# Exploring energy neutral development for Brainport Eindhoven

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# EXPLORING ENERGY NEUTRAL DEVELOPMENT FOR BRAINPORT EINDHOVEN

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**Introduction**

KENWIB (Kenniskluster Energie Neutraal Wonen in Brainport) is based upon cooperation between governmental organizations, university and entrepreneurial companies. The partners for this project are: the Municipality of Eindhoven, the Province of Noord Brabant, the Promotie Installatie Techniek and the University of Technology of Eindhoven. The aim of this project was to stimulate and realize energy neutral urban districts by joint interdisciplinary development and dissemination of knowledge. Therefore during a period of two years several groups of master graduation students have been directed at assignments for investigations and research on combined technical, organizational and socio-technical subjects. Also students have been stimulated to start up new entrepreneurial activities which could contribute to implement technology for energy neutral urban districts developments. The cooperation is established and financially supported for a period of two years. The project started in September 2009 and ended in February 2012. In the period from start until August 2010 already thirteen Master of Science graduation students elaborated their final studies within the context of this KENWIB project. The summaries of their reports have been published in the 'Part 1' Summary Book. Within the second period the KENWIB project an additional group of more than 20 students accomplished their graduation projects on relevant subjects. During this period also several special activities, such as workshops and an international study trip have been organized.

Besides the societal relevant results in terms of well trained and educated graduates and upgrading of knowledge of companies and institutions also an interesting collection of scientific elaborations was possible. Based upon the initial studies in the graduation reports a number of publications in scientific journals and papers for conferences were produced. The scientific output of the KENWIB project over a period from 2010 – 2012 has been collected and presented in this report.

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# Peak loads and network investments in sustainable energy transitions

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## Abstract

Current energy distribution networks are often not equipped for facilitating expected sustainable transitions. Major concerns for future electricity networks are the possibility of peak load increases and the expected growth of decentralized energy generation. In this article, we focus on peak load increases; the effects of possible future developments on peak loads are studied, together with the consequences for the network. The city of Eindhoven (the Netherlands) is used as reference city, for which a scenario is developed in which the assumed future developments adversely influence the maximum peak loads on the network. In this scenario, the total electricity peak load in Eindhoven is expected to increase from 198 MVA in 2009 to 591-633 MVA in 2040. The necessary investments for facilitating the expected increased peak loads are estimated at 305-375 million Euros. Based upon these projections, it is advocated that - contrary to current Dutch policy - choices regarding sustainable transitions should be made from the viewpoint of integral energy systems, evaluating economic implications of changes to generation, grid development, and consumption. Recently applied and finished policies on energy demand reduction showed to be effective; however, additional and connecting policies on energy generation and distribution should be considered on short term.

Keywords: Energy Transition; Peak Load; Scenario; Network Investments.

## 1. Introduction

The energy sector faces numerous problems, e.g. climate change, environmental and human accidents, reliability of energy supply, and oil dependency. It is therefore time to launch a fundamental course change with respect to our energy supply. The drivers for such a change originate in broad societal ambitions, and materialize in policy that is mostly formulated at national and cross-border level. For instance, the European Commission has formulated major objectives for future energy systems, e.g. to reduce carbon emissions by 20%, to increase the share of renewable energies by 20%, and to increase the energy efficiency by 20% before 2020 (CoEC, 2008a; CoEC, 2008b). This fundamental course change implies transitions towards new sustainable energy systems (Verbong and Geels, 2010).

The introduction of a sustainable energy system will alter the current patterns of electricity demand and generation (Shaw *et al.*, 2010), necessitating investments in the distribution network. The existing distribution networks do not have the quantitative and qualitative capacity to support the large-scaled introduction of sustainable energy generation and end-use technologies. Two major concerns for future electricity networks can be distinguished. The first concern is the possibility of increases in peak loads. This could either be caused by an increased total electricity use or by changing usage profiles. In case of increasing peak loads, additional investments in the network will be necessary to prepare the network for the future. Factors influencing the total electricity use and the usage profiles are economical growth, social developments (e.g. the increase in the number of single person households), energy system developments (e.g. the introduction of new smart balancing systems), and choices in end-use technologies like electric vehicles. The second concern is a large-scaled introduction of intermittent decentralized generation (DG). The current system is based on one way load flows and centralized system balancing. When DG contributes a relatively small part of the total production capacity, the system can still be stabilized at a central level. However, the decentralized generated power should never exceed the demand at any given time; this implies the requirement of a different method of balancing.

The consequences of the introduction of DG on energy networks are studied extensively, from the perspectives of finance (Ranieri *et al.*, 2005; Harrison *et al.*, 2007), regulation (De Joode *et al.*, 2009; Cossent *et al.*, 2009), network control (Lehtonen and Nye, 2009), and policy making (Pepermans *et al.*, 2005; Niesten, 2010). However, to date, the consequences of increases in peak loads – caused by sustainable energy generation and consumption – on energy distribution networks are not studied in detail. Additionally, it is expected that peak loads in the network constitute the main problem for urban environments (Van Lumig, 2009). Therefore, this article will focus on the effects of peak load increases on the necessity for electricity network extensions and the accompanying required financial investments. The central issue in this article is the statement that a higher level of sustainability in the energy system leads to a growing share of the energy carrier electricity compared to other energy carriers like solid, fluid, and gaseous fuels, and heat. Electricity has several advantages when comparing it to other energy carriers: the level of flexibility, the absence of waste, and the easy and safe way of connection. From a production point of view, electricity is the prevalent carrier for energy from important sustainable sources like hydropower, wind, and sun. Therefore, it is expected that electricity will play an important role in societies with a sustainable energy system, resulting in increasing peak loads on the electricity networks.

In order for cities, regions, and countries to be able to make more efficient, economical and sustainable choices on future network developments, it is important to have an estimate of what the required investments are in different sustainable policy scenarios (Sheblé, 1999; Shahidepour *et al.*, 2002). When discussing future energy systems, this information is essential yet lacking. Currently, the consequences of the implementation of sustainable measures on the necessity to invest in the electricity network are not considered in accompanying policy debates. In this article, the possible consequences of sustainable policy choices on the future electricity use and related network capacities in cities are explored. We want to show that apparent economical and sustainable policy choices can have severe financial and economical consequences for networks, in order to stress that choices regarding sustainable transitions should be made from the viewpoint of the integral energy system. To illustrate this, a worst case electricity use scenario is developed for the city of Eindhoven (the Netherlands), in which the upper limits for necessary network investments are explored.

## 2. Structure of the Dutch electricity sector

As most electricity networks in Europe, the Dutch network is a conventional electricity grid. The electricity system is dominated by large controllable generators. The centralized production in the Netherlands is based on numerous coal and gas power plants and a single nuclear facility, and is controlled by commercial energy companies. Furthermore, the network – locally owned by network operating companies – has very little storage capacity. Balancing generation and electricity use is currently executed by controlling production at the central generation facilities.

### *2.1 Generation technology*

The search for more sustainable resources has led to the introduction of a number of alternative generation technologies. In 2005, renewable electricity covered 6.1% of the Dutch national electricity production (CBS, 2010). In 2009, this has grown to 8.9% of the total national electricity production (CBS, 2010). It is expected that this percentage will continuously increase to somewhere between 35-40% in 2020 due to policy aimed at achieving the EU targets. For the Netherlands, the target is to cover 14% of the total national energy production with renewable energy technologies (European Parliament, 2009).

### *2.2 Infrastructure*

The Dutch national transfer network is owned and operated by TenneT. High voltage, high capacity circuits are used for cross country bulk transfer of electricity. Recently, a number of High Voltage Direct Current (HVDC) connections have been realized connecting the Dutch network to England, Norway and Denmark, which are used to solve national surpluses or shortages. TenneT delivers the electricity from central generation facilities to several regional network operators. These operators distribute it through medium and low voltage systems to the end user.

The existing infrastructure represents a huge financial value. In 2005, the economic value of the electricity and gas networks in the Netherlands was estimated at 24 to 30 billion Euros (Sequoia, 2005). The replacement value of the networks may even be many times higher, because the energy networks are largely integrated in the built environment; the majority of the network components are underground cables in urban areas. To replace or add components, extensive construction activities will be needed in the public domain.

### *2.3 Eindhoven infrastructure*

In the city of Eindhoven, the distribution network is operated by Endinet. The local network consists of three feed-in stations that are supplied by the network operator Enexis. From these stations, 10 kV is distributed from nine main distribution stations, through 30 neighborhood distribution stations, to about 1100 electricity substations, where the electricity is converted into 400 V. From these substations, the electricity is distributed to over 105,000 LV client connections in Eindhoven. There are about 570 clients directly connected to the MV network. The network in Eindhoven is laid out in MV rings that feed the transformer stations. Within these rings, the LV network is a mesh. The entire system is dimensioned to an ‘n-1’ specification; any cable may break down or be switched off without delivery to the clients being influenced. The same goes for transformer stations on the MV rings. Any of these may be switched off without delivery being interrupted (see figure 1).

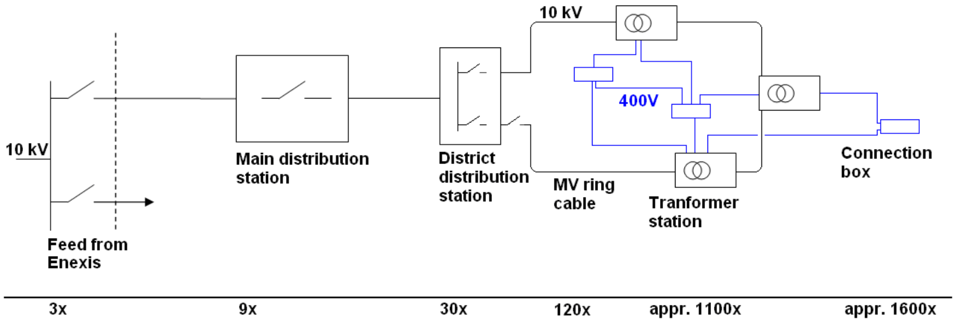

Figure 1: Schematic electricity network in Eindhoven

The existing grid does have some margins and options for expansion. New grid sections in Eindhoven are designed for peak loads of approximately 2 kW per connections while the actual peak load is averagely 1 kW per connection. In addition, the design often offers features that allow easy capacity expansion to an average of 2.5 kW per connection during peak times. Older grids were designed for significantly lower peak loads (1.5 kW), so the capacity surplus of existing grids is very diverse.

### *2.4 The development of Dutch energy networks*

Until a structured societal approach to energy is adopted, the development of energy networks remains reactive. The government waits for private parties to take up the challenge to provide an energy transition trough innovation and development. In order to stimulate this, they have liberalized the energy market as far as possible, keeping those parts of the sector in public ownership that are critical to ensuring quality and safety of energy supply, which are considered the most important factors in Dutch energy policy (Dutch Energy Chamber, 2009). This resulted in the energy networks and operators being split off and regulated. The government now stimulates market initiatives in the privatized parts of the sector for achieving a sustainable technology transition. The network regulation is focused at securing the public interests that the networks represent (figure 2).

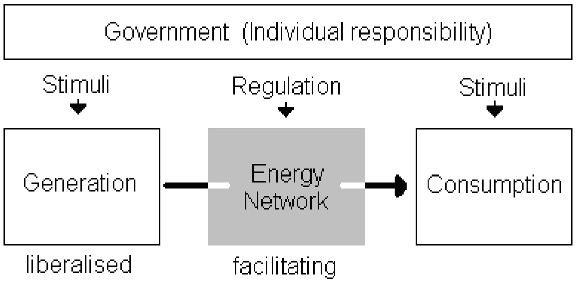

Figure 2: Current situation of the energy sector

The current general approach presents two problems to the development of smart energy systems. First, it isolates innovations in either generation or consumption, making system integration more difficult. This prevents the sector from being totally reformed, limiting developments to adjustments and localized innovation within the existing system. Secondly, the regulation – and the interests it protects – restricts the ability of the networks to pro-actively participate in innovations. From a financial point of view, the current system of yardstick competition between network operators actually punishes the first operator to invest in new developments by reducing the allocated investment resources in the next regulation period. This first-mover disadvantage prevents Dutch network operators from individually embarking on new and innovative developments.

## 3. Electrification of the energy supply

Network operators are an important player in the initiated sustainable energy transition, because this transition will cause a shifting of the current premises of distribution networks. This is partly caused by the expected electrification of energy consuming activities for which other energy carriers besides electricity are currently used. Specifically, it is expected that space heating and mobility will increasingly employ electricity as energy carrier (e.g. Lund, 2005; Lund and Kempton, 2008; Mathiesen and Lund, 2009; Kiviluoma and Meibom, 2010), for which respectively gaseous and fluid fossil fuels are currently used to a large extent.

Space heating can be electrified by applying electric heat pumps. The essence of a heat pump is that heat is not produced, as with central heating boilers, but transferred and upgraded from one heat source at a lower temperature – like the open air or groundwater – to another location at a higher temperature. For extremely cold weather, a resistive heating element can be added to the pump, which can be driven by gas or electricity. As long as there is a gas infrastructure in the urban area, a dual system with links to a gas boiler is more economical and sustainable, certainly in regions with a large green gas potential. However, the ambition exists to fully exclude the combustion of fossil fuels from urban areas in the future. Assuming that the consumed electricity is produced sustainably, an electric heat pump seems the most appropriate, currently available technology for truly sustainable space heating.

Electrifying mobility is more challenging than electrifying space heating. Here, we primarily focus on road mobility, which asks for the introduction of electric vehicles (EV). Without extensively discussing the future of electric vehicles, some comments should be made. First, from an energetic point of view, the electric car is without doubt the best alternative for making mobility more sustainable (MacKay, 2009). Sustainable electricity can be produced more efficiently than other forms of sustainable energy, and the ‘well to wheel’ efficiency is much higher than for instance cars running on fluid or gaseous bio-fuels or hydrogen, because the relative low efficiency of the oxidation process of fuels in internal combustion engines or fuel cells is avoided. Second, electric driving mechanisms have large mechanical efficiency and performance advantages compared to internal combustion engines. Combustion engines only survive in cars because cars have to carry their own energy, and the storage of electric energy is problematic. The ongoing development of adequate batteries with high power density, long life span, short charging times, and low prices are a main reason for the expected large scaled introduction of electric vehicles. Major industrial players and energy suppliers regard electric vehicles as an opportunity to extent the electricity storage capacity in cities; together with incentives from EU and national governments, this makes the market penetration of electric vehicles likely.

### *3.1 Flexibility in energy demand*

The electrification of heating and mobility implies that the demand for electricity becomes more flexible. For instance, many cars are left unused for 20 to 22 hours per day, while the daily kilometers can be charged in maximally 6 hours (Van der Sluijs, 2009). The possibility of spreading the necessary 6 hours charging over the period of time in which the car is unused introduces flexibility in the demand for electricity. This matter of flexibility is very important; it offers new possibilities to maintain the balance between demand and supply, because these cars can be charged during off-peak moments with high electricity supply and low electricity demand. Furthermore, an increasing flexibility creates the opportunity to smoothen peaks in the electricity demand. In moments when the time-critical, inflexible demand is high, the flexible demand can be reduced temporarily. This can lead to reduced network losses and a better use of the network capacity.

Even though this argumentation is technically correct, one should realize that – in a liberalized electricity sector – these objectives are managed by different players. Maintaining the balance between demand and supply of electricity is primarily the responsibility of commercial energy producers and transmission system operators. However, the optimal use of electricity networks is the responsibility of network operators. These different objectives can be conflicting, which might result in a non-optimal reduction of electricity peaks. Therefore, the structure of the Dutch electricity sector is regarded as an important aspect when studying the consequences of sustainable measures on peak load increases and network extensions and investments.

## 4. Consequences of electrification

The consequences of the expected electrification of the energy system are estimated using a scenario of the electricity demand in 2040. A scenario is developed in which all assumed future sustainable developments are adversely influencing the aspect *maximum peak loads* on the network.

The projected 2040 peak loads will be ascertained through two steps. In the first step, the representative annual usage for connections in Eindhoven will be extrapolated using the reference projections from the Energy Research Center of the Netherlands (ECN, 2010). The current Energy Data Services Nederland (EDSN) electricity load profiles in combination with this extrapolated representative annual use data will result in an extrapolated basic electricity load profile per connection. The second step will include individual adoption of end-use technologies. The effects of technologies on the energy use, usage pattern, and peak moments will be estimated and added to the peak loads from the earlier extrapolated energy use profiles. The adopted technologies include individual heat pumps and electrical mobility.

### *4.1 Socio-economic framework*

The examination of the future development of energy use in the Netherlands requires several assumptions regarding economic, demographical, structural, technological, and policy developments. ECN (2010) has created a strong socio-economic framework as basis for its future energy use projections. This framework is mainly based upon prognoses of the

Dutch Bureau of Statistics (CBS) and the Dutch Bureau for Economic Policy Analysis (CPB). In tables 1, 2 and 3, the most important assumptions are summarized.

Table 1: demographic developments 2008-2020 (derived from ECN, 2010)

| | **2008** | **2010** | **2020** | **Annual growth 2008-2020 [%]** |
|---|---|---|---|---|
| Total population | 16.4 million | 16.5 million | 17.0 million | 0.3 |
| Potential working population | 11.1 million | 11.1 million | 10.9 million | -0.1 |
| Total number of households | 7.24 million | 7.35 million | 7.86 million | 0.7 |
| Average household size | 2.24 | 2.22 | 2.14 | -0.4 |

The total population size is based on the population prognosis of CBS (van Duin, 2009), which assumes that the population size will increase from 16.4 million in 2008 to 17.0 million in 2020. Despite this expected increase, the potential working population will annually decrease by 0.1% in the next decade. Concerning the number of persons per household, Van Duin and Loozen (2009) expect a decrease from 2.24 in 2008 to 2.14 in 2020. As a result, the number of households will increase from 7.2 million in 2008 to 7.9 million in 2020.

Table 2: economic developments 2009-2020 (ECN, 2010)

| | Growth 2009 [%] | Growth 2010 [%] | Annual growth 2011-2020 [%] |
|---|---|---|---|
| Average economic growth (GDP) | -3.5 | -0.3 | 1.7 |
| Disposable income | -0.3 | -0.5 | 1.6 |
| Consumer expenditures | -0.3 | -0.5 | 1.9 |

The ECN reference projection assumes a structural growth of the economy that is based on the structural growth of labor productivity and on employment growth, thereby taking the impact of the credit crisis into account, which caused economic shrinkage in 2009 and 2010. The average economic growth between 2011 and 2020 is estimated at 1.7% annually, based on an annual growth in labor productivity of 1.4% and a growth of employment of 0.3% annually.

Table 3: economic development of individual production sectors (ECN, 2010)

| | Growth 2009 [%] | Growth 2010 [%] | Annual growth 2011-2020 [%] |
|---|---|---|---|
| Agriculture | -3.4 | 0.8 | 1.5 |
| Industry performance | -7.9 | -0.7 | 1.9 |
| Tertiary sector performance | -4.0 | -0.4 | 2.3 |
| Public services and Government | 1.4 | 0.9 | 1.7 |
| Other sectors | -3.1 | -0.8 | 0.3 |
| Total | -3.5 | -0.3 | 1.7 |

When establishing the expected future energy use, it is important to know the economic developments of the individual production sectors. In the period 2011-2020, the differences in growth among the various sectors are smaller than in the crisis years 2009 and 2010. The tertiary services and industry show a higher than average growth in 2011-2020; the foods industry shows a somewhat lower growth.

### *4.2 Future basic electricity load*

To determine the load profile for basic electricity use per connection for 2040, the current annual consumption per connection will be extrapolated. There are three important elements in determining the 2040 projected basic electricity load profile per connection: the representative annual electricity use per connection, the current load profiles, and a trend for the development of the annual electricity use per connection. The market penetration of new technologies and the related consequences for the electricity use and load profiles will be accounted for separately and added to the extrapolated loads. This allows assuming that the current standard electricity load profiles remain unchanged. The method of extrapolating therefore only includes the representative annual consumption per connection and a projected trend for the change thereof. The trend is based on electricity use projections by the Energy Research Center of the Netherlands (ECN, 2010).

