1,736	3,346
2005	1,664	3,397
2006	1,643	3,402
2007	1,560	3,521
2008	1,625	3,558
2009	1,608	3,430
2010	1,608	3,430

**Table 1:** Average Energy Consumption per household (CBS Energiebalans, 2010)

Energie.nl (ECN, 2010) has distinguished the energy consumption of households in 2008 in electricity, space heating, hot water supply, and cooking. Natural gas in households is utilized for space heating, for hot water supply, and for cooking. Electricity is mainly used for electronic devices and lighting. To compare both energy carriers in their share in the energy consumption of households, the numbers should be converted to a uniform unit; joule is the most appropriate unit for energy. This comparison is based on the energy consumption of households in 2008 from energie.nl. (ECN, 2010)

	Natural gas [m <sup>3</sup> ]	Electricity [kWh]	Energy [MJ]
Space Heating	1.180 m <sup>3</sup>		37.347
Hot Water Supply	380 m <sup>3</sup>		12.027
Cooking	65 m <sup>3</sup>		2.057
Electricity		3.558 kWh	12.808
<b>Total</b>			<b>64.239</b>

**Table 2:** Energy consumption households ([www.energie.nl](http://www.energie.nl))

Table 2 shows the average energy consumption of a household in 2008 is approximately 64 GJ. The greatest part (49 GJ) of the energy consumption can be addressed to space heating and the supply of hot water to consumers. Since the greatest part of the total energy consumption is represented by space heating and hot water, it shows that comfort comprises the greatest part of energy consumption in an average household. Therefore it might be possible to state that energy sources such as electricity, gas, and oil are not desired end-products, but end-products expressed in comfort, such as heating are more desired. Considering the built environment, it could be more appropriate to discuss about a comfort or warmth market instead of an energy market.

### 3.3 Future of Heating

Currently, 20 PJ of useful heat is generated from renewable resources. The generation of renewable heat does not refer to the primary energy consumption, but to the amount of useful heat that is generated. According to the Agentschap NL (2010), the useful generated heat represents 1.093 PJ in the Netherlands, of which approximately 20 PJ is generated on a sustainable manner. The preservation of heat generation represents a small part in the total useful heat, and lacks behind with the preservation of electricity; 1,8% of the heat is generated sustainably, while 6,6% of the total electricity is produced in a sustainable manner. This shows there is a great potential for increasing the part renewable heating represents, especially in comparison to electricity.

Although the fact that heat constitutes currently the greatest part in the energy consumption of the Netherlands and the sustainability of heat generation could be improved enormously, changes in legislation such as the energy performance of houses, and consumer behavior could result in a decrease in heating demand.

According to a scenario study of the CPB, MNP, and RPB, the heating demand increases under the Global Economy, Transatlantic Market scenarios, but decreases in the Strong Europe and Regional Communities scenarios. This increase or decrease in heating demand can be addressed to a decline in heating demand in the built environment due to the demolition and construction of houses, and energy saving measures in the existing building stock. (ECN, 2006) According to Agentschap NL (2010), the heating demand can vary between 900 and 1.450 PJ under different scenarios.

According to a research of Visser et al. (2011) on the energy supply in 2050, the energy demand of dwellings is reduced. By 2050, the average energy demand of a dwelling is reduced to 33 GJ per year, which is distinguished in:

- Hot Water Supply (4,5 GJ)
- Space Heating (6,5 GJ)
- Electricity (9 GJ)
- Exterior Electricity demand (0,3 GJ)
- Cooling demand (1,6 GJ)
- Transportation (11 GJ)

However, the research of Visser et al. (2011) did not incorporate the energy demand for cooking. According to ECN (2011), the energy demand for cooking depends on the energy carrier; gas (2,5 GJ), electricity (1,3 GJ).

Compared with the energy demand for space heating, hot water supply, cooking and electricity of an average house in 2008; the potential energy demand of households in 2050 is reduced incrementally. As mentioned previously the average household in 2008 consumes 64 GJ, while the energy demand in 2050 for these activities varies between 23,3 GJ and 24,5 GJ.

### 3.4 Conclusion

The Netherlands consumes approximately 3.260 PJ of energy per year, and 40% of this energy consumption can be addressed to heating. The built environment and industry are the biggest consumers of heat, while a small part is represented by agriculture. Approximately 60% of the heating demand (700 PJ), can be addressed to temperatures below 100°C. The energy consumption of households that can be related to heating constitutes the greatest part of the total consumption; approximately 49 GJ of the total 64 GJ is addressed to space heating, and hot water supply. Although the energy demand of households in 2050 is reduced to 33 GJ, a great part of the energy consumption is still constituted by space heating and hot water supply. (Visser et al., 2011)

It is possible to conclude that the energy demand related to heating still comprises an important part in the total energy consumption of future households. Currently, the energy for heating in households is mainly provided by burning natural gas, which is considered as a fossil fuel. The share of sustainable generated heat in the total useful generated heat represents a very small part, only 1,8% (20 PJ) is generated in a sustainable manner. (Agentschap NL, 2010)

The fact heating constitutes the greatest part in the total energy consumption, it mainly is provided by a fossil fuel, and only a fraction of heat is generated sustainably shows a focus on providing a sustainable alternative to consumers is appropriate.

## 4 Gas Consumption

### 4.1 Natural Gas; Exploration

The discovery of the natural gas field near Groningen in 1959 had a great impact on history of the energy supply in the Netherlands. After the first gas was discovered and additional drills proved the size of this gas field, the Dutch Petroleum Company (NAM) applied in 1961 for the concession of 'Groningen'. After a period of a year, the minister of Economical Affairs published a memorandum (Aardgasnota), which presented that the exploitation of the gas field in Groningen was regulated through a partnership. This partnership represented the State (50%), Esso (25%), and Shell (25%). Furthermore, the memorandum was the foundation for the 'Nederlandse Gasunie' that, after the concession was granted in 1963, had to provide the Netherlands with a pipeline network that would serve the local gas companies of the natural gas. Within ten years, 75 percent of the Dutch houses were able to use natural gas, which led to a decline in interest for oil and coal. Currently, the Netherlands counts 6.797.100 connections to the gas supply network; almost each house has space heating and hot water supply based on natural gas. (Ministerie van Economische Zaken, 2008)

During the following years, the government expected the development of nuclear energy would decline the use of natural gas and decided therefore that the gas had to be sold quickly. This resulted in a steep increase in the yearly gas production, from almost nothing in 1960 up to 90 billion m<sup>3</sup> in 1975. However, the first oil crisis, and the great social resistance against nuclear energy required a change in policy; the government introduced the small gas field directive, a law on natural gas and subsequently addressed a production ceiling to the gas field near Groningen. This policy stimulated the search for, and the production from alternative gas fields, while curbing the depletion of the gas field in Groningen.

Currently, the gas fields are estimated at approximately 1.390 billion m<sup>3</sup>; and represents approximately 25% of the European gas field reserves. (Ministerie van Economische Zaken, 2010) The actual amount of physical oil and gas reserves could be higher, since only the conventional resources are classified. The exploration of unconventional gas reserves, known as 'shale gas', is gaining attention; however, the potential amount of the technically and economically recoverable gas still needs to be proven, and are therefore not incorporated in the physical balance sheet. (TNO, 2010)

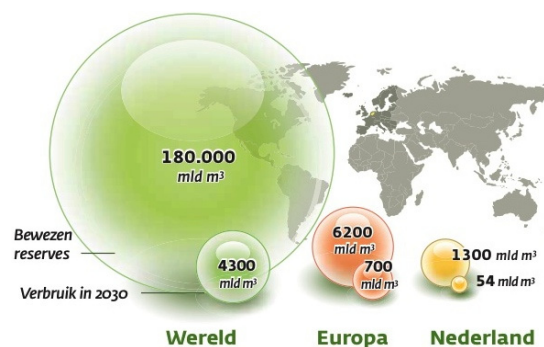
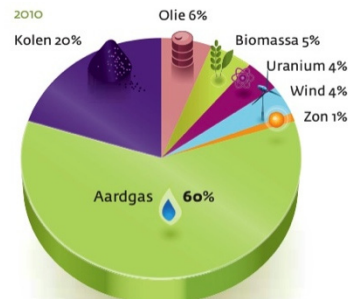


Figure 4: Proven Natural Gas Reserves (Gas Unie, 2011)

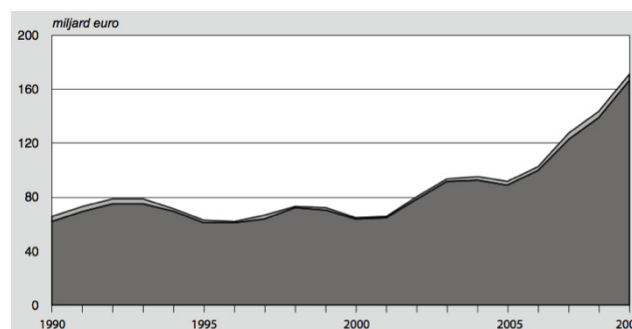
Mainly due these great resource reserves near Groningen, gas is in the Netherlands commonly applied for heating and cooking in the built environment, as raw material in chemical production processes, and as fuel for transportation. According to the Gasunie (2011), it is considered as the backbone of the Dutch energy supply; approximately 60% of the electricity in power stations is generated by this natural gas.



**Figure 5:** Share in energy mix for electricity generation per resource (Gas Unie, 2011)

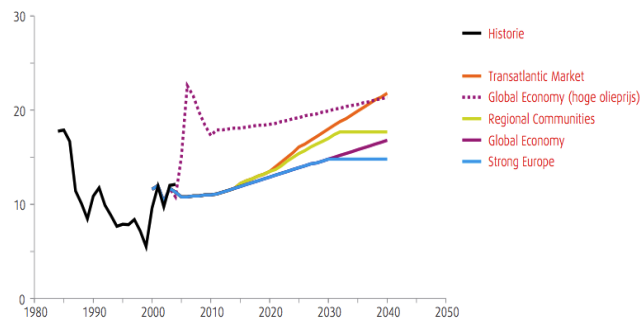
As the previous chapter already described, heating constitutes the greatest part in the total energy consumption. The factsheet of Agentschap NL (2010) shows that over 90% of the heating demand in households is provided by burning natural gas. According to the CBS Statline (2011), an amount of 2.363 PJ of natural gas is extracted domestically and 770 PJ of natural gas has been imported in 2009, approximately 1.169 PJ is consumed within the Netherlands.

Although this fossil fuel emits carbon dioxide when it is burned, the reserves of natural gas in the Netherlands, and the economic value of this resource to the Dutch government contribute to the fact that the current national policy on providing heat is mainly aimed on burning the domestic extracted gas. According to the CBS (2009), the economic value of the Dutch oil and gas reserves was in 2009 approximately 166 billion Euro, and the Dutch government received 14.8 billion Euros from natural gas revenues over 2008. The revenues in 2008 were five billion Euros higher than in 2007, despite the fact that in 2007 more natural gas had been extracted domestically; the price of gas is linked to the price of oil.



**Figure 6:** Monetary Valuation of Domestic Gas Reserves (CBS, 2009)

Additionally, according to a report of ECN (2006) by the order of CPB, MNP, and RPB the WLO scenarios show an increasing price for natural gas. The four different scenarios show different gas prices for the coming years. While the natural gas price increase will have positive results for the National government, it also increases the costs for the consumers of natural gas.



**Figure 7:** Commodity Gas Price under WLO Scenarios (ECN, 2006)

The Economic Report of the President (2006) stated that in the long run, households and businesses will respond to higher fuel prices by cutting consumption, purchasing products that are more efficient, and switching to alternative energy sources. Higher energy prices also encourage entrepreneurs to invest in the research and development of new energy conserving technologies and alternative fuels, further expanding the opportunities available to households and businesses to reduce energy use and switch to low-cost sources.

Another issue on the use of natural gas is the fact is concerns a fossil fuel; it is a finite resource and it emits CO<sub>2</sub>. Compared to coal and other fossil fuels, natural gas is relative clean; it provides the most energy with the least emission of CO<sub>2</sub>. (Gas Unie, 2011) Although it is considered as one of the cleanest fossil fuels, it still emits CO<sub>2</sub> and is considered as a finite resource, which is not widely available. This means when it will deplete in the future, the dependency on countries with these resources increases. According the Environmental Accounts of the CBS (2009), the lifespan of the domestic natural gas reserves has been estimated approximately 17,5 years; it has to be taken in mind this concerns the current proven stock of natural gas in the Netherlands.

Country	Natural Gas Imports from Russia	
	Quantity (billion cu. ft./yr)	% of Domestic Consumption
Germany	1,290	39%
Italy	855	31
Ukraine	850 <sup>a</sup>	40 <sup>a</sup>
Belarus	698	99
Turkey	506	65
France	406	24
Hungary	318	64
Czech Republic	253	77
Austria	212	69
Poland	212	43
Finland	163	98
Romania	138	22
Lithuania	103	100
Bulgaria	99	99
Netherlands	94	6
Greece	78	82
Moldova	77	100
Latvia	62	100
Georgia	39	100
Sweden	39	<sup>b</sup>
Estonia	34	100
Slovenia	20	52
Belgium	7	1

Recently Wikileaks (2010) published a cable on the Russian substantial under-investment in energy extraction infrastructure. It was such that Russia would not be able to meet European demand in four or five years. According to Gelb (2007), the European countries depend on the Russian gas ranging from six percent (the Netherlands), up to 98% (Finland). Although there is no direct need for the Netherlands in decreasing the dependency of Russian gas, the uncertainty in the supply of natural gas from Russia from other countries might increase the demand of natural gas from the Netherlands.

**Table 3:** Dependency on Russian Natural Gas (Bernard A. Gelb, Congressional Research Service, 2007)



Aaheim and Bundschuh (2002) state the combination of rapidly increasing energy demand and vulnerability to fluctuations in the energy markets calls for a development of energy supply systems that preferably are based on domestic resources. Furthermore, energy security issues are driving factors behind oil price movements and rising oil prices should help to spur greater demand and supply of alternative energy. (Henriques and Sadorsky, 2008)

#### *4.2 Conclusion*

Natural gas plays a significant role in the energy supply of the Netherlands; it constitutes a 60% share in the energy mix for the generation of electricity, and over 90% of the heating demand by households is provided by burning natural gas. Furthermore, the Netherlands has great natural gas reserves; almost a quarter of the European gas field reserves can be addressed to the reserves in the Netherlands. The domestic natural gas contributes to the Dutch wealth, in 2008 the Dutch government received 14.8 billion euro's on natural gas revenues; this constitutes more than nine percent of the total revenues of the National government. (CBS, 2009)

The domestic natural gas contributes to the wealth in the Netherlands, and is considered as a clean fossil fuel compared to coal and crude oil; however, since it is a finite source it might lead to future challenges such as uncertainty in energy supply as a result of the dependency on countries with these resources. According to the WLO scenarios gas prices will increase in the future, leading to an increasing value of the gas field reserves but also to increasing costs for consumers. As the Economic Report of the President (2006) states, consumers and businesses will respond to higher fuel prices by for instance cutting consumption, and switching to alternative energy sources. It will encourage entrepreneurs to invest in the research and development of new energy conserving technologies. Alternatives to fossil fuel should therefore provide financial benefits to governments, consumers, and investors.

## 5 Renewable Heating in the Netherlands

The terms renewable and sustainable are often confused. The former should refer to the nature of a resource, while the latter should refer how it is used. (Axelsson, 2010)

### 5.1 Room for Improvement; Preserving the Heating Supply

The previous chapters studied the energy demand in the Netherlands, and the part natural gas plays in the domestic energy supply. The Netherlands consumes yearly approximately 3.260 PJ, and the greatest part can be addressed to heating, which constitutes 40 percent of the total energy consumption. The energy consumption for heating comprises several purposes such as space heating, hot water supply and process heating; 700 PJ can be addressed to heating temperatures below a 100 °C. The most striking point is that only a fraction of the heating demand is generated on a sustainable manner; the heating demand of households is for over 90% met by burning natural gas. This natural gas is mainly extracted domestically, and the physical reserves represent almost a quarter of the total European natural gas reserves. Furthermore, it has great financial value to the Dutch government; the government received in 2008 14.8 billion euros on gas revenues, and the monetary value of the gas field reserves was in 2006 approximately 166 billion euro. (CBS, 2009) The monetary value is, due to fluctuations in the oil price, likely to rise in the future, which will increase the value of the reserves and will increase the yearly gas revenues for the Dutch government. Conversely to the advantages for the Netherlands, it is a fossil fuel: it emits carbon and is considered as a finite source.

The conservation of the heating supply in the Netherlands holds great potential since only a fraction, 20 PJ (1,8%) is generated sustainably. However the fact that increasing gas prices will increase the monetary value of the domestic gas fields, these increasing fuel prices will also encourage consumers and entrepreneurs to switch and invest in alternative energy sources. (Economic Report of the President, 2006) As Henriques and Sadorsky (2008) state there are several important factors, like energy security issues and environmental concerns, shaping the interaction between business, society and the environment which should generate a positive business environment for companies engaged in the production and distribution of alternative energy. Additionally, Aaheim and Bundschuh (2002) state that being an alternative to fossil fuels, the value of the clean energy resource will be subject to the uncertainties in the world market for fossil fuels, and the uncertainties in energy supply calls for a development of energy supply systems that preferably are based on domestic resources. Furthermore, as TNO (2007) states, the sharp rise in gas and oil prices is forcing 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.

Since a small part of the heating demand is met sustainably, it offers great potential for conserving the heating supply. In order to offer a sustainable alternative to natural gas successfully, the alternative should offer financial benefits to consumers, businesses and entrepreneurs. Pieters, van Hoegaerden and Hagedoorn (2007) state in an article about Aquifer Thermal Energy Storage that the determining factor for large-scale deployment is considered to be the financial approach; investment costs, maintenance costs, and revenues on long term. They conclude that this system will be the common standard for heating when consumers, operators, and governments benefit financially; we can assume this will also





count for other forms of sustainable alternatives. An alternative for conserving the heating demand, which could be offered, is geothermal energy.

## 5.2 *An Introduction to Geothermal Energy*

In general terms, geothermal energy is the thermal energy stored at accessible depth in the earth's crust. (Mock, et al., 1997) The origin of this heat is linked with the internal structure of our planet and the physical processes such as radioactive decay and volcanic activity occurring there. This heat is present in huge and practically inexhaustible quantities in the Earth's crust, but also the deeper parts of our planet. (Barbier, 2002) This heat can be accessed by drilling for a few kilometers from the surface; at this place there are magma bodies that are undergoing cooling, that are still in a fluid state or in the process of solidification, and are releasing heat. In other areas, where magmatic activity does not exist, the heat accumulation is due to particular geological conditions of the crust is such that the geothermal gradient reaches anomalously high values. (Barbier, 2002) The geothermal gradient is the difference in temperature between the core of the planet and its surface, and it drives a continuous conduction of thermal energy (heat) from the core to the surface. At every place 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. (Platform Geothermie, 2010)

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, electricity or heat, which may produce a high capacity all year round. For most other renewable energy sources, daily and/or seasonal variations in inflow require that the capacity cannot be fully utilized all the time. The importance of this property depends, however, on the fluctuations in demand. (Aaheim & Bundschuh, 2002) The application of geothermal energy can contribute significantly towards the reduction of greenhouse gases, because the emission of CO<sub>2</sub> is very low; it does not entail visual or noise nuisance; the security of supply is high, in principle a geothermal plant can operate all year long and its capacity is independent of seasonal fluctuations and weather conditions; and the technology is safe and proven, mainly based on extensive experience in oil and gas production. (Wong & Lokhorst, 2007)

## 5.3 *Utilization of Geothermal Energy*

For centuries, natural geothermal fluids have been used for bathing and cooking, but it was not until the early 1900s that geothermal energy was used for industrial purposes and for the generation of electricity in the Larderello steam fields of northern Italy. Certain conditions must be met before one has a viable resource, accessibility and sufficient reservoir productivity. The geothermal resource actually spans a continuum in at least three dimensions: temperature, depth, and permeability/porosity. (Mock, Tester, & Wright, 1997)

The heat is accessed by drilling and is extracted from a geothermal reservoir. Generally, from a depth of 1.5 kilometers the Earth's heat can be applied for direct heating of houses and greenhouses. From around 3 kilometers in depth, geothermal energy could possibly be used for the production of electricity. According to Barbier (2002) four types of geothermal systems are distinguished: hydrothermal, hot dry rock, geopressured and magmatic. The systems exploited at present are mostly hydrothermal systems. The other three may be

exploited industrially in the future after more technological development. The kind of application of geothermal energy is depending on the quality of the reservoir, the purposes can be divided into 2 categories i.e. electricity energy production and direct use. The upper and lower limits are, however, not stringent and serve only as guidelines. Conventional electric power production is limited to temperatures above 150°C, but considerably lower temperatures can be used in binary cycle systems, also called Organic Rankine cycles, (in this case the outlet temperatures of geothermal fluids are commonly above 85°C), and higher temperatures allow the utilization of a Flash Steam system. (Barbier, 2002; IF Technology, 2011). As a general rule, a higher temperature will increase the efficiency of converting heat to electricity.

This research focuses on conserving the heating demand in the Netherlands, and therefore only considers the direct use of geothermal energy for meeting the heating demand. The transportation of the heat from geothermal resources to households, greenhouses, and other buildings requires a heating grid. A geothermal district heating systems (GDHS) is defined as a system that uses a geothermal resource as a heat source and distributes heat through a distribution network connected to five or more buildings. Geothermal district heating systems mainly utilize direct use technology but are sometimes augmented using ground source heat pumps. (Thorsteinsson & Tester, 2010) According to Tester (2010), the technology for GDHS is mature and widely used, for instance in Iceland. A GDHS can provide multiple environmental and economic benefits to communities that utilize them. If deployed at a large scale, GDHS can provide a clean, essentially emission free form of space heating. The GDHS uses an energy source that is insulated from changes in fuel price or supply. This feature leads to long-term, stable space heating rates for GDHS which fossil fuel-fired facilities cannot guarantee. (Thorsteinsson & Tester, 2010)

#### *5.4 Emission Reduction from Geothermal Resources*

Wong & Lokhorst (2007) state the application of geothermal energy can contribute significantly towards the reduction of greenhouse gasses, because the emission of CO<sub>2</sub> (mainly generated by the necessary pumping) is very low. According to J.J. Buitenhuis (2008), geothermal energy provides sustainable heat that can reduce the energy consumption and carbon emissions with a 60-70 percent. More recently, a study of IF-Technology (2011) concluded that geothermal energy could provide substantial carbon reductions; the actual carbon reduction varies per chosen applications. When utilizing heat, steam, and cold the carbon reduction varies between 88-95%. The carbon reduction with power generation is strongly dependent on the kind of installation; an Organic Rankine Cycle reduces the carbon emission by 46-78% when 'grey' power is utilized for internal pumps, if additionally heat is transmitted the carbon reduction is respectively 46-80%. Furthermore, when the internal pumps use local generated electricity the carbon reduction can be 100%.

## 5.5 State of the Art; Geothermal Energy in Iceland and Opportunities for the Netherlands

In the Netherlands, geothermal exploitation from groundwater can be regarded as a potential source of energy. The theoretic technical potential of geothermal energy in the Netherlands is determined at 90.000 PJ. (TNO, 2009) The amount of this energy that may eventually be produced successfully, however, depends strongly on location specific reservoir properties. According to Platform Geothermie, TNO has estimated in 2010 the technical and economic recoverable potential up to a depth of four kilometers; the soil holds a potential of around 38.000 Petajoule, where one Petajoule corresponds with the energy use of 25.000 existing dwellings per year.