The total representative use per connection is measured in kWh. The standard load profiles show 15 minute periods and the fraction of the annual use associated with that 15 minute period. Dividing these by the time period spanned (in hours) gives the load in kW. The values on this curve are then multiplied by the determined extrapolation factor. This results in the following equation:

$$Use_{annual\_rep} * Fraction_{load\_profile} * (1 - Period_{load\_profile}) * Factor_{extrapolation} = Projected\ load\ (2040)$$

### *4.3 Customer database analysis*

The representative values for the annual electricity use per connection are produced from an analysis of the available invoicing data. In case a connection had no use recorded for more than 14 months, the connection was considered inactive. Endinet has 111,410 electricity connections of which 105,308 are active and for which the invoicing system contains billing data. For each resulting connection, the postal code, tariff system, physical capacity, and the network section to which it was connected is recorded. The type of connection is determined using EDSN user profiles (EDSN, 2009), which are based upon the physical capacity of the connection and the tariff structure that applies. The resulting values represent the average consumption per connection for the year 2009. In table 4, the representative values for the annual electricity use in Eindhoven are presented.

Table 4: representative electricity use in Eindhoven

| **EDSN profiles** | **Total annual use (kWh)** | **Connections** | **Use/connection (kWh)** |
|---|---:|---:|---:|
| E1a (households) | 301,144,000 | 91,713 | 3,284 |
| E1c (households) | 43,396,000 | 8,664 | 5,009 |
| E2a (services sector) | 67,779,000 | 2,736 | 24,773 |
| E2b (services sector) | 36,083,000 | 906 | 39,827 |
| E3 (industry) | 593,973,000 | 1,289 | 460,801 |
| **Total** | **1,042,375,000** | **105,308** | **9,898** |

The 570 clients that are directly connected to the MV network are not incorporated in this analysis, because it is difficult and insecure to predict the future electricity use of these individually connected industrial consumers; this depends heavily on for instance future orders. Furthermore, the tariff system for these connections is related to necessary investments in the network. Large MV electricity consumers pay directly for necessary capacity increases. This makes it less interesting to incorporate in this research.

### *4.4 Development trends in basic electricity use*

ECN (2010) translated the expected demographic and economic developments into projections of the future Dutch energy use, thereby focusing on primary energy use aggregated per sector. Primary energy use is regarded as the consumption of energy used in the same form as in its naturally occurring state, for example crude oil, coal, natural gas, e.g. before it is converted into electricity or heat. Within the context of this article, the sectors households, services, and industry are relevant. Furthermore, as the focus of this article lies on the electricity network and related peak load developments, the future electricity use projections stand central.

The ECN energy demand projections include possible future policy changes; three possible policy variants are distinguished: (1) without the new national and European policy as of 2007 (No Policy, NP); (2) with fixed national and European policy (Fixed Policy, FP); and (3) implementation of the intended national and European policy (Intended Policy, IP). Fixed Policy has completed the political decision-making stage is the most certain policy; in the Netherlands, this fixed policy is described in the Clean and Efficient program[1]. But new energy and climate policy has also been announced, which is an intended extension to the Clean and Efficient policy. Therefore, the ECN (2010) projection distinguishes policy variants, i.e. a variant that maps only the effects of fixed policy and a variant that maps the effects of fixed and intended Clean and Efficient policy. To be able to interpret the total effect of Clean and Efficient policy, there is also a variant without Clean and Efficient policy. The starting points of all policy variants are elaborated in detail in ECN (2010).

#### 4.4.1 Households

For households, ECN (2010) observes that primarily gas and electricity are consumed. Between 1990 and 2010, the total household consumption of gas decreased from 362 to 294 PJ ($294 \times 10^{15}$ J), and the electricity consumption increased from 59 $PJ_e$ to 91 $PJ_e$ in this period. Thus, the total primary energy use remained largely unchanged between 1990 and 2008. In 2010, the Netherlands accounted for 7,350,000 households. According to the constructed socio-economic framework, the number of households will increase to 7,860,000 by 2020.

It is expected that the use of gas will decrease significantly in the next 15 years, due to better insulation, more efficient boilers, and an increasing average temperature. Contrary, the projections on the future electricity use are more diverse. Under fixed policy, a slight decrease in electricity use of households is expected until 2020, resulting in an annual electricity use of 89 $PJ_e$ in 2020. Similarly, it is expected that in the intended policy scenario the electricity use will start decreasing as of 2010, resulting in an annual electricity use of 87 $PJ_e$ in 2020. Finally, in the case when the Clean and Efficient policy is not implemented, the electricity demand of households will increase, resulting in an annual use of 99 $PJ_e$ in 2020. The electricity use projections are displayed in table 5.

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[1] The Clean and Efficient program does not exist anymore, because it was part of the former Dutch government's (Balkenende IV) policy. However, as this program is the most recent fixed policy, and used by ECN (2010) in their projections, we still employ the results of the program as reference point.

Table 5: summarizing overview of households' electricity use

| | 2010 | 2020 (NP) | 2020 (FP) | 2020 (IP) |
|---|---|---|---|---|
| Electricity use | 91 $PJ_e$ | 99 $PJ_e$ | 89 $PJ_e$ | 87 $PJ_e$ |
| Number of households | 7,350,000 | 7,860,000 | 7,860,000 | 7,860,000 |
| Average annual electricity use per household | 12.4 GJ = 3,439 kWh | 12.6 GJ = 3,500 kWh | 11.3 GJ = 3,139 kWh | 11.1 GJ = 3,083 kWh |
| Annual growth (electricity use per household) '10-'20 | --- | 0.2% | -0.9% | -1.0% |

### 4.4.2 Tertiary sector

The tertiary sector consists of trade, services and government (TSG). The primary energy use of this sector amounts to approximately 15% of the total energy use in the Netherlands (ECN, 2010). About 64% of the energy use of TSG is used by the commercial sector, and the remaining 36% is used by the nonprofit sector. The total consumption of the TSG sector in 2010 was 157 PJ for gas and 123 $PJ_e$ for electricity (ECN, 2010). The TSG sector's future energy demand projections are mainly based on estimations of the development of total national employment in employment years. The current amount of TSG employment years is derived from CBS Statline (2010); it is expected that the yearly growth of TSG employment is 0.41% until 2020, after which the growth flattens. Furthermore, a growth in electricity use is predicted because an increased use of ICT and cooling of buildings. This results in an electricity use of 137 $PJ_e$ when the current national and European policies are not implemented. Under the fixed policy scenario, the electricity demand is expected to amount to 126 $PJ_e$, and under the intended policy scenario, an electricity demand of 125 $PJ_e$ is projected (table 6). These lower levels of electricity demand under fixed and intended policy are mainly caused by Ecodesign, a European guideline for efficiency in the energy use of appliances and products (ECN, 2010).

Table 6: summarizing overview of tertiary sector's electricity use

| | 2010 | 2020 (NP) | 2020 (FP) | 2020 (IP) |
|---|---|---|---|---|
| Electricity use | 123 $PJ_e$ | 137 $PJ_e$ | 126 $PJ_e$ | 125 $PJ_e$ |
| Employment years | 4,662,000 | 4,856,700 | 4,856,700 | 4,856,700 |
| Average annual electricity use per employment year | 26.4 GJ = 7,329 kWh | 28.2 GJ = 7,836 kWh | 25.9 GJ = 7,207 kWh | 25.7 GJ = 7,149 kWh |
| Yearly growth (electricity use per employment year) | --- | 0.7% | -0.2% | -0.2% |

### 4.4.3 Industry

The share of the industry in the total Dutch primary energy use is high (approximately 40%). Especially the sectors chemistry and metals have a large energy demand, which is expected to grow in the next decade. Because the city of Eindhoven accommodates a relative low share of chemical and metal industry, we employ the electricity demand figures excluding these specific industrial sectors. In 2010, the industrial electricity use (excluding chemical and metal industry) amounted to 98 $PJ_e$. Between 2010 and 2020, ECN (2010) anticipates an increase of the industrial electricity use in each policy variant (table 7). This is partly caused by a strong economic growth of the industrial sector; it is expected that the current amount of employment years (derived from CBS Statline, 2010) will annually increase with 0.34%. When the new national and European policy is not implemented, the industrial electricity demand – excluding the sectors chemistry and metal – will increase to 115 $PJ_e$. The projected industrial electricity demand remains almost equal under fixed policy (114 PJe) and intended policy (115 $PJ_e$) scenarios. These projections are based on predicted general economic development (table 2), on specific factors in energy-intensive industrial sectors (table 3), and on political developments on energy-efficiency in industrial sectors, like the sequence of the currently applicable Long-term Agreement Energy Efficiency 2001-2012 (ECN, 2010).

Table 7: summarizing overview of industry's electricity use

| | **2010** | **2020 (NP)** | **2020 (FP)** | **2020 (IP)** |
|---|---|---|---|---|
| Electricity use | 142 $PJ_e$ | 171 $PJ_e$ | 165 $PJ_e$ | 166 $PJ_e$ |
| Electricity use (excl. chemical and metal sector) | 98 $PJ_e$ | 115 $PJ_e$ | 114 $PJ_e$ | 115 $PJ_e$ |
| Employment years | 759,800 | 786,000 | 786,000 | 786,000 |
| Average annual electricity use per employment year | 129.0 GJ = 35,828 kWh | 146.3 GJ = 40,642 kWh | 145.0 GJ = 40,288 kWh | 146.3 GJ = 40,642 kWh |
| Yearly growth (electricity use per employment year) | --- | 1,3% | 1,2% | 1,3% |

### *4.5 EDSN electricity use profiles*

EDSN electricity profiles, which are used by energy companies to predict loads of new network sections during the design process, are drawn up annually. In this method, the load on 1000 connections is measured every 15 minutes during an entire year. The 1000 connections are divided in 9 categories based on the physical capacity of the connection and the tariff structure that applies (table 8).

Table 8: Profile categories EDSN (2009)

| | |
|---|---|
| E1a | ≤ 3x 25 Ampere, single tariff |
| E1b | ≤ 3x 25 Ampere, double tariff, night tariff |
| E1c | ≤ 3x 25 Ampere, double tariff, evening active tariff |
| E2a | > 3x25 Ampere ≤ 3x80A, single tariff |
| E2b | > 3x25 Ampere ≤ 3x80A, double tariff |
| E3a | > 3x80 Ampere, < 100 kW, BT ≤ 2000 hours |
| E3b | > 3x80 Ampere, < 100 kW, BT > 2000 hours, BT ≤ 3000 hours |
| E3c | > 3x80 Ampere, < 100 kW, BT > 3000 hours, BT < 5000 hours |
| E3d | > 3x80 Ampere, < 100 kW, BT ≥ 5000 hours |

EDSN then compensates for holidays and weather influences using data from the years before. The measurements are aggregated and every 15 minute period is assigned a portion of the total yearly consumption for that type of connection. The resulting value is a prediction for the fraction of the annual load required for individual connections in a random 15 minute period. By multiplying the appropriate fraction with the representative annual consumption of a connection, the predicted load for that specific time and date can be found. The profiles show fluctuations on different timescales. There is a daily fluctuation that differs between week and weekend days. There is also a seasonal fluctuation. The seasonal fluctuations of specific EDSN profiles are represented in figure 3 and 4; the daily fluctuations in figure 4 and 5.

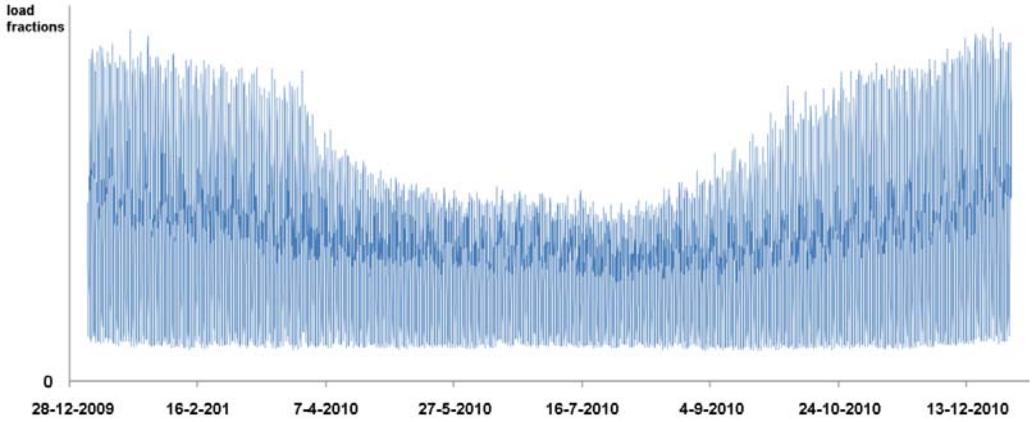

Figure 3: E1a profile, 2010

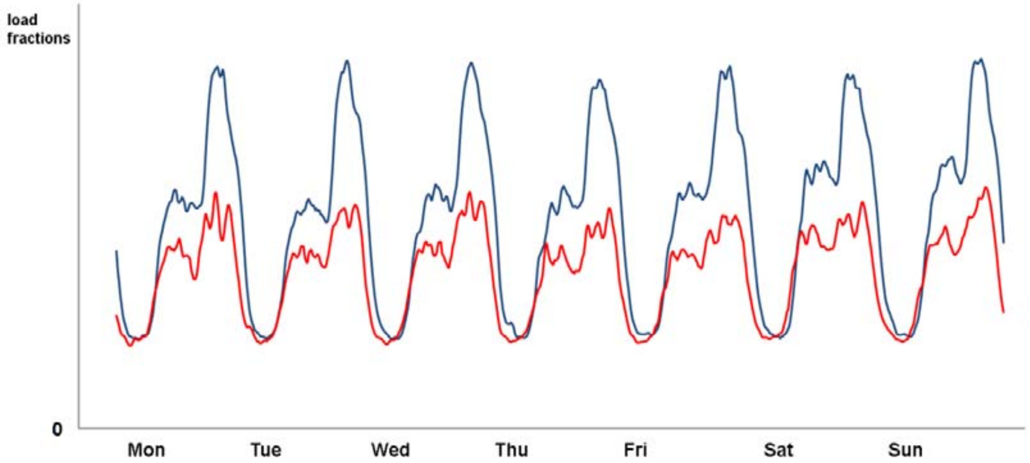

Figure 4: E1a summer (red) and winter (blue) week, 2010

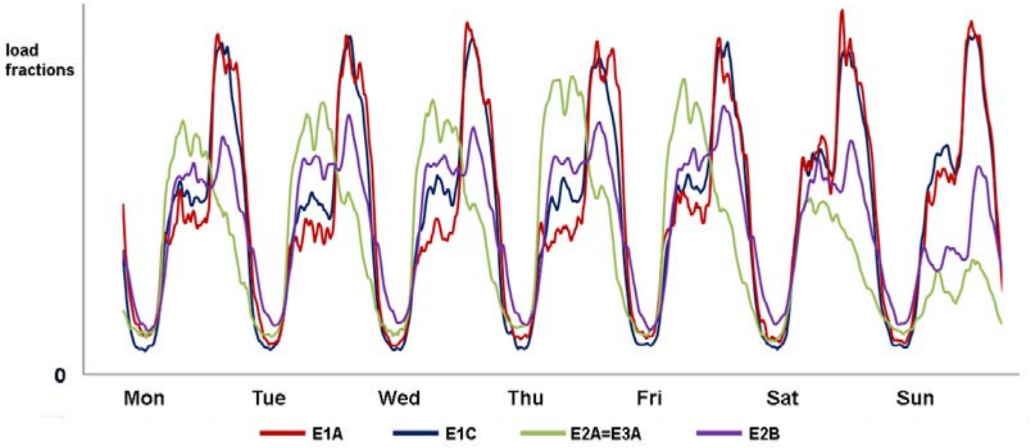

Figure 5: Different EDSN profiles for a winter week, 2010

### *4.6 Basic electricity load profile 2040*

Both the representative annual electricity use and the EDSN profiles are already connection specific. For the extrapolation factor, the values need to be defined and allocated to the connections. All the analyzed projections are derived from ECN (2010). However, these projections only cover developments until 2020, and imply a linear development of the electricity use for all categories in this period. This study aims to present a scenario of the electricity demand in 2040. There are three main reasons for choosing 2040 as the reference year. First, the large-scaled introduction of new end-use technologies requires a longer time-period; most studies after market penetrations of new energetic technologies employ 2040 as reference year. Second, network operators are often unable to restructure their networks within a period of 10 years; they formulate long-term visions because upgraded network elements have a life span of more than 70 years. And third, many Dutch municipalities have formulated policy goals for achieving a high level of renewable energy and energy reduction in the year 2040; it is expected that a thirty year period is necessary to achieve the stated goals. Therefore, we combine the general economic and demographic projections from ECN (2010) with the 2040 energy projections from ECN MonitWeb (2011).

According to this database, households will use 106 $PJ_e$ under NP, 81 $PJ_e$ under FP, and 75 $PJ_e$ under IP in 2040, resulting in annual growth figures of respectively 0.3%, -0.6%, and -0.8%. The connections that are characterized as E1a and E1c are considered households and their representative annual consumption will be extrapolated from 2009 to 2040 assuming these annual growth figures. The tertiary sector demands 170 $PJ_e$ under NP, 145 $PJ_e$ under FP, and 141 $PJ_e$ under IP in 2040, equaling annual growth figures of 1.1%, 0.4%, and 0.3%. The connections that are characterized as E2a and E2b are considered as tertiary sector connections and their representative annual consumption will be extrapolated from 2009 to 2040 assuming these annual growth figures. And finally, in 2040, the industry will use 135 $PJ_e$ under NP, 128 $PJ_e$ under FP, and 127 $PJ_e$ under IP; this equals annual growth figures of 1.2%, 1.0% and 0.9%. All E3 connections are considered as industrial connections, and for these industrial connections, the current consumption figures will be extrapolated from 2009 to 2040 using these annual growth figures. All assumed increases in annual electricity consumption exclude the effects of the introduction of specific technologies in the market. The possible effects of new technologies will be discussed in the next section.

### *4.7 Introduction of new technologies*

New technologies have specific characteristics and subsequent consequences for the total energy use, electricity use, load profiles, and reactive power components. There are multiple niche technologies that are candidates for penetrating their respective markets. At the urban distribution network level, the relevant new developments include PV, CHP, heat pumps, electric vehicles, smart meters, and district heating. Because it is impossible to regard energy carrier systems as standalone systems, the new developments that might influence electricity load profiles include end-use technologies as well as system altering developments and developments in other energy carrier systems.

In order to develop a worst case scenario, the developments were chosen that meet two criteria. First, the technologies should be individually and privately employed and require only a relatively limited amount of public investments (in proportion to the realized penetration degree). The second criterion is that they should adversely affect the maximum electricity load on the network. The developments that meet both criteria are heat pumps and electric vehicles with home loading (see figure 6).

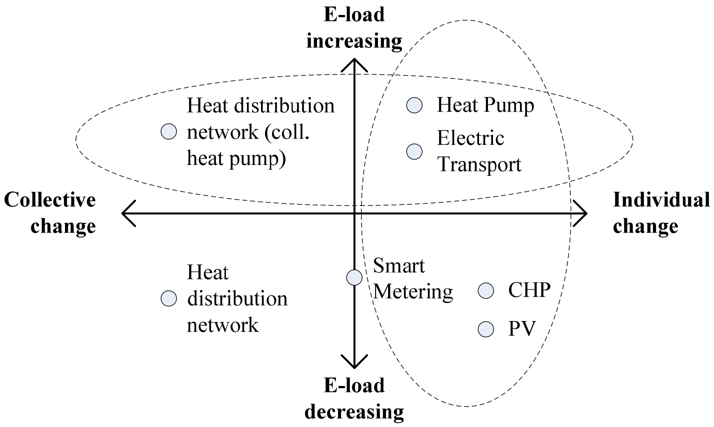

Figure 6: Relevant new technological developments

### 4.7.1 Heat pumps

With regards to the load profile, heat pumps are very inconvenient for the network. At the time of the maximum total use, the concurrency will rise very close to 100%. In practice, the problem might be smaller, for example in case a number of people decide to install micro CHP's. In case of a mix of heat pumps and CHP's, they will concurrently generate and use electricity, which significantly reduces the local load problem. In order to model a worst case scenario, it is assumed that heat pumps with electrical heating elements are introduced.

In our scenario, the heat pump will be introduced in households. The degree of penetration in the market is derived from the fast introduction scenario from the $CO_2$-reduction potential study by Harmsen *et al.* (2009), resulting in the prediction that 50% of all individually heated houses will have a heat pump in 2030. When extrapolating the penetration curve, a share of approximately 65% of all individually heated houses will have a heat pump in 2040, under the scenario assumptions of Harmsen *et al.* (2009).[2]

Heat pumps are not used evenly throughout the year. For a dwelling with an energy performance coefficient (EPC) of 0.8 (equaling the energy performance of newly built dwellings in 2010), the electrical load of a heat pump is expected to average 2.2 kWe during a standard winter week (Van Lumig, 2009). The biggest concurrent load is needed during extreme winter weather, because the electrical heating elements will then be used for heating purposes and for providing warm water. In most models of heat pumps, the pump itself has a capacity of 2-3 kWe, whereas the heating element needs 5-7 kW. During such a period, it is realistic to assume that the concurrency factor is 100% (Van Lumig, 2009); during a period of extreme cold, the load per heat pump may become 7 kWe for large detached dwellings and 5.3 kWe for row houses and apartments (Van Lumig, 2009). In Eindhoven, the share of large detached dwellings is 5% of the total housing stock; row houses account for 65%, and apartments for 30%. Since this scenario is statically modeled at key moments in the year, it will suffice to add a single 5.4 kWe ((7 × 0.05) + (5.3 × 0.95))

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[2] This means that still 35% of all households have a gas connection. As mentioned in section 3, the availability of gas networks in urban areas might decrease the penetration speed of electric heat pumps, possibly implying that that the increase in peak loads can take place later than 2040.

during the peak moments chosen to the load of those household connections that operate a heat pump. This would mean adding 3.5 kW (65% of 5.4 kWe) to the average household connection.

### 4.7.2 Electrical vehicles

The introduction of electric vehicles (EV) with home charging will increase the total use of electricity in households. The additional use and maximum load will specifically influence existing distribution networks in case home loading becomes standard, which is assumed in this worst-case scenario. Different institutes have drawn up projections of the number of electronic cars that will come in use (e.g. Dutch Ministry of Transport and Public Works, 2009; Federation Holland Automotive, 2009; Hanschke *et al.*, 2009). The calculation of Hanschke *et al.* (2009) – which also introduces market introduction scenarios of alternative fuels like bio-fuel, hydrogen, and natural gas – has the largest level of detail. Therefore, these projections are used to build this scenario. In this study, the amount of electrical cars is expected to be 250,000 in 2020 and rise to a total of 900,000 by 2040. They additionally foresee a total of 2,200,000 Plug in Hybrid Electric Cars to be in use in 2040. In total, electrical mobility would represent 35% of the total car transport (Hanschke *et al.*, 2009). Considering that current batteries have a capacity of 36 kWh, and allowing a battery to charge between 17.30 and 04.00h, the average load would be 3.3 kW (Van der Sluijs, 2009). Based on the figures presented in table 9, and the assumption that an electrical car drives 6.5 km per kWh (Ministry of Transport and Public Works, 2009), the load on the network can be estimated.

Table 9: Data and projections mobility (Hanschke *et al.*, 2009)

| | **2000** | **2040** |
|---|---:|---:|
| Total km/year by car in NL | 114 billion | 192 billion |
| Cars in use in NL | 6.5 million | 11.8 million |
| Average km/car per year | 17,500 | 16,771 |

For electrical cars to be interesting, they should be rechargeable in at least a single night. An unnecessary high capacity would be required in case people plug in every evening when they get home. If car charging is evenly spread over 10.5 hours (for example 17.30 – 04.00h), the load per charging car would be 3.3 kW. Current loaders can require up to 10 kW to charge a battery in a couple of hours which means that the peak loads from car charging could be up to four times higher, in case no measures are taken to spread out the load pattern. It would be beneficial for the electricity networks if demand was somehow spread using smart loading technology; the already existing double tariff system can achieve significant results in supporting this. We therefore assume an even distribution of EV charging between 17.30h and 04.00h. On average, each car drives 16,771 / 365 = 46 km per day, equaling 46 / 6.5 = 7.1kW. Therefore, we assume that every night, 7.1kW / 36kW = 19.6% of all cars need to be charged. This would result in an average load of 3.3kW × 19.6% = 0.65kW per electrical car. Given a total of 8,300,000 households in 2040 (Van Duin and Loozen, 2009), and 11,800,000 cars, there is an average of 1.42 cars per E1a,c and E2a,b connection of which 0.49 cars per connection are electrical. This results in a constant load added onto the representative load profile of 0.65kW × 0.49 = 0.32kW daily between 17.30h and 04.00h.

### *4.8 Scenario results*

The elements presented so far are integrated into a single projected load profile per connection. These load profiles are a projection that is coherent with a worst case scenario for maximum loads on the network. It is only valid during days with severe winter weather due to the assumed 100% concurrency of the heat pump load. The total 2040 profile build-up per connection is represented in table 10.

Table 10: Worst case scenario of the average electricity loads in Eindhoven

| Nr. of connections | Category | Annual index increase ('09-'40) | | | Electric cars | Heat pump |
|---|---|---|---|---|---|---|
| | | No policy | Fixed policy | Intended policy | | |
| 94,092 | E1a-E1c | 31 × 0.3<br>F = 1.09 | 31 × -0.6<br>F = 0.81 | 31 × -0.8<br>F = 0.75 | + 0.32 kW | + 3.51 kW |
| 3.985 | E2a-E2b | 31 × 1.1<br>F = 1.34 | 31 × 0.4<br>F = 1.12 | 31 × 0.3<br>F = 1.09 | + 0.32 kW | --- |
| 872 | E3a-E3d | 31 × 1.2<br>F = 1.37 | 31 × 1.0<br>F = 1.31 | 31 × 0.9<br>F = 1.28 | --- | --- |

#### 4.8.1 Peak loads Eindhoven

The time period with the highest peak load in 2009 was determined using the total electricity use (table 4) and EDSN (2009) usage profiles, and was found to be on Wednesday before Christmas between 17.00h and 18.00h. The resulting value as presented below is within 2.5% of the maximum peak load so far recorded in Eindhoven; the total peak load on the Eindhoven electricity network in 2009 is 198 MW (table 11).

Table 11: Annual usage and peak loads 2009 per connection type

| **2009** | **E1a** | **E1c** | **E2a** | **E2b** | **E3** | **Total** |
|---|---|---|---|---|---|---|
| Total annual use (kWh) | 301,144,000 | 43,396,000 | 67,779,000 | 36,083,000 | 593,973,000 | 1,042,375,000 |
| # Connections | 91,713 | 8,664 | 2,736 | 906 | 1,289 | 105,308 |
| Average annual use (kWh) | 3,284 | 5,009 | 24,773 | 39,827 | 460,801 | |
| **Peak moment** | | | | | | |
| Average peak load (kW) | 0.78 | 1.24 | 4.21 | 7.80 | 75.02 | |
| Peak load (kW) | 72,262 | 10,807 | 11,539 | 7,071 | 96,705 | **198,384** |

The scenario peak loads per connection are determined by extrapolating the peak loads found for 2009 (table 11) with the factors represented in table 10. Then, the loads projected for EV and heat pumps are added. The total peak load, in the worst case scenario for 2040, comprises 633 MW under the No Policy variant, 600 MW under the Fixed Policy scenario, and 591 MW under the Intended Policy variant (table 12). This means that the peak load will increase with respectively 220%, 203% and 198% compared to 2009.

Table 12: Peak loads scenario 2040 per connection type

| 2040 | E1a | E1c | E2a | E2b | E3 | Total |
|---|---|---|---|---|---|---|
| Average peak load 2009 (kW) | 0.78 | 1.24 | 4.21 | 7.80 | 75.02 | |
| Extrapolation factor (NP) | 1.09 | 1.09 | 1.34 | 1.34 | 1.37 | |
| Extrapolation factor (FP) | 0.81 | 0.81 | 1.12 | 1.12 | 1.31 | |
| Extrapolation factor (IP) | 0.75 | 0.75 | 1.09 | 1.09 | 1.28 | |
| Extrapolated average peak load (kW) (NP) | 0.86 | 1.36 | 5.65 | 10.46 | 102.78 | |
| Extrapolated average peak load (kW) (FP) | 0.64 | 1.01 | 4.72 | 8.74 | 98.28 | |
| Extrapolated average peak load (kW) (IP) | 0.59 | 0.94 | 4.60 | 8.51 | 96.03 | |
| Electric vehicles (kW) | 0.32 | 0.32 | 0.32 | 0.32 | --- | |
| Heat pumps (kW) | 3.51 | 3.51 | --- | --- | --- | |
| **Total peak loads No Policy** | | | | | | |
| Average peak load (kW) | 4.69 | 5.19 | 5.97 | 10.78 | 102.78 | |
| Peak load (kW) | 430,027 | 44,963 | 16,337 | 9,765 | 131,972 | **633,064** |
| **Total peak loads Fixed Policy** | | | | | | |
| Average peak load (kW) | 4.47 | 4.84 | 5.04 | 9.06 | 98.28 | |
| Peak load (kW) | 409,793 | 41,937 | 13,799 | 8,209 | 126,192 | **599,930** |
| **Total peak loads Intended Policy** | | | | | | |
| Average peak load (kW) | 4.42 | 4.77 | 4.92 | 8.83 | 96.03 | |
| Peak load (kW) | 405,458 | 41,289 | 13,453 | 7,997 | 123,302 | **591,498** |

In figure 7, a graphic representation of the built up of the 2040 extreme winter peak load (under the No Policy variant) for usage profile E1a is given. In the evening, the peak load reaches its maximum. This load profile consists of four parts: (a) the 2009 average basic use peak load (0.78 kW); (b) the extrapolated basic use peak load (0.86 kW); (c) the peak load for basic use including the use of heat pumps (4.37 kW); and (d) the total peak load, for basic use including heat pumps and electric car loading (4.69 kW).

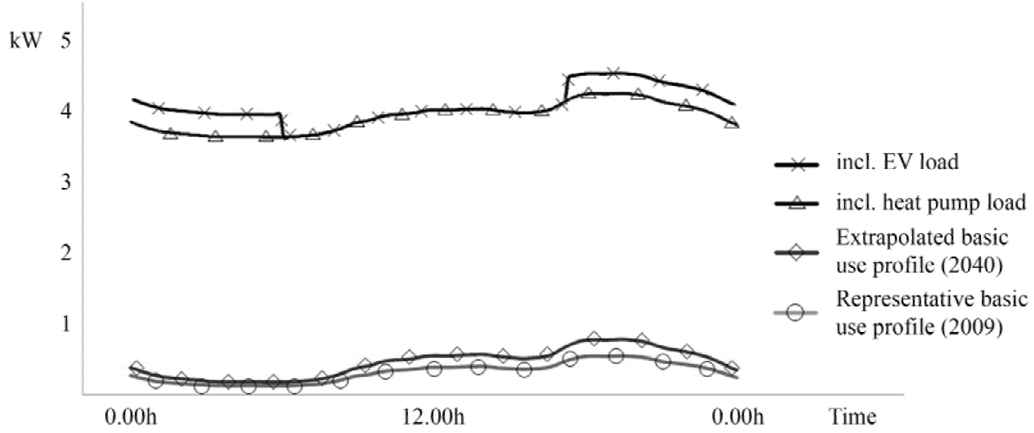

Figure 7: 2040 extreme winter load profile (E1a, No Policy variant)

## 5. Projected transition investments

Following the description of the current network technology, combined with the large value and replacement value of the current network and the need for more complex network planning, it is expected that the future electricity network will be a hybrid grid that combines traditional central generation facilities with decentralized and smart components, both central and decentralized elements contributing to balancing the network. The current networks are expected to largely remain the same though 'smart' changes and additions will be needed (ERGEG, 2009; Verbong and Geels, 2010).

Assuming that a hybrid grid will service our future electricity needs, it is interesting to calculate the investments in that grid for facilitating the projected peak demand through traditional means. For this calculation, four aspects are important: the current network capacity, the network load compared to the maximum capacity, the scenario peak loads, and the price of network components at all levels.

### *5.1 Network capacity*

The Eindhoven network is analyzed at seven different levels. These levels follow the network structure as presented in figure 1 and the cable routes connecting them. The seven levels are main feeder cables, main distribution stations, transport cables, district distribution stations, MV ring cables, transformer stations and finally the LV cables. For each of these levels, the average and total capacity in Eindhoven is determined. MV network sections solely serving industry are excluded from the analysis. For distribution stations, the total number and average capacity of sections is determined. For all MV cables, the number of cables and the average capacity is used. The load percentage at transformer stations is analyzed by the number and the capacity of transformers. Finally, for the LV capacity, the number of switch bays connected to the transformers and their capacity is used.

At each of these levels, the number of components in the network and their average capacity is determined. At each level, the 'n-1' redundancy criterion is used in the Eindhoven network. This is accounted for by reducing the real number of components by the number of cables, sections or cable routes at each level. The capacity was then calculated for all levels (except transformers) using:

$$P_{(n-1)} = N_{(n-1)} * U(V) * I(Amp) * \sqrt{3} * \cos(\varphi) = \textit{max. capacity (MW)}$$

In which:

| | |
|---|---|
| $N_{(n-1)}$ | number of components (n-1) |
| $U(V)$ | voltage level (MV = 10 kV; LV = 400 V) |
| $I(Amp)$ | average component capacity (Amp) (for cables $I_{nom}$(G=0.75 K.m/W)) |
| $\cos(\varphi)$ | factor representing the difference between real (used energy) and apparent (transported energy) power |

Transformer capacity is given in kVA, so the capacity at the level of transformer stations was determined by multiplying the average capacity with the number of transformers and $\cos(\varphi)$. Both the current and the total projected peak loads for 2040 are presented in tables 11 and 12. Since network sections that exclusively serve industry are excluded, the peak generated by these industrial connections is also excluded. This means that at both the main distribution level and the district distribution level, the loads from a number of industrial connections are subtracted. This results in three different peak loads that apply to different levels of the network. In table 13, these maximum loads are represented for the all policy variants.

Table 13: Maximum loads at different levels of the network (three policy variants)

| | **2009** | | | **2040 (NP)** | | **2040 (FP)** | | **2040 (IP)** | |
|---|---|---|---|---|---|---|---|---|---|
| Network section type | Max. netw. cap. (n-1) | Load Industry | Load Mixed | Load Industry | Load Mixed | Load Industry | Load Mixed | Load Industry | Load Mixed |
| Eindhoven peak load | | | 198 MW | | 633 MW | | 600 MW | | 591 MW |
| Main feeder cables | 290 MW | 8 MW | 190 MW | 12 MW | 621 MW | 12 MW | 588 MW | 12 MW | 579 MW |
| Main distribution station | 249 MW | | 190 MW | | 621 MW | | 588 MW | | 579 MW |
| Transport cables | 352 MW | 12 MW | 178 MW | 16 MW | 606 MW | 15 MW | 574 MW | 16 MW | 566 MW |
| District distribution stations | 299 MW | | 178 MW | | 606 MW | | 574 MW | | 566 MW |
| MV ring | 374 MW | | 178 MW | | 606 MW | | 574 MW | | 566 MW |
| Transformer stations | 458 MW | | 178 MW | | 606 MW | | 574 MW | | 566 MW |
| LV network | 1,526 MW | | 178 MW | | 606 MW | | 574 MW | | 566 MW |

In order to determine the 2040 capacity requirements, utilization percentages are used. The basis for further calculations is the current utilization percentage. This is the maximum peak load in 2009 divided by the 2009 network capacity. Table 14 shows the current capacity, current maximum load and load percentage for the different network levels.

Table 14: Capacity, peak load and load percentage situation 2009

| **Network level** | **Situation 2009** | | |
|---|---|---|---|
| | Network capacity (n-1) | Maximum peak load (2009) | Utilization percentage (2009) |
| Main feeder cables | 290 MVA | 190 MVA | 65% |
| Main distribution station | 249 MVA | 190 MVA | 76% |
| Transport cables | 352 MVA | 178 MVA | 51% |
| District distribution stations | 299 MVA | 178 MVA | 60% |
| MV ring | 374 MVA | 178 MVA | 48% |
| Transformer stations | 458 MVA | 178 MVA | 39% |
| LV network | 1,526 MVA | 178 MVA | 12% |

For the extrapolated basic use and electric mobility, it is assumed that consumer behavior stays the same as it is in 2009. This means that the spread in usages at peak time and the concurrency of these loads remains the same. With these stable conditions, it is wise to maintain the same redundancy, and thus utilization percentage, to be sure that the network can cope with local variances.

The heat pumps are assumed to be 100% concurrent loads, with every heat pump operating at full capacity at peak times. For the average load, the distribution of the load over the connections is identical every time because all pumps are at maximum capacity per connection. With predictability being higher for this type of load, the network redundancy can be allowed to drop with respect to these loads. Since the current higher network levels already go up to a utilization percentage of 76%, it is safe to assume the Eindhoven network can cope with this percentage. In theory, the concurrent heat pump loads can probably be allowed a higher utilization percentage, but since it cannot be proven with current information, 76% is a safe assumption.

The acceptable utilization percentage for scenarios therefore consists of two components. Parts of the projected load for which consumer behavior is assumed to be the same as they are today require the same network redundancy as the current network. The heat pump loads, which have a more predictable behavior and cannot locally exceed the projected peak loads, only need a 24% redundancy (76% utilization) of the network. The following formula is used to calculate the acceptable utilization percentage (AUC):

$$AUC_{total} = 1/(((load\_share_{heat\_pump})/AUC_{heat\_pump}) + ((load\_share_{basic+EV})/AUC_{basic+EV}))$$

In table 15, the buildup of the acceptable utilization percentage and required network capacity for the LV level is shown as an example. The heat pump load in the NP variant is 353 MVA out of the total 606 MVA peak load. The current utilization of the LV level is 12%. By dividing the load component by the required utilization percentage, the required network capacity per component is determined. Once the total required capacity and total peak load are known, the total acceptable utilization percentage is found by dividing the load by the required capacity.

Table 15: required utilization percentage for LV level

| **Load component** | | **Load share** | **Acceptable utilization percentage** | **Required network capacity** | **Mean acceptable utilization percentage** |
|---|---|---|---|---|---|
| | | **No Policy variant** | | | |
| Basic use + EV | 253 MVA | 42% | 12% | 2,172 MVA | |
| Heat pumps | 353 MVA | 58% | 76% | 462 MVA | |
| **Total peak load** | **606 MVA** | **100%** | | **2,634 MVA** | **23%** |
| | | **Fixed Policy variant** | | | |
| Basic use + EV | 221 MVA | 38% | 12% | 1,898 MVA | |
| Heat pumps | 353 MVA | 62% | 76% | 463 MVA | |
| **Total peak load** | **574 MVA** | **100%** | | **2,361 MVA** | **24%** |
| | | **Intended Policy variant** | | | |
| Basic use + EV | 214 MVA | 38% | 12% | 1,831 MVA | |
| Heat pumps | 352 MVA | 62% | 76% | 463 MVA | |
| **Total peak load** | **566 MVA** | **100%** | | **2,294 MVA** | **25%** |

## 5.2 *Required investments*

Next, the investments needed to realize the required network capacity at each level are projected. Since the number of current network assets and the standard prices are confidential, we only present the outcomes of the calculations. The standard prices used are all inclusive prices for stations or meters cable. For all network levels, the same method of calculating the required investments is used:

$$\text{Required network capacity (RNC)} = \text{Peak load / Acceptable utilization factor}$$

$$\text{Required investment} = ((\text{RNC / Current network capacity}) - 1) * N_{components} * \text{Component price}$$

The required investments are calculated in 2009 Euro currency, without inflation correction, for the entire period to 2040. Table 16 shows the impact of the NP scenario for 2040 on the network and the cost estimate for facilitating these requirements.