However, the utilization of geothermal energy lacks behind compared to other countries as Germany and Iceland; especially the latter has utilized geothermal energy many times. Iceland began utilizing the large hydro and geothermal energy resources in the early 20<sup>th</sup> century. In the 1940s programs emphasizing the use of Iceland's renewable resources began to accelerate the decrease of total dependence on imported oil to supply Iceland's primary energy need. Thorsteinsson and Tester (2010) further state that by 2005, 71,2% of Iceland's primary energy was supplied by its hydro and geothermal resources providing almost all of the country's heating needs and 99,9% of its electrical power. (Loftsdottir & Thorarinsdottir, 2006) During the oil crisis in 1970, the emphasis on domestic energy sources and geothermal development increased significantly. (Gunnlaugsson, Ragnarsson, & Stefansson, 2001) Today about 89% of the country's space heating needs are provided by geothermal energy, with the other 11% provided by renewable electricity (10%), and oil (1%). Figure 10 shows Iceland's primary energy supply from 1940 until 2005. The government of Iceland established in 1967, the Icelandic Energy Fund to increase use of geothermal resources. The fund gives out loans for geothermal exploration and drilling. If a resource is not found the loans are turned into grants with no repayment required. Moreover, government backed loans are available to geothermal developers in Iceland. However, due to the evolvement of the industry the government's role in geothermal energy development decreased. (Thorsteinsson & Tester, 2010) Important to mention is that the Icelandic National Energy Authority was founded in 1940 to endorse geothermal energy development, and among other things its mission was to make utilization of the nation's geothermal resource profitable for Iceland's economy. (Thorsteinsson & Tester, 2010)

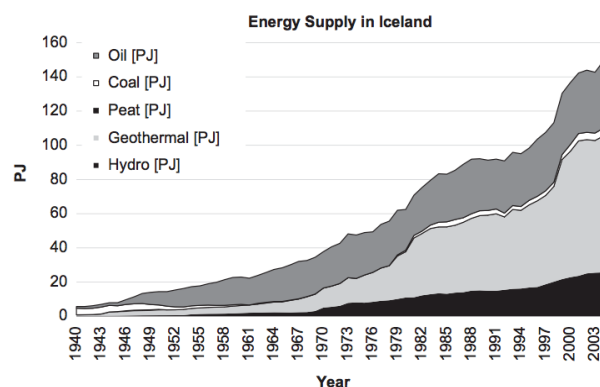


Figure 8: Iceland's primary energy supply 1940-2005 (National Energy Authority of Iceland, 2007b)

The geological conditions of Iceland cannot be compared with those of the Netherlands; in the volcanic regions geothermal energy can be recovered from a small depth, while the geological conditions in the Netherlands require drilling to deeper situated regions. High enthalpy ( $T > 180^{\circ}\text{C}$ ) geothermal energy sources such as geysers and steam fields are not present in the Netherlands. (Wong and Lokhorst, 2007)

Although the geological conditions are not such as Iceland's conditions, the economic recoverable potential at a depth of 4.000 meters is substantial. The under soil of the Netherlands is of such condition that it has good aquifers; layers that contain warm water and have potentially good circulation characteristics for an economical exploitation of geothermal energy. (Platform Geothermie, 2010) Furthermore, there is there is much data available of the Dutch under soil due to many explorations, and extraction drills, but also because of the seismic tests that have been performed for recovering oil and gas; over 3000 wells have been drilled mainly by the oil and gas industry. (IF Technology, 2011) Drilling for geothermal energy does not differ much from a drill for gas or oil, drilling for deep geothermal energy is still in a development phase in the Netherlands. In Heerlen has been drilled up to a depth of 800 meters and in 2007 a depth of 1700 meter has been realized for a greenhouse company in Bleiswijk. More recently, in 2010 there have been drills for a company in Pijnacker, greenhouses of Koekoekspolder, but also for dwellings in Den Haag and Delft. The Hague has the ambition to connect 4.000 houses and 20.000 m<sup>2</sup> of commercial buildings to the geothermal energy district-heating grid. However, the number of realized projects still contrasts to Germany and France, while the geological conditions in Germany do not differ much from the Dutch conditions Despite this fact, they already have realized 30-40 big projects. Some of the oldest installations are already operating for tens of years. Moreover, about 100,000 residences in the Paris Basin are heated by a GDHS. (Thorsteinsson & Tester, 2010)

### 5.6 Deeper Geothermal Energy; Enhanced Geothermal Energy

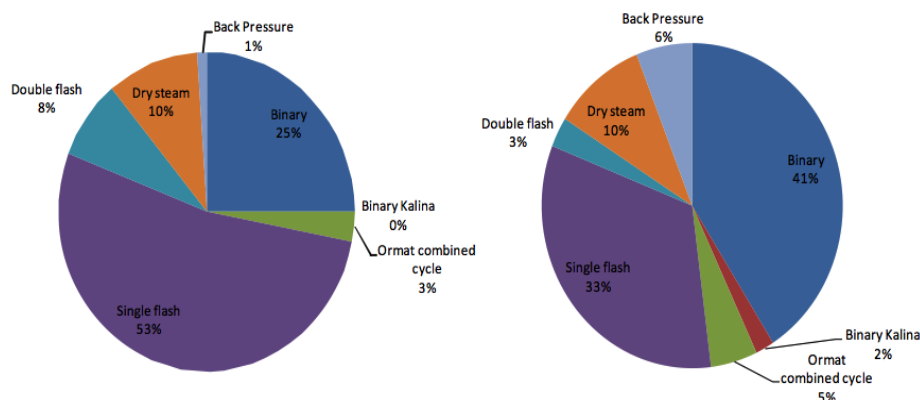
Recently, IF Technology (2011) researched the sustainable potential of geothermal energy from locations deeper than four kilometers for the domestic heating and electricity supply. The study focused on the potential energy at a depth of 5,5 and 7,5 kilometers. Since there is currently no precise data available on the kind of rock formation at a certain location and depth, the energy content has been estimated by the use of Heat in Place; IF Technology assumed that approximately 5% of the heat in place could be recovered economically. The total amount of recoverable heat has been divided over 1.000 year and compared to the expected energy consumption in 2020, as has been determined in the National Renewable Action Plan for the Netherlands.

Application	Depth	Recoverable per year	National final energy consumption 2020	Share of geothermal energy
Heating	5,5 km	228 PJ	1.048 PJ	22%
Heating	7,5 km	325 PJ	1.048 PJ	31%
Electricity	5,5 km	34 PJ	490 PJ	7%
Electricity	7,5 km	65 PJ	490 PJ	13%

**Table 4:** Percentage renewable energy / final energy consumption 2020 (IF Technology, 2011)

These numbers show there is great potential of geothermal energy at locations deeper than four kilometers; 7-13% of the total electricity consumption and 22-31% of the final heating consumption can be met by deep geothermal energy. (IF Technology, 2011)

Geothermal energy can also be utilized for the generation of electricity, which requires higher temperatures than for direct use purposes. The generation of power requires a temperature of 100 °C at the surface, considering the thermal gradient of 31°C/km water should be extracted at a depth greater than 3.000 meters. There are several techniques to generate electricity; the greatest part of the installed capacity of geothermal plants is utilized by the conventional steam cycle with single flash; however, considering the number of installed plants, a binary cycle technique has been utilized more often.



**Figure 9:** Power generation plants; installed capacity vs. amount of units (Bertani, 2008)

It depends, besides other factors, on the temperature of the geothermal reservoir, what technique is most appropriate. With temperatures below 190 °C, the electricity will be generated mainly with a binary system, while a conventional steam cycle (Flash Steam) can be utilized for temperatures above 190 °C. Globally, a flash steam is the most applied technique for power generation. The heat from geothermal resources comes to the surface as water under high pressure and temperature, by decreasing its pressure a mix of water and steam arises; this process is known as flashing. The steam is subsequently transported to a turbine that drives a generator, which will generate the power. The advantage of this system is that high temperatures will result in relatively high efficiencies. A Rankine cycle has a binary system with two closed cycles; one for the geothermal water and one for the fluid in the system. Between these cycles the heat will be exchanged by a heat exchanger; since the fluid has a lower boiling temperature than water, it will be evaporate at a lower temperature. Besides the geothermal cycle and the organic Rankine cycle, a cycle is required for cooling; this increases the efficiency of power generation from geothermal heat.

In spite of the possibility to generate electricity from geothermal heat, it will not be incorporated in my research. This thesis focuses on increasing the role of renewable resources in the heating supply by applying geothermal heat, therefore only the direct use of geothermal energy is considered.

### 5.7 *Barriers to Deployment; Challenges and Opportunities*

In spite of the great opportunities and the potential for geothermal energy in the world, there are systemic barriers concerning the utilization of these projects. Seyboth et al., (2008) identified that barriers to further deployment of renewable energy technologies are the comparatively high up-front cost of installation, a lack of investor awareness, existing infrastructure constraints, and landlord/tenant incentive splits. The cost of geothermal energy plants consists mainly of capital costs, which often constitute more than 90%. The capital costs can be divided into costs of exploration, development of the steam field and construction of the plant. (Aaheim & Bundschuh, 2002) Furthermore, Thorsteinsson and Tester (2010) endorse the systemic barriers to implement geothermal district heating in the US, whether using direct or co-generation approaches of any type. These include relatively affordable gas and oil supplies and separate, well-developed electricity and fuel delivery infrastructures; this can be compared to the Dutch situation. Considering the Dutch situation TNO (2007) states many factors are holding back the development of deep low-enthalpy geothermal applications in the Netherlands: wealth of the Dutch gas resources, the tariff structure imposed on gas for agricultural application and the lack of a subsidiary instrument for the use of green heat. However, there has been a resurgence of interest in the use of deep geothermal heat in the Netherlands. The sharp rise in gas and oil prices is forcing private enterprises to consider the use of alternative energy sources. (TNO, 2007) Buitenhuis (2008) also subscribes the same barriers, geothermal energy and its district heating system is characterized by high upfront costs; 7-15 million euros for the geothermal source, and 15-25 million euros for a district heating system concerning 3000 residences. The upfront capital costs for geothermal energy are substantially higher, and depreciation periods are considerably longer. Conversely, the energy costs for geothermal energy will decrease incrementally compared to gas-fired generation. Furthermore, the energy costs of geothermal energy are barely influenced by fluctuations in fossil fuel energy costs. (Buitenhuis, 2008)

Additionally, direct use requires an infrastructure to distribute the heat. The distributions systems are usually very costly to establish, but expansion of the system's capacity or linking of new users to an existing system may be undertaken at low cost. In order to establish a new system, investors need to make sure a sufficient number of users will connect to it. Once built, the owners of the distribution system may, however, turn into a natural monopoly, unless they are subjected to some regulation. (Aaheim & Bundschuh, 2002) However, Wong and Lokhorst (2007) state that an important and restricting condition in the operation of geothermal heat is the balance between supply and heat demand. Bloomquist and Lund (2000) cited in their analysis several potential barriers to GDHS development that had been identified by previous studies. For example local authorities are frequently unaware of geothermal energy system benefits and GDHS are perceived to be complex, high-risk undertakings. Also, local leaders lack the necessary knowledge to develop GDHS and consequently are often not interested in utilizing geothermal energy. (Congressional Research Service, 1983; Gleason, 1993) Bloomquist and Lund (2000) emphasized the need for a balanced approach to encourage district-heating development.

Moreover Barbier (2002) states 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 mayor constraint in this process is the financial side in the use of natural hot water because the benefits come after a long time and there are large investments



required from the beginning of the project. The use of hot water can be viable and economic option in the right conditions especially if the fossil fuels need to be imported.

Nevertheless Lund (2002) states that given the right environment, and as gas and oil supplies dwindle, the use of geothermal energy will provide a competitive, viable and economic alternative source of renewable energy. Furthermore, as been mentioned before, TNO (2007) stated 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

## 5.8 Conclusion

The conservation of the heating supply in the Netherlands holds great potential since only a fraction is provided by renewable resources. Therefore an enormous opportunity exists for directly utilizing indigenous geothermal energy as a cleaner, nearly emissions-free renewable source of heat whose production characteristics are ideal for local district heating applications. (Thorsteinsson & Tester, 2010) Approximately 40% of the Dutch energy demand is consumed in the form of 'low-temperature' power for heating homes and offices (at the municipal level) and industrial greenhouses. As TNO (2007) explains this demand for low temperature power can easily be supplied by geothermal energy in its various forms.

The amount of energy that may eventually be produced successfully from geothermal resources depends strongly on location specific reservoir properties. TNO estimated in 2010 the technical and economic recoverable potential up to a depth of four kilometers; the soil holds a potential of around 38.000 PetaJoule, where one Petajoule corresponds with the energy use of 25.000 existing dwellings per year. In order to distribute the heat a district heating systems (GDHS) should be utilized. A GDHS is defined as a system that uses a geothermal resource as a heat source and distributes heat through a distribution network connected to five or more buildings. The GDHS uses an energy source that is insulated from changes in fuel price or supply. This feature leads to long-term, stable space heating rates for GDHS which fossil fuel-fired facilities cannot guarantee. (Thorsteinsson & Tester, 2010) However the potential of geothermal energy in the Netherlands, it still lacks behind compared to countries such as Iceland and Germany. Especially Iceland is considered as leading country on geothermal energy; currently, about 89% of the country's space heating needs is provided by geothermal energy, with the other 11% provided by renewable electricity (10%), and oil (1%). Additionally, about 100,000 residences in the Paris Basin (France) are heated by a GDHS. (Thorsteinsson & Tester, 2010)

Despite the potential of geothermal energy in the Netherlands, there are barriers to the deployment. Seyboth et al., (2008) identified comparatively high up-front cost of installation, a lack of investor awareness, existing infrastructure constraints, and landlord/tenant incentive splits. Moreover, relatively affordable gas and oil supplies and separate, well-developed electricity and fuel delivery infrastructures are also considered as barriers. (Thorsteinsson & Tester, 2010) Additionally, TNO (2007) identified the wealth of the Dutch gas resources, the tariff structure imposed on gas for agricultural application and the lack of a subsidiary instrument for the use of green heat as barrier for deploying geothermal energy.

However, there has been a resurgence of interest in the use of deep geothermal heat in the Netherlands. The sharp rise in gas and oil prices is forcing private enterprises to consider the use of alternative energy sources. (TNO, 2007) 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. In addition, Lund (2002) states that given the right environment, and as gas and oil supplies dwindle, the use of geothermal energy will provide a competitive, viable and economic alternative source of renewable energy.





## **Part II: MODELLING BUSINESS DYNAMICS, SCENARIOS AND CASES**



## 6 INTRODUCTION TO MODEL AND PARAMETER DEVELOPMENT

This chapter will discuss the models that have been developed according to the System Dynamics methodology, the geothermal energy solutions that have been designed in collaboration with experts, and parameters derived from scenarios.

As discussed in the contextual orientation of Part I, geothermal energy knows various forms and kind of applications; geothermal energy can be applied for either providing heat, cooling or electricity to consumers. However, since this research focuses on providing heat, the generation of electricity will not be discussed. Nevertheless, geothermal heat alone already has various application possibilities; greenhouse heating, process heating for industry, space heating for new estates, or space heating for an existing building stock. Each application has different requirements and characteristics. Nonetheless, crucial for the type of application are the characteristics of the subsoil, such as temperature and permeability of the aquifer. Considering a regular developing process, at first the possibilities of geothermal heat in the subsoil on a specific location is investigated, while subsequently the possibilities above ground will be examined. The type of application is dependent on the possibilities that the subsoil offers. Still, the thermal capacity of a power plant is also dependent on the characteristics of the application. The different system solutions will be simulated and tested on three cases in Eindhoven, while subjecting them to scenarios. The systems are designed on the current situation and do not incorporate changes that might arise in the future. It seems quite probable that the energy consumption will change, and fossil fuel prices will increase in the future. These changes could have either a positive or a negative effect on the application of these kind of large-scale energy solutions. The Welfare, Prosperity and Quality of the Living Environment (WLO) scenario study allowed the selection of two contradicting scenarios, of which the effects on the utilization of geothermal energy is researched by the use of System Dynamics.

The first paragraphs will introduce the application of System Dynamics and will discuss the causal loop diagram and the developed system dynamics model. The second paragraph will comprise a description on the applied scenarios, and how their influence is incorporated in the dynamic model. Subsequently, three realistic geothermal energy solutions will be discussed on input and output parameters. The final paragraph will discuss the cases that have been applied in this research to test the geothermal energy system and the influence of scenarios.

### 6.1 Introduction to System Dynamics

Sterman (2000) states that system dynamics allows the testing of alternative assumptions, decisions, and policies. Furthermore, since models contain several assumptions and approximations, it is mandatory to examine the sensitivity of the result to plausible alternative structural assumptions, including changes in the model boundary. (Sterman, 2000) The methodology of System Dynamics has been applied to design a business case and visualize the effect of uncertainties that may arise over time.

The contextual orientation concluded that barriers to the deployment of geothermal energy are among others, high investment costs of the production plant and the heating grid, and affordable fossil fuels. However, this does not incorporate future events that influence the business case for geothermal energy. These exogenous variables develop over time and

probably will have positive and/or negative effects on the financial and social attractiveness of large-scale energy solutions in the future. The time horizon to which the future refers, is considered set from 2015 up to 2045. The time horizon relates to the WLO scenario study of CPB, ECN, et al. (2006), and the energy neutral ambitions of the municipality of Eindhoven by 2045. This system dynamics modeling allows us to test the effect of exogenous variables on the social, technical and financial aspects of a geothermal energy solution.

The first paragraph will discuss the causal loop diagram, which is applied to capture the hypothesis about the cause of the dynamics and to communicate the feedbacks that cause the problem. However, a causal loop diagram has an important limitation since it is unable to capture the stock and flow structure of systems. (Sterman, 2000) Therefore paragraph 6.1.2 introduces and describes the developed stock and flow diagrams for this research; these diagrams are the states of the system upon which decisions and actions are based.

### **6.1.1 Causal Loop Diagram**

The causal loop diagram is a visual representation of the feedback loops in the system; it is used to describe basic causal relationships and how these relationships might behave over time, and it is used to create insight how system behavior is generated. One of the greatest advantages of a causal loop diagram is the fact that it is very useful as a communication tool to discuss important feedback processes which involve a problem and hypothesis.

It consists of variables connected by arrows that denote the causal influence among the variables; each link is a causal relationship that is assigned with a polarity, either positive (+) or negative (-) to indicate how the dependent variable changes when the independent variable changes. A **positive** link means that if the cause increases, the effect increases, and if the cause decrease, the effect decreases. A **negative** link has the opposite effect, if the cause increases, the effect decreases, and if the cause decreases, the effect increases. The effect will increase/decrease, above/below what it otherwise would have been. However, this only describes what would happen, if there was a change. The most important loops are highlighted by a loop identifier, which shows whether the loop is a positive (reinforcing) or negative (balancing) feedback. (Sterman, 2000) In general, this causal loop diagram consists out of four main loops; technical characteristics and policy influence, social awareness, renewable heating, and attractiveness of large-scale solutions.

The complete causal loop diagram can be found in the appendix. The complexity of the map does not allow an effective discussion of the separate loops. Therefore each figure corresponds with a part of the dynamic story and problem identification.

Figure 10 represents the Technical Characteristics and Policy Influence Loop (R1), and the Social Awareness loop (B1). The R1 loop is a reinforcing loop and is characterized by the variables Energetic Quality, Heating Demand, Carbon Emission, and Tightness of Legislation. The energetic quality has a negative link to the heating demand variable, since a higher energetic quality will result in a lower heating demand. Moreover, a decrease in heating demand will increase the gas consumption, which subsequently will increase the emitted carbon. However, a higher rate of carbon emission will decrease the contribution to the carbon emission goals of the government, and will decrease the governments' satisfaction. The loop B1 is a balancing loop and concerns the social awareness on heating costs for

consumers. Both the heating demand and costs of fossil fuel heating are positively linked to the heating costs; a higher heating demand will increase heating costs, while higher fossil fuel costs also increase the heating costs. The higher heating costs will increase the awareness on energy consumption. (Economic Report of the President, 2006)

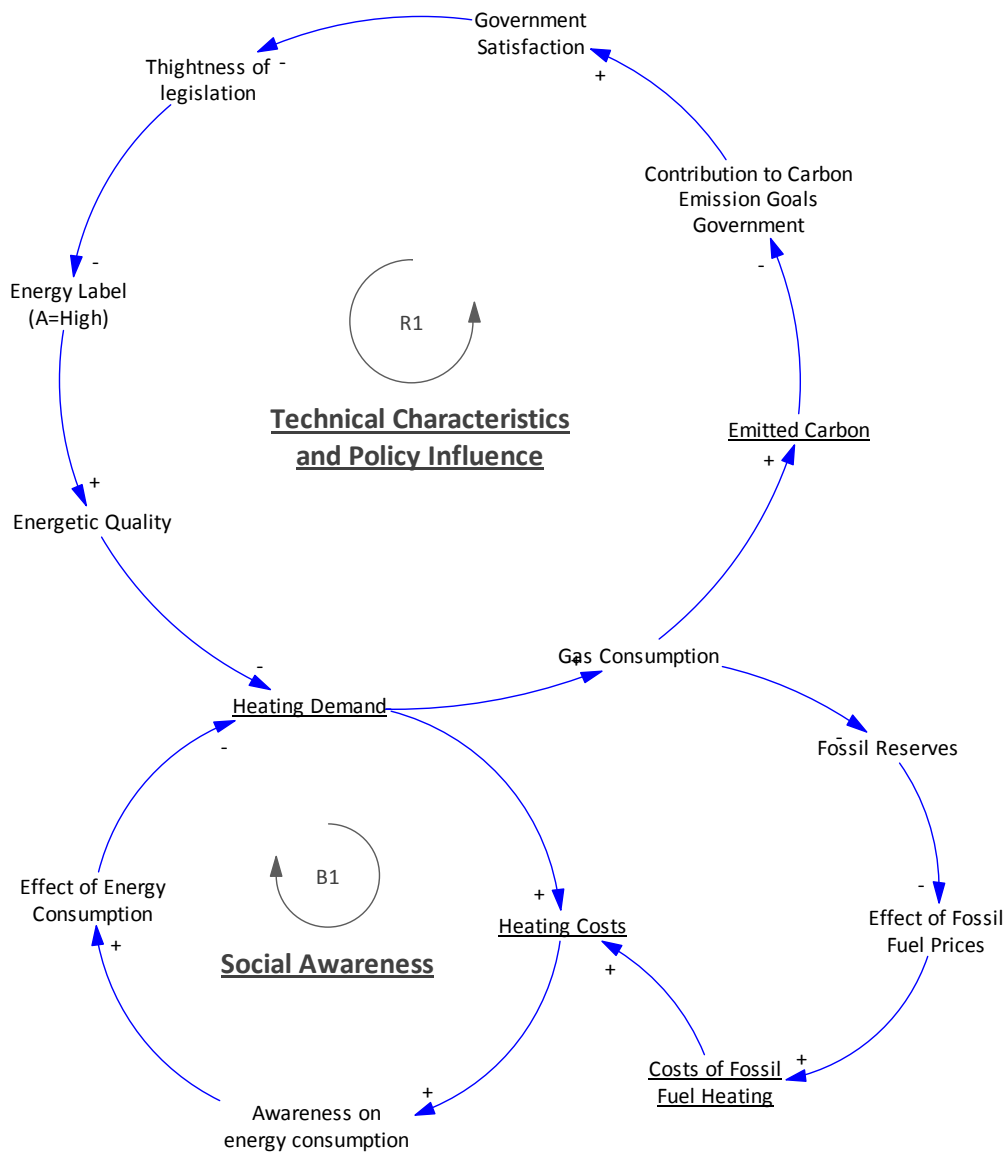


Figure 10: Technical Characteristics and Social Awareness loops

Figure 11 illustrates the renewable heating loop (B2), this loop is linked through the Costs for Fossil Fuel Heating and the Attractiveness of Renewable Heating. The positive link between these variables shows the causal relationship; the higher (or lower) the costs for fossil fuel heating, the higher (or lower) the attractiveness of a renewable solution. Other key variables in this loop are considered to be the Demand for Renewable Heating, the number of Connections to the Heating Grid, Depth of Drilling, and the Investment costs. The investment costs is an effect of the number of connections to the heating grid, and the depth of drilling; the higher or lower one of these causes, the higher or lower the investment costs.

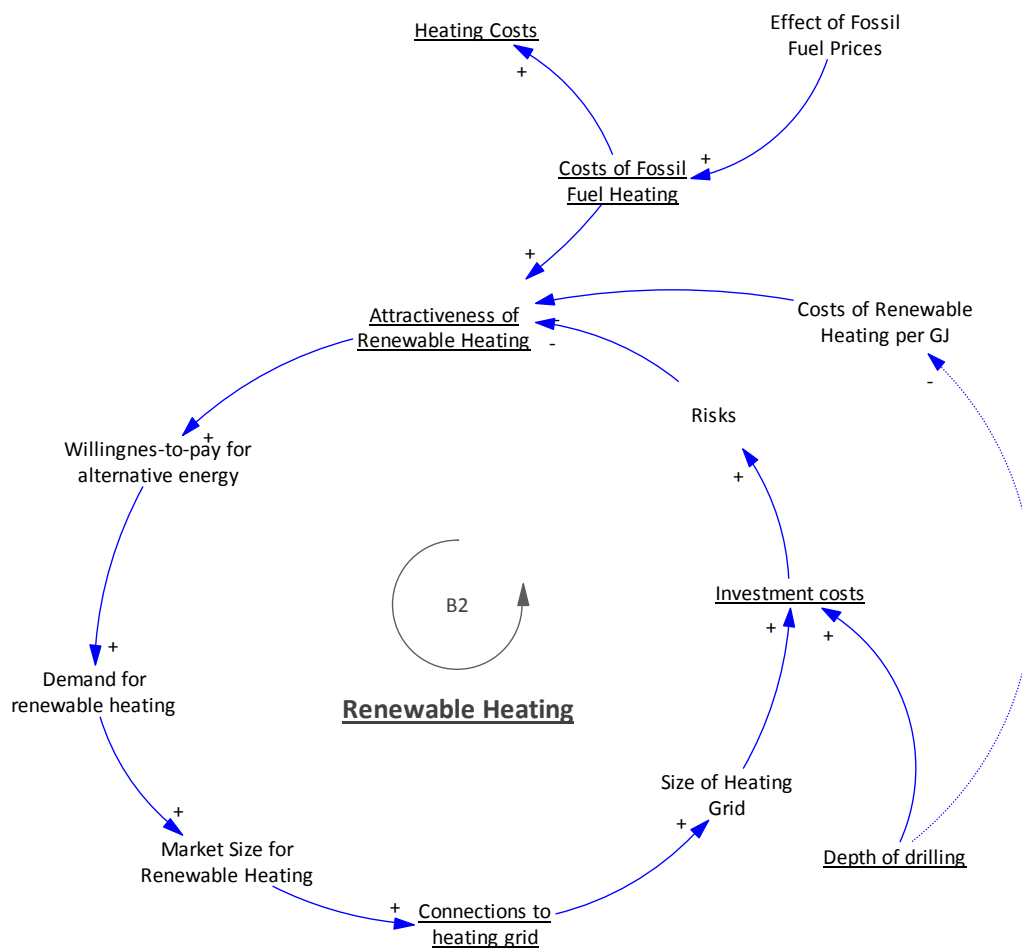


Figure 11: Renewable Heating Loop

Figure 12 illustrates the feedback of the attractiveness of large-scale energy solutions. This loop (B3) is characterized by the variables Connections to heating grid, Demand for renewable heating, Attractiveness Large Scale Renewable Heating Solutions, Investor Awareness, #Renewable Energy Projects Finished, and Emitted Carbon. It is crucial to illustrate the fact that the attractiveness is influenced by the demand for renewable heating, the number of connections to the heating grid and the density of the energy demand; the higher the demand, the number of connections and the density of demand, the higher the attractiveness of a large scale renewable heating solution. Furthermore, investor awareness increases when the attractiveness increases, but declines when the risk increases. Consequently, the annual carbon emission will decline when the energy generated from renewable resources increases.