Table 16: Investment estimate for NP scenario

| **Network level** | **2040 (basic use, electric vehicles, and heat pumps)** | | | | |
|---|---|---|---|---|---|
| | Projected max load (MW) | Permitted load (%) | Required network capacity (MW) | Required expansion factor | Estimated required investments |
| Purchase stations | | | | 2.82 | € 5,000,000 |
| Main feeder cables | 621 | 76 | 816 | 2.82 | € 35,000,000 |
| Main distribution station | 621 | 76 | 816 | 3.28 | € 35,000,000 |
| Transport cables | 606 | 63 | 963 | 2.74 | € 30,000,000 |
| District distribution stations | 606 | 68 | 888 | 2.97 | € 35,000,000 |
| MV ring | 606 | 61 | 995 | 2.66 | € 75,000,000 |
| Transformer stations | 606 | 54 | 1,115 | 2.43 | € 100,000,000 |
| LV network | 606 | 23 | 2,634 | 1.73 | € 60,000,000 |
| | | | | **Total required investment** | **€ 375,000,000** |
| | | | | **Cost per connection** | **€ 3,750** |

These investments figures are distracted from the current number of network assets on the seven network levels, the calculated expansion factor for each of these network assets, and the prevailing prices for individual network assets. The calculated required investments are necessary investments for network expansion; replacement investments for network components that are at the end of their life span are not considered. Under the FP variant, the required expansion investments amount to 325 million Euros, while the IP variant results in necessary investments of 305 million Euros.

### *5.3 Business-as-usual*

Finally, the calculated required investments in the network are put into the perspective of regular expansion investments in the Eindhoven electricity network. In table 17, the expected and allocated network expansion investments are represented for the period until 2014, which Endinet, the network operator in Eindhoven, uses in their operational management. These expansion investments amount to between 3.2 and 4.2 million Euros annually. For the period 2010-2040, this means a total investment of 96 to 126 million Euros. Under the calculated scenario assumptions, the necessary expansion investments will heighten with a factor 3.

Table 17: Business-as-usual expansion investments

| | **Year** | | | | |
|---|---|---|---|---|---|
| | **2010** | **2011** | **2012** | **2013** | **2014** |
| Expansion investments | € 4,246,000 | € 3,666,000 | € 3,252,000 | € 3,363,000 | € 3,275,000 |

## 6. Uncertainty Analysis

The presented scenario is a worst case image of the future of the electricity network of Eindhoven, developed to confront policy makers with the effects of certain policy choices.

The developed scenario has two main sources of uncertainty, namely the future socio-demographic developments and the introduction and penetration degree of new technologies.

The employed scenario for social-demographic and economic developments is mainly derived from ECN (2010), of which the framework is based upon the most recent prognoses of the Dutch Bureau of Statistics (CBS) and the Dutch Bureau for Economic Policy Analysis (CPB). The ECN projection can be characterized by a business-as-usual image: except for changes in policy, the projection assumes trend-wise development (ECN, 2010). As the social-demographic and economic future development is surrounded by uncertainties, the ECN projection also maps the uncertainties of the main assumptions and translates them into effects on energy use on a 90% reliability interval.

The main uncertain factors related to the electricity demand of households are population growth, established agreements on energy-efficiency of new appliances, and the average electricity use per household per year. Aggregating the effects of these uncertainty factors results in a maximal electricity demand deviation of +/- 14.8 PJ. For TSG connections, the uncertainty factors are largely the same as for households, resulting in an electricity demand deviation of +/- 23.5 PJ. For the energy demand of industrial connections, the main uncertainty factors are economic growth, choice of location of companies, distribution of growth over activities, fuel prices, $CO_2$ prices, potential of saving measures, and electricity covenants. In total, this can result in a reduction of the electricity demand of maximally 34.8 PJ to an increase of maximally 33.2 PJ.

In table 18, the effects of these uncertainty margins on the necessary network expansion investments are represented. The most favorable economic and social-demographic conditions result in necessary investments of around the business-as-usual investment plans of the network operator. However, the least favorable conditions result in necessary investments of around 500 million Euros. The effects of the economic and social-demographic uncertainties on the necessary investments are substantial.

Table 18: investments at lower and upper uncertainty boundaries

| | **No Policy variant** | **Fixed Policy variant** | **Intended Policy variant** |
|---|---|---|---|
| **Lower boundary** | € 190,000,000 | € 130,000,000 | € 115,000,000 |
| **Upper boundary** | € 565,000,000 | € 490,000,000 | € 475,000,000 |

The second source of uncertainty is the introduction and penetration degree of new technologies. In this scenario study, we chose two technologies: heat pumps and electric vehicles. As mentioned before, the introduction of heat pumps with electrical heating elements is a worst case assumption. It is uncertain whether this type of heat pumps will be employed in existing buildings when gas infrastructure is available; in such situations, heat pumps with a link to a gas boiler seems more economic. Furthermore, additional insulation should be added to a large share of the existing housing stock in order to make the heat pump efficient; Harmsen et al. (2009) assumed all houses to have an energy performance coefficient of 0.8, equal to the value of newly built houses in the period 2006-2010. Adding insulation to privately owned dwellings will only be achieved when energy prices will rise, or if the government actively stimulates it. However, as the gas prices are expected to increase strongly, the introduction of heat pumps becomes an interesting alternative. Furthermore, when aiming to create urban environments in which no fossil fuels are combusted, heat pumps with electrical heating elements might become the standard technology for space heating. Finally, as the individual and collective gas infrastructure will eventually need restructuring, we expect heat pumps with electrical heating elements to penetrate the heating market. Still, because of the large uncertainties as price development and active policy on insulation, the necessary network investments are also calculated in situations with no introduction of the heat pump, resulting in much lower network expansion costs of approximately 105 million Euros. This indicates a large effect of heat pumps on the total necessary network expansion investment costs.

On the other hand, the introduction of electric vehicles seems likely. Firstly, electric vehicles have large mechanical advantages over other types of vehicles, like gas-fuelled cars or hydrogen cars. Furthermore, the major obstacle for a large scaled introduction of electric vehicles (the battery) is subject of immense national and international research projects, allowing for large technical and economical progress. Major industrial players and energy suppliers regard electric vehicles as an opportunity to extent the electricity storage capacity in cities; together with incentives from EU and national governments, this makes the market penetration of electric vehicles likely. From the viewpoint of storage capacity, we expect a large progress in electricity storage, especially in battery technology. However, the extent to which batteries will have additional capacity is very uncertain; we have assumed the use of current battery technology and capacities.

The social-demographic and economic assumptions and the introduction of heat pumps with electrical heating elements have a large influence on the necessary network expansion investments. The ECN (2010) framework has a strong methodological underpinning, and therefore we assume that the future will not deviate strongly from the stated framework. Furthermore, we expect the market introduction of heat pumps with electrical heating elements, because the expected price developments, the suitability of electricity for implementing renewable energy sources in the built environment, and the governmental strive for energy neutral urban environments. Therefore, we expect the network operators – and thus the governmental agencies and eventually the energy consumers – to face large additional investments in the next thirty years.

## 7. Conclusions

The current energy distribution networks are not equipped for facilitating future sustainable transitions in energy systems. Two major concerns for the future electricity network exist, which are expected to require large investments: maximum peak loads and distributed generation capacity. This article addresses the maximum peak load aspect, and intends to explore the upper limits for necessary future network investments using a scenario approach. In the constructed scenario, three policy variants are incorporated. Furthermore, heat pumps and electrical vehicles are identified to be technologies that present the biggest threat to peak load increases. In the constructed, the total maximum electricity peak load in Eindhoven is expected to increase from 198 MVA in 2009 to approximately 600 MVA in 2040. The maximum load flow increases more than the average load on the network in this scenario, which implies that the average yearly network utilization will decrease.

The necessary investment for facilitating the developed scenario is estimated at 305-375 million Euros. This number is not corrected for inflation and would have to be invested in the period between 2010 and 2040. The estimate is based on facilitating the scenario using only the traditional network, without the benefits of new technologies like distributed generation or smart functionalities like active demand. Over 80% of the total required investment has to be invested in the MV network levels, and only 20% in the LV network. The total required investment would mean an average investment of more than €3,000 per connection. The required network capacity is determined by the load profile, the average peak load, and the variance in the individual loads. For example, even though heat pump loads represent the biggest increase in peak loads, the price per kW increased peak load is lower than for the basic use peak load increase. The total cost projections show that the increase in total annual electricity use is not an important factor in determining the network investments needed.

Presenting an estimate of the financial consequences of the developed scenario is necessary. In order for municipal, regional, or national governments to be able to make more efficient, economical and sustainable choices on future network developments, it is important to have an estimate of what the required investments are in different scenarios. In an open discussion about future energy systems, this can be helpful. This article shows that apparent economical and sustainable policy choices, like introducing heat pumps and electric vehicles, can have severe financial and economical consequences for electricity networks. Changes in time, place, and form of electricity demand and supply have potential consequences for energy networks and systems. Therefore, such policy choices should be made from the viewpoint of the total integral system of energy, thereby evaluating the economic implications of changes to the entire energy system, including generation, (smart) grid development, and consumption. Governmental agencies should communicate and tune their actions in stimulating sustainable energy generation, changing energy consumption patterns, and introducing new end-use technologies with the network operators in order to avoid unexpected necessary investments or network capacity shortages. Furthermore, it is important for policy makers to formulate a vision on the future energy system of cities on short term, because achieving a different – more sustainable – energy system requires time and demands for investments to be made on short term. This implies that this vision should exceed the political cycles of 4 years, and requires long term guarantees for market parties.

Concerning the former application of the fixed and intended Clean and Efficient policy in the Netherlands, we can conclude that the effects on electricity demand, peak loads and necessary network investments are substantial. So, from a consumption point of view, the governmental policy is very effective. However, from the point of view of the distribution of energy, the necessary policy is almost absent. For instance, regulators should be aware that the introduction of the unbundling of the energy system components (generation, distribution, and consumption) obstructs the development of an optimal and integrated energy system. Additionally, it is advisable to reconsider the regulations with which the network operators are currently assessed and funded; the current regulation prevents network operators to participate actively in developing the energy systems of the future. Finally, from the viewpoint of end-use technologies and energy generating technologies, governments should make clear supporting choices and reserve investment space for the introduction of the most promising technologies.

## 7. Discussion

Energy carriers are often interchangeable; only when the choice of energy carrier for specific purposes can be predicted, can accurate projections for individual networks be generated. This research focused on the future of the electricity network. Given the limitations in projecting future requirements for individual energy networks, providing insight into the extremes seems the best option, through creating a lower and upper limit to the range of possible future requirements. This project aimed to provide the upper limit for the electricity network requirements and the related necessary investments. It discarded the potential risk that distributed generation poses to network operations. However, the aspects on which a worst case scenario can be modeled do affect each other (e.g., Lamont, 2008). Even though their relation was not studied in detail, it stands to reason that combining both scenarios (peak load increases and the expected growth of decentralized energy generation) will positively affect the impact of the effects of the individual scenarios. It is therefore important to realize that the projected result is an upper limit.

Furthermore, the projected required investment is specific to Eindhoven to a certain extent. Whereas the general scenario is based on national projections and therefore valid for most urban areas in the Netherlands, the cost estimate is not. Network philosophy, design, operational procedures and prices on which the projection is based are specific to the network of Eindhoven. It would thus be unwise to literally assume the projected investment requirement to be valid for other urban areas. However, it gives an indication of what might happen under certain circumstances; we showed that choices in energy generation and end-use technologies can have large impacts in network capacities and necessary investments. The assumptions made are location specific and will need to be checked or reconsidered for every simulation. For example, these base loads will not apply to any environment where a heat distribution network is or will be installed, nor will it apply to newly (re)developed areas.

The method of estimating required investments is based upon figures on the number of current network components, on estimated necessary addition of these components for satisfying the demand during peak times, and on component prices. Due to confidentiality, which is related to market positions and security, these figures are not represented in this article. The method of estimating investments has been developed in close cooperation with experts from the network operators Endinet and Alliander, utilizing their expertise and experience to come to sensible assumptions.

### References

CBS (Netherlands Central Bureau for Statistics), 2010. Hernieuwbare energie in Nederland 2009, The Hague, The Netherlands.

CBS Statline, 2010. Werkgelegenheid, arbeidsduur en lonen van werknemers, The Hague, The Netherlands. [www.statline.cbs.nl]

Commission of the European Communities (CoEC), 2008a. COM(2008) 772: Energy efficiency: delivering the 20% target, MEMO/08/699, Brussels.

Commission of the European Communities (CoEC), 2008b. COM(2008) 782: Green Paper: Towards a secure, sustainable and competitive European energy network, MEMO/08/694, Brussels.

Commission Kist, 2006. Bevindingen van de Commissie Validatie “Splitsing Energiebedrijven”, Ministry of Economic Affairs, Final Report.

Cossent, R., Gomez, T., Frias, P., 2009. Towards a future with large penetration of distributed generation: Is the current regulation of electricity distribution ready? Regulatory recommendations under a European perspective, Energy Policy, 37, 1145-1155.

Duin, C. Van, 2009. Bevolkingsprognose 2008-2050: naar 17,5 miljoen inwoners. In: CBS, Bevolkingstrends, Statistisch kwartaalblad voor de demografie, year 57, quarter 1, pp 15-22.

Duin, C. Van, and Loozen, S., 2009. Huishoudensprognose 2008-2050: uitkomsten. In: CBS, Bevolkingstrends, Statistisch kwartaalblad voor de demografie, year 57, quarter 3, pp. 14-19.

Dutch Energy Chamber, 2009. Bespiegelingen op de toekomst van de regulering van het netbeheer, Netherlands Competition Authority (NMa), Ministry of Economic Affairs, The Hague.

ECN, 2010. Reference Projection Energy and Emissions 2010-2020, Energy Research Centre of the Netherlands (ECN), Petten, the Netherlands.

ECN MonitWeb, 2011. Energie in Nederland, www.energie.nl, Energy Research Centre of the Netherlands (ECN), Petten, the Netherlands.

Energy Data Services Nederland (EDSN), 2009. Profielen 2010 Elektriciteit, version 1.00, Baarn.

European Parliament, 2009. Directive 2009/28/EC on the promotion of the use of energy from renewable sources, Publication Reference 2009/28/EC, Brussels.

European Regulators Group for Electricity and Gas (ERGEG), 2009. Position Paper on Smart Grids, Publication Reference E09-EQS-30-04, Brussels.

Federation Holland Automotive, 2009. Naar een snelle en grootschalige introductie van de elektrische auto in Nederland, Hoofdlijnen voor een nationaal programma elektrische voertuigen, Zoetermeer, the Netherlands.

Hanschke, C.B., Uyterlinde, M.A., Kroon, P., Jeeninga, H., and Londo, H.M., 2009. Duurzame innovatie in het wegverkeer, een evaluatie van vier transitiepaden voor het thema Duurzame Mobiliteit, Energy Research Centre of the Netherlands (ECN), Petten, the Netherlands.

Harmsen, R., Breevoort, P. van, Planje, W., Bakker, E., Wagener, P., 2009. Energiebesparing- en CO2-reductiepotentieel hybride lucht/water warmtepompen in de bestaande woningbouw, Ecofys, Utrecht.

Harrison, G.P., Piccolo, A., Siano, P., Wallace, A.R., 2007. Exploring the Tradeoffs between incentives for distributed generation developers and DNOs, IEEE Transactions on Power Systems, 22(2), 821-828.

Joode, J. de, Jansen, J.C., Welle, A.J. van der, Scheepers, M.J.J., 2009. Increasing penetration of renewable and distributed electricity generation and the need for different network regulation, Energy Policy, 37, 2907-2915.

Kiviluoma, J., and Meibom, P., 2010. Influence of wind power, plug-in electric vehicles, and heat storages on power system investments, Energy, 35, 1244–1255.

Lamont, A.D., 2008. Assessing the long-term system value of intermittent electric generation technologies, Energy Economics, 30(3), 1208-1231.

Lehtonen, M., and Nye, S., 2009. History of Electricity network control and distributed generation in the UK and Western Denmark, Energy Policy, 37, 2338-2345.

Lumig, L. van, 2009. Impact DG en ‘nieuwe belastingen’ op het LSnet in bestaande woonwijken, Research report Laborelec, HERMES DG 3 Phase 2, Publication Reference LBE00865320, Linkebeek.

Lund, H., 2005. Electric grid stability and the design of sustainable energy systems, International Journal of Sustainable Energy, 24(1), 45–54.

Lund, H., and Kempton, W., 2008. Integration of renewable energy into the transport and electricity sectors through V2G, Energy Policy, 36, 3578– 3587.

MacKay, D.J.C., 2009, Sustainable Energy - Without the Hot Air, UIT Cambridge Ltd., Cambridge, UK.

Mathiesen, B.V., and Lund, H., 2009. Comparative analyses of seven technologies to facilitate the integration of fluctuating renewable energy sources, IET Renewable Power Generation, 3(2), 190-204.

Ministry of Transport and Public Works, 2009. Plan van aanpak elektrisch rijden, Publication Reference VENW/DGMO_2009/4571, The Hague.

Pepermans, G., Driesen, J., Haeseldonckx, D., Belmans, R., D’haeseleer, W., 2005. Distributed generation: definition, benefits and issues, Energy Policy, 33, 787-798.

Raineri, R., Rios, S, Vasquez, R., 2005. Business opportunities and dynamic competition through distributed generation in primary electricity distribution networks, Energy Policy, 33, 2191-2201.

Sequoia, 2005. Waardering van de Nederlandse Energiedistributiesector, Study for Dutch Ministry of Economic Affairs, see: Commission Kist (2006).

Shahidehpour, M., Yamin, H., and Li, Z., 2002. Market Operations in Electric Power Systems: Forecasting, Scheduling, and Risk Management, John Wiley and Sons, New York.

Shaw, R., Attree, M., Jackson, T., 2010. Developing electricity distribution networks and their regulation to support sustainable energy, Energy Policy, 38, 5927-5937.

Sheblé, G.B., 1999. Computational Auction Mechanisms for Restructured Power Industry Operation, Kluwer, Norwell, MA.

Sluijs, P. van der, 2009. Elektrisch vervoer en elektrische netten, Liander, Arnhem.

Verbong, G.P.J. and Geels, F.W., 2010. Exploring sustainability transitions in the electricity sector with socio-technical pathways, Technological Forecasting and Social Change, 77(8), 1214-1221.

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

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### Abstract

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

**Keywords:** Geothermal Heat Implementation, System Dynamics, Scenarios

### 1. Introduction

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

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

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

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

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

## 2. Geothermal energy

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

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

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

### *2.1 Barriers to deployment; challenges and opportunities*

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

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

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

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

## 3. System Dynamics

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

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

## 4. Stock and flow model

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

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

### *4.1 Sub-model 1: Consumer costs for geothermal heat*

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

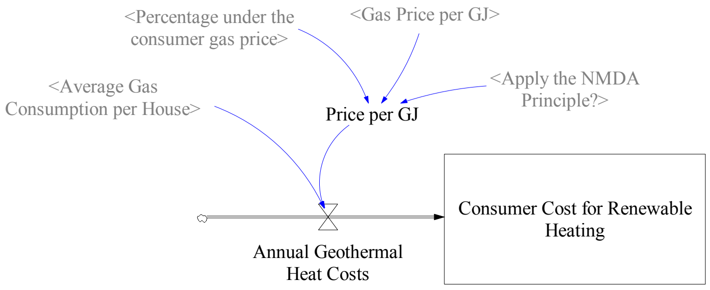

Figure 1: Consumer costs for geothermal heat

### *4.2 Sub-model 2: Heating grid connections*

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

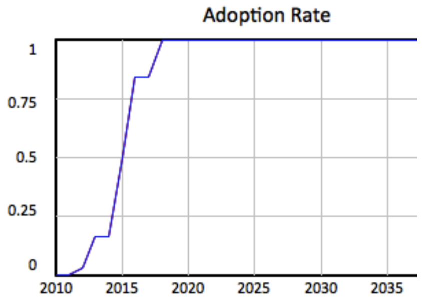

Figure 2: Assumed Adoption Rate

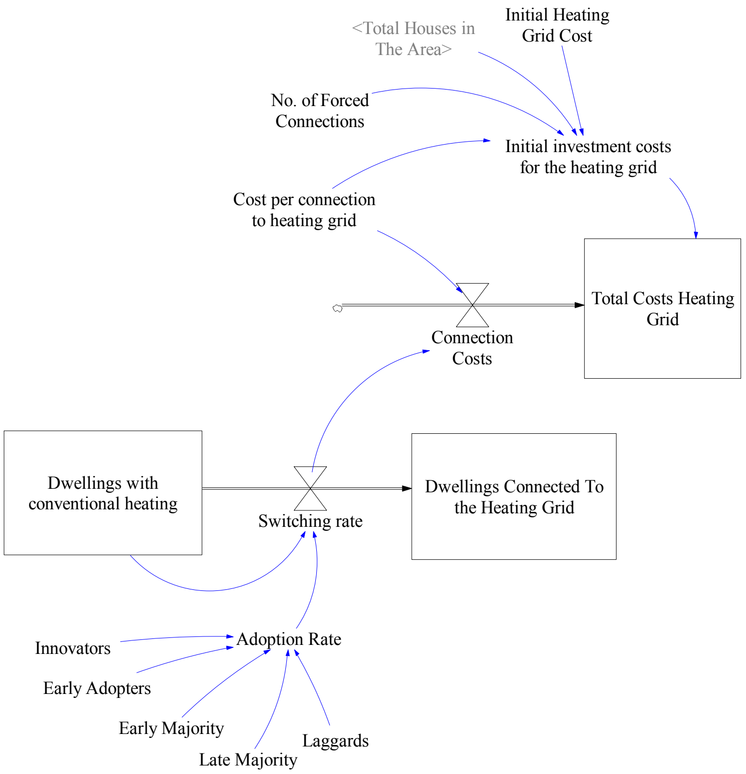

Figure 3: Heating Grid Connections

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

*Switching rate =*

*Adoption Rate * Dwellings with conventional heating*

*Connection costs =*

*Switching rate * Cost per connection to heating grid*

*Initial investment costs for the heating grid =*

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

*Total Costs Heating Grid =*

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

### *4.3 Sub-model 3: Financial calculations*

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

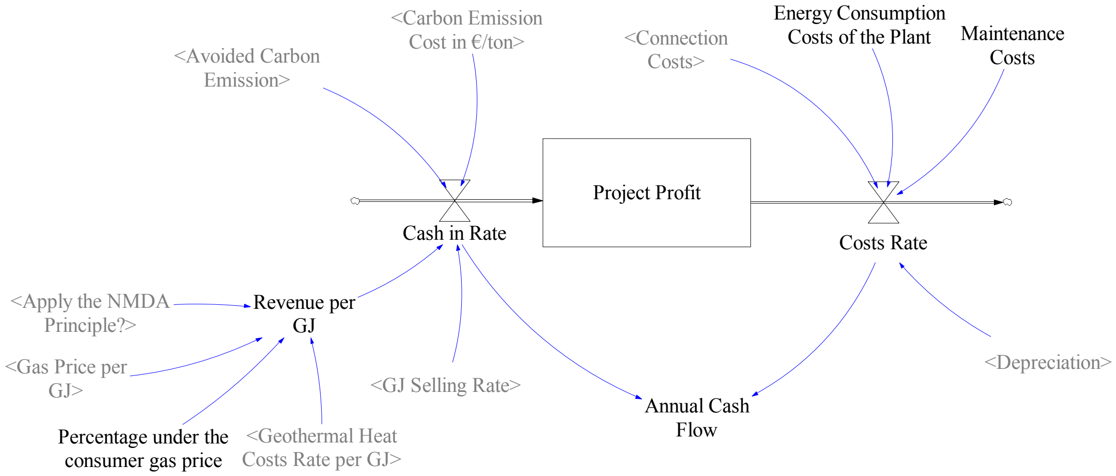

Figure 4: Cash flow Calculation

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

*Revenue per GJ =*

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

*Cash in Rate =*

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

*Costs Rate =*

*Connection Costs + Energy Consumption Costs of the Plant +*
*Depreciation + Maintenance Costs*

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

## 5. Scenarios

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

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

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

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

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

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

| | **Strong Europe** | **Global Economy** |
|---|---:|---:|
| Renewable energy | Continue on current policy, although lower subsidy prices | Same to SE, although policy will be cancelled after 2020 |
| Carbon Trading before 2020 | 2 €/ ton (2005)<br>7 €/ ton (2010)<br>35 €/ ton (2020) | Same to SE |
| Carbon Trading after 2020 | 58 €/ton (2030)<br>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)<br>230 PJ (2040)<br>annual decline 1% | 340 PJ (2006)<br>305 PJ (2040)<br>annual decline 0.3% |
| Gas Price | annual increase 0.4% | annual increase 0.8% |

## 6. System Solutions for Geothermal Energy Applications

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

### *6.1 Geothermal Energy Plant Capacity*

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

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

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

### *6.2 Geothermal energy plant and heating grid costs*

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

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

### *6.3 Three geothermal energy solutions*

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

Table 3: Geothermal Energy Plant Specifications

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

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

## 7. Case selection

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

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

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

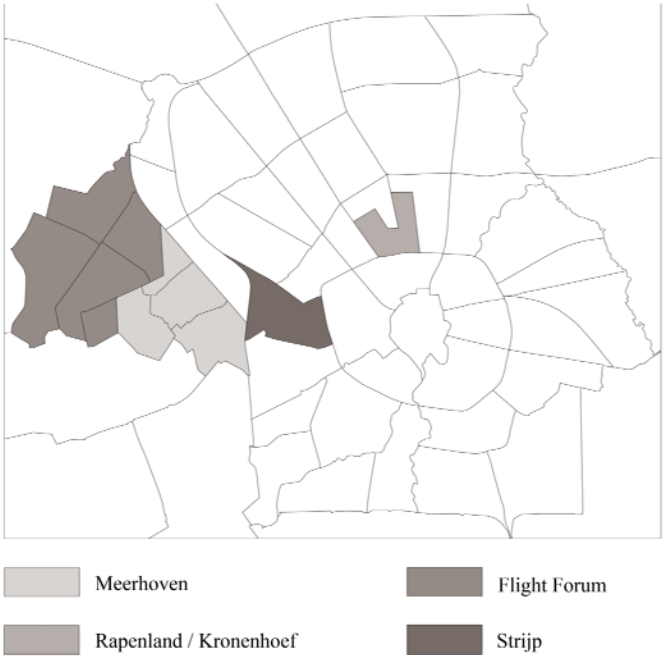

Figure 5: Selected cases in Eindhoven (case 1 = Meerhoven; case 2 = Rapenland / Kronehoef; case 3 = Flight Forum, Meerhoven, and Strijp)

### *7.1 Case 1: Meerhoven*

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

### *7.2 Case 2: Rapenland & Kronehoef*

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

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

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

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

Table 4: Case details

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

## 8. Results

### *8.1 The feasibility of geothermal heat under different scenario assumptions*

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

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

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

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

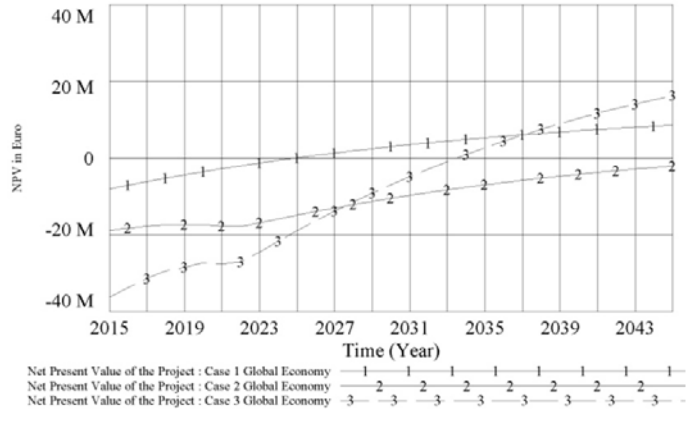

Figure 6: Net Present Value under Global Economy scenario

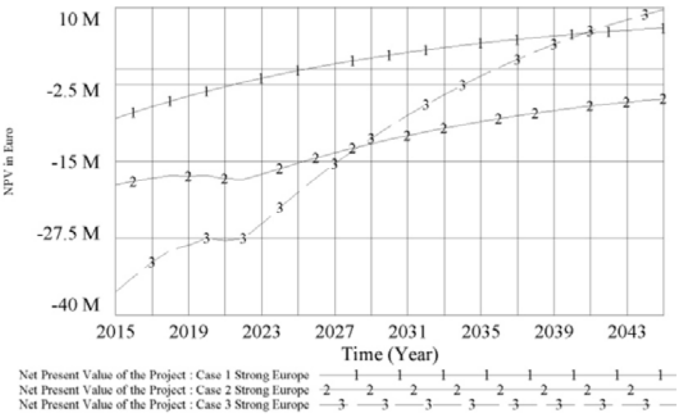

Figure 7: Net Present Value under Strong Europe scenario

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

### *8.2 Avoided carbon emission under scenarios*

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

Table 6: Cumulative avoided carbon emission

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

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

### *8.3 Consumer Costs for Geothermal Heat under Scenarios*

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

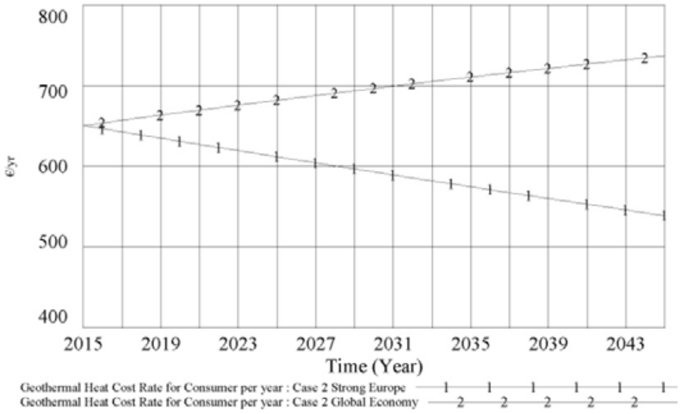

Figure 8: The Geothermal Heating Costs for Consumers for case 2

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

## 9. Sensitivity Analysis

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

### *9.1 Connection Rates*

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

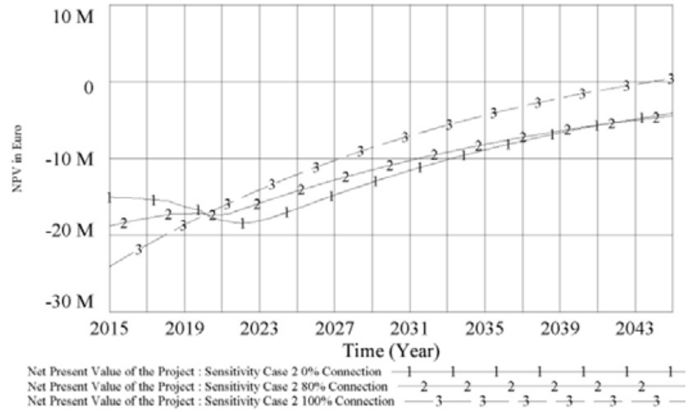

Figure 9: Sensitivity analysis – Connection Rates (Case 2, GE scenario)

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

*9.2 NMDA Price*

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

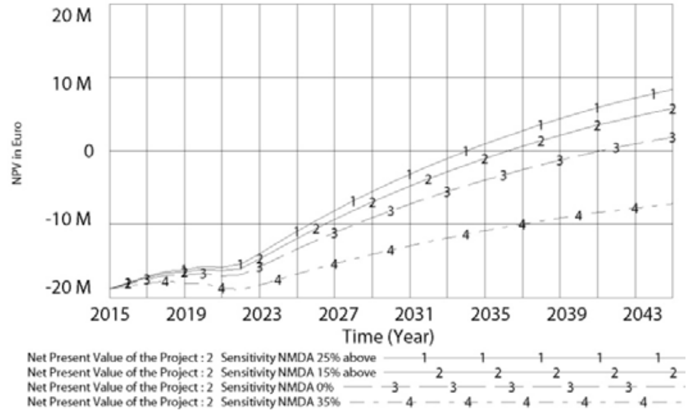

Figure 10: Sensitivity analysis – NMDA Rates (Case 2)

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

### *9.3 Heating Grid Costs*

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

Table 7: Sensitivity analysis – Heating grid costs

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

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

### *9.4 Selling Carbon Rights*

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

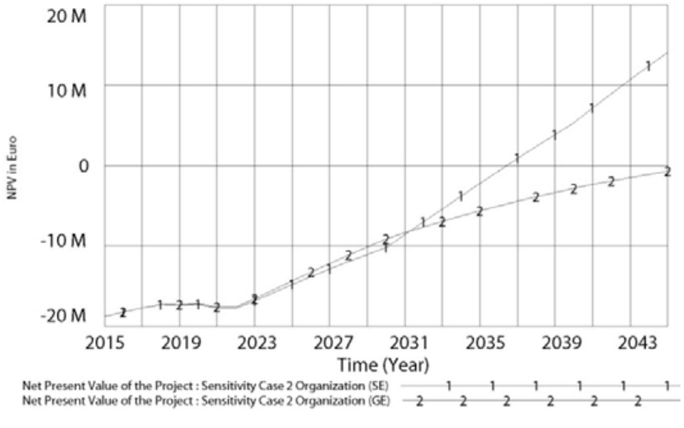

Figure 11: Sensitivity analysis – Selling carbon emission rights (Case 2)

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

## 10. Conclusions

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

### *10.1 Benefits for governments*

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

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

### *10.2 Benefits for consumers*

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

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

### *10.3 Benefits for investors*

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

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

### *10.4 System interventions*

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

## References

Aaheim, H., Bundschuh, J., 2002. The Value of Geothermal Energy for Developing Countries, in: Chandrasekharam, Bundschuh (Eds) Geothermal Energy Resources for Developing Countries, Lisse, Swets&Zeitlinger, pp 37-51

AgentschapNL, 2010. Wamte in Nederland. AgentschapNL, Dutch Ministry of Economic Affairs, the Hague, the Netherlands..

Axelsson, G., 2010. Sustainable geothermal utilization - Case histories; definitions; research issues and modeling. Geothermics 39, 283-291.

Barbier, E., 2002. Geothermal energy technology and current status: an overview. Renewable and Sustainable Energy Reviews 6 (1-2), 3-65.

Bloomquist, R., Lund, J., 2000. Resource delopment potential-revenue generation potential: only a balanced approach can lead to district energy development. World Geothermal Congress. Kyushu-Tohoko, Japan.

CBS Statline, 2011a. Energiebalans. Centraal Bureau voor de Statistiek, Heerlen / The Hague, The Netherlands. [statline.cbs.nl]

CBS Statline, 2011b. Industrie en Energie. Centraal Bureau voor de Statistiek, Heerlen / The Hague, The Netherlands. [statline.cbs.nl]

ECN, 2006. Welvaart en Leefomgeving 2002-2040. Chapter 5: Energy. Energy Research Centre of the Netherlands (ECN), Petten, the Netherlands.

ECN, 2009. Actualisatie referentieramingen: Energie en emissies 2008-2020. Energy Research Centre of the Netherlands (ECN), Petten, the Netherlands.

ENGINE, 2007. Economic Analysis of Geothermal Energy Provision in Europe. Enhanced Geothermal Network of Europe, Workpackage 5, Deliverable D35.

Forrester, J.W., 1961. Industrial dynamics. Waltham, MA, Pegasus Communications.

Gleason, T.C.J., 1993. Renewable energy for America's cities: advanced communities energy systems. Proposed Research Development and Demonstration.

Gunnlaugsson, E., Ragnarsson, A., Stefansson, V., 2001. Geothermal energy in Iceland. International Symposium, Izmir, Turkey.

Henriques, H., Sadorsky, P., 2008. Oil prices and the stock prices of alternative energy companies. Energy Economics 30(3), 998-1010.

IF Technology, 2011. Diepe geothermie 2050. In cooperation with Ecofys and TNO. AgentschapNL, Dutch Ministry of Economic Affairs, the Hague, the Netherlands.

Janssen, L., Okker, R., Schuur, J., 2006. Welvaart en Leefomgeving, scenarios for the future of the Netherlands. MNP, CPB, RPB, the Netherlands.

Lako, P., Luxembourg, S.L., Ruiter, A.J., Groen, B. in 't, 2011. Geothermische energie en de SDE: Inventarisatie van de kosten van geothermische energie bij opname in de SDE. Energy Research Centre of the Netherlands (ECN), Petten, the Netherlands.

Loftsdottir, A., Thorarinsddottir, R., 2006. Energy in Iceland. Reykjavik, Iceland: Ministries of Industry and Commerce.

Lund, J.W., 2002. Direct Heat Utilization of Geothermal Resources, in: Chandrasekharam, Bundschuh (Eds) Geothermal Energy Resources for Developing Countries, Lisse, Swets & Zeitlinger, pp. 129-147.

Lund, J.W., Freeston, D.H., Boyd, T.L., 2011. Direct Utilization of Geothermal Energy 2010 Worldwide Review. Geothermics 40, 159-180.

Mock, J.E., Tester, J.W., Wright, P.M., 1997. Geothermal Energy from the Earth: its Potential Impact as an Environmental Sustainable Resource. Annual Reviews of Energy and the Environment 22, 305-356.

Mulder, E.F.J. de, Geluk, M.C., Ritsema, I., Westerhoff, W.E., Wong, T.E., 2003. De ondergrond van Nederland. TNO, The Hague, the Netherlands.

Richardson, G.P., Pugh, A.L., 1981. Introduction to System Dynamics Modeling with DYNAMO. Cambridge: MIT Press, reprinted by Productivity Press, Portland.

Rogers, E.M., 1962. Diffusion of innovations. Glencoe, Free Press.

Seyboth, K., Beurskens, L., Langniss, O., Sims, R., 2008. Recognising the potential for renewable energy heating and cooling. Energy Policy 36, 2460-2463.

Tao, Z., 2010. Scenarios of China's oil consumption per capita (OCPC) using a hybrid Factor Decomposition–System Dynamics (SD) simulation. Energy 35(1), 168-180.

Thorsteinsson, H. H., Tester, J.W., 2010. Barriers and enablers to geothermal district heating system development in the United States. Energy Policy 38, 803-813.

TNO, 2007. Exploration: Renewed interest in geothermal energy. Utrecht, TNO Energy: Oil and Gas.

TNO, 2009. Toekomstverkenning Nederlandse Energiehuishouding. Delft: TNO Bouw en Ondergrond.

TNO, 2010a. Delfstoffen en aardwarmte in Nederland: Jaarverslag 2009. The Hague.

TNO, 2010b. Natural Resources and Geothermal Energy in the Netherlands, Annual Review 2010 – A review of exploration and production activities and underground storage. TNO, Dutch Ministry of Economic Affairs, Agriculture and Information, The Hague.

Wong, T.E., Lokhorst, A., 2007. Geothermal energy. Geology of the Netherlands, 341-346.

Blokhuis, E.G.J., Advokaat, B., Schaefer, W.F. Assessing the Performance of Dutch Local Energy Companies, Energy Policy, 2nd round review, minor revisions

## Assessing the Performance of Dutch Local Energy Companies

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### Abstract

According to binding European Union agreements, the Netherlands has to cover at least 14 percent of its total energy use with renewable energy sources by 2020. However, the share of renewable energy in the Netherlands is small and hardly increasing. In 2010, renewable energy in the Netherlands accounted for only 3.8% of the national energy use, and has decreased with 0.4% compared to 2009. A cause of the stagnating renewable energy generation in the Netherlands is the absence of a nation-wide, clear and consistent long-term policy on the introduction of renewable energy. In order to overcome the current standstill in renewable energy adoption, several Dutch municipalities take the initiative and establish Local Energy Companies (LECs). However, to date, it is unclear which LEC type performs best. This research aims to compare the performance of existing LECs on three aspects: technology, finance, and organization. Furthermore, the performance of existing LECs is compared with theoretical reference LECs, in order to estimate efficiencies and opportunities for improvements. Finally, the influence of the recent changes in the Dutch subsidy scheme on LEC performance is examined. In order to achieve these aims, the benchmark method Data Envelopment Analysis is employed.