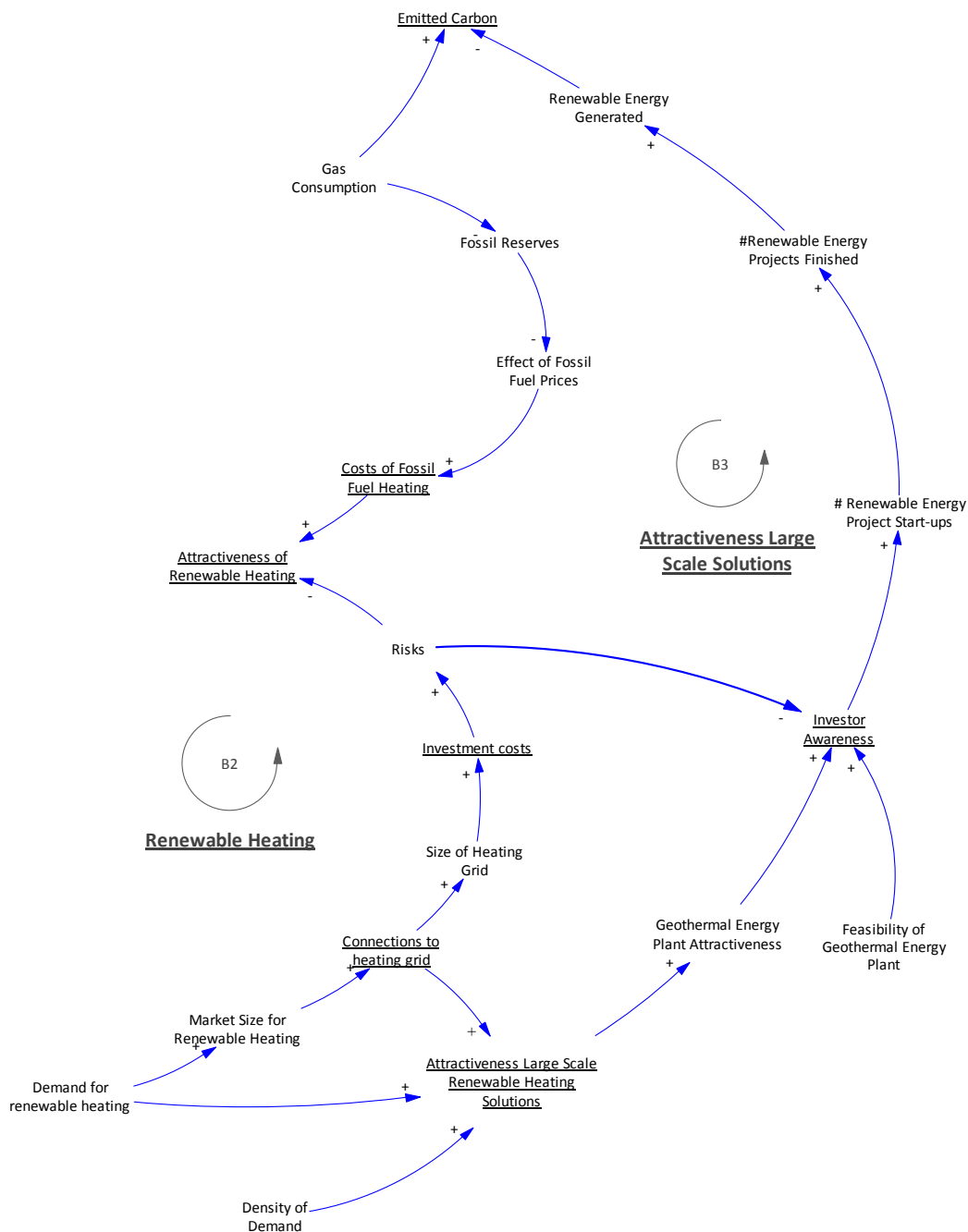


Figure 12: Attractiveness of Large Scale Solutions



### 6.1.2 Stock and Flow Models

This paragraph introduces the stock and flow model, which is based on the causal loop diagram; the diagramming notation for stocks and flows makes it easier to relate the causal diagram to the dynamics of the system. The stocks are characterized by its flows; it accumulates their inflows less their outflow. It characterizes the state of the system and generates the information upon which decisions and actions are based; these decisions and actions will be discussed in the results and findings chapter.

The developed stock and flow model comprises four views that are both technically and financially related. The first view is the input screen, which contains the variables that will be adjusted for each system solution, and scenario and the sensitivity analysis. However, the stock and flow diagram can be distinguished in three sub-models. The first sub-model comprises the calculation of the heating demand and the carbon emission for a particular area. The second model comprises the geothermal energy solution and the heating grid, while the third model applies all the previous gained data for the calculation of the net present value of the project. These sub models are discussed in the subsequent paragraphs; the most striking variables influencing the rates will also be discussed. The document of all formulas can be found in the appendix.

### 6.1.3 Financial Calculation Sub-Model

The calculation of the Net Present Value (NPV) of the project comprises two main stocks and flow models; the calculation of the cash flow, and the NPV calculation based on the yearly cash flow. The yearly cash flow is calculated by subtracting the Costs Rate from the Cash in Rate. The exact formula for the calculation of the costs and revenue is discussed on the next page, while the overview of the stock and flow model is illustrated by Figure 13.

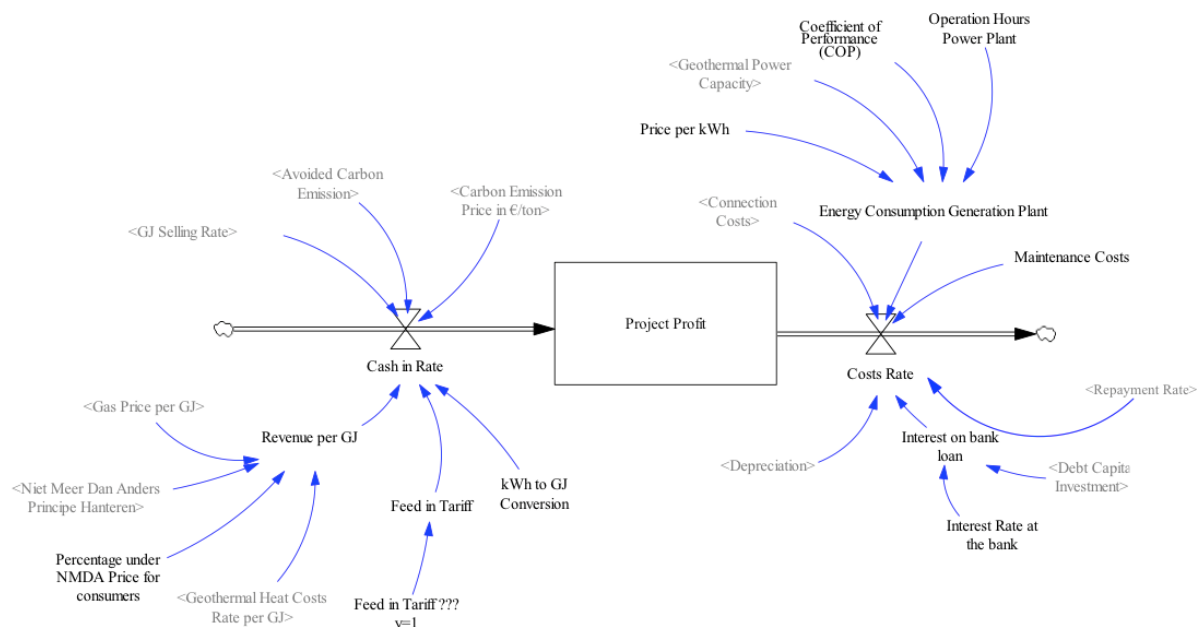


Figure 13: Cash flow Calculation

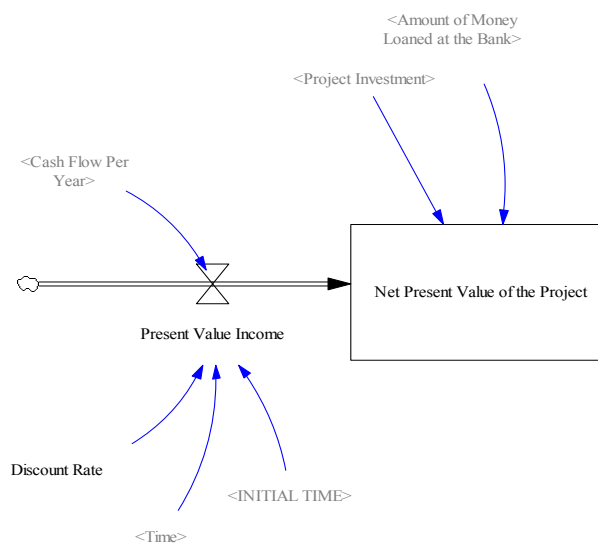
$$\text{Cash in Rate} = (\text{Revenue per GJ} * \text{GJ Selling Rate}) + (\text{Avoided Carbon Emission} * \text{Carbon Emission Costs in } \text{€}/\text{ton})$$

$$\text{Costs Rate} = \text{Energy Consumption Plant} + \text{Maintenance Costs} + \text{Connection costs} \\ + \text{Interest on Investment} + \text{Depreciation}$$

The calculation of the *Revenue per GJ* is dependent on the case if the principle for the NMDA is applied; this principle means the consumer will not pay more for its heat per GJ than it would when using a conventional gas fired generation system. This means that instead of selling geothermal heat against costs price, geothermal heat will be sold against the fixed NMDA price or a certain percentage under it. As the appendix of the parameter overview clarifies, the percentage under the NMDA price is set at 15%. Furthermore, if it is decided to incorporate the costs for carbon emission, selling carbon emission rights can also be considered as revenue to the organization.

$$\text{Revenue per GJ} = \text{IF THEN ELSE}(\text{Niet Meer Dan Anders Principe Hanteren} = 0, \\ \text{Geothermal Heat Costs per GJ}, \\ \text{Gas Price per GJ} * (1 - \text{Percentage under NMDA Price}))$$

The *Connection Costs* is a result of the number of connections made per year, and the cost per house to connect it to the heating grid. Moreover, the *maintenance costs* are assumed to be 1,5% of the investment costs, assumption has been validated by experts. The energy consumption of the geothermal energy plant is considered to be the power production divided by the *Coefficient of Performance* of the power plant multiplied by the *Operation Hours* and *Price per kWh*.



**Figure 14:** Net Present Value, Geothermal Energy Plant

The Net Present Value of the Project is a stock, which accumulates by the *Present Value Income* but is reduced by the *Project Investment*. The Present Value is calculated by discounting the annual cash flow. The formulas below clarify how the Net Present Value and Cash Flow is discounted.

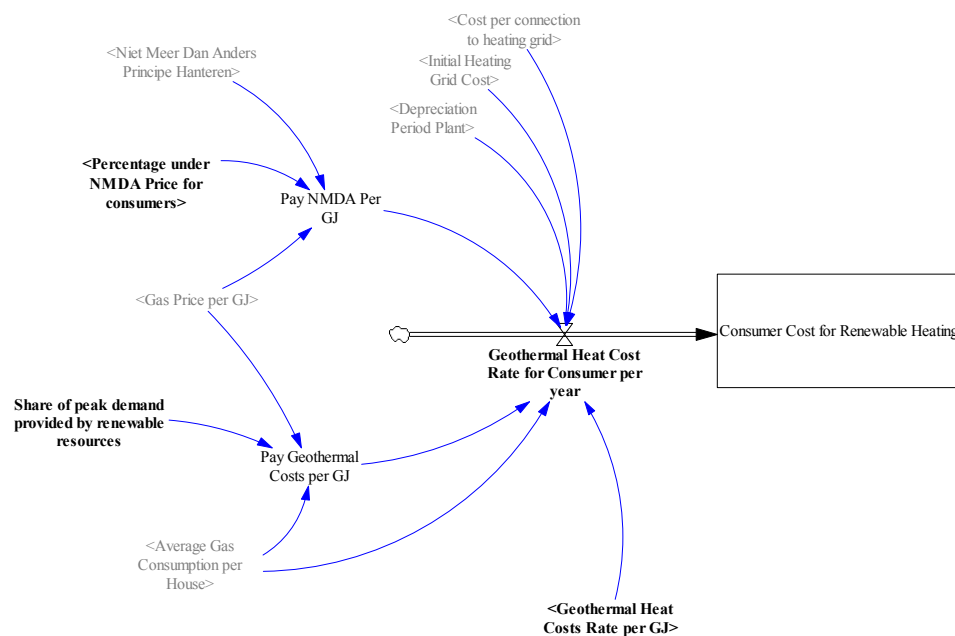
$$\text{Net Present Value of the Project} \\ = \text{INTEG}(\text{Present Value Income}, -(\text{Project Investment} \\ - \text{Amount of Money Loaned at the Bank}))$$

$$\text{Present Value Income} = \text{Cash Flow Per Year} * (\text{Discount Rate}^{(\text{INITIAL TIME} - \text{Time}))}$$

### 6.1.4 Geothermal Heating Grid Sub-Model

This sub-model constitutes the calculation of the power production of the energy plant, the geothermal heat costs for consumers, the switching rate, and the annual rate of sold Gigajoules to customers. The exact calculation of the geothermal plant capacity is discussed in paragraph 6.3, and will therefore not be discussed in this paragraph. The *Geothermal Heat Cost Rate for Consumer per year* is related to the power production of the geothermal plant; the *Geothermal Heat Cost per GJ* is an auxiliary resulting from the power production of the energy plant, and the number of connections to the heating grid.

Figure 15 is the model for the *Geothermal Heating Cost Rate for Consumers per Year*. As the figure illustrates, the cost rate for consumers is determined mainly on the decision to apply the principle of NMDA; this determines the price of geothermal energy for consumers. Furthermore, the costs for the heating grid are incorporated in the the GJ price for geothermal energy.



**Figure 15:** Consumer Costs for Renewable Heating

The formula related to this figure illustrates that the consumer costs for geothermal heat either is based on the NMDA price, or on the costs for producing geothermal energy and the connections to the heating grid.

$$\begin{aligned}
 & \textit{Geothermal Heat Cost Rate for Consumer per year} \\
 & = \textit{IF THEN ELSE}(\textit{Pay NMDA Per GJ} \\
 & = 0, \textit{Pay Geothermal Costs per GJ} + (((\textit{Initial Heating Grid Cost} \\
 & + \textit{Cost per connection to heating grid}) / \textit{Depreciation Period Plant}) \\
 & / \textit{Average Gas Consumption per House}), \textit{Pay NMDA Per GJ} \\
 & * \textit{Average Gas Consumption per House})
 \end{aligned}$$

As stated in the contextual orientation, one of the greatest challenges in developing a geothermal energy plant is having sufficient energy consumption at the start of the project. Since it is a capital-intensive investment, each discrepancy between the power production and heating demand is an expensive loss. However, generally a neighborhood already

generally a heating infrastructure, and it cannot be assumed that consumers switch initially. Expert interviews showed that it might be assumed that after eight years each consumer has switched to the renewable alternative. Nevertheless, this means that for the first eight years the energy plant is not operating to its full potential, and has overcapacity. Subsequently, this means that the generated income at the start of the project is substantially lower than after the period of eight years; this has a strong and negative influence on the feasibility of the project. However, the exact effect of the switching rate is examined in the paragraph concerning the sensitivity analysis.

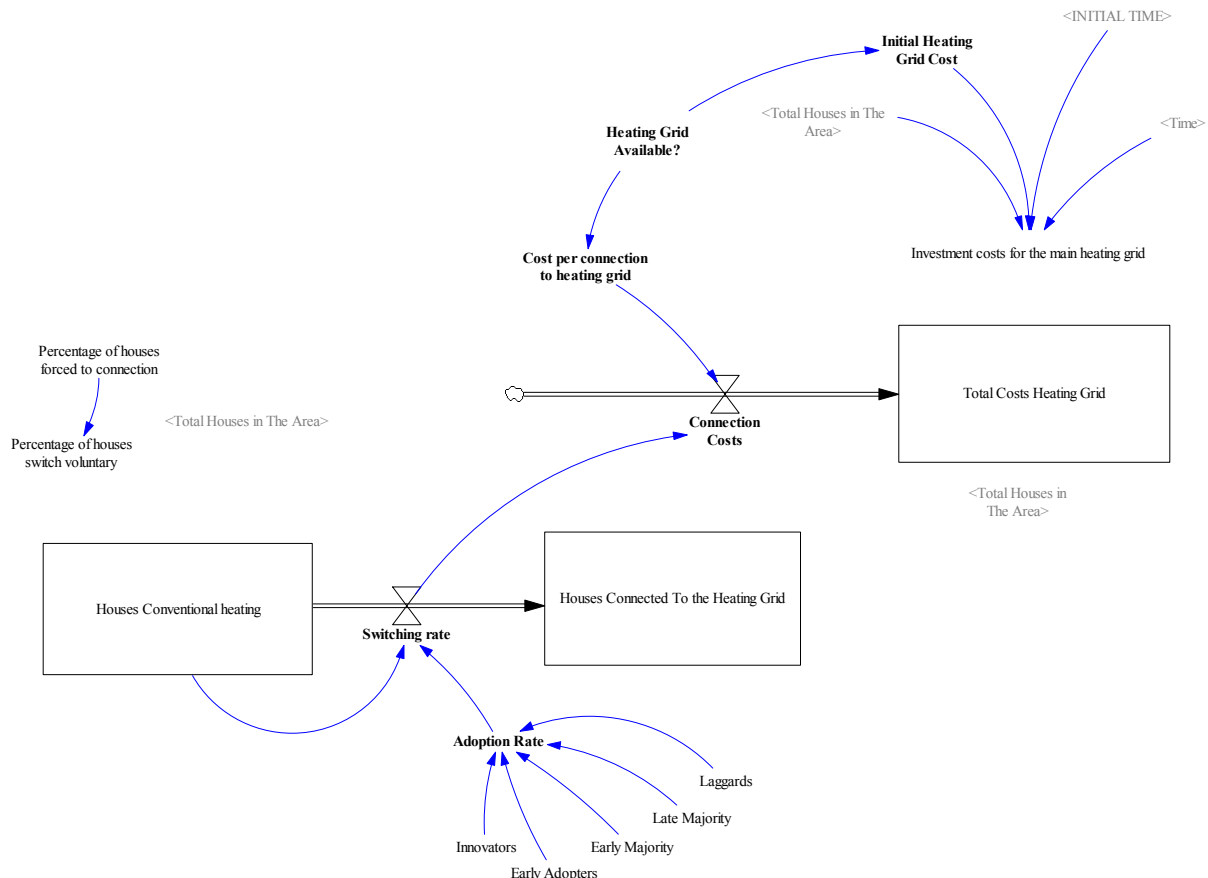


Figure 16: Heating Grid Connections

As discussed previously, the connection rate is distributed over eight years. This connection rate is based on the product diffusion model of Rogers (1962). This means that each distinguished group will adopt the renewable alternative after a period of 1,6 years.

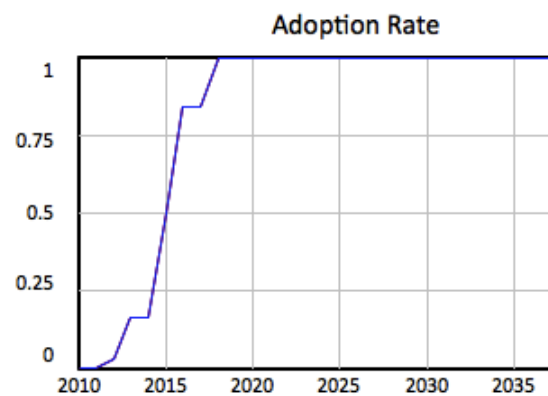


Figure 17: Adoption Rate

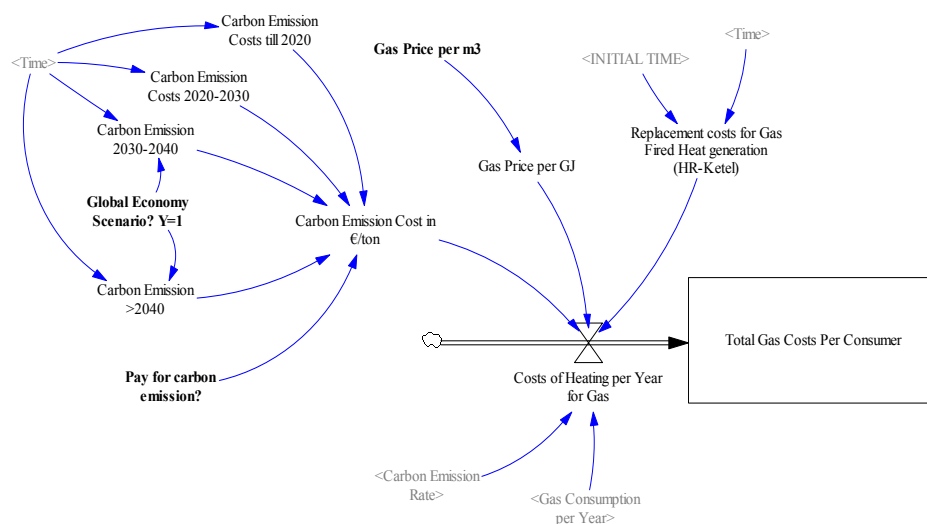
Moreover, the stock that shows the number connections to the heating grid relates to the *GJ Selling Rate*. The approximate energy consumption in GJ per house is multiplied by number of houses connected to the heating grid. This means the amount of GJ's that are sold behave according to the switching rate; the more connections made over the years, the higher the sold amount of energy to the house

*GJ Selling Rate*

$$= \text{Base Energy Demand from industry or commercial buildings} + \left( \frac{\text{Gas Consumption per Year}}{\text{Total Houses in the Area}} \right) * \text{Houses Connected to the Heating Grid}$$

### 6.1.5 Gas Consumption Sub Model

This sub-model comprises the calculation of the energy demand in the area and the consumers' costs for gas-fired generation of heat. The effect of scenarios is incorporated in this model, since it contains the annual increase in gas price, the costs for emitting greenhouse gasses and the decline in heating demand.



**Figure 18:** Gas Fired Heating Costs per Year

The *Costs of Heating per Year for Gas* is calculated according to the formula below. It illustrates that costs for carbon emission only is incorporated in the yearly gas fired heating costs, if it is explicitly mentioned.

*Costs of Heating per Year for Gas*

$$= \text{Gas Consumption per Year} * \text{Gas Price per GJ} + \text{IF THEN ELSE}(\text{Pay for carbon emission} = 1, \text{Carbon Emission Rate} * \text{Carbon Emission Cost in € / ton}, 0)$$

Furthermore, the consumption of gas per year, per house, of a total area is gained from gas consumption data that has been made available by the university. These exact numbers are not allowed for publication and are therefore not in this report.

## 6.2 Scenarios for Geothermal Energy

The contextual orientation, part I, briefly mentioned the Welfare, Prosperity, and Quality of the Living Environment (WLO) scenario study from ECN et al. (2006). The study assesses the long-term effects of current policy, given the international economic and demographic context of the Netherlands. The qualitative and quantitative results can be applied as reference, for instance, policy-makers involved in spatial planning, housing, natural resources, infrastructure, and the environment. (ECN, 2006) One of its scenario studies focused on the energy consumption in the Netherlands, both on energy demand and the supply of energy in the Netherlands.

The goal of applying scenarios is to study the effects of exogenous variables on the feasibility of geothermal energy; what are the effects on the business case when the heating demand declines, or when the gas prices increases.

The first paragraph will introduce the WLO scenarios as they are presented in the study of the CPB, CBS and ECN in 2006. This paragraph contains the introduction of the most important parameters for a large-scale energy solution, and how they change over time. Subsequently, the second paragraph will comprise the decision for a scenario and will discuss the applied parameters in the system dynamics model.

### 6.2.1 Scenario and Policy Influence

The scenario study from ECN et al. (2006) distinguishes four scenarios that outline the physical and environmental developments of the Netherlands until 2040. The four developed scenarios can be distinguished in focus points on International Corporation or National Sovereignty, and in Public or Private Responsibilities.

Each specific scenario has its own specific characteristics, which are distinguished in the figure below.

<u>Strong Europe</u>	<u>Global Economy</u>
<ul style="list-style-type: none"> <li>- High Population Growth</li> <li>- Moderate Economic Growth</li> <li>- Global trade, environmental restrictions</li> <li>- Effective international climate policy</li> </ul>	<ul style="list-style-type: none"> <li>- High Population Growth</li> <li>- High Economic Growth</li> <li>- Global trade, no environmental restrictions</li> <li>- No climate policy</li> </ul>
<u>Regional Communities</u>	<u>Transatlantic Market</u>
<ul style="list-style-type: none"> <li>- Low Population Growth</li> <li>- Low Economic Growth</li> <li>- Trading blocs keep sustained</li> <li>- Effective national climate policy</li> </ul>	<ul style="list-style-type: none"> <li>- Moderate Population Growth</li> <li>- High Economic Growth</li> <li>- Trading blocs keep sustained</li> <li>- No effective environmental policy</li> </ul>

**Figure 19:** Characteristics of WLO energy scenarios (ECN, 2006)

CPB, ECN et al. (2006) have assumed a governance trend in each scenario on, for instance, carbon emission trading, energy consumption in the built environment, and renewable energy. This governance for both energy saving and climate policies remains unchanged under every scenario until 2020; thereafter it will lapse in Global Economy and Transatlantic market. (ECN, 2006) After 2020, each scenario will present other parameter outcomes that influence the application of renewable energy; either on a positive or negative way. Political forces can strongly influence large-scale renewable energy systems, such as geothermal



energy. For example, future governance could lead to a decline in energy consumption within the built environment, or focus on promoting the application of renewable energy.