**Keywords:** Local Energy Company, Renewable Energy Technology, Data Envelopment Analysis

### Introduction

In 2010, the energy use in the Netherlands summed up to 3,495 PJ (CBS Statline, 2011), and according to recent ECN (2010) predictions, the Dutch energy demand will slightly increase under all policy scenarios. A large share of this energy demand is provided by combusting fossil fuels. However, numerous problems occur as a result of the large scaled fossil fuel combustion in the conventional energy sector, like climate change – due to an increasing level of greenhouse gas emissions – and international conflicts concerning the property rights of stocks of oil, coal or gas. In order to reduce the negative effects of the current conventional way of generating energy, it is important to increase the share of renewable energy.

Therefore, the Dutch government entered into a binding agreement with the European Union in the beginning of 2009, in which it was recorded that the Netherlands has to cover at least 14 percent of its total energy use with renewable energy sources by 2020. However, the share of renewable energy in the Netherlands is small and hardly increasing. In 2010, renewable energy in the Netherlands accounted for only 3.8% of the national energy demand, a decrease of 0.4% compared to 2009 (CBS, 2010). In the years before 2009, the renewable energy share grew on average with 0.5% annually. Possible causes of the stagnating renewable energy generation in the Netherlands are the absence of a clear and consistent long-term policy on the introduction of renewable energy – resulting in a lack of long-term contracts and political obligations for utilizing renewable energy – and the opposite interests of the established conventional energy industry; one cannot expect this industry to initiate renewable energy transitions (Hvelplund, 2006; Lund, 2010).

In response, several Dutch municipalities took the initiative by setting ambitious goals regarding energy neutrality. This local bottom-up approach fits the characteristics of renewable energy technology, which typically benefits from local realization and distribution. This has led to a number of municipalities establishing their own Local Energy Company (LEC), in order to initiate renewable energy projects and to achieve the energy neutrality ambitions. In most cases, the municipality aims to collaborate with other local stakeholders, like housing associations; in other cases, local residents take the initiative to establish a LEC.

Establishing a LEC involves many technical, financial, and organizational complexities. These include legal conditions under which organizations or projects can operate, and the establishment of a scheme's economic and technical viability (Dunning and Turner, 2005). Furthermore, it is essential to learn from previous experiences (e.g. Walker *et al.*, 2007). Therefore, this research aims to compare the performance of existing LECs on three major aspects: technology, finance, and organization. Furthermore, the performance of existing LECs is compared with theoretical reference LECs, in order to estimate efficiencies and opportunities for improvements. Finally, the influence of the recent changes in the Dutch subsidy scheme on LEC performance is examined. In order to achieve these aims, the benchmark method Data Envelopment Analysis (Charnes *et al.*, 1978; Cooper *et al.*, 2006) is employed.

## Local Energy Companies

Local Energy Companies (LECs) are regarded as a promising option to accelerate the production of renewable energy and to increase energy efficiency. Existing LECs encompass a variety of local initiatives, often involving the local government. Collaboration with local governments is important for achieving business success, especially in the case of new LECs, because local governments have possibilities to perform feasibility studies, to establish contacts and contracts with other local actors, and to provide bank loan guarantees.

A main characteristic of a LEC is that it operates as a commercially independent and autonomous entity. In addition, a LEC has a strong local focus. The production, supply, and/or saving of energy are accommodated in a geographically demarcated area. Often it involves a partnership of local actors and citizens together with a municipality or housing association (Manfren *et al.*, 2011), but other market participants can also participate. It is essential to provide end-users with power and interest in the LEC; local actors should benefit from the LEC activities. This is important for two reasons. Firstly, an increased involvement of local residents and companies leads to a higher acceptance of renewable energy. Secondly, this increased involvement – and thus investment – of local stakeholders will raise the equity of the LEC. In order to guarantee the involvement of local actors, local energy companies generally aim at delivering social returns on investments.

Summarizing, Local Energy Companies are regarded as autonomous entities, with the aim of implementing one or more of the following activities on a local scale: (a) production, delivery and management of renewable energy in their region; (b) financing and/or participation in the renewable energy projects; and/or (c) energy savings. In this research, we focus on LECs that employ proven renewable energy techniques, which will be discussed in the next paragraph.

### *Renewable Energy Techniques*

The activities of a LEC may relate to producing renewable heat as well as renewable electricity. In this research, four proven renewable energy techniques (RETs) are regarded: photovoltaic systems, wind turbines, biomass and bio-gas installations, and geothermal heat and cold storage. The different techniques are described in detail with focus on performance facts and figures on investments, costs and yields; the technology behind the different RETs is not discussed.

#### Photovoltaic (PV) systems

In 2010, the worldwide installed PV capacity reached 18.2 GW, representing an annual growth of 139%. The PV industry generated $82 billion in global revenues in 2010, growing 105% from $40 billion in 2009. Meanwhile, worldwide solar cell production reached 20.5 GW in 2010, up from 9.86 GW in 2009. This resulted in a strong price decrease of PV systems; prices per Watt Peak decreased from $5.50 in 2000 to approximately $2.50 in 2010. In the Netherlands, 68 MW was installed in 2009, producing 46 million kWh (CBS, 2010). According to ECN (2011), current investment costs of solar panels in the Netherlands are approximately €2.20/Wp.

#### Wind energy

In 2010, a total capacity of 194.4 GW of wind turbines was installed worldwide. In the Netherlands, the capacity of wind energy in 2009 added up to 2,221 MW, of which 1,993 MW was installed on land. This makes wind energy an important renewable energy source in the Netherlands, covering 30% to the total renewable energy production in the Netherlands in 2009 (CBS, 2010). According to AgentschapNL (2010a), the investments for wind energy are €1,430/kW; operational costs are €0.011/kWh, grid costs €11/kW/year, and land costs approximately €15/kW/year. Furthermore, taxes account for €18,600/year, making the development of wind farms without subsidiary support almost impossible.

#### Bio-energy

Depending on the conversion-technique, bio-energy can be transformed into electricity, heat, and gaseous or liquid fuels. In the Netherlands, about 150 bio-energy plants are realized; bio-energy is the most important Dutch renewable energy source. It yielded 111,098 TJ in 2009, of which the most important large-scale applications – e.g. waste-incineration, the use of bio-gas in electricity power plants, and the use of bio-fuels in transportation – contributed 68,957 TJ (CBS, 2010). Average figures on investments, costs and performance are difficult to combine. The numbers are very divergent and there are many techniques to invert biomass into bio-energy. Furthermore, the yields depend strongly on the employed technique to create bio-energy. However, there are enough examples of bio energy plants build in the Netherlands; financial and performance figures can be derived from these cases. In table 1, two examples are presented: a wood-fired biomass plant Schijndel – operating since 1997 – and a fertilizer-fermentation plant in Sterksel, operating since 2002.

Table 1: Two biomass project in the Netherlands (AgentschapNL, 2009)

| | Schijndel (wood-fired biomass plant) | Sterksel (fertilizer fermentation plant) |
|---|---|---|
| Capacity | 7.4 MWth<br>1,400 kWe | 45 kWth<br>31 kWe |
| Energy production | 8.4 GWh / year<br>13,500 GJ / year | 180,000 kWh / year |
| Availability | 8,000 hrs / year (91%) | 4600 ton fertilizer |
| Investments | € 4,800,000,-<br>€ 3,400 / kWe | € 200,000,-<br>€ 6,450 / kWe |
| Operation/Management | € 100,000 / year<br>Excl. biomass costs | Unknown |
| ROI time | 11 years | 7 years |

### Shallow geothermal applications

Shallow geothermal applications use the heat and cold that is stored in the subsurface for the heating (in winter) and cooling (in summer) of buildings. Heat pumps are applied for upgrading the heat or cold from the subsurface. In the Netherlands, a capacity of 121 MW was installed in 2009 (CBS, 2010). The heat pump investment depends on the type of heat pump and varies from €500/kWth to €2,000/kWth, including installation costs and individual source systems. The investment costs of a collective groundwater source are approximately €1,500/kWth. In the expanding heat pump market, the investments costs are continuously decreasing. The costs of an electric heat pump with ground source vary widely depending on capacity. For individual applications in new buildings, prices are between €9,000 and €20,000 for a plant capacity of 10 kWth. Project prices including ten to forty homes are considerably lower and in some cases well below €10,000 (AgentschapNL, 2010b). In major renovation projects, the investment costs of individual heat pumps are between €10,000 and €15,000. Typically, this involves smaller homes with a reduced capacity (4 to 10 kW per system). Payback periods of heat pump systems often exceed ten years. However, this situation changes because of decreasing heat pump prices and improvements in the systems.

### *Financial aspects*

When considering LECs and related renewable energy techniques, it is important to regard financial aspects of both the organization and the technology. In table 2, estimated financial parameters for most available RETs are represented. These parameters will be included in the data collection and analysis section; they form the basis of theoretical LEC performance with different renewable energy technologies (ECN and KEMA, 2010). In this article, the performance of existing LECs is compared to these theoretical LECs, in order to estimate efficiencies and opportunities for improvement.

Table 2: Financial parameters of renewable energy sources (ECN and KEMA, 2010)

| Financial parameters | Share equity | Interest | Return on equity | Economical lifetime | Yields per kWh | Yields per GJ |
|---|---|---|---|---|---|---|
| *RET* | *%* | *%* | *%* | *Years* | *€/kWh* | *€/GJ* |
| Manure co-fermentation | 20 | 6 | 15 | 12 | 0,182 | - |
| Green waste fermentation | 20 | 6 | 15 | 12 | 0,134 | - |
| Solid biomass 0-10 MWe | 20 | 6 | 15 | 12 | 0,213 | - |
| Solid biomass 10-50 MWe | 20 | 6 | 15 | 12 | 0,122 | - |
| Wind on land < 6MW | 20 | 5,1 | 15 | 15 | 0,096 | - |
| Solar Panels 1-15 kW | 0 | 2,6 | 2,6 | 15 | 0,333 | - |
| Solar Panels 15-100 kW | 15 | 5,1 | 15 | 15 | 0,280 | - |
| Heat & cold storage (incl heat pump) | 20 | 6 | 15 | 15 | - | 11,81 (+ 285,64) |

## Subsidies

From a financial point of view, the available subsidies are very important for the financial feasibility of renewable energy projects. In the Netherlands, the prevailing subsidy scheme is called SDE (incentive scheme for sustainable energy production). The original SDE subsidy scheme, erected in 2008, subsidized the exploitation of new energy projects in which renewable gas or electricity is produced. The original SDE scheme was not designed as an investment subsidy; it functioned as a feed-in premium subsidy scheme (SenterNovem, 2008), and applied to different renewable energy production methods, e.g. onshore wind energy, solar PV systems, biomass, waste combustion, and renewable gas. Basically, the SDE scheme should provide a long-term security for the feasibility of projects; it covers the additional costs of producing renewable energy by paying the difference in cost price between fossil-based and sustainable energy.

The available budget is determined annually, and the project registration is open until the budget is finished. For some categories (solar panels and biomass), the registrations exceed the available budget, while for others (e.g. wind energy on land) the budget remains largely unused. The level of unused budget is much larger in reality because the SDE has to be requested before project realization and many investors (mainly individuals applying solar panels) decide not to install the production assets after the subsidy is granted.

In 2011, a new version of the subsidy scheme is introduced: SDE+. The main changes in the new SDE+ scheme are the introduction of one integral budget maximum, a phasing in the availability of the budget, the establishment of a maximum base amount (e.g. 15 ct/kWh for renewable electricity, and 104 ct/Nm$^3$ for renewable gas), and the introduction of a free category. Among the changes in permissible technologies are the allowance of larger scaled biomass projects, the exclusion of small scaled PV system projects with a capacity of less than 15 kWp, and the allowance of PV system projects that are larger than 100 kWp. With the new SDE+ scheme, almost 600 projects in the production of green gas and renewable electricity can be realized. The available annual budget is approximately €1.5 billion.

Compared to the subsidy schemes of other European countries, the Dutch scheme still offers relatively little security for investors due to unstable and often changing regulations and stimulations. Additionally, the Dutch scheme offers little technological and location-dependent differentiation in promoting renewable energy systems; all renewable energy projects get the same promotion, irrespective of employed technology or location of the project (Reiche and Bechberger, 2004). The consequences of the differences in subsidy approaches are discussed in the results section.

*Ownership models*

Choices in organizational structures (i.e. Partnership, Limited Liability Company) and ownership structures (i.e. how many owners, allocation of equity, changes over time) determine a range of important project variables, including access to and cost of capital, risk allocation, ability to use tax incentives, amount of local investment, and the complexity of the project. Various legal and financial models of ownership have been adopted in local initiatives. Generally, two different ownership model types can be distinguished. The first type of model is generally referred to as cooperative models (e.g. Walker *et al.*, 2007; Walker, 2008). The second 'individual' ownership model is specifically aimed at attracting investments, and is often legally organized as Limited Liability Company (LLC) (e.g. Bolinger, 2001; Bolinger and Wiser, 2006).

The main differences between these models are the aspects of profitability and investments. On the one hand, individual ownership models are regarded as more effective, because of the strong focus on achieving profit targets. On the other hand, it is estimated that cooperative models are necessary for ensuring the successful participation of community organizations in local renewable initiatives. Furthermore, the cooperative is said to fit perfectly with social trends of a growing need for transparency, local bonding, self-organization and responsibility.

Cooperative energy companies often have an association structure, in which local consumers are the members. To join, consumers pay a membership fee, which is used as the association's investment capital. Any profit is distributed annually among the organization's members. However, cooperative energy companies are not aimed at making profit but at providing its members with reliable and cost effective utility services. This model was one of the main success factors behind the development of renewable energy in Denmark (Hvelplund, 2006). Similar to cooperative ownership models are Community Charities – often organized as associations – and Development Trusts, which are community enterprises working to create wealth in communities and keep it there; these trusts trade on a 'not-for-personal-profit' basis, re-investing revenues back into the community and affecting social, economic and environmental outcomes.

The investment based individual ownership models were originally developed for farmers interested in investing in energy projects. In this respect, Bolinger and Wiser (2006) constructed a list of potentially viable ownership structures, like the Multiple Local Owner structure and two possible 'Flip' structures. The main advantages of individual ownership models are the lower transaction costs, lower levels of complexity, higher decision efficiencies, higher professionalization, and the availability of financing sources.

To determine the legal framework in which participation of end-users should be structured, it is important to trace how the project is financed and what rights are granted to participants. A common method of financing is the provision of capital by the founders of the LEC, which might by extended by joining participations. In these cases, the legal structures of public or private LLC are often used (in the Netherlands: N.V. (joint-stock company) or B.V. (limited company)), in which participation is achieved through shares. In addition, a cooperative legal form can be used, involving (negotiable) membership rights associated with subscription obligations. Other possible organizational structures are that of a foundation – in which the involvement of customers is structured through member participation with an annual financial fee – and that of a partnership (in the Netherlands: VOF or C.V.). Depending on the project, different legal forms are often combined in a group structure. Opposite to direct LEC participation, an investment institution can be established, for instance as a partnership, a mutual fund, or a limited liability participation. In this construction, the participant becomes partly owner of the assets or shareholder of the investment institution; in turn, this investment institution participates in a LEC.

**Benchmarking**

Benchmarking seems an interesting approach for comparing the performance of LECs with differing financial, organizational and technological characteristics. In general, benchmarking can be divided into two main categories: informal and formal benchmarking. Informal benchmarking can be defined as an unstructured approach to learn from the experience of other organizations, not following a defined process. Formal benchmarking is conducted consciously and systematically by organizations, and is again divided in two categories: Performance Benchmarking and Best Practice Benchmarking. Performance Benchmarking compares the performance levels of specific processes to identify opportunities for improvement and to set performance targets. Best Practice Benchmarking is searching for the best way or solution by studying other organizations that are high performers in particular areas of interest.

Several methods can be distinguished in executing a benchmark (Chung, 2011), of which the most important are Simple Normalization, Simple Regression Analysis, Data Envelopment Analysis, Stochastic Frontier Analysis, and Artificial Neural Network analysis. In this research, Data Envelopment Analysis (DEA) – a specific Best Practice Benchmarking method – is employed for benchmarking the existing Dutch Local Energy Companies. The contribution of DEA to assessing organizational efficiency has been intensified in recent years (e.g. San Cristobal, 2011), especially in the fields of Energy and Environment. DEA is focused on assessing efficiency of a limited and relatively homogeneous set of organizational Decision Making Units (DMUs), while other methods often focus on regression analysis rather than on identifying the 'best practice'.

*Data Envelopment Analysis (DEA)*

DEA, first introduced by Charnes *et al.* in 1978, is a linear programming technique for comparing the efficiency of a set of organizational Decision Making Units, in their use of multiple resources (inputs) to produce multiple outcomes (outputs) (e.g. Chung, 2011; Camanho, 2011). The comparison with the benchmark organizations allows determining the input and output targets corresponding to an efficient operation. If the greatest possible output per unit of input is achieved, a state of *absolute* or *optimum efficiency* has been reached; at this point, it is not possible to become more efficient without new technology or other changes in the production process (Scherman and Zhu, 2006). Differences in efficiency are due to the employed technology or production process, the management of that process, and/or the scale or size of the unit. DEA allows for the computation of the necessary improvements required in the inefficient unit's inputs and outputs to make it efficient.

Linear programming techniques are used to find the set of coefficients that will give the highest possible efficiency ratio of outputs to inputs for the unit being evaluated. The basic objective function in a DEA model – in which the efficiency rating $\theta$ for Unit *o* is maximized – is represented as follows:

$$\text{Maximize } \theta = \frac{u_1 y_{1o} + u_2 y_{2o} + \ldots + u_r y_{ro}}{v_1 x_{1o} + v_2 x_{2o} + \ldots + v_m x_{mo}} = \frac{\sum_{r=1}^{s} u_r y_{rj}}{\sum_{i=1}^{m} v_i x_{ij}}$$

where $u_r$ and $v_i$ are weight coefficients for respectively output *r* and input *i* ; $y_{rj}$ is the amount of output *r* , and $x_{ij}$ is the amount of input *i*. The weights can be determined with the help of the model: in this case, the numerator is maximized while the denominator is held constant. Additionally, a value of efficiency $\theta \leq 1$ is required. This results in the following linear programming model (Cooper *et al.*, 2006):

$$\max h_o = \sum_{r=1}^{s} u_r y_{ro}$$

$$\sum_{i=1}^{m} v_i x_{io} = 1$$

$$\sum_{r=1}^{s} u_r y_{rj} - \sum_{i-1}^{m} v_i x_{ij} \leq 0$$

$$u_r, v_i \geq 0$$

*DEA applications in Energy and Environmental studies*

DEA has attracted much attention as a relatively new and efficient approach to studying energy and environmental efficiency matters (Zhou *et al.*, 2008). The first DEA application in the electricity generation sector was the work of Färe *et al.* (1983), who measured the efficiency of electricity power plants in Illinois (USA) between 1975 and 1979, in order to relate the scores obtained to the regulation of the sector. Since, there are numerous applications of DEA in this research field. For instance, the study of Pollitt (1996) on the productive efficiency of nuclear power stations showed that DEA is a very powerful method in measuring performance of energy generation plants. More recently, several studies used DEA benchmarking for gaining insight in the efficiency of different types of thermal power plants (e.g. Sözen *et al.*, 2010; Liu *et al.*, 2010). There are also specific studies linked to the efficiency in the renewable energy sector, for example the DEA application of Iglesias *et al.* (2010), San Cristobal (2011) and Lins *et al.* (2012).

*DEA model for Local Energy Companies*

The executed DEA models in this research are CCR and Allocation models, which both give extensive results on efficiency scores. CCR is one of the most basic DEA models, which was initially proposed by Charnes *et al.* (1978). In this model, the optimal weights of the input and outputs may vary between DMUs; the weights are derived from the data instead of being fixed in advance. Weights are chosen in a way that assigns a best set of weights to each DMU, in which the term 'best' means that the resulting input-to-output ratio is maximized for each and relative to all other DMUs. CCR-efficiency exists of two parts: Radial and Technical efficiency. Radial efficiency is reached when the score of the DMU is one but there are nonzero slacks, which are excesses and shortfalls of inputs or outputs. Technical efficiency is achieved when the score of the DMU is one and has zero-slacks; in this situation the DMU is so-called CCR-efficient.

CCR models focus on the technical aspects of production. In contrast, the DEA Allocation models can be used to identify types of inefficiencies which can emerge for treatment when information on prices and costs are known. There are two different situations: one with common unit prices and costs for all DMUs and the other with differing prices and costs between DMUs. In this research, the prices and costs are expected to be different for all DMU's; therefore focus will be on the new cost-efficiency related models. Summarizing, the following efficiency models will be executed in the performance measurement of existing LECs (see Cooper *et al.*, 2006): CCR technical efficiency ($\theta^*$), CCR new technical efficiency ($\overline{\theta}^*$), new cost efficiency ($\overline{\gamma}^*$), and new allocation efficiency ($\overline{\alpha}^*$).

*Parameter estimation*
This research departs from the assumption that the chosen renewable energy technique, the financial aspects, and the organizational structure are important aspects for LECs. However, organizational structure is difficult to measure; this will be analyzed separately to derive lessons learned for future LECs. This leaves the techno-economic and financial aspects to be analyzed with DEA. In Iglesias *et al.* (2010) San Cristobal (2011), five interesting techno-economic and financial input parameters and four output variables are used. Inputs (I) are investment ratio or capital, implementation period, operating and maintenance (O&M) costs, labor, and fuels. Output parameters (O) are generated power, operating hours, useful life, and tons of $CO_2$ avoided. Interesting aspects that are not included in these studies are for example the plant size, revenues, profits (partly from subsidies), Return on Investments, and payback time of investments.

Including a wide range of parameters in DEA analyses requires the availability of many DMUs; a basic rule of thumb says that the number of DMUs should be at least twice the number of included parameters. In the Netherlands, the development of new LECs occurs only on a small scale, and most examples of Dutch LECs are still under construction or have no actual projects. Furthermore, the required information concerning in- an outputs of these companies is often not available. Therefore, it is necessary to reduce the number of in- and outputs, by aggregating similarities. When regarding input variables (I), plant size, investment ratio and O&M costs are indispensible. Other identified input parameters are incorporated within these three variables; for instance, labor is taken into account in the O&M costs parameter. Selecting the output (O) parameter is more complex. Since this research focuses on the business approach of LECS, the variables Tons of $CO_2$ avoided and Cost of avoided GJ energy are regarded less important and excluded; these variables become relevant in case emission trading is introduced. In the current situation, Produced energy and Revenue are most important variables from a business approach. Other variables – for example Profit and Payback time – can be derived from these output parameters.

**Data collection**

For the benchmarking model, a data collection among existing Dutch LECs is required. In the Netherlands, 62 LECs are established, of which 26 are initiated by local residents, 16 by local governments – this group is growing strongly in recent years – and 9 by private actors (mainly waste contractors and horticulture collectives). Furthermore, 5 LECs were organized as Public-Private Partnership (PPP), 4 were initiated by farmers, and 2 by housing associations. The established LECs also apply different types of RETs: 11 companies apply bio-energy, 16 companies use geothermal energy, 14 companies use wind energy, in 11 cases PV is applied, and 10 companies use a combination of techniques. Out of the total 62 LECs, twelve companies are selected to serve as DMU in the DEA analysis; this selection is made largely on the availability of sufficient technical, financial and organizational data. In table 3, the inputs and outputs of the selected LECs are presented.

Table 3: DEA data sheet of all analyzed DMUs

| Local Energy Company (LEC) | (I) Plant size $10^3$ kW | (I)Investment $10^3$ Euro/kW | (I)O&M costs $10^3$ Euro/year | (O)Energy $10^3$ GJ/year | (O)Revenue $10^3$ Euro/year |
|---|---:|---:|---:|---:|---:|
| Bio-energy Eindhoven (bio / E) | 11.50 | 1.52 | 880.00 | 64.19 | 2,050.00 |
| Bio-energy Fleringen (bio / H+E) | 0.42 | 1.46 | 66.00 | 3.24 | 118.00 |
| Patrimonium Energie (bio / H) | 0.40 | 0.53 | 29.67 | 2.28 | 48.64 |
| Thermo Bello (bio / H) | 1.75 | 0.34 | 244.37 | 9.10 | 258.61 |
| NDSM-Wharf (comb / H+E) | 2.45 | 0.42 | 232.44 | 7.80 | 282.90 |
| Onze Energie (wind / E) | 2.00 | 2.00 | 106.00 | 18.00 | 480.00 |
| SVDW Windpark (wind / E) | 12.60 | 0.89 | 611.10 | 93.60 | 2,496.00 |
| Windvogel (wind / E) | 2.76 | 0.99 | 167.79 | 18.11 | 448.51 |
| Meewind (wind / E) | 165.00 | 3.72 | 30,921.00 | 1,980.00 | 104,280.00 |
| Zonvogel (PV / E) | 0.12 | 2.13 | 4.90 | 0.37 | 23.46 |
| Zon op Noord (PV / E) | 0.02 | 3.05 | 1.05 | 0.05 | 2.92 |
| Boer En Buur (PV / E) | 0.01 | 2.56 | 0.31 | 0.04 | 2.17 |

Generally, the share of local initiatives in producing heat for use in built environment is very small, and there is little data and knowledge available at for example the governmental level about heat producing LECs. Therefore, a second benchmarking measurement will be performed, which focuses solely on the LECs that produce local renewable electricity. In this second measurement, three companies of the previous data sheet have been excluded: Patrimonium, Thermo Bello and NDSM-Wharf. The two big bio-energy companies (Eindhoven and Fleringen) remain included in the second benchmark, in which only their electricity production efforts are measured (table 4). To make the data sheet complete, we also included theoretical LEC reference projections from ECN and KEMA (2010).

Table 4: Data sheet including only the electricity producing DMUs

| Local Energy Company (LEC) | (I) Plant size $10^3$ kW | (I)Investment $10^3$ Euro/kW | (I)O&M costs $10^3$ Euro/year | (O)Energy $10^3$ kWh/year | (O)Revenue $10^3$ Euro/year |
|---|---|---|---|---|---|
| Bio-energy Eindhoven (bio / E) | 11.50 | 1.52 | 880.00 | 6,720.00 | 2,050.00 |
| Bio-energy Fleringen (bio / E) | 0.17 | 3.62 | 66.00 | 900.00 | 118.00 |
| Onze Energie (wind / E) | 2.00 | 2.00 | 106.00 | 5,000.00 | 480.00 |
| SVDW Windpark (wind / E) | 12.60 | 0.89 | 611.10 | 26,000.00 | 2,496.00 |
| Windvogel (wind / E) | 2.76 | 0.99 | 167.79 | 5,031.66 | 448.51 |
| Meewind (wind / E) | 165.00 | 3.72 | 30,921.00 | 550,000.00 | 104,280.00 |
| Zonvogel (PV / E) | 0.12 | 2.13 | 4.90 | 102.00 | 23.46 |
| Zon op Noord (PV / E) | 0.02 | 3.05 | 1.05 | 12.70 | 2.92 |
| Boer En Buur (PV / E) | 0.01 | 2.56 | 0.31 | 10.00 | 2.17 |
| Manure fermentation | 1.10 | 3.10 | 1,083.50 | 8,800.00 | 1,601.60 |
| Solid biomass 0-10 MW | 2.00 | 4.45 | 1,651.00 | 16,000.00 | 3,408.00 |
| Solid biomass 10-50 MW | 25.00 | 3.60 | 14,350.00 | 200,000.00 | 24,400.00 |
| Wind on land < 6 MW | 15.00 | 1.35 | 750.00 | 33,000.00 | 3,168.00 |
| Solar Panels 1-15 kWp | 0.01 | 3.11 | 0.09 | 2.98 | 0.99 |
| Solar Panels 15-100 kWp | 0.10 | 2.15 | 2.13 | 85.00 | 23.80 |
| Solar Panels self supply | 0.10 | 2.15 | 2.13 | 85.00 | 19.55 |

Performing the second benchmark measurement has two advantages. First, it is possible to compare the real-world renewable electricity generating companies with theoretical cases, which gives us insight in the performance of existing LECs compared to what is feasible in theory. Second, the adding of the theoretical cases introduces the possibility to evaluate the effects of the mentioned renewed subsidy schemes.

In order to measure the effects of the renewed subsidy scheme, we have to introduce another version of the second benchmark. The differences between the performances of LECs under both the old and new subsidy scheme are mainly found in the financial parameters; the techno-economic aspects do not change with the new SDE+ subsidy scheme. In table 5, the performance indicators of LECs under the SDE+ subsidy scheme are presented.

Table 5: Data sheet including only the electricity producing DMUs with new SDE+

| Local Energy Company (LEC) | (I) Plant size $10^3$ kW | (I)Investment $10^3$ Euro/kW | (I)O&M costs $10^3$ Euro/year | (O)Energy $10^3$ kWh/year | (O)Revenue $10^3$ Euro/year |
|---|---|---|---|---|---|
| Bio-energy Eindhoven (bio / E) | 11.50 | 1.52 | 880.00 | 6,720.00 | 2,050.00 |
| Bio-energy Fleringen (bio / E) | 0.17 | 3.62 | 66.00 | 900.00 | 118.00 |
| Onze Energie (wind / E) | 2.00 | 2.00 | 106.00 | 5,000.00 | 480.00 |
| SVDW Windpark (wind / E) | 12.60 | 0.89 | 611.10 | 26,000.00 | 2,496.00 |
| Windvogel (wind / E) | 2.76 | 0.99 | 167.79 | 5,031.66 | 448.51 |
| Meewind (wind / E) | 165.00 | 3.72 | 30,921.00 | 550,000.00 | 104,280.00 |
| Zonvogel (PV / E) | 0.12 | 2.13 | 4.90 | 102.00 | 23.46 |
| Zon op Noord (PV / E) | 0.02 | 3.05 | 1.05 | 12.70 | 2.92 |
| Boer En Buur (PV / E) | 0.01 | 2.56 | 0.31 | 10.00 | 2.17 |
| Manure fermentation | 1.10 | 3.10 | 1,083.50 | 8,800.00 | 1,504.80 |
| Solid biomass 0-10 MW | 2.00 | 4.45 | 1,651.00 | 16,000.00 | 2,736.00 |
| Solid biomass 10-50 MW | 25.00 | 3.60 | 14,350.00 | 200,000.00 | 30,800.00 |
| Wind on land < 6 MW | 15.00 | 1.35 | 677.40 | 24,600.00 | 3,168.00 |
| Solar Panels 15-100 kWp | 0.10 | 2.15 | 2.5 | 100.00 | 11.00 |
| Solar Panels self supply | 0.10 | 2.15 | 2.13 | 85.00 | 19.55 |

*Techno-economic characteristics*

When comparing the heat producing LECs in table 3, we find that Thermo Bello has relative low investment costs due to the acquisition of existing plants and infrastructural grid. However, the maintenance costs are high because the grid is relatively old. Furthermore, heat producing LECs have a relatively small plant size; in case of Patrimonium, the plant is installed in an apartment building. This decreases the costs of the grid, because it is very compact, and thus makes the LEC financially more feasible. NDSM-Wharf is the only LEC employing shallow geothermal energy, in combination with electricity generation from one wind turbine; their investment costs are relatively competitive, but energy production and revenues of the plant are low compared to other LECs.

In case of electricity generation from bio-energy, the LEC in Eindhoven required high investments, especially compared to the reference LECs from ECN and KEMA (2010) (table 4). The O&M costs of the LEC in Eindhoven are comparable to the reference assumptions. The reason for these competitive O&M costs is that the biomass fuel is purchased from the local government. The bio-fermentation plant in Fleringen represents very competitive techno-economic parameters. The investments per kW are slightly higher because of the age of the plant and the recent improvements in fermentation techniques. The O&M costs are much lower due to the fact that the biomass fuel is manure waste from the owner's farm.

Existing LECs employing wind energy on land perform well compared to reference projection LECs (table 4). Especially the early established LECs have profited from lower investments per kW, and O&M costs have not changed much. The results also show that wind on sea (LEC: Meewind) is expensive; both investment costs and O&M costs values are approximately three times higher.

LECs that currently utilize solar energy perform comparable with reference assumptions (table 4). Furthermore, the figures clearly show possible scalar advantages when investing in solar panels. For instance, Zonvogel has a significantly lower investment value per kW than reference projection LECs, because of the large size of the plant. However, the O&M costs of Zonvogel are relatively high, which is due to additional security costs. All LECs employing PV cells have significantly higher O&M costs than the theoretic cases, which might indicate that the reference assumptions from ECN and KEMA (2010) are quite optimistic. Finally, the differences in the investments of the LECs are probably caused by a continuously decreasing price of solar panels, reducing necessary investments.

*Financial aspects*

Major difference in the financial aspects of heat producing LECs (table 3) is the revenue per GJ, ranging from €19,868/GJ to €28,410/GJ. Most LECs can expect revenues of around €22,000 per GJ. The relative profits of the heat producing LECs do not differ much. Furthermore, the figures show that compact plants, which are building-specific or connecting a few larger apartment buildings, are more feasible due to the reduced infrastructural grid requirements.

LECs with bio-energy (table 4) are more difficult to compare on financial aspects, because the plant sizes differ strongly. Furthermore, the plants require biomass which must be purchased. Only the biomass of fermentation plants is regularly available for free. This is a big advantage for this type of LECs, and explains why their performance is better.

LECs utilizing wind energy show very few differences in the yields per kWh (table 4). The main reason is that all these LECs receive SDE subsidies; these SDE subsidies ensure that LECs in wind energy are very profitable. The new SDE+ subsidy scheme slightly improves the situation in case of wind energy (table 5). Differences between the subsidies are a relative small increase in yields per kWh (Meewind: +€0.14/kWh; Wind on Land < 6MW: +€0.11/kWh). However, full load hours have decreased slightly, resulting in the grossly the same revenues in the old and the new situation.

Finally, the output in produced energy by PV panels is low compared to other RET outputs (table 4). For LECs employing PV panels, there are two different ways of receiving yields per produced kWh, either through SDE subsidies or through the so called “Self Supply model”, which excludes subsidies. In the old SDE situation, LECs receiving subsidies have higher revenues. However, in the new SDE+ scheme, subsidies are strongly reduced and the Self Supply model becomes more profitable (table 5). Therefore, most LECs entering the solar energy market are trying to achieve a profitable business without SDE subsidy.

*Organizational structures*

From an organizational point of view, the existing Dutch LECs can be divided in two main streams of ownership models, engaged by two different groups of stakeholders. The first stakeholder group entails residents, and the second group professional local actors, mainly the municipality, housings associations and other private actors. The residential model is applied in 40% of all identified LECs in the Netherlands. Residents are almost always organized in a cooperative ownership model, apart from a few cases in which a foundation is established, which has comparable legal rights.  The main advantages of local residents being shareholder are having decision power (including on decisions concerning subscription fees and investments in new projects), a high level of transparency, and little liability risks. In some cases an operating company is established as subsidiary of the cooperative parent company. This operating company can adopt different legal forms, for instance that of a Limited Liability Company or a Cooperative. Such operating companies are established to decrease the liability risks in case a project fails. This is especially useful when multiple projects on different locations and/or different RETs are utilized.

The second type of ownership model – often used in case of local professional actors' involvement – consists of a main LLC-structured holding in which all shareholders are represented. To avoid liability risks at the parent company, operating companies are established in the form of Ltd. This way, it can operate next to shareholders' other core businesses, for example in case of a housing association. Furthermore, it prevents the possibility of the holding going bankrupt. The operating company is responsible for all the business activities of a LEC. The main activities are the realization of renewable energy projects and the operation and management afterwards. In table 6, the organizational structures of the twelve selected LEC cases are represented in detail.

Table 6: Organizational characteristics of selected DMUs

| DMU | Information | Organization | Key aspects | Advantages |
|---|---|---|---|---|
| *Bio-energy Eindhoven* | Municipality of Eindhoven is initiator; steering group is responsible for energy projects | Steering group | Outsourcing business activities | Project risks are transferred |
| | | | Steering group in control of total project | Total decision power |
| | | | Biomass from own municipal area | Long term contracts for cheap biomass supply |
| | | | Outsourcing installation & grid | No responsibility, only interested in ROI |
| *Bio-energy Fleringen* | Bio-installation is part of the business activities of a local farmer | Limited Liability Company | Part of the farm | Double profit: disposal of fertilizer and energy |
| | | | Additional revenues, efficient use of farm waste | Farm gains more income from product chain |
| | | | Possible expansion to neighborhood | Collaborate with neighborhood (heat supply), larger sales |
| *Patrimonium Energie B.V.* | Housing association is initiator; energy company functions as operating business | Limited Liability Company | Transparency | Costs and business activities |
| | | | Possibility to create operating company | Parent company not liable |
| | | | Social financial return | Profit, ROI |
| | | | Participation of actors | Share risks |
| *Thermo Bello B.V.* | Currently organized as foundation. Final structure consists of an LLC, an | Foundation | Multiple local shareholders | More equity and less debt |
| | | | No liability | Through underlying operating company |
| | | | Local decision power | Involves residents |
| | | Limited | Board of directives have | Speed up business activities and |

| | | | | |
|---|---|---|---|---|
| | administration office, a supervisory board and group of residents | Liability Company | decision-making power | decision making |
| | | | Administration office guards financial interests, owns all property, and issues certificates of non-voting shares to capital providers | Reduces risk of indecisive behavior, increases effectiveness, enlarges access to capital |
| *NDSM N.V.* | Goal is to make an Amsterdam wharf site energy neutral | Joint Stock Company | Independent company | Local actors / shareholders are not liable |
| | | | Diverse shareholders | Shares are easier to transfer than in a Dutch BV, possible tax benefits |
| | | | Co-ownership of end users | Low entry thresholds, decision power |
| | | | Local actors benefit | The residents and companies receive the profits |
| *Onze Energie* | Independent company without profit targets, aiming to realize local renewable energy. Dynamic organization, one CEO supported by volunteers and supervisors | Cooperative | Independent company | No external influences |
| | | | Members are shareholders | Increase equity, decision making by residents |
| | | | No profit targets | No high returns expected |
| | | Limited Liability Company | Invest with partners | Equity is divided 50%-50% |
| | | | Attracting technical expertise | Extra security for banks, reduction of |
| | | | Shares cannot be sold to a third party | Continuity in the project team, long term commitment |
| | | | Energy production sold to cooperation | Relatively cheap – renewable – energy for members |
| *SVDW Windpark* | Cooperation between six farmers, all owning equal shares in seven wind turbines. Energy is sold to a renewable energy supplier | Cooperative | Independent company | Can not harm any of the members' farms; parent companies are not liable |
| | | | Members are shareholders | All local farms are involved; high level of community involvement |
| | | | Profit goes to the investors (thus to the farmers) | Yield of energy remains in the community |
| *De Windvogel B.A.* | Manages four wind turbines on different locations in the Netherlands | Cooperative | Transparent | All shareholders have decision power |
| | | | Only citizens can buy shares | Citizens profit from renewable energy |
| | | | Members often provide loans | Higher capital of cooperative, member receives fluctuating ROI |
| | | | Experiment with business model (self supply model) | More yields per kWh of renewable electricity |
| *Meewind* | Utilizes large wind farms on sea. Mutual fund with a manager and keeper. Registered with Dutch Authority of Financial Markets (AFM) | Investment fund | Professional | Control on company by national authorities |
| | | | No burdens for investors | No renewable energy knowledge required |
| | | | Increase involvement citizens in renewable energy | Citizens can simply buy shares; investments are responsibility of fund |
| | | | Participants' contributions are deposited in the account | Secure, the keeper (ANT Custody B.V.) has obtained permission from |

|  |  |  |  |  |
|---|---|---|---|---|
|  |  |  | of the keeper | Dutch Authority of Financial Markets (AFM) |
| *Zonvogel* | Zonvogel assists citizens and organizations in taking initiative in solar projects, using feed-in tariff system | Cooperative | Everybody can participate | Also placement of PV cells on citizen's own roofs |
|  |  |  | Scale advantages through the corporate structure | Less dependent of subsidies |
|  |  |  | Completely transparent | Members have all the decision power |
|  |  |  | Tariff system copied from Germany and Spain | Best practice examples used in underlying principle |
| *Zon op Noord* | The aim is to manage and operate solar panels of members which are placed on roofs of public buildings | Cooperative | Involvement of residents | Organizational interests are best represented |
|  |  |  | Agreements with municipality | Easier to make agreements through Cooperative |
|  |  |  | Small local cooperatives (maximum of 50 members per local cooperative) | Maintains and ensures maximum involvement of local members |
| *Boer en Buur* | Residents can invest in shares of €3000. With these revenues, solar panels are places on farm roofs. Energy is consumed locally. | Cooperative | Citizens invest in renewable energy. | Without burdens of installation or business |
|  |  |  | Collaboration with local farmers | More local activity in renewable energy |
|  |  |  | Farm can take shares in the plant, but no more than 49% | Strong involvement of farmers |
|  |  |  | All shareholder benefit equally | Secure investments |
|  |  |  | After 25 years, the panels turn in ownership of the farm | Provides an additional 5 to 7 years of solar energy |

## Results

The efficiency measure results of the four DEA analyses on the DMU data sheet from table 3 are presented in table 7, in which the value '1' represents an optimal efficiency. The results show that the best performer cannot easily be identified, because no DMU scores optimally in all analyses. However, a number of conclusions can be drawn.  Regarding the cost-based measurement, Thermo Bello scores a full efficiency mark. Although Thermo Bello almost has the worst CCR score (0,476), its lower unit costs are sufficient to place its cost-based performance in top rank. The CCR score of Thermo Bello indicates that there is room for input reductions compared to other technically efficient DMUs. This means that the operation and management costs are too high compared with other LEC, especially considering the relatively small installation size.