The governance could have a great impact on renewable energy systems in the future. Large-scale renewable heating solution requires a substantial heating demand, to utilize the energy system to its full potential. Moreover the density of the heating demand is also considered to be crucial, due to the incremental costs of the heating grid and the heating loss during transportation. Therefore the heating demand of a specific area is crucial; the designed geothermal power plant should be utilized to its full capacity, since it is a capital-intensive investment. Therefore, any small change in policy could have a great influence on the feasibility of these systems.

Since geothermal heat is presented as a renewable alternative to natural gas and it is mandatory to have a sufficient demand of heat in that particular area. This means the most influencing factors for the feasibility of these systems are considered to be the gas prices, and the heating demand. As has been concluded previously, the higher the gas price and the higher the heating demand, the greater the feasibility of the geothermal heating plant. Lower gas prices and a decrease in heating demand will negatively effect on the feasibility of the solution. In contrast, 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.

### 6.2.2 Applied Scenario and its Aspects

As the previous paragraphs illustrated, each scenario presents its advantages and disadvantages for renewable energy solutions. Financial support and increasing fossil fuel prices increase the attractiveness of large-scale solutions, while decreasing energy consumption negatively influences the attractiveness of these energy solutions. These are considered to be the most determining forces, since geothermal energy replaces the fossil fired generation and because the transportation of heat is costly.

It is possible to distinguish the WLO scenarios in policies that support and favor the application of renewable energy, while others curb the utilization of renewable energy technologies. The following scenarios are the most contrasting, and will show the most diverging results.

*“**Strong Europe** favors the application of renewable energy; it has a high technical development. As Figure 19 illustrates, this scenario has a high economical growth combined with a strong climate policy. This scenario presents an agreement on a global climate policy, which would limit the global increase in temperature to a maximum of two degrees Celsius. This agreement contains the carbon trading mechanism. Additionally in this scenario, governance is focused on promoting renewable energy technologies by subsidies. However, the international climate agreement will lead to a decline in gas consumption; the gas consumption will decline to 230 PJ in 2040. As the WLO study concludes, this agreement and decline in energy consumption will lead to a stabilization of gas prices. (ECN, 2006)”*

*“In contrast to the Strong Europe scenario, the **Global Economy** scenario pays little attention to the environment. The European emission trading system will be terminated after 2020, because there will not come an agreement on an international climate policy. Furthermore,*

*the subsidies on renewable energy will be cancelled after 2020. The Global Economy scenario curbs the promotion of renewable energy technologies. In spite of this little attention, it still has a high technical development; however, this technical development is lower than in the Strong Europe scenario. The consumption of gas will increase to 320 PJ in 2040; this can be addressed to the fact that newly built estates will no longer be restricted to energy performance legislation. Gas prices increase due to the demand for energy and the fluctuations in energy supply. The increase in gas price is a result of the peak in oil price. The gas price will grow with 0,7-0,8 percent per year. (ECN, 2006)”*

ECN (2009) updated the reference calculations on the Global Economy Scenario, in contrast to the calculation in 2005 were also other scenarios were incorporated. Since the introduction in 2005 the Global Economy scenario has been commonly applied, and gained the status of reference scenario for other research. This scenario outlines a future, which is based on a consistent set of assumptions on long-term trends. As ECN (2009) states, the scenario is considered as a conservative scenario: if governance is adequate in this scenario to achieve certain goals, then it will also be under other scenarios. Fluctuations in energy prices forced an update of the energy prices since these have been substantially higher, than was predicted on forehand. Additionally, the prices for carbon emission credits are substantially higher: € 35 per ton in 2020. The economic growth and the high demographic growth will be obtained. (ECN, 2009)

These two scenarios show great differences; the Strong Europe scenario has a strong focus on the environment and renewable energy, while the Global Economy scenario pays little attention to these points. However, 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 4 shows the scenario parameters that will be incorporated in the System Dynamics model.

	<b>Strong Europe</b>	<b>Global Economy</b>
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) yearly decline 1% per year	340 PJ (2006) 305 PJ (2040) yearly decline 0,3% per year
Gas Price	yearly increase 0,4%	yearly increase 0,8%

**Table 4:** Assumed policy in WLO scenarios (ECN, 2006) (ECN, 2009)





### **6.2.3 Scenarios Conclusions**

As mentioned before, System Dynamics will integrate scenario planning. The reference scenario is considered as the Global Economy scenario; due to the fact it is widely applied and reliable as reference scenario. The other scenario is Strong Europe, since it contrasts the most to the reference scenario in energy consumption and fossil fuel prices. Furthermore, it is interesting to study the effect of the international climate agreement and the policy on renewable energy in the Strong Europe scenario. The examination of the effects of increasing fossil fuel prices and declining energy consumption can be addressed to one of the barriers that are identified in the contextual orientation. TNO, Thorsteinsson and Tester (2007, 2010) stated that among other factors, affordable fossil fuel prices are a constraint to the development of geothermal energy plants and that a sharp increase in gas prices is forcing private enterprises to consider the use of alternative energy sources.

By applying parameters from the WLO scenarios, the effect of increasing fossil fuel prices on the economic attractiveness of geothermal energy has been examined. The geothermal energy solutions that will be subjected to the scenarios are introduced hereafter.

### 6.3 System Solutions for Geothermal Energy in Eindhoven

This paragraph will discuss the geothermal energy solutions; the solutions vary from each other in thermal capacity and investment costs. These energy solutions will be tested on three different cases, which are discussed in this chapter, and will be subjected to different scenarios. The input and parameters for the energy solution 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 the specific energy solution. The index numbers concern the increase of temperature per kilometer, the cost per kilometer drilling, the flow rate of the water, and the operation hours of the geothermal energy plant. This paragraph distinguishes the parameters in capacity, and costs. Finally, a summary of the designed system solutions concludes this paragraph.

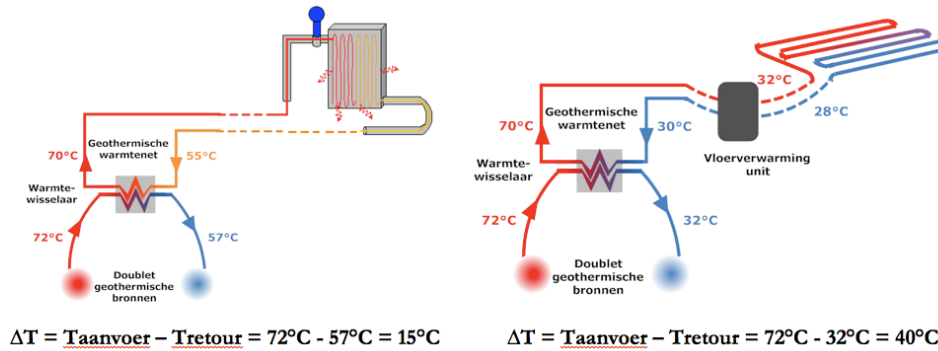
#### 6.3.1 Geothermal Energy Plant Capacity

The contextual orientation (Part I) explained that the capacity of the geothermal energy plant is dependent on several factors. The following formula shows the factors that influence the thermal capacity of the geothermal energy plant.

$$W_{th} = Q \times \rho \times c_v \times \Delta T$$

The formula shows the thermal power production of the energy plant is based on the characteristics of the aquifer in the under soil. Q represents the flow rate of the water in the aquifer in m<sup>3</sup> per hour,  $\rho \times c_v$  represent the heat capacity per volume of the water in Joule per m<sup>3</sup>K, and  $\Delta T$  is the difference between the inflow and return temperature. The variables Q,  $\rho$ , and  $c_v$  concern the aquifer characteristics. Expert interviews allowed a realistic assumption on the flow rate and thermal capacity of the aquifer water in Eindhoven.

Delta T ( $\Delta T$ ) results from the drilling depth, and the chosen application. The inflow temperature is determined on the temperature at which the geothermal water can be extracted from the aquifer. The temperature increases with 31°C per kilometer in depth. However, a constraint to this fact is that not each temperature can be utilized for each application i.e. the existing build stock requires a higher inflow temperature than newly built houses, due to the applied heating system. The return temperature is subsequently dependent on the type of heating system applied in the concerned case; high temperature systems with radiators have a higher return temperature (90/70°C or 70/50 °C), while heating systems such as under floor heating are designed for lower temperature heating. Figure 20 illustrates this.



**Figure 20:** Illustration of geothermal heating applications (Platform Geothermie, 2011)

In general, newly built houses are utilized with a low temperature heating system, while the existing building stock requires high temperature heating. Delta T will be greater for new built estates, than in the existing building stock situation; the low temperature system has a higher rate of cooling down, which increases the power plant capacity.

### 6.3.2 Geothermal Energy plant and Heating Grid Costs

The previous 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. Additionally, according to the experts, a drill deeper than three kilometers is more expensive per kilometer than a less deep drill. Table 5 illustrates the costs for drilling per kilometer.

Depth	Cost per km
< 3 kilometers	€ 2.000.000
> 3 kilometers	€ 3.500.000

**Table 5:** Index numbers, drilling costs per km

What has not been not incorporated in these system solution designs are the costs for the heating grid, because not each case requires the construction of a new heating grid. Experts state the costs for the construction of the heating grid represent approximately 75% of the total project investment, while just 25% can be addressed to the geothermal energy plant. Based on expert knowledge, the cost for a heating grid is approximately € 4.000 per house; however, the costs can be distinguished in costs for the main heating grid and connection costs to the house. Table 6 shows how the costs are be distinguished:

Heating Grid	Cost per house
Main heating grid	€ 1.000
Connection to the house	€ 3.000

**Table 6:** Index numbers, heating grid costs per house

These costs cannot always be made at the start of the project. The heating infrastructure in an existing neighborhood is most of the times already present, which means the heating grid has to be constructed parallel to the existing gas network. As stated previously, it might be expected that after 8 years, everybody has switched to the renewable alternative; this could be addressed to the replacement of the high efficiency boiler. This means according to the product diffusion curve, each group and its related percentage can be distributed over eight years.

### 6.3.3 Conclusion: Three Geothermal Energy Solutions

The table below summarizes the designed system solutions. The different solutions vary from each other in depth, geothermal plant costs, capacity, and costs per Gigajoule. Furthermore, each geothermal solution will provide 70% of the total heating demand in the area, and 30% of the heating demand will be supplied by the use of so-called peak boilers that are situated at the geothermal plant site. The exact calculation can be found in the appendix, the design of the geothermal system.

	System Solution 1	System Solution 2	System Solution 3
Depth	2.000 meters	3.000 meters	4.000 meters
Costs of the Plant	€ 8.000.000	€ 12.000.000	€ 28.000.000
Delta T	27 °C	33 °C	89 °C
Capacity	4,7 MWth	5,8 MWth	15,5 MWth
Operation Hours	4000	5000	5000

**Table 7:** Geothermal Energy Plant Specifications (Expert Validation)

It is striking to see that although the investment costs and drilling costs (solution 3) are incrementally higher, the cost for producing one Gigajoule seems to decline when the drilling depth increases. The capacity of the energy plant increases faster per kilometer, than the costs per kilometer. The greater the thermal capacity (MWth) of the plant, the more energy that can be distributed and sold to customers.

As been mentioned previously, 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 the existing building stock area while 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 paragraph.



## 7 Case Description

Each system solution will be tested on a particular case in the area of Eindhoven; one focused on a newly built project, one studies the existing building stock, while the third system solutions is focused on a cascade connection between a low temperature and high temperature system. It is important to mention that there is little knowledge on the geological conditions in the under soil of Eindhoven; in collaboration with experts realistic assumption are made on the characteristics. The little knowledge of the soil can be addressed to the fact there have not been performed many drills for oil and gas in the southeast of Noord-Brabant, in contrast to other regions of the Netherlands. The next paragraphs will discuss why the particular cases are selected, and discuss the most important parameters.

### 7.1 Selection Criteria

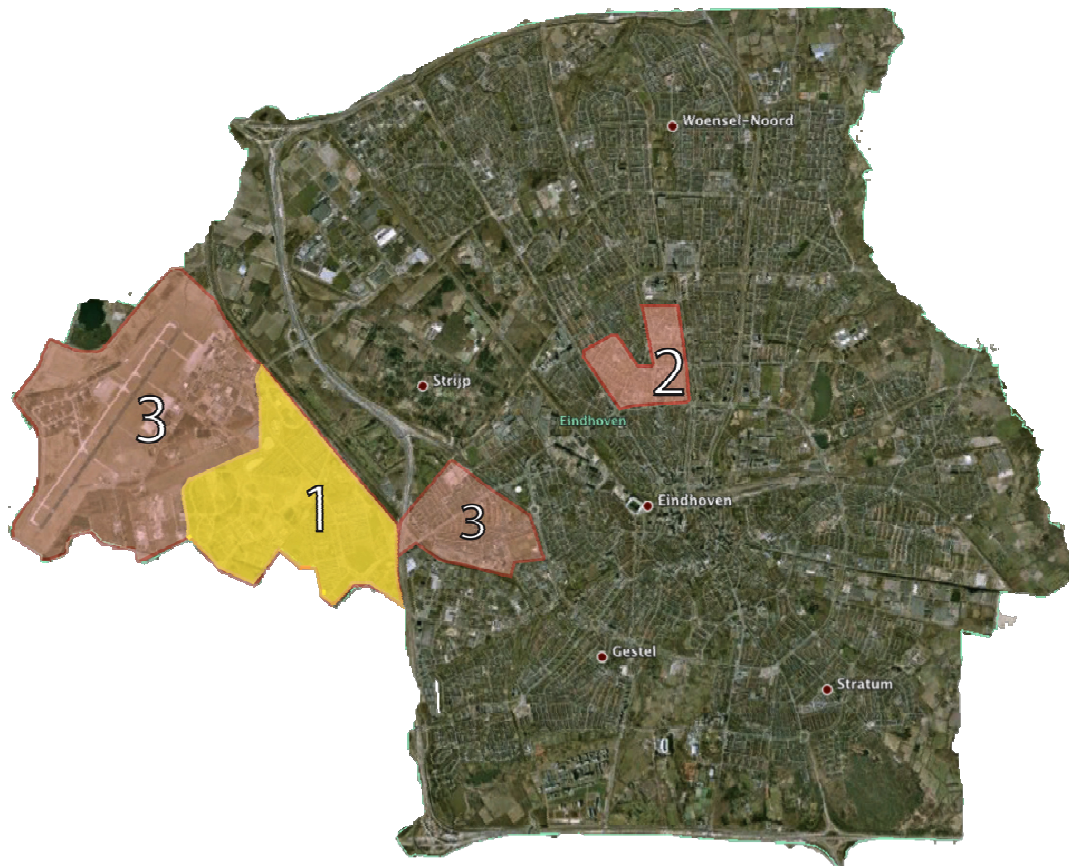
The selection criteria for the cases are based on technical, social and financial related parameters. The technical parameters are addressed to the required heating temperature of the concerned houses. The social related parameters concern the selection of the type of houses that will be provided with geothermal energy. The existing building stock holds great potential in the preservation of its energy consumption; newly built estates are currently remarkably more efficient in their energy consumption. The financial related parameters are selected to address the effect of the heating grid on the feasibility of the project.

For a depth of 2 kilometers, it is required to have a new built area, since the temperature at which the water can be extracted from the aquifer is too low for the existing building stock. A new housing development project in Eindhoven, which also includes a heating grid, has been selected.

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 building stock project has been selected, since this stock contains the greatest potential for the preservation of the Dutch energy consumption. Furthermore, this area requires the construction of a heating grid, which will have an incremental influence on the projects feasibility. Furthermore, this case should include a substantial number of houses in possession of the housing corporations in Eindhoven.

The third case has been selected because of its cascade connection between commercial buildings, existing building and new estates. The case should include these characteristics, and have a sufficient size of scale since this system solution has a great capacity output. It should provide a base energy demand resulting from the commercial buildings. Therefore, an industrial area should be selected that is close to the city of Eindhoven.

This criteria lead to the selection of three cases that are discussed in the following paragraphs. The map illustrates the location of the particular cases.



**Figure 21:** Overview on the cases in Eindhoven

### 7.2 Case 1: Meerhoven

Meerhoven is a new housing development project, situated in the western part of Eindhoven. It is the most recent and greatest city expansion of Eindhoven. The development project comprises, besides other functions, the development and construction of 5.800 houses. Since the heating demand in this area is met by a biomass power station, a heating grid is already present in this area.

The houses 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 might be assumed that a newly built estate consumes around 20 GJ for heating and 8 GJ for hot water supply per year. (Platform Geothermie, 2011) Given this fact, and by applying geothermal system solution 1, it is possible to provide 3.463 houses with geothermal heat. The overview of the calculation can be found in the appendix on the parameter overview.

### 7.3 Case 2: Rapenland en Kronehoef

The second case that is examined comprises the existing building stock. This case is interesting because the existing building stock holds great potential in the preservation of the energy supply in the Netherlands. Additional advantages are the fact this stock is built in considerably density, and the energetic quality of these houses is low. These characteristics

are more favorable for the feasibility for the project, than a new project development project with a high energetic quality and lower building density. However, an important constraint is the heating grid, which is generally not present in these areas. Since these costs could comprise four times the costs of the power plant, it is interesting to study the effect of the development of a heating grid on the geothermal business case.

This case is situated in Woensel-Zuid, which is located north to the centre of Eindhoven. Based on CBS statistics, there are 3.144 houses situated the neighborhoods Rapenland and Kronehoef, and approximately 1.255 houses (42%) are possessed by housing corporations. (Domein, et al. 2011) For the elaboration of the case it has been assumed that this percentage of houses switch initially, because the incentive for housing corporation is an increase in housing rent due to the improvement of the energy label. The legislation on energy label improvement will be discussed in the organizational design paragraph. The houses in this area are designed with a high temperature heating system, 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 the provided gas consumption data in this area. Based on this data the heating demand per house has been determined on 49 GJ per year.

#### *7.4 Case 3: Flight Forum, Meerhoven and Strijp*

The third case comprises the application of the third geothermal energy solution. This solution is a cascade connection between commercial buildings, the existing building stock, and a new housing development project. This results in a combination of a high temperature heating system and a low temperature heating system. This results in a high thermal capacity due to the great difference between the inflow and return temperature. This case is interesting due its cascade connection and its scale of utilization; it could be possible to connect over 8.000 existing buildings with a considerably heating demand.

The third case is, just like the first case, situated in the western part of Eindhoven. However, the scale is considerably greater since it is extended to Eindhoven Airport and to the city district Halve Maan in Strijp. This case comprises besides new estates in Meerhoven, commercial buildings (Flight Forum, Eindhoven Airport), and existing buildings (Het Ven and Lievendaal in Strijp). The city districts, Meerhoven, Het Ven and Lievendaal constitute in total 9.261 houses. Based on the provided gas consumption data, the commercial buildings consume 83.501 GJ annually, the new estate approximately 28 GJ per year, while the existing houses (Het Ven and Lievendaal) consume yearly 49 GJ.

As has been discussed at the first case, heating grid is already constructed in Meerhoven. However, the city district Strijp has no heating grid since the existing building stock is connected to a gas infrastructure. This means there should be a heating grid constructed in this particular area. Nevertheless, housing corporations possess 1.698 (49%) of the houses in this particular area.

### 7.5 Conclusion: Correlation and Discrepancy Between the Cases

Based on the barriers that have been identified in Part I, three system solutions will be tested on three cases which all have other characteristics. First of all, the three cases are selected based on output characteristics of each system solution; for instance the low extraction temperature of first system solution is not suited for the existing building stocks since this requires a higher inflow temperature in the geothermal heating grid.

Besides the technical output parameters, these specific cases also have been selected to distinguish and identify the influence of the barriers on the economic attractiveness of the geothermal energy plant. The first case is selected because it comprises newly built houses and since there is already a heating grid is present in this particular area, while the second and third require the construction of a heating grid. This allows examining the effect of a heating grid on the feasibility of the geothermal energy project. The heating grid is the most expensive element in the supply of renewable heat, and it is mandatory for a feasible project to have an initial number of switchers. Currently, dwellings cannot be forced to connect to a heating grid; as a result the construction of such an expensive element is an enormous liability to its feasibility when there is no initial number of connections.

By studying these cases it is possible to research the effect of the barriers. Such as the infrastructure constraint, and the incentive splits of landlords and tenants. The results from this study could contribute to a concept organization of local energy company.

Heating System	<u>Case 1</u>	<u>Case 2</u>	<u>Case 3</u>	
	Low Temp. 70/40	High Temp. 90/70	High and Low Temp. 90/40	°C
Average Heating Demand Household	28	49	28	GJ/yr
Commercial Heating Demand	-	-	83,501	GJ/yr
Share of Geothermal Heating in Total Heating Demand	70	70	70	%
Number of Houses Provided With Geothermal Heat	3,463	3,023	5,811	houses (28 GJ) (new estates)
			3,129	houses (49 GJ) (existing stock)
Heating Grid Connections (Housing Corporation)	Already constructed	1,255	7,509	houses
Percentage Forced to switch	100	41.51	84	% of total
Percentage of existing stock			54	% of existing stock



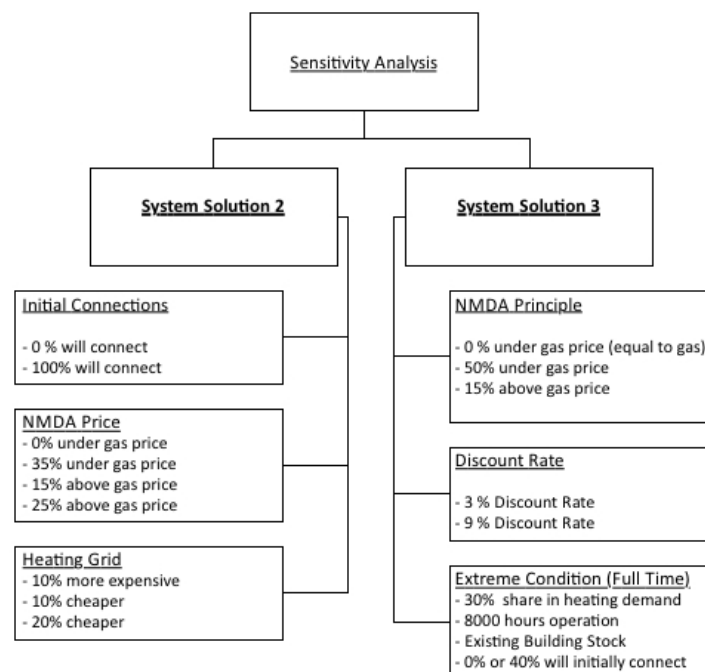


## 8 What if... A Sensitivity Analysis

The final chapter of the second part comprises the introduction of the sensitivity analysis of this research. The developed models contain approximations and assumptions; it is mandatory to examine the sensitivity of the results to plausible alternative structural assumption, including changes in the boundary model. (Sterman, 2000)

The geothermal energy solutions, and case studies contain assumptions either on financial parameters, as well as on the technical numbers. The sensitivity of the results will be examined by changing parameters for particular cases. A case is selected based on the greatest effect on changed parameters; the financial changes will be addressed to the case with the highest investment costs (Solution 3), while the technical related parameter changes will be addressed to the case without an existing heating grid (Solution 2).

The goal of this sensitivity analysis is to examine the effects of parameter changes on the financial attractiveness of the project. The subsequent paragraphs will discuss the sensitivity analysis, while the results will be discussed in the results and findings chapter.



**Figure 22:** Sensitivity Analysis, Parameter changes



### *8.1 Initial Connections and Switching Rate*

As has been discussed previously, geothermal energy projects are characterized by its high upfront investment costs. The heating grid is considered as one of the most important cost drivers of the geothermal energy project. The costs of a heating grid could be up to four times as expensive as the actual geothermal energy plant. It is therefore desired to have a good match between supply and demand from the start, and each discrepancy between the production of energy and the sold amount of energy has a negative impact on the feasibility of the project.

So, what is the actual effect of zero initial connections on the feasibility and what is the effect if 100% will connect to the heating grid initially? This allows the discussion the barrier regarding the existing infrastructure constraint.

### *8.2 NMDA Principle*

The NMDA principle means consumers will not pay more for heat than they would have in a gas-fired situation. However, in practice this means consumers will also not pay less than they would in a gas-fired situation. This means, when anyone has a high efficient manner of generating and delivering heat to consumers it could make great profits.

Nevertheless, in a situation where a heating grid is constructed parallel to a fossil fueled infrastructure, consumers will not switch to the renewable alternative by oneself when the price for renewable heat is the same as the fossil fired situation. In order to tempt consumers to switch to the alternative, it should provide enough (financial) benefits.

Thus, this sensitivity analysis examines the percentage under the gas price, at which the project is feasible. This part also examines at which price geothermal energy should be sold so a project becomes financial attractive to project developers. This could address the advice to governments at what price geothermal heat should be subsidized.

### *8.3 Heating Grid Costs*

The geothermal heating grid is an important costs driver in the projects feasibility. Experts provided realistic assumptions on the costs of a heating grid per connection. However, an important remark is the fact that this price can differ a lot per situation; the costs for constructing a heating grid in a Greenfield area are substantially lower than in a high-density existing neighborhood. Furthermore, technological developments and competition on the market might even decrease the costs of the heating grid.

Since it has such a strong influence on the projects feasibility, and since case two demands the construction of a complete heating grid, the sensitivity of decreasing and increasing heating grid costs have been tested. This analysis can be addressed to the discussion on the infrastructure constraints regarding presence of a gas network in existing neighborhoods.

#### 8.4 Discount Rate and Internal Rate of Return

The net present value is calculated by subtracting the investment from the sum of the yearly discounted cash flows. Since the research previously studied the correlation in feasibility between the different solutions, a fixed discount rate of 5 percent is applied to illustrate which geothermal energy solution financially would be more attractive. However, it is interesting to research how the discount rate influences the break-even moment of the geothermal energy solutions.

$$NPV = \sum_{t=1}^T \frac{C_t}{(1+r)^t} - C_0$$

The discount rate is considered as an important element in the feasibility of an investment, it is part from the net present value calculation. The net present value is a commonly applied method for using the time value of money to appraise long-term projects. This net present value is an indicator for the value of an investment under a certain (fixed) discount rate. However, it is also possible to indicate the yield of an investment; this is based on the internal rate of return. The IRR of an investment is the discount rate at which the net present value of costs (negative cash flows) of the investment equals the net present value of the benefits (positive cash flows) of the investment. It is commonly used to investigate whether an investment or project is desired; the higher the internal rate of return, the more desirable it is to undertake the project. From expert interviews it became clear that energy companies at least demand an IRR of 10-15%.

Although the internal rate of return indicates the annual return percentage on the project, and is considered as figure for investment decision in this research, the net present value is applied to illustrate when the project will reach its break-even point, and has been applied to compare the different geothermal energy solutions.

#### 8.5 Increasing the Size of Scale

Since a geothermal energy solution is capital intensive, it is desired to have a geothermal energy system operating for at least 4.000 hours a year. This has been incorporated in the design of the system solutions; the energy plants operate between 4.000 and 5.000 hours per year and will provide 70% of the energy demand in the area. However, what is the size of scale when the operation time is extended up to 8.000 hours, and when the power plant will provide 30% of the total heating demand in the area.

This extreme situation is designed to investigate the scale on which this energy solution could be applied, and how attractive this situation is for investors. Furthermore, this extreme condition also incorporates an examination how the percentage of initial connections influences the financial attractiveness of this business case. Moreover, the influence of selling carbon emission rights is incorporated in this sensitivity analysis, which could be a possibility for a local energy company. The recommendations chapter will discuss possible stakeholders for a local energy company. It should be considered as an initiation towards a possible organization that provides geothermal heat to its consumers.



## **PART III: RESULTS, CONCLUSIONS AND DISCUSSIONS**



## 9 RESULTS AND FINDINGS

### 9.1 Executing System Dynamics and Scenarios

This chapter will discuss the results and findings that are derived from the model output. The output of the model is the result of the experiment where three different geothermal energy solutions are applied on three cases in Eindhoven, while they are subjected to the Global Economy and Strong Europe scenario from the WLO study.

As discussed in part II, the cases have been selected because of its specific characteristics: the presence of a heating grid, type of building, and the size of the project in terms of investment and application range. However, these projects are mutually compared on financial output, but also on other aspects such as avoided carbon emission and the consumer costs for heating. The latter is considered as the most interesting for investors, governments and municipalities and consumers. If these conditions are favorable enough, the previously identified barriers will probably be withdrawn; the lack of investor awareness will probably be outweighed when it is possible to make high profits on these projects. By comparing the different geothermal energy solutions with each other, and by executing a sensitivity analysis it should be possible identify the importance of specific characteristics in the cases.

The previous discussed scenarios from the WLO scenario study (ECN, 2006) are applied to examine the effects on the financial output of these system solutions. The Global Economy scenario is the reference scenario (ECN, PBL, 2009), while the Strong Europe is considered as most contrasting to the reference situation.

The results will be discussed according to the triple bottom line: People, Planet, and Profit. The first paragraph constitutes the results concerning the Profit discussion. It will discuss the correlation between the different geothermal energy solutions concerning the financial attractiveness under two scenarios. The second paragraph is focused on the benefits for a local energy company, municipality or government since it discusses the yearly-avoided emission of carbon. Finally, the people paragraph examines consumer costs for geothermal heat resulting from the different solutions. These results will be compared to the costs for fossil fueled heat generation.

#### 9.1.1 Profit: the Feasibility of Geothermal Energy under Scenarios

##### *Introduction*

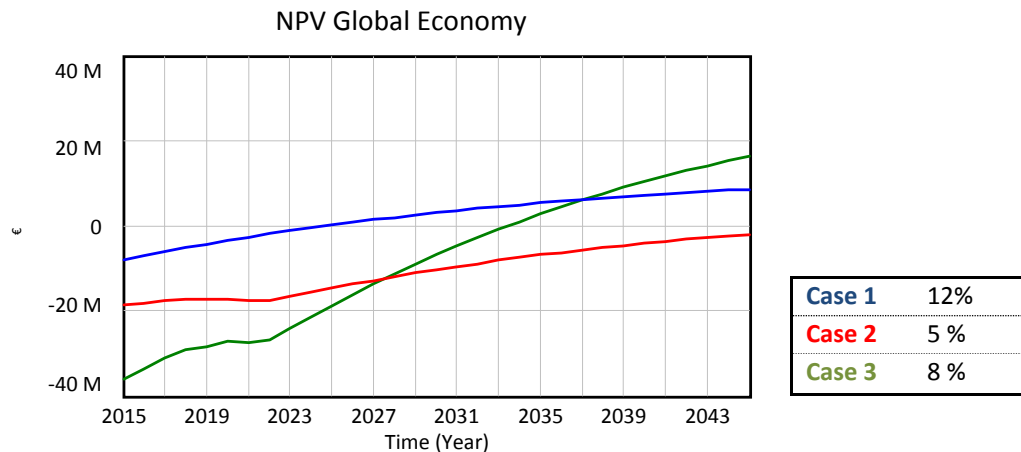
Several barriers relate to the financial outcomes of the geothermal energy applications; the contextual orientation identified amongst others the high up-front costs, and the lack of investor awareness. Considering these specific barriers, each geothermal energy solution will be reviewed on the rate of return of the project and its NPV. The NPV illustrates the correlation between the different geothermal energy solutions under a certain discount rate, while the internal rate indicates the yield of an investment. 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 to undertake the project. As became clear during the expert interviews, the internal rate of return should be high enough attract investors; however, a business case is considered to be feasible at eight percent.





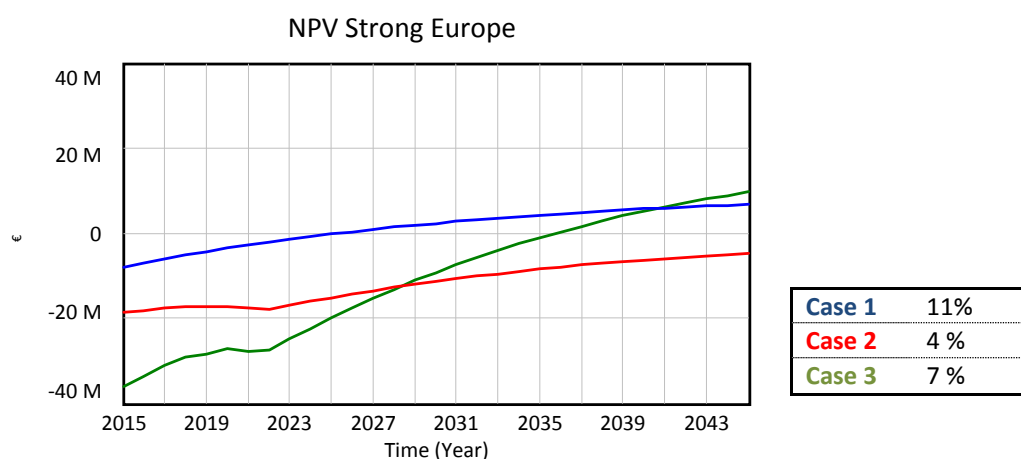
### Analysis

The three geothermal energy solutions are visualized in Figure 23 and Figure 24. The graphs illustrate the correlation between the three geothermal energy solutions in a particular situation. The NPV has been applied to test the correlation between the different geothermal energy solutions, while the internal rate of return is applied to indicate the yield on the investment. Each line color represents a particular case and a particular system solution; blue represents case one, the red line illustrates the second case while the green line is addressed to the third case.



**Figure 23:** Net Present Value and IRR under Global Economy

Considering the financial output under the GE scenario, the first case and the third case are considered as interesting. Based on the IRR, the first case is far more desired. The figure below illustrates the NPV and the IRR of the three geothermal energy solutions under the SE scenario; at a first glance it is possible to state case two is not interesting for investors, since it reaches break even at 2045 and has a internal rate of return of only 4%. This illustrates that the construction of a heating grid has a strong influence on the projects feasibility.



**Figure 24:** Net Present Value and IRR under Strong Europe

Comparing these results with the Strong Europe scenario shows how these scenarios influence the NPV and the IRR; the GE scenario has earlier break-even moment for all cases and the generated value at 2045 is remarkable 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 euro.

This suggests that under the SE scenario the first case is more desired, while under the reference scenario (GE) the third case would be more interesting when considering the annual internal rate of return. However, the reference scenario seems to be more desirable than the SE scenario.

The change in revenue under different scenarios can be addressed to the decline in energy consumption of households, and the increasing prices for fossil fuels. The energy consumption in the GE scenario declines 0,3 percent per year, while the energy consumption in the SE scenario will decrease with 1 percent per year. Furthermore, the fossil fuel prices increase differently in the applied scenarios; GE incorporates a yearly increase of 0,8 percent, while SE assumes an annual increase of 0,4 percent.

The larger the energy solution in terms of investments, the more advantageous the Global Economy scenario is. In contrast to the GE scenario, the SE scenario favors the smaller energy solutions such as case one. This means 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 sold amount of energy to consumers. However, when the discrepancy between the energy demand and generation of energy is great enough, it could be interesting to expand the heating grid and connect additional houses. This increases the energy demand, so the yearly income will be on its initial level.

### 9.1.2 Planet: Avoided Carbon Emission under Scenarios

#### Introduction

Governments are interested in renewable energy since it decreases the dependency on fossil fuels from political instable countries. Additionally, it will also decrease the annual carbon emission. The latter is important since the government agreed upon an international protocol to reduce its yearly greenhouse gas emission. This means that besides financial reasons, one of the main interests of governments in applying geothermal energy is the annual avoided carbon emission.

#### Analysis

The figures below illustrate the results on the annual avoided emission of carbon. Each graph presents the three geothermal energy solutions, under the two scenarios.

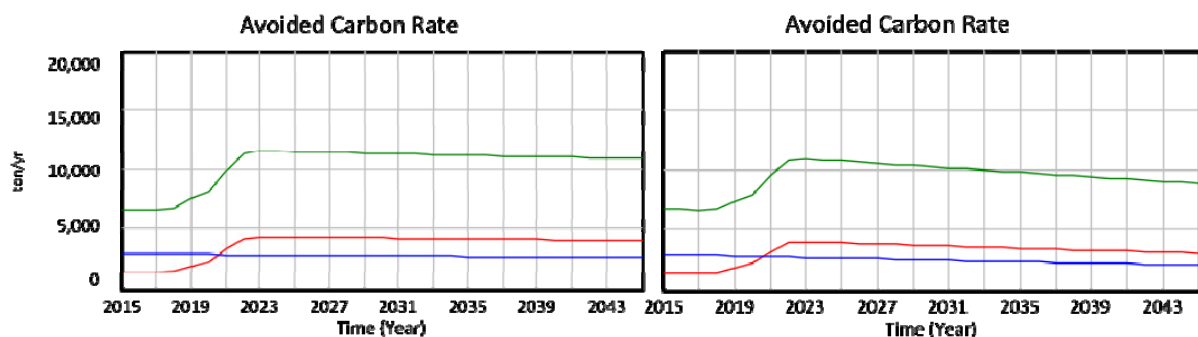


Figure 25: Avoided Carbon Emission per Year, under Global Economy and Strong Europe

The blue line distinguishes the first case, while the second and third cases represent respectively the red and the blue line. The rate of avoided carbon emission is the highest in the third situation, while the first case has avoids the least emission of greenhouse gasses.

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. This contrasts to the first case, since a heating grid is already present with all houses connected to the grid from the first year.

Furthermore, as shown in the parameter overview in the appendix, there are more houses connected to the geothermal plant in the first case than the second case; 3.463 houses in case one, in contrast to 3.023 houses in the second case. However, the annual avoided carbon emission of the second case is greater than in the first case. This is the result of the fact that the existing building stock has a higher energy demand, and a higher consumption of gas per year than the new built estates in the first case. This also addresses the fact why there could be connected more houses to a smaller geothermal plant. The graphs illustrate that a government could annually prevent the emission of 2.800 – 6.600 tons of CO<sub>2</sub>. This could also be interesting for either a local energy company, when it is possible to sell carbon emission rights, or for consumers when the emission of carbon will be charged.

The effect of scenarios is illustrated by the two graphs above; the decrease in energy consumption under the Strong Europe scenario is remarkable greater than under the Global Economy scenario.

### **9.1.3 People: Consumer Costs for Renewable Heat under Scenarios**

#### *Introduction*

One of the previously identified barriers comprises the existing infrastructure constraint in a particular area. More specifically, this addresses the constraint between the existing gas network and the new heating grid. This means the heating grid has to be constructed parallel to the existing heating grid, so consumers have the possibility to decide whether they desire a connection to this grid or desire to keep their current connection to the gas network. Consumers cannot be forced to connect to the heating grid; however, it might be assumed that one of the main criteria to choose for this renewable alternative is the cost difference between the fossil fueled generation of heat and its renewable form.

As has been discussed in part II, the cost per GJ for geothermal heat is dependent on the geothermal energy plant capacity, the number of connections to the heating grid, and the gas price (NMDA). The two graphs below illustrate the geothermal heating costs for consumers under the two scenarios.

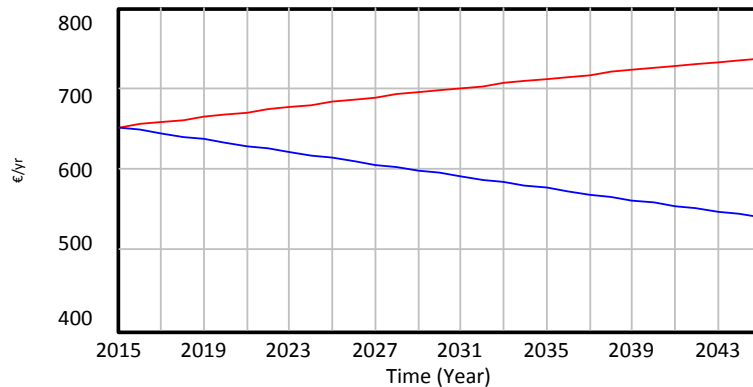
#### *Analysis*

The figures illustrate how the geothermal costs are distributed over the years for the second case. During the first year the geothermal energy plant is operating, consumers pay depending on the geothermal energy solution between € 370 –€ 650 per year for their heating. This depends on the energy consumption of the houses. The heating demand per house is considered to be higher in case 2 than in the first case. This can be addressed to the fact existing houses have a remarkably higher energy consumption.

In the base simulations it has been assumed that the NMDA determines the price a consumer has to pay for geothermal heat. Otherwise, the costs are based on the costs for producing geothermal heat and the costs related to the heating grid. This means for case

two the heating costs will be remarkably higher than in the first and third case. As mentioned in part II, the costs of the heating grid might be four times the investment costs of the geothermal energy plant. However, in case three a great part of the heating grid is already present and does not have to be financed. This leads to the result that consumer costs related to heating, in the third case are considerably lower than in the second case.

As discussed previously, the geothermal energy will be sold to the consumers at 15% under the NMDA price. This means consumers who are provided with geothermal heat will always pay 15% less than they would have in the gas-fired situation. However, the effects of changes in this percentage will be examined in the sensitivity analysis.



**Figure 26:** The Geothermal Heating Costs for Consumers under scenarios

This means consumers will benefit financially from the renewable alternative; however, how do the GE and SE scenario influence the consumer costs for geothermal heat.

The figure above illustrates the effect of these scenarios. The SE scenario incorporates a decrease in energy consumption and less increase in fossil fuels than the GE scenario. As the figure illustrates, the GE scenario will increase the heating costs while the costs for heating are decreased in the other scenario. Considering the SE scenario, in spite of the increase in gas price, the consumer cost for geothermal heat will decrease. This shows that the decline in energy consumption has a stronger influence than the increase in gas. The GE scenario illustrates that the increase in gas price has a stronger influence than the decline in consumption. This allows concluding that the SE scenario has more favorable characteristics for consumers than the GE scenario; this is opposite to the case for the investors.

## 9.2 *What if... Executing a Sensitivity Analysis*

As has been discussed previously, developed models contain approximations and assumptions. It is therefore mandatory to examine the sensitivity of the results to plausible alternative structural assumptions, including changes in the model boundary. (Sterman, 2000) This examination is executed to discuss the credibility of the results, and to test the robustness of the model and the results. Furthermore, it is interesting to study the effect of extreme changes in variables, and to provide insight in the *what if...* questions.

Two of the geothermal energy solutions are subjected to a sensitivity analysis, as it has been discussed in the last chapter of part II. By this sensitivity analysis it is possible to examine the effect of these parameters changes on the barriers as they have been identified in the contextual orientation. The conclusion on this chapter will contain the identification of the most influencing parameters in the social and financial attractiveness of the utilization of geothermal energy in the Netherlands. The analyses on the sensitivity of the results are performed on the GE scenario, since this is considered as the reference scenario.

The first paragraph will discuss the sensitivity analysis on the changes in the switching rate in the second case, but will comprise an additional examination of the effect when there is no switching rate as discussed in the product diffusion model of part II. The subsequent paragraphs constitute analyses on the effect of the NMDA price, and the effect of increasing or decreasing costs for the heating grid.

### 9.2.1 *What if... Switching Rate*

#### *Introduction*

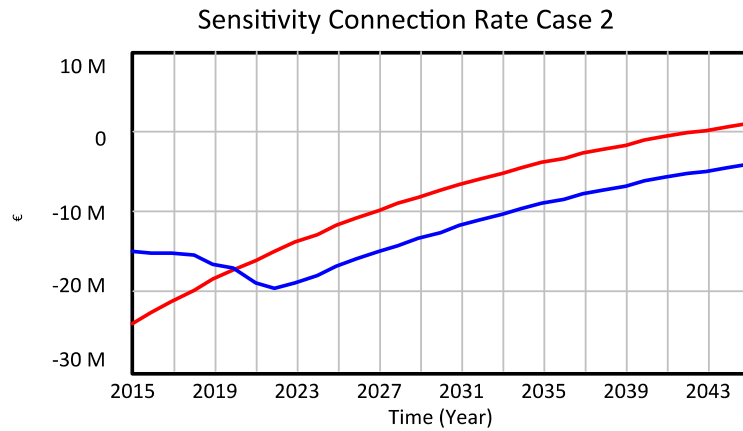
When developing a geothermal energy project, it is important that the plant has sufficient consumers and sufficient demand to match the produced energy from the geothermal plant. This means that if the power plant has overcapacity, it will result in lower annual generated revenue. Any discrepancy in the power production and the annually sold energy will negatively influence the feasibility of the project. However, considering the second case a heating grid has to be constructed parallel to the existing gas infrastructure, and the fact consumers cannot be forced to connect to the heating grid, shows it is impossible to have a guaranteed number of consumers at the first year.

The overall results included the assumption that the initial number of connections is based on the number of houses in possession of the housing corporation in the particular area. This means an initial number of switchers are guaranteed. However, this sensitivity analysis examines the how a zero number of initial numbers will affect the feasibility of the project, and how it will be influenced by a 100% of initial switchers.

#### *Analysis*

Figure 26 illustrates the effect of the connection rate on the feasibility of the project. The red line illustrates the case at which 100% initially will connect, while the blue line illustrates the situation where no house will connect initially. As the figure illustrates, all connections made at the start of the project mean a higher project investment; however, these connection costs will be paid under the other sensitivity analysis distributed over a period of eight years. It is clear in this picture that a less generated income over the first eight years has a incremental influence on the project; while the case with a 100% initial connections

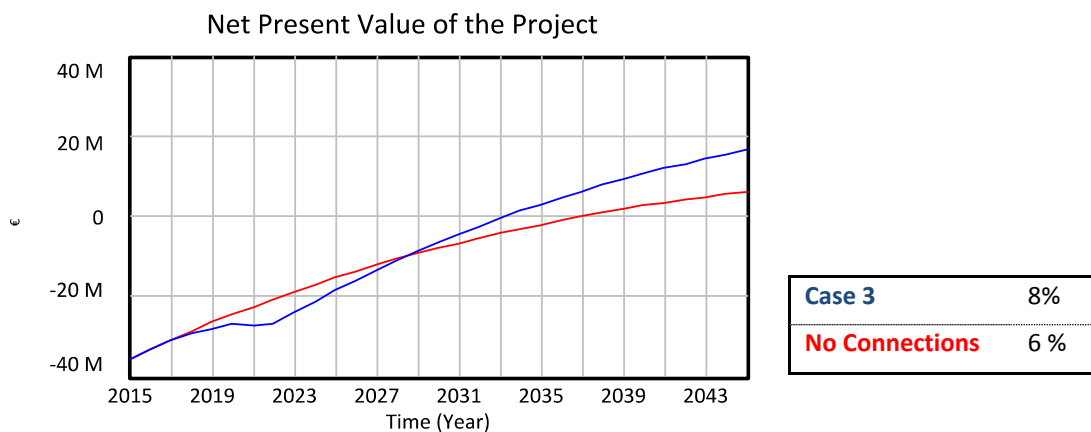
will turn break even at 2043, the other case with no initially switchers will not reach break even after 30 years. This means a certain number of initial connections are required to get at least a positive net present value over the concerned period.



**Figure 27:** Connection Rate under GE Scenario

A constraint to this result has been discussed in part II; it has been assumed that all consumers finally will switch after eight years and this period is distributed according to the product diffusion model of Rogers (1962).

Considering this remark, an additional sensitivity analysis has been performed for the third case; this could create insight whether it is required for the feasibility of the case to have additional connections when there is already base energy consumption present. This could be the case for greenhouses. This means the product diffusion and distribution over eight years is removed from the calculation. The figure below illustrates the relation between a certain number of additional connections over eight years, and the situation without additional connections.



**Figure 28:** Case 3 vs. No Additional Connections under GE Scenario

As the paragraph and the graph illustrate, the project could be feasible; however, the additional sold energy to consumers has a high strong and positive influence on the IRR and NPV of the project. The blue line illustrates the effect when more consumers will connect to the heating grid and will start using geothermal energy. It should be mentioned this project is characterized by its large scale and large investments. The missed revenue on sold energy has a strong influence on the financial attractiveness of the case.

### 9.2.1 What if... NMDA Price

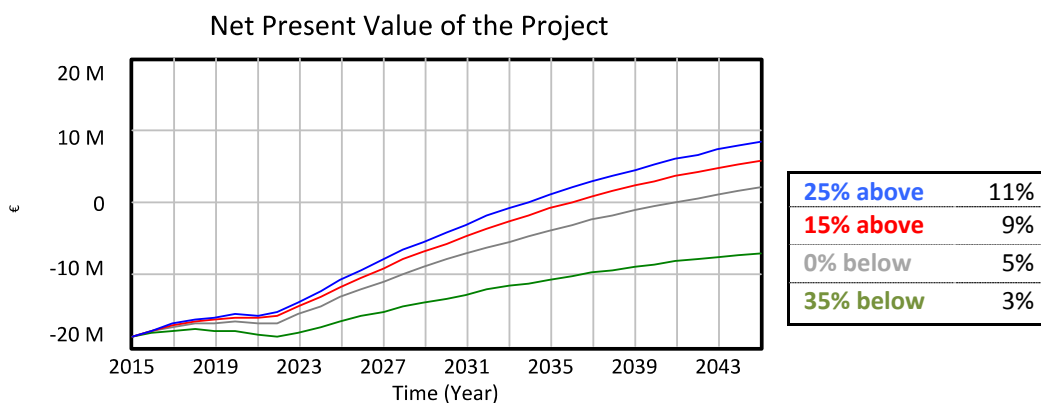
#### Introduction

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 a percentage of 15% has been applied, which means that a GigaJoule of geothermal heat will be sold for 15% below the price a consumer would pay in the gas-fired situation for a Gigajoule. However, it is interesting to study how a change in this percentage would influence 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. This analysis has been performed both on the second as on the third case. The second case has been selected because this comprises the construction of a new heating grid, and is considered as a realistic situation for the preservation of the energy supply in the built environment.

#### Analysis

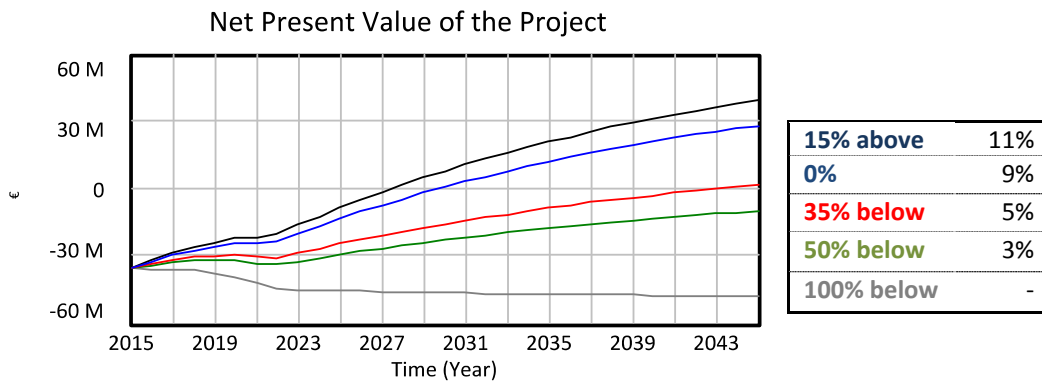
The second case is normally speaking not feasible, since the IRR is considered as too low. However, as the figure and table illustrate selling it against gas price does not improve the projects feasibility. Therefore a governmental subsidy is necessary for attracting investors, but also to present the desired benefits to consumers.



**Figure 29:** NPV and IRR of NMDA Rates for case 2

Derived from presented table, it should be possible to conclude that at least a subsidy of 15% over the current gas price is demanded; this will increase the projects IRR to 9%, which is considered as feasible. However, to attract investors for this project, higher yields on the financial investments are desired. If the government will subsidize 25%, the project will have an IRR of 11%, which means investors possibly might become interested in geothermal energy projects.

For the third case the results are remarkably different since a great part of the heating grid has already been constructed, and there is a great base energy demand from the commercial buildings. As the figure and table illustrate, for the most favorable output the geothermal heat should be sold at the same price as the price for gas.



**Figure 30:** NPV and IRR of NMDA Rates for case 3

However, to tempt consumers to choose for this renewable alternative, it should provide financial benefits. On the contrary, it is not considered as feasible to sell the produced energy 35% below the price of gas. The assumption of 15% is justified, since it has an IRR of eight percent.

This could be considered as acceptable, but is still not sufficient to withdraw the barrier concerning the lack on investor awareness. Therefore governments should subsidize energy by increasing the GJ price of geothermal heat. Considering case 3, a subsidy of 15% over the gas price per GJ shows the IRR is 11%, while case 2 demands a subsidy of 25%. This subsidy should withdraw the barrier regarding the lack of investor awareness, since investors demand at least a 10% return on the project.

### 9.2.2 What if... Heating Grid Costs

#### Introduction

The costs related to the heating grid can differ a lot per situation; 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 has been assumed that the costs are approximately 4000 Euros per house; however, this part examines the effect of increasing or decreasing costs of the heating grid on the projects feasibility.

#### Analysis

The costs of a connection to heating grid has been increased by 10%, but also decreased by 10 and 20%. As the figure illustrates, lower heating grid costs influence the rate of return of the project. The difference between the expensive situation and the cheaper situation is over 2%. However, the decreasing prices will not withdraw the barrier regarding the feasibility of the project.

Expensive (+10%)	4%
Normal	5%
Cheap (-10%)	6%
Cheaper (-20%)	6%





### 9.2.3 What if... Project Expansion

#### Introduction

An interesting discussion is to see what will happen to the NPV and its IRR of the third case when the operation time is extended from 5.000 to 8.000 hours, and the percentage of peak demand will be reduced from 70% to 30%. In this case the power plant is operating almost a full year, and will provide 30% of the peak demand. This means the remaining heat demand during the winter period should be supplied by supporting boilers located at the geothermal plant site. Furthermore, this case is focused on the existing building stock, instead of a cascade connection between newly built and existing houses; this means the difference between inflow and return temperature is remarkable lower.

#### Analysis

Applying these changes allowed the connection of 21.891 houses with an average heating demand of 49 GJ per year. This increase in scale, increase the investment costs for the heating grid. Furthermore, it has also been examined when 40 percent will switch initially or when nobody will connect initially but will switch over the coming eight years. Respectively the blue and the red line illustrate this situation.

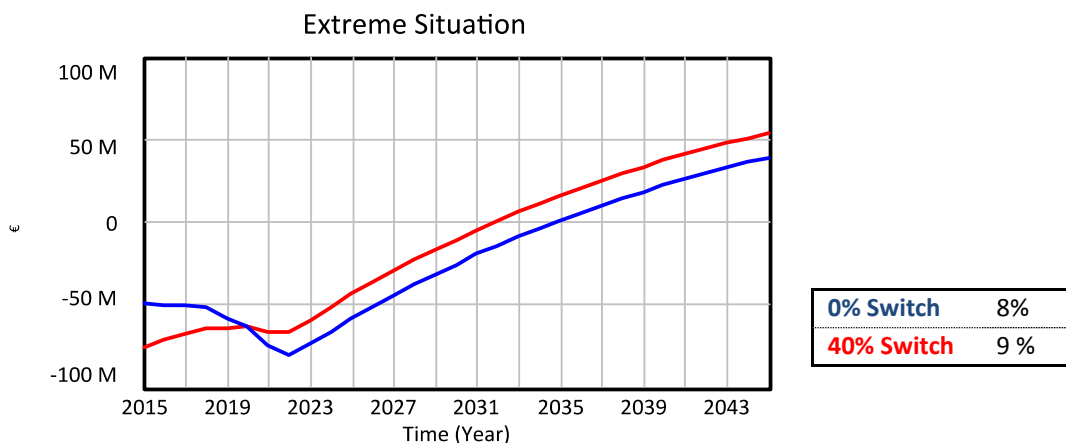


Figure 31: Extreme Condition (0-40% initial switchers)

The IRR and NPV illustrate that the greater the number of initial switchers, the higher the yield on the investment and the NPV of the project. It is interesting to see that although this enormous investment, a project still has favorable outcomes. However, the size of these investments could also require a higher IRR, since the effects of risks are far greater and have far more impact than a relatively smaller investment as in the first or second case.

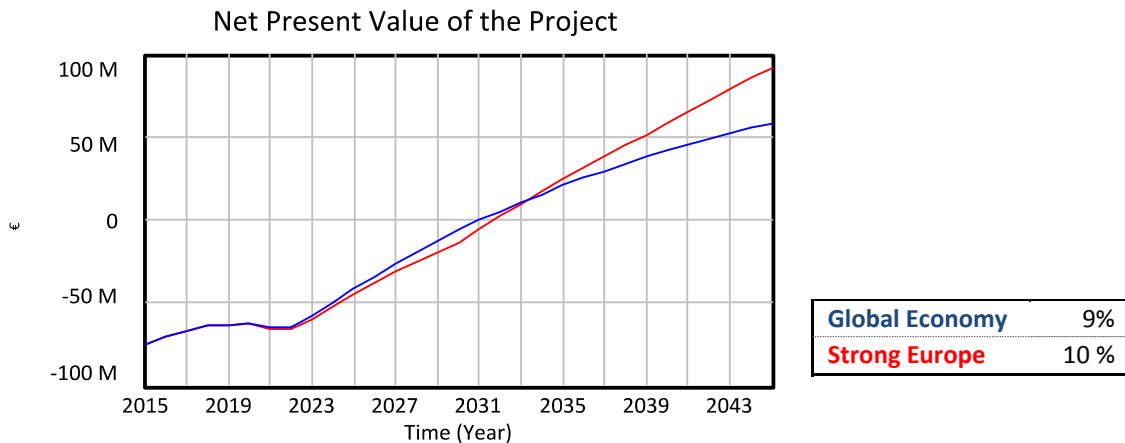
### 9.2.4 What if... Selling Carbon Rights

#### Introduction

What if an organization would be set up for this geothermal energy project and its additional heating grid? Considering that this local energy company is allowed to sell carbon rights because it avoids the emission of carbon by this renewable alternative. The effects of the scenarios illustrate which case would be most desired for an organization.

#### Analysis

The graph and the table below illustrate the results from this change in parameters.



**Figure 32:** Selling Carbon Emission Rights

The blue line represents the GE scenario, which has a lower decrease in energy consumption but a higher increase in fossil fuel prices compared to the red line. The red line represents the SE scenario, which shows that the project is more desired under these conditions. This can be addressed to the fact that the carbon emission trading mechanism will be terminated after 2020, and no additional revenue will be generated. The additional revenue in the SE scenario is expected to be € 58 per ton CO<sub>2</sub> by 2030, and € 84 per carbon right in 2040. However, the GE scenario has more favorable financial conditions until 2032. After 2032 the SE scenario is considered as more desired for a local energy company.



### 9.3 Conclusions

The system dynamics model incorporated three geothermal energy solutions that have been applied on three cases subjected to two scenarios. Subsequently, the reference scenario has been subjected to a sensitivity analysis on changing the initial number of connections, the percentage under the NMDA price, the costs for the heating grid, while additionally an extreme situation is designed. The latter comprises the study on the benefits for a local energy company; it also incorporates an additional study on the effect of selling carbon emission rights.

The Global Economy scenario is considered as the reference scenario, and has the most favorable characteristics for a large-scale energy solution. It seems that the Strong Europe scenario favors the relatively smaller investments. Furthermore, interesting is to see the effect of the initial number of connections on the projects NPV; it shows that any missed revenue at the start negatively influences the feasibility of the business case. This means it is mandatory for a project to at least have a certain number of initial connections. Moreover, the results from NMDA parameters show that the produced energy should be sold at the price for gas; however, a discount on the NMDA price is required to tempt consumers to choose for this renewable alternative. This is addressed to the discussion on the barriers; how important are they for the feasibility of these particular projects?

The extreme condition comprises the feasibility of the project when there are no initial connectors, or when 40% of the houses initially will connect. Furthermore, considering an initial number of connections at 40% the financial benefits of selling carbon rights under the SE and GE scenario, show SE is most favorable for the financial result of the project. However, a constraint is the legal framework concerning the possibility to sell carbon emission rights.

## 10 CONCLUSIONS AND DISCUSSION

This chapter will present the conclusion and discussion on the findings and results from my research. By executing a literature review, applying the system dynamics and scenarios methodology, knowledge has been gained on the potential and feasibility of geothermal energy in Eindhoven. Each part in this thesis is addressed to the specific research questions; this allowed reflecting the findings to the problem statement and the main research question.

The first paragraph will comprise the conclusion on the main research question from chapter 1. Secondly, the answers to the main research questions allow a discussion on the importance and influence of the barriers on the feasibility of a project. Answering this question should provide more insight in the problem statement and the identified barriers that block the deployment of geothermal energy in the Netherlands. Finally, the discussion will review the research targets from chapter 1.

### 10.1 Conclusion

The research is divided in three parts, and each part addresses a particular research question. Answering the sub-research questions allows a conclusion on the problem statement and the main research question as stated in chapter 1. The identified problem is the fact that investors, governments and consumers currently are unaware of the social and financial benefits that geothermal energy could offer.

#### **Research Question:**

*“What are the social, and economic benefits for governments, project developers, and consumers in geothermal energy projects? How do economic and demographic scenarios influence the business case of these renewable energy projects?”*

The previous parts identified that geothermal energy offers great potential in the preservation of the Dutch heating demand. Currently, this heating demand is mainly provided by natural gas, a fossil fuel, and only a fraction is generated from renewable sources. In spite of the great resource reserves of the Netherlands regarding natural gas, it will deplete eventually which requires governments to look ahead and present alternatives. Additionally, natural gas will emit carbon and it is subject to price fluctuations; as supplies dwindle, it is likely that prices will increase. This introduces the opportunity for utilizing geothermal energy. TNO has estimated in 2010 the technical and economic recoverable potential up to a depth of four kilometers; the soil holds a potential of around 38.000 petajoule, where one petajoule corresponds with the energy use of 25.000 existing dwellings per year.

#### Benefits for Governments

One of the greatest benefits of geothermal energy is the fact it is independent to seasonal influences, and the security of supply is high. It is therefore very suited to provide the base energy demand in a particular area. 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 supplying a large number of consumers with renewable energy. This decreases the use of fossil fuels, the emission of carbon, and increases the share of renewables in the energy supply of the Netherlands.



Due to the great production capacity it is possible to provide a substantial amount of houses with renewable heat. As part II examined the number of houses that can be provided with geothermal heat. Depending on the geothermal plant capacity and the heating demand per house, it should be possible to provide 3.023 – 21.891 houses with geothermal heat. Based on the assumptions, it should be possible to state that it reduces the fossil fuel consumption in the particular areas with 70 percent. In the extreme condition, 30% of the peak demand is provided by geothermal heat. This corresponds approximately with 6.567 houses.

Furthermore, governments and municipalities benefit from applying geothermal energy since it reduces the emission of carbon. Dependent on the case and system solution, it is possible to avoid yearly the emission of 2.800 – 13.000 tons of carbon. This amount of avoided carbon can eventually be higher since peak boilers, situated at the geothermal plant site, utilize fossil fuels. However, when it is possible to provide the peak demand by a renewable alternative, the annual avoided carbon emission could increase by 30% and even with 70% in the extreme situation.

#### Benefits for Customers

Besides the emission reduction, another great advantage is the fact that geothermal heat is insulated from changes in prices or supply. The fact geothermal heat is insensible to fluctuations in prices or supply, will lead to stable prices on the long term. However, in this research it has been assumed that the price for geothermal heat is linked to the gas price according to the NMDA principle; consumers will pay 15% less than they would in the gas-fired situation. This means consumers will benefit from the renewable alternative since the heating costs are reduced by 15% compared to the gas-fired situation.

#### Benefits for Investors

On the contrary, this restriction to sell the geothermal heat at 15% below the gas price is disadvantageous for investors. The generated revenue from geothermal heat will be lower, which negatively influences the financial attractiveness of the geothermal energy solution. A constraint is that it is legally not allowed to sell geothermal heat above the price of gas.

Besides the price, the financial benefits for investors are strongly dependent on the case characteristics. As the case study illustrated, the presence of a heating grid has an incremental positive influence on the feasibility of the project. However, it is considered not to be realistic since it probably will mean that the geothermal energy 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 will be constructed in the concerned area. This means that additional costs have to be made, which could be up to four times as expensive as the actual energy plant. While the first case, which is already in possession of a heating grid, has a remarkable higher rate of return compared to the situation at which a total heating grid has to be constructed.

Furthermore, as one of the case studies revealed it is not required for the projects feasibility to have additional connections, when there is already a substantial heating demand. This could constitute greenhouses; these have a base energy demand, and have overcapacity, which allows connecting additional consumers. However, for the projects feasibility this is not necessary, although it would increase the projects feasibility. However, an initial demand for energy is required; this is considered, as one of the challenges for investors.

The social benefits to governments will provide financial benefits to investors. The avoided emission of carbon will generate so-called carbon emission rights, which can be traded for money. So, the more carbon emission that is avoided, the greater the revenue on the project. This favors large-scale geothermal energy projects, since great revenue can be generated from selling carbon emission rights.

Although the internal rate of return is too little to attract investors, it has numerous benefits for them. Once the plant is operating, it has a stable and guaranteed production of energy and it is insensitive to seasonal influences. The offset of energy is only dependent on the demand for energy in the concerned area. Additionally, if the risks can be reduced by for instance a guarantee on the drill, a geothermal project will probably attract more investors.

Geothermal energy is a proven technology, but it takes additional steps to attract commercial parties to invest in these projects. Opportunities to attract investors are: the possibility to sell carbon emission rights, decrease the risks for drilling, subsidize geothermal heat, or increase the price of natural gas.

### The Influence of Scenarios

It is likely that events in the future will influence the attractiveness of geothermal energy either for consumers, governments or investors. The WLO scenario study allowed to select parameters that is the most contrasting to the reference scenario. The Strong Europe scenario has a strong emphasis on the environment, which focuses on reducing the energy consumption and the use of fossil fuels.

For investors, the SE scenario is not desirable since the energy consumption decreases more than the fossil prices increase. The reference scenario is more in favor of investors, since the costs increase faster than the energy consumption declines. The most important share in the revenue is generated from the sold amount of energy to its consumers, and any decline in revenue will strongly affect the projects feasibility. So, although the fact geothermal is insulated from price fluctuations and energy is produced against a fixed price, the fact it is linked through the NMDA principle allows investors to benefit from increasing fossil fuel prices. This means the marge between costs and revenue will be enlarged if fossil fuel prices increase. However, as concluded previously, any discrepancy in the produced and sold amount of energy will reduce the projects feasibility.

However, when the investor can sell the carbon emission rights the SE scenario is more in favor of the projects feasibility. SE assumed prices at which carbon rights will be sold in the future, while the reference scenario assumed that the agreement on carbon trading will be terminated after 2020.

For governments, and customers the SE scenario is desired. At first, the use of fossil fuels is reduced and renewable alternatives are promoted. This leads to a decline in carbon emission, and it will lead to a decline in heating costs for consumers. The latter can be addressed to the fact that the energy performance of houses is improved and the energy consumption will decline. As stated previously, the decline in energy consumption is higher than the prices for fossil fuels will increase the heating costs.

## *10.2 Discussion*

This paragraph will discuss the results and the previous formulated conclusions of the research regarding the problem statement and the identified barriers. Furthermore, it will comprise the evaluation according to the goals that have been set previously.

### **10.2.1 Results Discussion**

Despite the benefits geothermal energy could offer, governments, investors and consumers, are currently unaware of them. This could be addressed to the barriers that have been identified in the contextual orientation; however, the results from this research allow a discussion on the barriers to the deployment of geothermal energy.

#### *Selling Price of Geothermal Heat*

The most important barrier is considered as the lack of investor awareness, since investors are crucial to get projects initiated. Investor awareness will be increased when the yield on the project is attractive for them; the rate of return should be worth the risk for investing. Commercial parties demand at least an IRR of 10 percent, while the projects IRR vary between 5 and 12 percent; however the case with 12 percent is not very realistic because the heating grid is already present in that area.

The yield on the investment can be increased by subsidies. For the examined cases, a subsidy of 15-25% on the NMDA price is appropriate. When fossil fuel prices increase the amount of subsidy can be reduced since the price at which geothermal heat is sold, is linked through the NMDA principle. Furthermore, another possibility is that natural gas will be increased by adding tax; the literature study identified one the barriers concerns the affordable fossil fuels. This extra revenue could be used for the subsidy on renewable heat.

#### *Existing Infrastructure Constraint*

Another strong constraint in the development of geothermal energy is the presence of an existing infrastructure. This constraint could be withdrawn when the existing network is close to its replacement moment, which could create an incentive for grid operators or other investors.

However, the greatest challenge in this case is not so much the costs of constructing a heating grid parallel to the existing network, but more the uncertainty in having sufficient connections and demand for geothermal heat. When the latter is the case, geothermal energy should provide sufficient financial benefits in order to tempt consumers to switch to the renewable alternative.

As the sensitivity analysis concluded, an initial number of connections to the heating grid are required for a financial feasible project. This initial number of connections could be provided by the housing stock that housing corporations possess. The incentive for housing corporations could be the energy label improvement. This allows them to recover the costs by raising the rents. However, this is currently not possible for geothermal heat, and other forms of external heat delivery; the energy label only incorporates measures on own property. (Wolferen, 2010) It is expected that this will change in the soon future since a new directive is under construction.

### **10.2.2 Research Discussion**

The aims of this research comprised the exploration on the potential of geothermal energy in the domestic heating supply, and to study the feasibility of this large-scale energy solution while incorporating the influence of exogenous variables that arise from future events.

Through expert interviews and an extensive literature review on the domestic energy consumption and on geothermal energy, knowledge has been gained and barriers to the deployment of geothermal energy have been identified. The problems regarding renewable heating and geothermal energy have been made explicit by designing a causal loop diagram. Next, the causal loop is translated in a stock and flow model which incorporated the scenarios and the geothermal system solutions.

Modeling the business cases according to system dynamics theory allowed examining the effects of exogenous variables on the feasibility of a large-scale energy system. Current business cases do not incorporate the effects of changes in energy consumption or increasing fossil fuel prices. An important conclusion on this research showed that a scenario with a strong climate policy is not favorable for the application of a large-scale energy solution. Furthermore, as the sensitivity analysis illustrated, some parameters are of greater importance than others. The heating grid related variables would have considerably greater impact than variables that concern the thermal capacity of the system. The sensitivity analysis visualized these large-scale solutions are strongly dependent on an initial number of switchers and the price at which energy can be sold to its consumers.

The research contributes to the opportunities that geothermal energy could offer the Netherlands. Especially when considering the effect of changing environments and future events like sharp increases in fossil fuel prices. Practically this model contributes to the examination on the feasibility of geothermal energy solutions in the Netherlands. The model contains indications on the drilling costs, heating grid costs and geological conditions. The fact that experts have validated these numbers allows us to assume the results are realistic. Furthermore, the variables in the model illustrate the relationships, the influence of endogenous and exogenous variables on the financial, social and technical results. The model allows incorporating new insights that could be gained in practice.





## 11 RECOMMENDATIONS FOR FURTHER RESEARCH

The results of this research have answered the research questions as they have been set at the start of the research project. Furthermore, the targets that have been set are also achieved. However, the research boundaries limited the research in some way and new insights and developments on technical and political surfaces lead to new and interesting subject to examine. Besides my recommendations for further research, it will also contain a recommendation to the municipality for a local geothermal energy company in Eindhoven.

This research focused on the supply of heat to consumers, because the heating demand constitutes the greatest part of the energy consumption and holds great potential for its preservation. However, geothermal energy knows also other forms; it can either be applied for the generation of electricity but also for cooling. Considering the current attention regarding the energy transition, a focus on the generation of electricity could be appropriate and it would be interesting to study the possibility of generating electricity from geothermal resources.

Furthermore, the government published recently the energy report of 2011. The government assigned the energy sector as a so-called 'economic top-sector'. Due to the date of publishing it was impossible to incorporate the information from the report in my research. The government will subsidize new energy technologies, such as a guarantee on geothermal energy drills. Heat will not be subsidized separately, but will be incorporated in the current directives. As became clear during expert interviews, geothermal heat will be included in the SDE+ subsidy of 2012. However, it is currently examined how geothermal heat should be subsidized, and what the amount of subsidy should be.

Furthermore, in this research I assumed that it is possible for the local energy company to sell carbon emission rights. However, it did not investigate whether it is legally possible to sell these rights. Since carbon emission rights represent such a big amount of money, it is interesting to study the legal framework regarding carbon emission trading.



### *11.1 Recommendations for Eindhoven; an Organizational Design*

The final paragraph must be considered as a recommendation towards the municipality for the initiation of a local energy company on geothermal heat. The goal of this paragraph is to identify the most important stakeholders, their interest and the role they can fulfill for making a geothermal project a success.

The reason why a professional organization should manage the geothermal source is for example the result of recent developments in the Netherlands. Currently, there are several projects under construction in the Netherlands. At three drills oil and gas came to the surface, which could have a serious impact on the safety and the environment. This started the discussion whether greenhouse owners have the knowledge, skills and the financial means to manage the subsoil or deal with problems that could occur. Besides the technical knowledge and skills, the organization should also have the financial means to deal with possible problems.

#### **Energy Companies and Grid Operators**

At first, the energy companies and grid operators are considered to be most interesting participants; as they also participate in other geothermal projects in the Netherlands. However, due to a lack on incentive they desire a high internal rate of return on the project. However, for grid operators there could be an incentive when the technical lifespan of the gas network is almost met. This could enforce the construction of a heating grid, which will replace the current gas infrastructure.

#### **Housing Corporations**

As the sensitivity analysis concluded, it is crucial for the feasibility of the project that there are an initial number of connections. As already has been discussed, this could be provided by housing corporations since it any improvement of the energy label allows the housing corporation to raise the rent. However, a constraint is the current legislation, which does not incorporate external delivery of heat. It is expected that the new directive will be introduced in the soon future.

#### **Government and Municipality**

The municipality and government benefit from the geothermal energy project by the reduction in carbon emission. Furthermore, it contributes to the municipality's goal to become energy neutral by 2040. However, an important role could be addressed to this stakeholder to initiate a local energy company; it could guarantee investors an internal rate of return that is market-conform. This should attract investors to invest in geothermal energy. To some extend the municipality could grant a certain percentage of the company to the residents, so they also benefit from the investments made in renewable energy.

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## Appendix 1: Parameter Overview

### Parameter overview

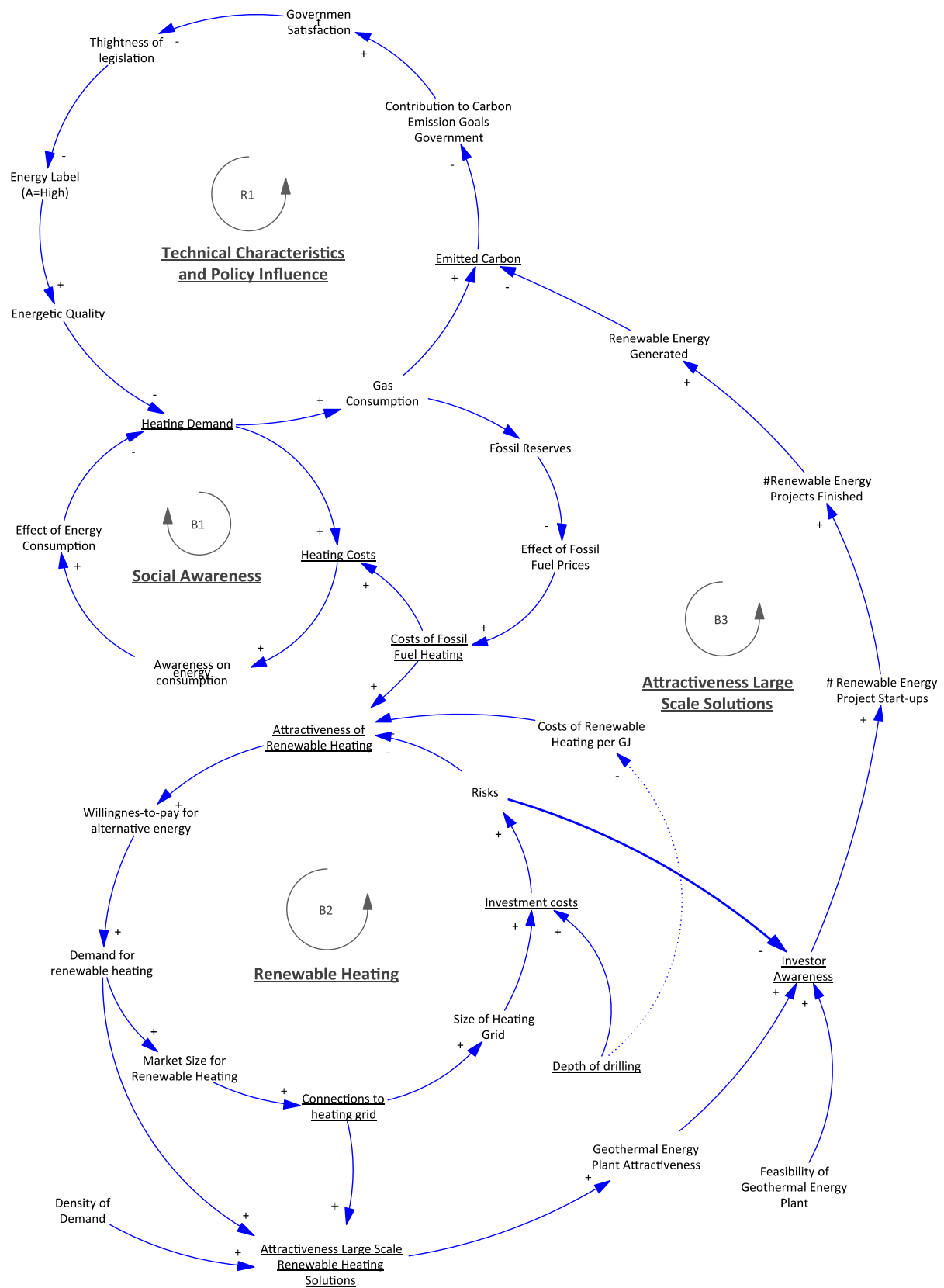
		<b>Case 1</b> (New Estates)	<b>Case 2</b> (Existing Building Stock)	<b>Case 3</b> (Cascade Connection)	<b>Case 3</b> (Extreme Condition)
Geothermal Plant Design	Drilling Depth	2,000 m	3,000 m	4,000 m	4,000 m
	Cost per m	2,000 €	2,000 €	3,500 €	3,500 €
	<b>Total Costs</b>	<b>€ 8,000,000</b>	<b>€ 12,000,000</b>	<b>€ 28,000,000</b>	<b>€ 28,000,000</b>
	Flow Rate	150 m <sup>3</sup> /hr	150 m <sup>3</sup> /hr	150 m <sup>3</sup> /hr	150 m <sup>3</sup> /hr
	Heating Capacity	4.19 m <sup>3</sup> K	4.19 m <sup>3</sup> K	4.19 m <sup>3</sup> K	4.19 m <sup>3</sup> K
	<b>Thermal Capacity</b>	<b>4.7 MWth</b>	<b>5.8 MWth</b>	<b>15.5 MWth</b>	<b>11.2 MWth</b>
Operational Design	Operation Time	4,000 hours	5,000 hours	5,000 hours	8,000 hours
	Energy Production	18,855 MWh/yr	28,806 MWh/yr	77,690 MWh/yr	89,387 MWh/yr
	GJ per year (1MWh=3,6 GJ)	67,878 GJ/yr	103,703 GJ/yr	279,683 GJ/yr	321,792 GJ/yr
	Production cost at the source	7.86 €/GJ	7.71 €/GJ	6.67 €/GJ	5.80 €/GJ
Case Characteristics	Heating System	Low Temp. 70/40 °C	High Temp. 90/70 °C	High and Low Temp. 90/40 °C	High Temp. 90/40 °C
	Average Heating Demand Household	28 GJ/yr	49 GJ/yr	28 GJ/yr	49 GJ/yr
	Commercial Heating Demand	-	-	83,501 GJ/yr	- GJ/yr
	Share of Geothermal Heating in Total Heating Demand	70 %	70 %	70 %	30 %
	Number of Houses Provided With Geothermal Heat	3,463 houses	3,023 houses	5,811 houses (28 GJ) (new estates) 3,129 houses (49 GJ) (existing stock)	- houses (28 GJ) (new estates) 21,891 houses (49 GJ) (existing stock)
	Heating Grid Connections (HousingCorporation)	Already constructed	1,255 houses	7,509 houses	- houses
	Percentage Forced to switch	100 %	41.51 %	84 % of total 54 % of existing stock	0-40 % of total
	Percentage of existing stock				
Financial Parameters	Discount rate	5 %	5 %	5 %	5 %
	Percentage under NMDA	15 %	15 %	15 %	15 %
	Percentage loaned at bank	0 %	0 %	0 %	0 %
	Depreciation Period	25 years	25 years	25 years	25 years
	Gas price	0.55 €/m <sup>3</sup>	0.55 €/m <sup>3</sup>	0.55 €/m <sup>3</sup>	0.55 €/m <sup>3</sup>
	kWh Price	0.065 €/kWh	0.065 €/kWh	0.065 €/kWh	0.065 €/kWh
	Connection Cost per House	3000 €/house	3000 €/house	3000 €/house	3000 €/house
Main Heating Grid Cost	1000 €/house	1000 €/house	1000 €/house	1000 €/house	
Fixed Parameters	Carbon Emission Gas	1.78 kg/m <sup>3</sup>	1.78 kg/m <sup>3</sup>	1.78 kg/m <sup>3</sup>	1.78 kg/m <sup>3</sup>
	Carbon Emission Electricity	0.608 kg/kWh	0.608 kg/kWh	0.608 kg/kWh	0.608 kg/kWh
	Coefficient of Performance	20	20	20	20
	Pay for Carbon Emission Costs	No	No	No	No





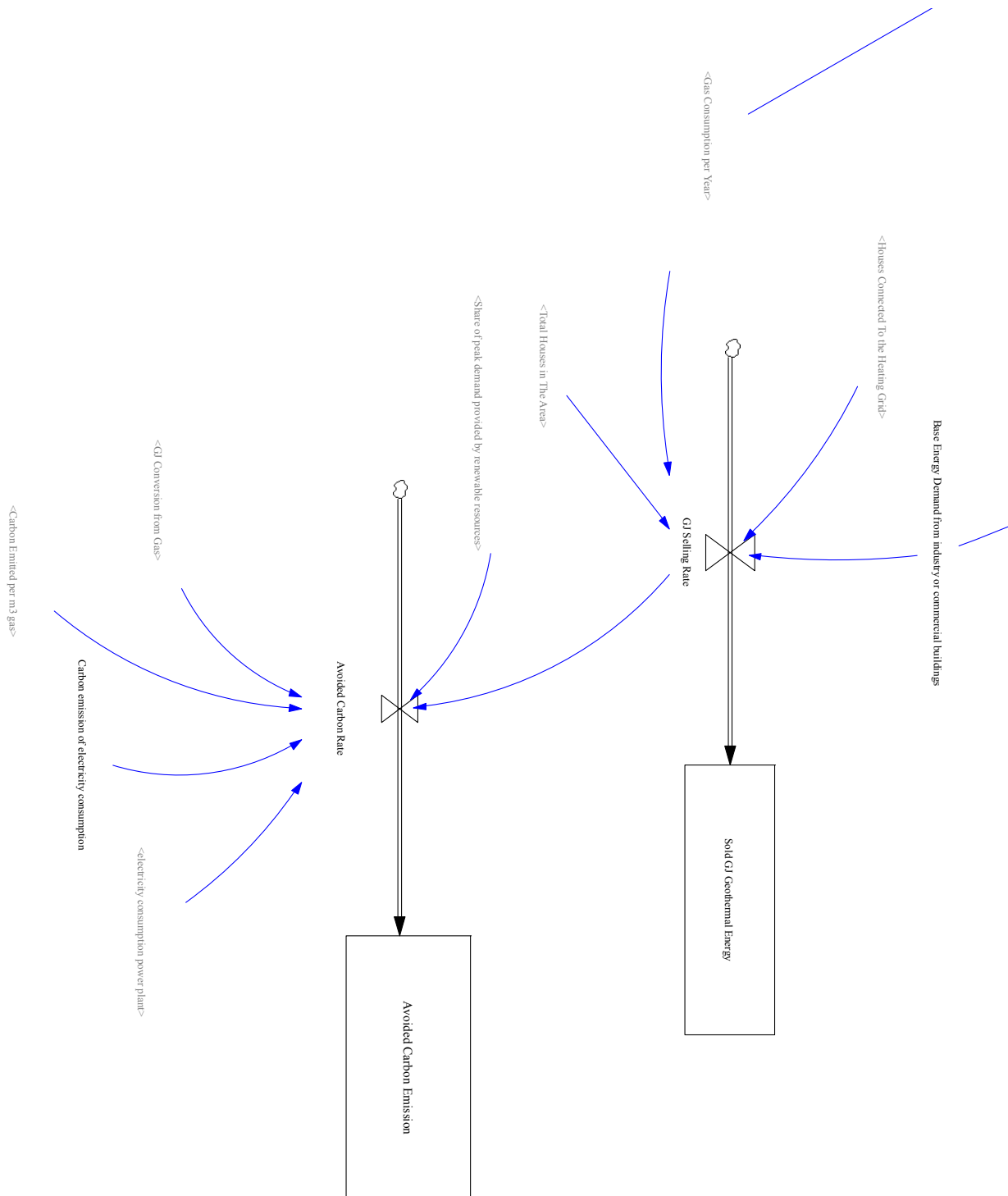
		<b>Results overview</b>		
		<b>Case 1</b>	<b>Case 2</b>	<b>Case 3</b>
Financial Results	IRR (Strong Europe)	11%	4%	7%
	IRR (Global Economy)	12%	5%	8%
	Sensitivity 0% Connection Rate (GE)	x	3%	x
	Sensitivity 100% Connection Rate (GE)	x	5%	x
	Nobody will initially switch	x	x	6%
	Sensitivity 0% under NMDA (GE)	x	6%	9%
	Sensitivity 50% under NMDA (GE)	x	x	3%
	Sensitivity 100% under NMDA (GE)	x	x	#NUM! <i>Not possible</i>
	Sensitivity 35% under NMDA (GE)	x	3%	5%
	Sensitivity 15% above NMDA (GE)	x	7%	11%
	Sensitivity 25% above NMDA (GE)	x	8%	
	Sensitivity 0% Private Equity	x	x	8% <i>Not possible</i>
	Sensitivity 25% Private Equity	x	x	6%
	Sensitivity 50% Private Equity	x	x	5%
	Sensitivity 100% Private Equity	x	x	2%
	Case Extreme Condition (0% Switch)	x	x	8%
	Case Extreme Condition (40% Switch)	x	x	9%
	Organizational Benefits when Selling Carbon Rights (GE)	x	x	9%
	Organizational Benefits when Selling Carbon Rights (Strong Europe)	x	x	10%
	Heating Grid 10% Cheaper	x	6%	x
	Heating Grid 20% Cheaper	x	6%	
	Heating Grid 10% Expensive	x	4%	x

## Appendix 2: Causal Loop Diagrams









## Appendix 4: Vensim Formulas

(001) **Adoption Rate**=IF THEN ELSE( "Sensitivity Analysis on 0% switchers in case 3"=1 , 0 , Early Adopters+Early Majority+Innovators+Laggards+Late Majority)  
Units: Dmnl

(002) Amount of Money Loaned at the Bank= Percentage loaned at Bank\*Project Investment

Units: €

(003) Annual debt payment=Interest on investment+Repayment Rate

(004) "Average Gas Consumption End-house"=

(005) Average Gas Consumption Existing Houses=

(006) Average Gas Consumption New Built Estates=

(007) Average Gas Consumption per Flat=

(008) Average Gas Consumption per House= IF THEN ELSE( Total Houses in The Area=0 , 0 , Gas Consumption per Year/Total Houses in The Area)  
Units: GJ/house

(009) Average Gas Consumption Row House=

(010) Avoided Carbon Emission= INTEG (Avoided Carbon Rate,0)  
Units: ton

(011) **Avoided Carbon Rate**=(((GJ Selling Rate\*Share of peak demand provided by renewable resources)/ GJ Conversion from Gas\*Carbon Emitted per m3 gas)-(Carbon emission of electricity consumption \*electricity consumption power plant))/1000  
Units: ton/yr

(012) Base Energy Demand from industry or commercial buildings=0  
Units: GJ/yr [0,1e+06,25]

(014) **"Carbon Emission 2030-2040"**= IF THEN ELSE("Global Economy Scenario? Y=1"=0:AND:2030<=Time:AND:Time<2040, 58, 0)  
Units: €/ton

(015) **"Carbon Emission >2040"**= IF THEN ELSE("Global Economy Scenario? Y=1"=0:AND:Time>=2040, 80, 0)

(016) **"Carbon Emission Cost in €/ton"**=IF THEN ELSE( "Pay for carbon emission?"=1 , Carbon Emission Costs till 2020:OR:"Carbon Emission Costs 2020-2030":OR:"Carbon Emission 2030-2040":OR:"Carbon Emission >2040", 0 )  
Units: €/ton

(017) **"Carbon Emission Costs 2020-2030"**= IF THEN ELSE (Time >= 2020 :AND: Time<2030,11,0)  
Units: €/ton

(018) Carbon Emission Costs till 2020= IF THEN ELSE(Time<2020, 7, 0)  
Units: €/ton

(019) **Carbon emission of electricity consumption**= 0.608  
Units: kg/kWh

(020) Carbon Emission Rate=(Carbon Emitted per m3 gas\*(Gas Consumption per Year/GJ Conversion from Gas))/1000  
Units: ton/yr

(021) Carbon Emitted per m3 gas= 1.78  
Units: kg/m3

(022) **Cash Flow**= Cash in Rate-Costs Rate

(023) Cash Flow Per Year= (Cash in Rate-Costs Rate)\*(1-BTW over profit)+Depreciation  
Units: €/yr

(024) **Cash in Rate**= (Revenue per GJ+(Feed in Tariff/kWh to GJ Conversion))\*GJ Selling Rate+Avoided Carbon Emission\*"Carbon Emission Cost in €/ton"  
Units: €/yr

(025) **Coefficient of Performance**= 20  
Units: \*\*undefined\*\*

(026) **Connection Costs**= Switching rate\*Cost per connection to heating grid  
Units: €/house

(027) Consumer Cost for Renewable Heating= INTEG (Geothermal Heat Cost Rate for Consumer per year,0)  
Units: €

(028) **Cost per connection to heating grid**=3000  
Units: €/house

(029) Costs for Energy Consumption Generation Plant= ((Geothermal Power Capacity/Coefficient of Performance)\*1000)\*Operation time plant per year\*Price per kWh  
Units: €/yr

(030) **Costs of Heating per Year for Gas**= IF THEN ELSE( Total Houses in The Area=0 , 0 , Average Gas Consumption per House \*Gas Price per GJ+Replacement costs for Gas Fired Heat generation+(Carbon Emission Rate\*"Carbon Emission Cost in €/ton")/Total Houses in The Area)  
Units: €/yr



- (031) Costs per km of Plant= IF THEN ELSE( "Depth of Drilling (km)"<=3 ,  
2000\*1000, 3500\*1000)  
Units: €/km
- (032) Costs Rate= Annual debt payment+Connection Costs+Costs for Energy  
Consumption Generation Plant+Depreciation+Maintenance Costs  
Units: €/yr
- (033) **Debt Capital Investment**= INTEG (-Repayment Rate, Amount of Money  
Loaned at the Bank)  
Units: €
- (035) Delta T= Final Temperature-Return Temperature  
Units: °C
- (036) **Depreciation**= IF THEN ELSE (Time-INITIAL TIME<=Depreciation Period  
Plant, (Investment Costs of Plant+Initial Heating Grid Cost\*Total  
Houses in The Area) /Depreciation Period Plant, 0)  
Units: €/yr
- (037) Depreciation Period Plant=25  
Units: yr [1,30,1]
- (038) **"Depth of Drilling (km)"**=  
Units: km [2,6,1]
- (039) Discount Rate=1.05  
Units: Dmnl [1,1.1,0.01]
- (040) **Early Adopters**= IF THEN ELSE(Innovators>=0.025, STEP(0.135, INITIAL  
TIME+3.2) , 0)
- (041) **Early Majority**= IF THEN ELSE( Early Adopters>=0.135, STEP(0.34,  
INITIAL TIME+4.8), 0)  
Units: Dmnl
- (042) Electricity consumption power plant=((Geothermal Power Capacity /  
Coefficient of Performance)\*1000)\*Operation time plant per year  
Units: kWh/yr
- (044) Feed in Tariff= IF THEN ELSE( "Feed in Tariff y=1"=1, 0.2, 0)  
Units: €/kWh
- (046) **Final Temperature**="Depth of Drilling (km)"\*Temperature Gradient+10
- (047) FINAL TIME = 2045  
Units: Year
- (048) Flow Rate= 150  
Units: m<sup>3</sup>/h [70,180,10]  
Debiet in m<sup>3</sup>/h
- (049) **Gas Consumption**= INTEG (Gas Consumption per Year,0)  
Units: Total Gas Consumption
- (051) Gas Consumption per Year= IF THEN ELSE("Exact Information on  
Gas Consumption Available?"=1, (Gas Consumption per House \*Yearly  
decrease in gas consumption\*"No. of Houses")\*GJ Conversion from Gas ,  
(Total Gas Consumption Detached\*Yearly decrease in gas consumption+  
Total Gas Consumption Flats\*Yearly decrease in gas consumption+"Total  
Gas Consumption Semi-Detached"\*Yearly decrease in gas consumption+Total  
Gas Consumption Row Houses\*Yearly decrease in gas consumption+Total Gas  
Consumption End Houses\*Yearly decrease in gas consumption)\*GJ  
Conversion from Gas)  
Units: GJ/yr
- (052) Gas Price per GJ= (Gas Price per m<sup>3</sup>/GJ Conversion from  
Gas)\*(1+(Yearly Gas Price Increase/100)\*(Time-INITIAL TIME))  
Units: € € /GJ
- (053) Gas Price per m<sup>3</sup>= 0.55  
Units: €/m<sup>3</sup> [0,0.7,0.1]
- (054) **Geothermal Heat Cost Rate for Consumer per year**=  
IF THEN ELSE(Pay NMDA Per GJ=0, Pay Geothermal Costs per GJ+(((Initial  
Heating Grid Cost +Cost per connection to heating grid)/Depreciation  
Period Plant)/Average Gas Consumption per House), Pay NMDA Per  
GJ\*Average Gas Consumption per House)  
Units: €/yr
- (055) **Geothermal Heat Costs Rate per GJ**= (Investment Costs of Plant/Power  
Production)/Depreciation Period Plant  
Units: €/GJ
- (056) Geothermal Heat production Costs= INTEG (Geothermal Heat Costs Rate  
per GJ,0)  
Units: €

- (057) **Geothermal Power Capacity**=(Delta T\*Flow Rate\*Thermal Capacity of Water)/3600  
Units: Mwth
- (058) GJ Conversion from Gas= 0.03517  
Units: GJ
- (059) **GJ Selling Rate**=IF THEN ELSE( Total Houses in The Area=0 , Base Energy Demand from industry or commercial buildings , (Gas Consumption per Year/Total Houses in The Area\*Houses Connected To the Heating Grid )+Base Energy Demand from industry or commercial buildings)  
Units: GJ/yr
- (061) **Heating demand area rate**=(Base Energy Demand from industry or commercial buildings+Gas Consumption per Year )\*Share of peak demand provided by renewable resources  
Units: GJ/yr
- (063) "Heating Grid Available?"=0  
Units: Dmnl [0,1,1]
- (064) **Houses Connected To the Heating Grid**= INTEG (Switching rate, Total Houses in The Area\*Percentage of houses forced to connection)  
Units: house
- (065) **Houses Conventional heating**= INTEG (-Switching rate, Percentage of houses switch voluntary\* Total Houses in The Area+Number of houses switch voluntary)  
Units: houses
- (066) **Initial Heating Grid Cost**=1000  
Units: €/house
- (067) INITIAL TIME = 2015  
Units: Year  
The initial time for the simulation.
- (068) **Innovators**= STEP( 0.025, INITIAL TIME+1.6)  
Units: Dmnl
- (069) Interest on investment=Debt Capital Investment\*Interest Rate at the bank  
Units: €/yr
- (070) Interest Rate at the bank=0.1  
Units: Percent [0,0.2,0.01]  
in decimal
- (071) **Investment costs for the main heating grid**= IF THEN ELSE(INITIAL TIME=Time, (Total Houses in The Area\*Initial Heating Grid Cost +Percentage of houses forced to connection\*"No. Existing Houses" \*Cost per connection to heating grid)-("Heating Grid Available?"\*"No. New Built Estates"\*Initial Heating Grid Cost),0)  
Units: €
- (072) **Investment Costs of Plant**=(Costs per km of Plant\*"Depth of Drilling (km)")\*2  
Units: €
- (073) **Investment Heating grid**=(Total Houses in The Area\*Initial Heating Grid Cost+Percentage of houses forced to connection\*"No. Existing Houses"\*Cost per connection to heating grid)-("Heating Grid Available?"\*"No. New Built Estates"\*Initial Heating Grid Cost)
- (074) **Investment of Plant**=IF THEN ELSE(INITIAL TIME=Time, Investment Costs of Plant, 0)
- (075) kWh to GJ Conversion=0.0036  
Units: Dmnl
- (076) **Laggards**=IF THEN ELSE(Late Majority>=0.34, STEP(0.16, INITIAL TIME+8), 0)  
Units: Dmnl
- (077) **Late Majority**= IF THEN ELSE(Early Majority>=0.34, STEP(0.34, INITIAL TIME+6.4), 0) Units: Dmnl
- (078) **Maintenance Costs**=0.015\*Investment Costs of Plant  
Units: €/yr
- (079) **Net Present Value of the Project**= INTEG (Present Value Income, -(Project Investment-Amount of Money Loaned at the Bank))  
Units: €
- (088) Operation time plant per year=
- (089) "Pay for carbon emission?"=0  
Units: Dmnl [0,1,1]





- (090) **Pay Geothermal Costs per GJ**= Average Gas Consumption per House\*(Geothermal Heat Costs Rate per GJ+((1-Share of peak demand provided by renewable resources)\*Gas Price per GJ))  
Units: €/yr
- (091) **Pay NMDA Per GJ**= IF THEN ELSE(Niet Meer Dan Anders Principe Hanteren=0, 0, Gas Price per GJ \*(1-Percentage under NMDA Price for consumers))  
Units: €/GJ
- (092) **Percentage Decline in Gas Consumption**= 0.003  
Units: Percent [0,0.5,0.01]
- (093) Percentage loaned at Bank=0  
In DECIMAL
- (094) **Percentage of houses forced to connection**= 0.4151  
Units: Dmnl [0,1,0.05]
- (095) Percentage of houses switch voluntary= 1-Percentage of houses forced to connection
- (096) **Percentage under NMDA Price for consumers**=0.15  
Percentage in decimal
- (097) **Power Production**= (Operation time plant per year\*Geothermal Power Capacity)/0.27778  
Units: GJ/yr
- (098) Present Value Income=  
Cash Flow Per Year/(Discount Rate^(Time-INITIAL TIME))  
Units: €/yr
- (099) **Price per kWh**=0.065\*(1+Yearly Gas Price Increase/100\*(Time-INITIAL TIME))  
Units: €/kWh [0,3,0.1]
- (101) Project Profit= INTEG (Cash in Rate-Costs Rate,0)  
Units: €
- (103) Repayed Capital= INTEG (Repayment Rate,0)  
Units: \*\*undefined\*\*
- (104) Repayment Period= 25  
Units: Year
- (105) Repayment Rate= IF THEN ELSE(Time-INITIAL TIME>=Repayment Period, 0, (Investment Heating grid +Investment Costs of Plant)\*Percentage loaned at Bank/Repayment Period)  
Units: €/yr
- (106) Replacement costs for Gas Fired Heat generation= 3070/15  
Units: €/yr  
milieucentraal gaskeur hr 107 ketel 3070 euro
- (107) **Residual Heat**= INTEG (Power Production-Heating demand area rate, 0)  
Units: GJ
- (108) Return Temperature=70  
Units: °C [35,90,5]
- (109) **Revenue per GJ**=IF THEN ELSE(Niet Meer Dan Anders Principe Hanteren=0, Geothermal Heat Costs Rate per GJ, Gas Price per GJ\*(1-Percentage under NMDA Price for consumers))  
Units: €/GJ
- (111)"Sensitivity Analysis on 0% switchers in case 3"=0  
0 when no analysis or 1 at the analysis
- (112) **Share of peak demand provided by renewable resources**=0.7  
Units: Percent [0,1,0.05]  
Hoeveel procent van de vraag wordt gedekt door geothermiebron in dmnl
- (113) **Sold GJ Geothermal Energy**= INTEG (GJ Selling Rate,0)  
Units: GJ
- (114) **Switching rate**=Adoption Rate\*Houses Conventional heating  
Units: houses
- (115) **Temperature Gradient**=31  
Units: °C/km
- (116) **Thermal Capacity of Water**=4.19  
Units: kJ/kg/K
- (118) **Total Carbon Emitted**= INTEG (Carbon Emission Rate,0)  
Units: CO2/ton
- (119) Total Cashflows= INTEG (Cash Flow Per Year,0)  
Units: €

- (120) **Total Costs Heating Grid**= INTEG (Connection Costs, Investment costs for the main heating grid)  
Units: €
- (121) **Total Costs Project**= INTEG ( Costs Rate, 0)  
Units: €
- (122) **Total Gas Consumption Detached**= Average Gas Consumption New Built Estates\*"No. New Built Estates"  
Units: m3/yr
- (123) **Total Gas Consumption End Houses**="Average Gas Consumption End-house"\*"No. of End Houses"  
Units: m3/yr
- (124) **Total Gas Consumption Flats**= Average Gas Consumption per Flat\*"No. Flats"  
Units: m3/yr
- (125) **Total Gas Consumption Row Houses**= Average Gas Consumption Row House\*"No. Row Houses"  
Units: m3/yr
- (126) **"Total Gas Consumption Semi-Detached"**=Average Gas Consumption Existing Houses\*"No. Existing Houses"  
Units: m3/yr
- (127) **Total Gas Costs Per Consumer**= INTEG (Costs of Heating per Year for Gas, 0)  
Units: €
- (128) **Total Houses in The Area**=IF THEN ELSE("Exact Information on Gas Consumption Available?"=1, "No. of Houses", "No. New Built Estates"+"No. Flats"+"No. of End Houses"+"No. Row Houses"+"No. Existing Houses")  
Units: houses
- (129) **Yearly decrease in gas consumption**= IF THEN ELSE("Decline of Gas Consumption?"=1, (1-Percentage Decline in Gas Consumption)^(Time-INITIAL TIME), 1)  
Units: Dmnl
- (130) **Yearly Gas Price Increase**=0.8  
Units: Percent



## **Appendix 5: Summary**

### **THE VALUE OF GEOTHERMAL ENERGY UNDER SCENARIOS Exploring the potential of geothermal energy in Eindhoven**

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**ABSTRACT**

*Heating related energy consumption constitutes the greatest part of the total energy consumption in the Netherlands. However, the heating demand is mainly met by natural gas and only a small part is provided from renewable resources. Besides the emission of*

*greenhouse gasses, this fossil fuel will also deplete eventually. The uncertainty on in the energy supply calls for the development of systems that preferably are based on domestic resources. This introduces the opportunity for utilizing indigenous geothermal energy as a cleaner, nearly emissions free renewable source of heat. However, large-scale deployment still lacks behind compared to other countries. This research presents the results on the study of the exploration of the potential and the feasibility of these systems in Eindhoven, under certain scenarios. Applying system dynamics allowed the discussion on plausible results, and required steps for withdrawing the barriers to the deployment of geothermal energy in the Netherlands.*

**Keywords:** Geothermal Energy, Renewable Heat, Heating Grid, System Dynamics, Scenario Planning, Heating Demand

## INTRODUCTION

The Netherlands consumes approximately 3.260 PJ of energy per year; 40% of this energy consumption can be addressed to heating. The energy consumption of households that can be related to heating constitutes the greatest part of the total consumption. Currently, the energy demand for heating in households is mainly provided by a fossil fuel, natural gas. Only a small part of the generated heat comes from renewable resources. This shows a focus on providing a sustainable alternative to consumers is appropriate.

This introduces an enormous opportunity exists for directly utilizing indigenous geothermal energy as a cleaner, nearly emissions-free renewable source of heat whose production characteristics are ideal for local district heating applications. (Thorsteinsson & Tester, 2010) Approximately 40% of the Dutch energy demand is consumed in the form of 'low-temperature' power for heating homes and offices (at the municipal level) and industrial greenhouses. As TNO (2007) explains this demand for low temperature power can easily be supplied by geothermal energy in its various forms.

TNO estimated in 2010 the technical and economic recoverable potential up to a depth of four kilometers; the soil holds a potential of around 38.000 Petajoule, where one Petajoule corresponds with the energy use of 25.000 existing dwellings per year. Geothermal energy is insulated from changes in fuel price or supply. This feature leads to long-term, stable space heating rates for GDHS which fossil fuel-fired facilities cannot guarantee. (Thorsteinsson & Tester, 2010) However the potential of geothermal energy in the Netherlands, it still lacks behind compared to countries such as Iceland and Germany. Especially Iceland is considered as leading country on geothermal energy; currently, about 89% of the country's space heating needs is provided by geothermal energy.

Despite the potential of geothermal energy in the Netherlands, there are barriers to the deployment. Seyboth et al., (2008) identified comparatively high up-front cost of installation, a lack of investor awareness, existing infrastructure constraints, and landlord/tenant incentive splits. Moreover, relatively affordable gas and oil supplies and separate, well-developed electricity and fuel delivery infrastructures are also considered as barriers. (Thorsteinsson & Tester, 2010) Additionally, TNO (2007) identified the wealth of the Dutch gas resources, the tariff structure imposed on gas for agricultural application and the lack of a subsidiary instrument for the use of green heat as barrier for deploying geothermal energy.

However, there has been a resurgence of interest in the use of deep geothermal heat in the Netherlands. The sharp rise in gas and oil prices is forcing private enterprises to consider the use of alternative energy sources. (TNO, 2007) 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. In addition, Lund (2002) states that given the right environment, and as gas and oil supplies dwindle, the use of geothermal energy will provide a competitive, viable and economic alternative source of renewable energy.

Investors, consumers, and governments are currently unaware of the social and financial benefits of geothermal energy in the built environment. To introduce geothermal energy for heating as a substitute of natural gas successfully, the financial benefits of geothermal energy compared to natural gas should be made explicit. Several studies assumed that the feasibility and attractiveness of geothermal energy increases when fossil fuel prices increase; however, the exact effect of scenarios has not been calculated yet. Furthermore, the importance of the identified barriers demand further examination. Applying a dynamic model allows a discussion on the potential and feasibility of geothermal energy in Eindhoven under scenarios.

## **METHODOLOGY**

As stated previously, future events can have an incremental effect on the feasibility of geothermal energy projects. However, the exact effect of these future events requires dynamic modeling tested upon a case study in Eindhoven.

### **Scenarios**

The Welfare, Prosperity, and Quality of the Living Environment (WLO) scenario study from ECN et al. (2006) assesses the long-term effects of current policy, given the international economic and demographic context of the Netherlands. One of its scenario studies focused on the energy consumption in the Netherlands, both on energy demand and the supply of energy in the Netherlands. The qualitative and quantitative results can be applied as reference, for instance, policy-makers involved in spatial planning, housing, natural resources, infrastructure, and the environment. (ECN, 2006)

The reference scenario is considered as the Global Economy scenario; due to the fact it is widely applied and reliable as reference scenario. The other scenario is Strong Europe, since it contrasts the most to the reference scenario in energy consumption and fossil fuel prices. It is interesting to study the effect of the international climate agreement and the policy on renewable energy in the Strong Europe scenario. The WLO scenarios allowed deriving parameters concerning gas price increase, decline in energy consumption, and costs for carbon emission. By applying parameters from the WLO scenarios, the effect of increasing fossil fuel prices on the economic attractiveness of geothermal energy has been examined. The geothermal energy solutions that will be subjected to the scenarios are introduced hereafter.

### **System Dynamics**

The dynamic modeling comprises, the development of technical parameters, the development of scenario parameters and the development of a financial calculation that is subject to changes in the technical and scenario parameters. System Dynamics is suited for

this, since it deals with problems that develop over time. The researcher represents the problem situation in a model comprising the variables of interest. The system state at any time is captured by a set of state variables. A fundamental idea in System Dynamics modelling is the “principle of accumulation.” This principle says that all dynamic behaviour in the world occurs when flows are accumulated (integrated) in stocks. (Tao, 2010) System Dynamics is applied in this research to support the decision making process, by forecasting the costs and benefits for concerned parties of a geothermal energy solution under certain scenarios.

Applying the system dynamics methodology incorporates the development of a causal loop diagram and a stock and flow model. The causal loop diagram is a visual representation of the feedback loops in the system; it is used to describe basic causal relationships and how these relationships might behave over time, and it is used to create insight how system behavior is generated. One of the greatest advantages of a causal loop diagram is the fact that it is very useful as a communication tool to discuss important feedback processes which involve a problem and hypothesis. Based on the causal loop diagram a stock and flow model will be developed. The stocks are characterized by its flows; it accumulates their inflows less their outflow. It characterizes the state of the system and generates the information upon which decisions and actions are based.

### **Case Study**

The research has been focused on three cases in Eindhoven: Meerhoven, Woensel-Zuid and Eindhoven Airport. The cases have been selected based on the criteria, the composition of the neighborhood (new, existing or commercial buildings), and the presence of a heating grid. The reason why a heating grid is incorporated in this research is due its costs and therefore its influence on the projects feasibility. Furthermore the composition of the neighborhood is a strong determining factor in the number of connections to the heating grid. Based on parameters resulting from the geothermal system solutions design, it is applied on a new built area, because a heating grid is already present in this area. The other case study comprised an examination of geothermal energy on the existing building stock, since this constitutes the greatest challenge in the preservation of the energy consumption and since it is considered as the most realistic one since it addresses the future challenge in the preservation of the energy consumption, and the barrier regarding the existing infrastructure constraint.

### **MODEL DEVELOPMENT**

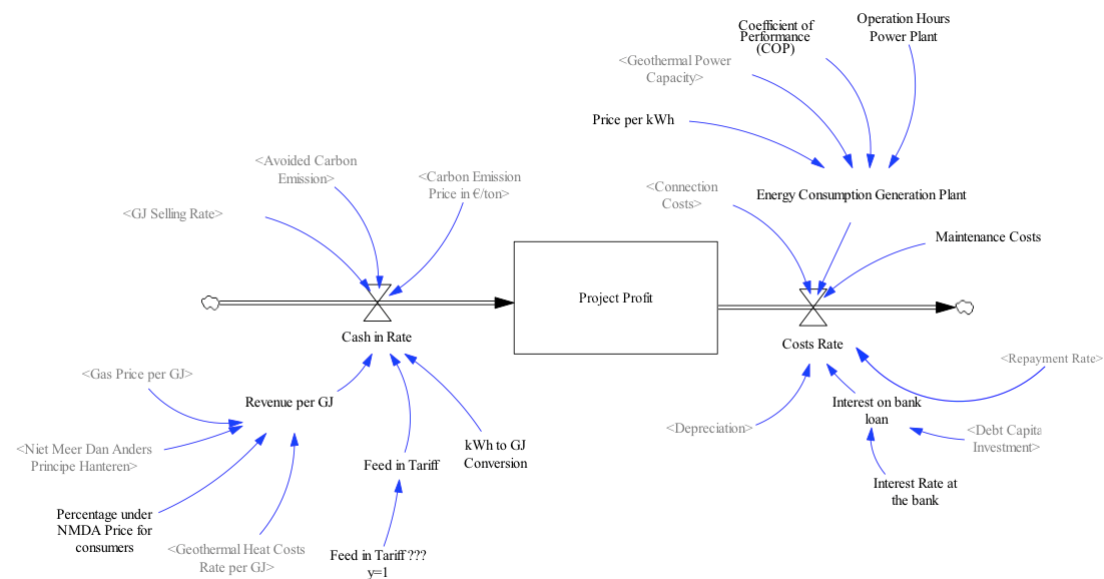
A causal loop illustrates the reaction of consumers on increasing fossil fuel prices; they will cut their energy consumption. However, the increase in prices will increase the attractiveness of renewable heat for consumers. The greater the attractiveness for consumers, and the more consumers demanding renewable heat the greater the attractiveness for investors to invest in geothermal heat. However, the technical and financial risks for investors limit the attractiveness of the renewable alternative. In order to tempt and attract consumers, the renewable alternative should provide sufficient benefits.

Based on the causal loop diagram, a stock and flow model is designed. This developed stock and flow model comprises four views that are both technically and financially related. The stock and flow diagram can be distinguished in three sub-models; the calculation of the

heating demand and the carbon emission for a particular area, the geothermal energy solution and the heating grid, and the calculation of the net present value of the project.

### Financial Sub Model

The financial model comprises the calculation of the annual cash flow, and the projects Net Present Value. The cash flow calculation incorporates the annual revenue generated from selling geothermal energy, and the annual costs rate based on the additional connections, the maintenance costs and the energy consumption of the geothermal energy plant. The shadow variables illustrate the relation to the other sub models; the annual sold energy and the additional made connections are related to the energy demand in the particular area and the switching rate of consumers to the renewable alternative.



**Figure 1: Cash Flow Calculation**

The generated cash flow will be discounted with 5% annually by a rate. The stock accumulates the annual discounted cash flow and will present the Net Present Value of the project.

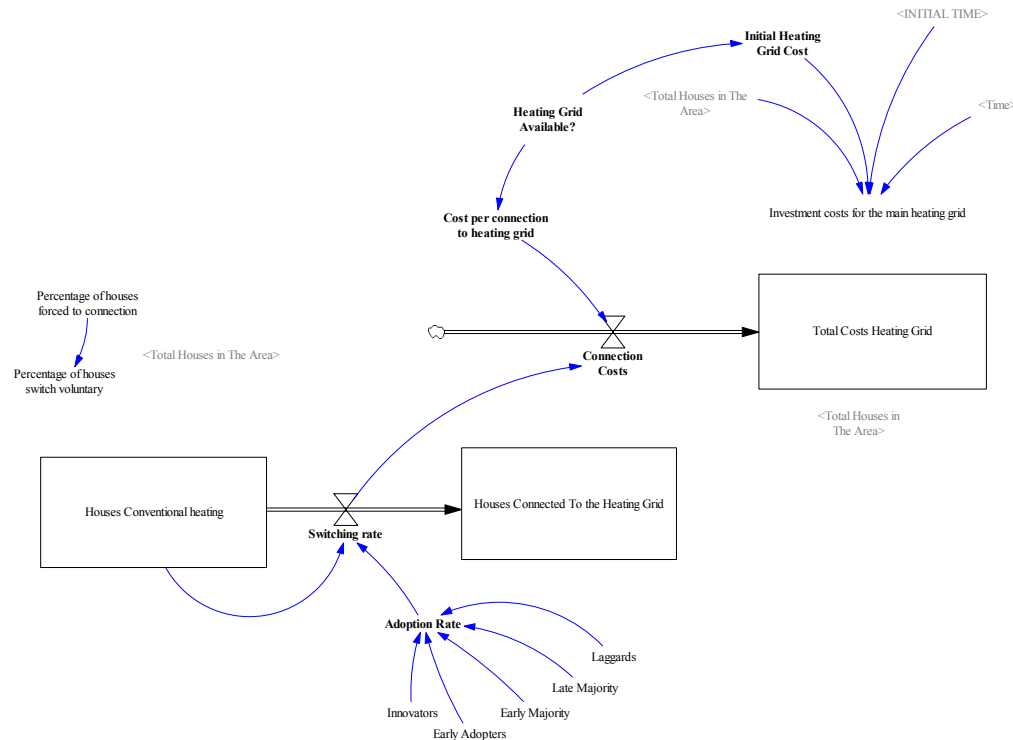
### Geothermal Heating Sub Model

This sub-model constitutes the calculation of the power production of the energy plant, the geothermal heat costs for consumers, the switching rate, and the annual rate of sold Gigajoules to customers. The rate of sold energy to consumers is based on number of connections to the heating grid, and the related heating demand. The costs for consumers can be addressed to the gas price, since each produced gigajoule will be sold to consumers at 15% below NMDA (price of gas).

However, the generated income is dependent of the number of connections to the heating grid. The formula illustrates the relationship of the number of connections with the generated income.

$$\begin{aligned}
 &GJ \text{ Selling Rate} \\
 &= \text{Base Energy Demand from industry or commercial buildings} \\
 &+ \left( \frac{\text{Gas Consumption per Year}}{\text{Total Houses in the Area}} \right) * \text{Houses Connected to the Heating Grid}
 \end{aligned}$$

It has been assumed that all consumers will switch according to the product diffusion model of Rogers (1962), distributed over eight years. This means each specific group will switch after 1,6 years. The effect of changes in the number of switchers per year, or the number of initial connections will allow a discussion on the importance of the identified barriers and the importance of an initial heating demand on the projects feasibility.



**Figure 2: Calculation of the connections to the heating grid**

**FINDINGS AND RESULTS**

By incorporating the derived parameters in the designed system dynamic models, it is possible to present the most striking results. Additionally a sensitivity analysis is performed, since the developed models contain approximations and assumptions. It is therefore mandatory to examine the sensitivity of the results to plausible alternative structural assumptions, including changes in the model boundary. (Sterman, 2000) This examination will incorporate the analysis on the price at which geothermal energy should be sold since this is considered as a study on the subsidy of geothermal heat. It has been executed to discuss the credibility of the results, and to test the robustness of the model and the results.

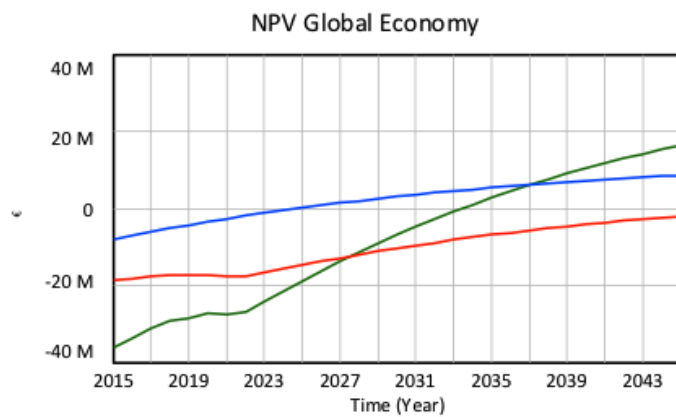
**Profit: Financial results**

The graph below illustrates the correlation between the three geothermal energy solutions under the reference scenario. The project with the lowest investment comprises the project at which a heating grid already is present, while the project with the highest investment demanded partly the construction of a new heating grid. The middle line represents the case at which a total heating grid has to be constructed.

Based on the internal rate of return, the project without the investment in the heating grid is far more desired. However, the case, which is considered as most realistic, is not feasible



since the return is considered as too low and because it will not reach the break-even moment.



**Figure 3: The NPV of three geothermal energy solution**

The results from this scenario compared to the Strong Europe scenario shows how these scenarios influence the NPV and the IRR; the GE scenario has earlier break-even moment for all cases and the generated value at 2045 is remarkable 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 euro. This suggest that under the SE scenario the first case is more desired, while under the reference scenario (GE) the third case would be more interesting when considering the annual internal rate of return. However, the reference scenario seems to be more desirable than the SE scenario.

The change in revenue under different scenarios can be addressed to the decline in energy consumption of households, and the increasing prices for fossil fuels. The larger the energy solution in terms of investments, the more advantageous the Global Economy scenario is. In contrast to the GE scenario, the SE scenario favors the smaller energy solutions such as case one. This means 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 sold amount of energy to consumers. However, when the discrepancy between the energy demand and generation of energy is great enough, it could be interesting to expand the heating grid and connect additional houses. This increases the energy demand, so the yearly income will be on its initial level.

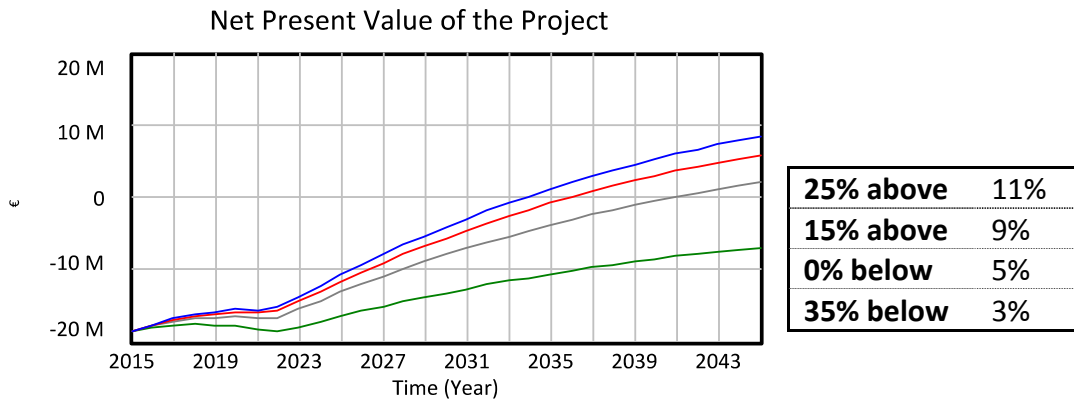
### **Planet: Avoided Carbon**

An interesting focus point for governments is the annual avoided carbon emission. The results show the greater the capacity of the energy plant, and the greater amount of renewable energy that could offset to its consumers the greater the amount of avoided carbon will be. The graphs illustrate that a government could annually prevent the emission of 2.800 – 6.600 tons of carbon.

The fact that two 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. This contrasts to the first case, since a heating grid is already present with all houses connected to the grid from the first year.

### Sensitivity of the selling price

The most striking results from the sensitivity analysis are discussed; the price at which geothermal energy. It is interesting to study how this would influence 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.



**Figure 4: Effect of selling prices**

Derived from presented table, it should be possible to conclude that at least a subsidy of 15% over the current gas price is demanded; this will increase the projects IRR to 9%, which is considered as feasible. However, to attract investors for this project, higher yields on the financial investments are desired. If the government will subsidize 25%, the project will have an IRR of 11%, which means investors possibly might become interested in geothermal energy projects. Since this represents the most realistic case, it might be assumed that the government has to subsidize geothermal heat by at least 15 percent.

### CONCLUSION

By executing a literature review, applying the system dynamics and scenarios methodology, knowledge has been gained on the potential and feasibility of geothermal energy in Eindhoven. The goal of the research was to present the benefits to governments, investors and consumers.

### Governments

One of the greatest benefits of geothermal energy is the fact it is independent to seasonal influences, and the security of supply is high. It is therefore very suited to provide the base energy demand in a particular area. It can provide a stable energy supply to consumers all year long, depending on the operational hours of the energy system. Depending on the geothermal plant capacity and the heating demand per house, it should be possible to provide 3.023 – 21.891 houses with geothermal heat. Furthermore, governments and municipalities benefit from applying geothermal energy since it reduces the emission of carbon. Dependent on the case and system solution, it is possible to avoid yearly the emission of 2.800 – 13.000 tons of carbon. This amount of avoided carbon can eventually be higher since peak boilers utilize fossil fuels. When it is possible to provide the peak demand by a renewable alternative, the annual avoided carbon emission increases by 30% -70%.



### **Investors**

Besides the price at which geothermal energy is sold, the financial benefits for investors are strongly dependent on the case characteristics. As the case study illustrated, the presence of a heating grid has an incremental positive influence on the feasibility of the project. However, it is considered not to be realistic since it probably will mean that the geothermal energy plant has to compete with the current energy plant. It is more realistic that a heating grid should be constructed in the concerned area, which could be up to four times as expensive as the actual energy plant.

The social benefit of avoided emission of carbon will generate so-called carbon emission rights, which can be traded for money. So, the more carbon emission that is avoided, the greater the revenue on the project.

Although the internal rate of return is too little to attract investors, it has numerous benefits for them. Once the plant is operating, it has a stable and guaranteed production of energy and it is insensitive to seasonal influences. The offset of energy is only dependent on the demand for energy in the concerned area. Additionally, if the risks can be reduced by for instance a guarantee on the drill, a geothermal project will probably attract more investors.

Geothermal energy is a proven technology, but it takes additional steps to attract commercial parties to invest in these projects. Opportunities to attract investors are: the possibility to sell carbon emission rights, decrease the risks for drilling, subsidize geothermal heat, or increase the price of natural gas.

### **Consumers**

One of the greatest advantages is the fact that geothermal heat is insulated from changes in prices or supply. The fact geothermal heat is insensitive to fluctuations in prices or supply, will lead to stable prices on the long term. However, it has been assumed that the price for geothermal heat is linked to the gas price according to the NMDA principle; consumers will pay 15% less than they would in the gas-fired situation. This means consumers will benefit from the renewable alternative since the heating costs are reduced by 15% compared to the gas-fired situation.

## **DISCUSSION**

Despite the benefits geothermal energy could offer, governments, investors and consumers, are currently unaware of them. This could be addressed to the barriers that have been identified in the contextual orientation; however, the results from this research allow a discussion on the barriers to the deployment of geothermal energy.

### **Selling Price of Geothermal Heat**

The most important barrier is considered as the lack of investor awareness; this will be increased when the yield on the project is attractive for them. The yield on the investment can be increased by subsidies like the SDE. For the examined cases, a subsidy of 15-25% on the NMDA price is appropriate. Furthermore, government could add up tax to the natural gas so the commercial attractiveness increases.

### **Existing Infrastructure Constraint**

Another strong constraint in the development of geothermal energy is the presence of an existing infrastructure. This constraint could be withdrawn when the existing network is close to its replacement moment, which could create an incentive for grid operators or other investors. However, the greatest challenge in this case is not so much the costs of constructing a heating grid parallel to the existing network, but more the uncertainty in having sufficient connections and demand for geothermal heat. When the latter is the case, geothermal energy should provide sufficient financial benefits in order to tempt consumers to switch to the renewable alternative.

As the sensitivity analysis concluded, an initial number of connections to the heating grid are required for a financial feasible project. This initial number of connections could be provided by the housing stock that housing corporations possess. The incentive for housing corporations could be the energy label improvement. This allows them to recover the costs by raising the rents. However, this is currently not possible for geothermal heat, and other forms of external heat delivery; the energy label only incorporates measures on own property. (Wolferen, 2010) It is expected that this will change in the soon future since a new directive is under construction.

### RECOMMENDATIONS FOR FURTHER RESEARCH

This research focused on the supply of heat to consumers, because the heating demand constitutes the greatest part of the energy consumption and holds great potential for its preservation. However, geothermal energy knows also other forms; it can either be applied for the generation of electricity but also for cooling. Considering the current attention regarding the energy transition, a focus on the generation of electricity could be appropriate and it would be interesting to study the possibility of generating electricity from geothermal resources.

Furthermore, due to recent developments further research on a professional organization that manages the geothermal well is appropriate. Currently, there are several projects under construction in the Netherlands. At three drills oil and gas came to the surface, which could have a serious impact on the safety and the environment. This started the discussion whether greenhouse owners have the knowledge, skills and the financial means to manage the subsoil or deal with problems that could occur. Besides the technical knowledge and skills, the organization should also have the financial means to deal with possible problems.

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This research is performed within the context of the KENWIB graduation program, and is the final part of the MSc. Construction Management and Urban Development. Arcadis gave me the opportunity to perform a research according to my interest. I hope this research can contribute the challenge towards preserving the energy consumption in the Netherlands.

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