Table 7: DEA results of all DMUs including all efficiency measurements

| Local Energy Company (LEC) | CCR Score | New Technical Score | New Cost Score | New Allocative Score |
|---|---|---|---|---|
| Bio-energy Eindhoven (bio / E) | 0.586 | 0.563 | 0.270 | 0.479 |
| Bio-energy Fleringen (bio / E) | 0.686 | 0.755 | 0.447 | 0.592 |
| Patrimonium Energie (bio / H) | 0.602 | 1 | 0.703 | 0.703 |
| Thermo Bello (bio / H) | 0.476 | 1 | 1 | 1 |
| NDSM-Wharf (comb / H+E) | 0.320 | 0.842 | 0.627 | 0.744 |
| Onze Energie (wind / E) | 1 | 1 | 0.294 | 0.294 |
| SVDW Windpark (wind / E) | 0.902 | 1 | 0.546 | 0.546 |
| Windvogel (wind / E) | 0.717 | 0.777 | 0.434 | 0.558 |
| Meewind (wind / E) | 1 | 0.819 | 0.391 | 0.477 |
| Zonvogel (PV / E) | 0.879 | 0.904 | 0.211 | 0.234 |
| Zon op Noord (PV / E) | 0.641 | 0.557 | 0.147 | 0.264 |
| Boer En Buur (PV / E) | 1 | 1 | 0.162 | 0.162 |

On the other hand, DMU Boer En Buur is rated worst with respect to cost-based measures, although it receives full efficiency marks in terms of CCR scores. This gap is due to its relative high cost structure. This DMU needs to reduce its unit costs to attain good cost-based scores. We can conclude that solar panels are still too expensive compared to other RETs. This also shows in the analysis of DMUs Zonvogel and Zon op Noord, although the results indicate that the performance can be raised by increasing the project scale. Overall, we can conclude that DMUs utilizing wind energy perform well, especially on technical efficiency.

In the second efficiency analysis, only renewable electricity producing LECs are included. The results show that the best performer is the theoretical DMU based on Manure fermentation, with all its efficiency scores equaling one (table 8). The reason is that – although the investment costs are high – O&M costs are low because manure is a waste product of farmers. Furthermore, the SDE subsidy is relatively large, resulting in high returns and a high profit. Despite the fact that the best performance is achieved by a theoretical DMU, the other DMU employing Manure fermentation (Bio-energy Fleringen) also scores above average. Similar results on the efficiency of LECs using local waste products are presented by Oliveira *et al.* (2008) and Lins *et al.* (2012).

Table 8: DEA results of electricity-employing DMUs with old SDE subsidy scheme

| Local Energy Company (LEC) | CCR Score | New Technical Score | New Cost Score | New Allocative Score |
|---|---|---|---|---|
| Bio-energy Eindhoven (bio / E) | 0.483 | 0.553 | 0.250 | 0.452 |
| Bio-energy Fleringen (bio / E) | 0.901 | 0.675 | 0.566 | 0.839 |
| Onze Energie (wind / E) | 1 | 1 | 0.484 | 0.484 |
| SVDW Windpark (wind / E) | 0.902 | 1 | 0.898 | 0.898 |
| Windvogel (wind / E) | 0.707 | 0.793 | 0.715 | 0.901 |
| Meewind (wind / E) | 1 | 0.800 | 0.362 | 0.452 |
| Zonvogel (PV / E) | 0.699 | 0.684 | 0.195 | 0.286 |
| Zon op Noord (PV / E) | 0.548 | 0.445 | 0.136 | 0.306 |
| Boer En Buur (PV / E) | 0.764 | 0.764 | 0.150 | 0.196 |
| Manure fermentation | 1 | 1 | 1 | 1 |
| Solid biomass 0-10 MW | 1 | 1 | 0.816 | 0.816 |
| Solid biomass 10-50 MW | 1 | 0.917 | 0.861 | 0.939 |
| Wind on land < 6 MW | 0.933 | 0.986 | 0.631 | 0.640 |
| Solar Panels 1-15 kWp | 1 | 0.962 | 0.170 | 0.177 |
| Solar Panels 15-100 kWp | 1 | 1 | 0.236 | 0.236 |
| Solar Panels self supply | 0.959 | 0.959 | 0.194 | 0.202 |

By comparing the actually operating DMUs with the theoretical DMUs, it can be concluded that overall the theoretical DMUs perform better than the real-world DMUs. When regarding the different scores per RET, real-world DMUs utilizing wind energy perform comparable with the theoretical case. The largest difference is found in the DMUs utilizing bio-energy with solid biomass. Although this is based upon the insights of just one practical case, it seems that the performance of this type of RET can be improved drastically in practice. Again, companies employing solar energy have the highest unit costs and therefore perform poorly in both New Cost and New Allocation measurements.

In table 9, the results from the analysis incorporating the new SDE+ subsidy scheme are summarized. There are few differences between the performances of DMUs under old en new SDE subsidy schemes. Overall, the practical DMUs perform slightly better compared to the theoretical DMUs.

Table 9: DEA results of electricity-employing DMUs with new SDE+ subsidy scheme

| Local Energy Company (LEC) | CCR Score | New Technical Score | New Cost Score | New Allocative Score |
|---|---|---|---|---|
| Bio-energy Eindhoven (bio / E) | 0.523 | 0.558 | 0.266 | 0,477 |
| Bio-energy Fleringen (bio / E) | 0.877 | 0.678 | 0.566 | 0,835 |
| Onze Energie (wind / E) | 1 | 1 | 0.484 | 0,484 |
| SVDW Windpark (wind / E) | 0.902 | 1 | 0.898 | 0,898 |
| Windvogel (wind / E) | 0.707 | 0.793 | 0.715 | 0,901 |
| Meewind (wind / E) | 1 | 0.807 | 0.385 | 0,477 |
| Zonvogel (PV / E) | 0.792 | 0.775 | 0.208 | 0,268 |
| Zon op Noord (PV / E) | 0.602 | 0.493 | 0.145 | 0,294 |
| Boer En Buur (PV / E) | 0.875 | 0.794 | 0.160 | 0,201 |
| Manure fermentation | 1 | 1 | 1 | 1 |
| Solid biomass 0-10 MW | 1 | 0.858 | 0.697 | 0,813 |
| Solid biomass 10-50 MW | 1 | 1 | 0.861 | 0,861 |
| Wind on land < 6 MW | 0.890 | 0.974 | 0.471 | 0,483 |
| Solar Panels 15-100 kWp | 0.864 | 0.864 | 0.181 | 0,209 |
| Solar Panels self supply | 1 | 1 | 0.207 | 0,207 |

Compared to other European countries, the Dutch subsidy scheme offers little investor security due to unstable and often changing regulations (Reiche and Bechberger, 2004); this is reflected in the relative poor performance of all Dutch DMUs on financial efficiency. For instance, the leading wind energy countries Germany, Denmark and Spain have attractive feed-in tariffs. In case of Germany, this feed-in tariff system also supports the large scaled introduction of photovoltaic systems (Reiche and Bechberger, 2004). In these countries, long-term security is offered to investors, and the tariff systems are updated annually to be able to anticipate on market developments. Additionally, all renewable energy techniques receive the same promotion in the Dutch subsidy system; there is no technology-specific or location dependent differentiation. According to Reiche and Bechberger (2004), such differentiation is an important success factor in introducing renewable energy; successful countries like Germany, Portugal, and Luxembourg all introduced technology-specific tariffs and Germany also introduced a location dependent differentiation in wind energy tariffs.

### *Ownership structures*

Although the ownership structures are not part of the DEA measurements, it is possible to derive some preliminary conclusions from the efficiencies of the differently organized companies. First, when comparing heat producing LECs, NDSM performs worst on technical efficiency, which might indicate that their specific LLC form of Joint-Stock company (N.V.) does not yield the same efficiencies as the LLC form of Limited company (B.V.). The possibility to easily sell and buy company shares in the N.V. structure is a possible cause; the long term commitment of shareholders in a B.V. structure results in stronger incentives to optimize the performance on longer terms.

Secondly, the two bio-energy companies producing electricity (Eindhoven and Fleringen) are organized differently. Eindhoven constructed a steering group, which outsources the realization, operation, and management of all bio-energy projects, while in Fleringen one farmer is responsible for the realization and exploitation of the bio-energy plant. When comparing their performance, we can conclude that the organizational structure in Fleringen produced better efficiencies in both technology and cost/allocation. This indicates that outsourcing might not be the optimal solution; it seems that project responsibilities should lie with actors that have the strongest incentives to make it into a success.

Wind energy LECs have a relative high score on technical efficiency. However, the cost and allocation efficiency of the LECs Onze Energie and Meewind are relatively low. This is odd, since the organization structures of these LECs are assumed to be more professional. LECs SVDW and Windvogel are organized as cooperative, and outperform the other LECs on cost efficiency. Several factors can play a role here – e.g. the size of the projects, start-date, etc. – but this result shows that individual ownership structures do not necessarily result in a better allocation performance. Interestingly, the cooperative model significantly increased the acceptance of wind energy in Germany and Denmark (Reiche and Bechberger, 2004), resulting in a large number of successful wind energy LECs.

Finally, the LECs employing PV solar systems perform quite poorly, especially on cost and allocation efficiency. Although there are several reasons for this poor performance – e.g. high PV cell prices, disappointing full-load hours, small scale of existing projects, etc. – it might be interesting to experiment with other, individual ownership structures.

## Conclusions

The aim of this research is twofold. First, we want to compare the performance of existing LECs on three major aspects, namely technology, finance, and organization. This should provide local governments with important preconditions when initiating new Local Energy Companies. The majority of the analyses addresses this part. Second, we want to show the influence of recent adaptations in the Dutch subsidy scheme on LEC performance, in order to gain insight in possibilities to effectively support local renewable energy initiatives. To achieve the stated aim, the benchmark method Data Envelopment Analysis is used.

In case of Local Energy Companies, it is difficult to conclude about a best practice case in the Netherlands. The DEA measurement including all types of LECs shows that heat producing companies are performing best in cost efficiency. From the viewpoint of technical efficiency, LECs employing wind energy perform best. Although we cannot assign one case to be the best practice, we conclude that the LEC Thermo Bello is the closest to full efficiency.

The benchmark including only electricity producing LECs reveals a best practice; the theoretical reference LEC running on manure fermentation. Additionally, the real-world DMU employing manure fermentation (Bio-energy Fleringen) also scores above average. Oliveira *et al.* (2008) and Lins *et al.* (2012) presented similar results; they conclude that energy technologies using local waste products should be assigned a high priority in future Brazilian energy policy, because these LECs are characterized by a high efficiency. We also found that PV panels are still too expensive compared to other RETs; this is also the case in other European countries (Reiche and Bechberger, 2004). However, in several of these European countries it is demonstrated that smart supportive policies can increase the attractiveness of photovoltaic systems.

Overall, we can conclude that the majority of the theoretical reference LECs (ECN and KEMA, 2010) performs more efficiently than the operating LECs; the theoretical assumptions set by the Dutch research institutions and national governments are not yet achieved in practice. Only LECs utilizing wind energy come close to the theoretically possible performance; Dutch wind energy projects perform well, especially on technical efficiency. Similar results on the performance of wind energy LECs are presented by San Cristobal (2011).

The analyses of real-world LECs indicate that it is possible to set up a profitable RET business. Still, most companies are strongly dependent on additional subsidies. Recently, several new initiatives are established that utilize photovoltaic panels without requesting a SDE subsidy, through the application of the self supply model. In this model, the yields per kWh are higher compared to models in which the energy is sold to the grid. Furthermore, this model ensures that the local community benefits from the efforts. In case of Windvogel, a self supply model is applied with wind energy generation, and it can be considered successful. The authors think that the self supply model can be a good reference model for making LECs profitable and less dependent on subsidies.

Concerning these subsidies, the effects of the newly installed SDE+ scheme are analyzed. The authors conclude that there are few differences between the performances of LECs under old en new SDE subsidy schemes; overall, the real-world LECs perform slightly better than the theoretical LECs. Furthermore, the changes in budget allocations will result in larger amounts to be spent on renewable energy. However, the authors feel that the Dutch subsidy system on renewable energy is not very effective, especially when comparing it to subsidy systems in other European countries. The Dutch approach is very complicated and bureaucratic, it lacks a long-term continuity, the available budget is determined on a yearly basis and depends strongly on political consensus finding, and – to date – the available budgets and related investment security are not enough to realize substantial investments and to close the ‘renewable’ gap on many surrounding countries like Germany, Denmark and Sweden.

## References

AgentschapNL, 2009. Voorbeeldproject Bio-energie Fleringen vergisting. AgentschapNL, Dutch Ministry of Economic Affairs, The Hague, the Netherlands.
AgentschapNL, 2010a. Wind energie. AgentschapNL, Dutch Ministry of Economic Affairs, The Hague, the Netherlands. [www.windenergie.nl]
AgentschapNL, 2010b. Infoblad Warmtepompen. AgentschapNL, Dutch Ministry of Economic Affairs, The Hague, the Netherlands.
Bolinger, M., 2001. Community Wind Ownership Schemes in Europe and their Relevance to the United States. Lawrence Berkeley National Laboratory. CA.
Bolinger, M., Wiser, R., 2006. A comparative analysis of business structures suitable for farmer-owned wind power projects in the United States. Energy Policy, 34, 1750-1761.
Camanho, P.M., 2011. Evaluation of performance of European cities with the aim of promote quality of life improvements. Omega, 39, 398-409.
CBS, 2010. Hernieuwbare Energie in Nederland 2009. Centraal Bureau voor de Statistiek, The Hague / Heerlen, the Netherlands.
CBS Statline, 2011. Industrie en Energie. Centraal Bureau voor de Statistiek, the Hague, the Netherlands. [www.statline.cbs.nl]

Charnes, A., Cooper, W., Rhodes, E., 1978. Measuring the efficiency of decision-making units. European Journal of Operational Research, 2, 429-444.
Chung, W., 2011. Review of building energy-use performance benchmarking methodologies. Applied Energy, 88, 1470-1479.
Cooper, W., Seiford, L., Tone, K., 2006. Introduction to Data Envelopment Analysis and Its Uses. Springer Science + Business Media Inc.
Dunning, J., Turner, A., 2005. Community-owned wind farms - aspirations, suspicions and reality. Power UK, 131, 42–45.
ECN, KEMA, 2010. Eindadvies basisbedragen 2011; voor elektriciteit en groen gas in het kader van de SDE-regeling. Energy Research Centre of the Netherlands (ECN), Petten, the Netherlands.
ECN, 2010. Reference Projection Energy and Emissions 2010-2020. Energy Research Centre of the Netherlands (ECN), Petten, the Netherlands.
ECN, 2011. Marktconsultatie SDE-basisbedragen 2010 en 2011. Energy Research Centre of the Netherlands (ECN), Petten, the Netherlands.
Färe, R., Grosskopf, S., Logan, J., 1983. The relative efficiency of Illinois electric utilities. Resources and Energy, 5, 349-367.
Hvelplund, F., 2006. Renewable energy and the need for local energy markets. Energy, 31, 2293-2302.
Iglesias, G.C., Castellanos, P., Seijas, A., 2010. Measurement of productive efficiency with frontier methods: A case study for wind farms. Energy Economics, 32, 1199-1208.
Lins, M.E., Oliveira, L.B., Moreira da Silva, A.C., Rosac, L.P., Pereira Jr., A.O., 2012. Performance assessment of Alternative Energy Resources in Brazilian power sector using Data Envelopment Analysis. Renewable and Sustainable Energy Reviews, 16, 898– 903.
Liu, C.H., Lin, S.J., Lewis, C., 2010. Evaluation of thermal power plant operational performance in Taiwan by data envelopment analysis. Energy Policy, 38, 1049-1058.
Lund, H., 2010. The implementation of renewable energy systems: Lessons learned from the Danish case. Energy, 35, 4003-4009.
Manfren, M., Caputo, P., Costa, G., 2011. Paradigm shift in urban energy systems through distributed generation: Methods and models. Applied Energy, 88, 1032-1048.
Oliveira, L.B., Muylaert de Araujo, M.S., Rosa, L.P., Barata, M., Lebre La Rovere, E., 2008. Analysis of the sustainability of using wastes in the Brazilian power industry. Renewable and Sustainable Energy Reviews, 12, 883–890.
Pollit, M.G., 1996. Ownership and efficiency in nuclear power production. Oxford Economic Papers, 48 (2), 342-360.
Reiche, D., Bechberger, M., 2004. Policy differences in the promotion of renewable energies in the EU member states. Energy Policy, 32, 843-849.
San Cristobal, J., 2011. A multi criteria data envelopment analysis model to evaluate the efficiency of the Renewable Energy Technology. Renewable Energy, 36 (10), 2742-2746.
Scherman, H., Zhu, J., 2006. Service Productivity Management: Improving Service Performance using DEA. Springer Science + Business Media.
SenterNovem, 2008. Boosting the production of sustainable energies: wind, solar and bioenergy. SenterNovem, Ministry of Economic Affairs, the Hague, the Netherlands.
Sözen, A., Alp, I., Ozdemir, A., 2010. Assessment of operational and environmental performance of the thermal power plants in Turkey by using data envelopment analysis. Energy Policy, 38, 6194-6203.
Walker, G.P., Devine-Wright, P., Evans, B., 2007. Community energy initiatives: embedding sustainable technology at a local level. ESRC End of Award report.
Walker, G., 2008. What are the barriers and incentives for community-owned means of energy production and use? Energy Policy, 36, 4401-4405.
Zhou, P., Ang, B., Poh, K., 2008. A survey of data envelopment analysis in energy and environmental studies. European Journal of Operational Research, 189, 1-18.

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## Asset Valuation of Renewable Heat Sources in the Netherlands

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### Abstract

According to binding European Union agreements, the Netherlands has to cover at least 14 percent of its total energy use with renewable energy sources by 2020. However, in 2010, renewable energy in the Netherlands accounted for only 3.8% of the national energy use, and has decreased with 0.4% compared to 2009. In the years before 2009, the renewable energy share grew on average with 0.5% annually. Especially the production of renewable heat stagnates, covering only 2% of the total heat demand. In case of the Netherlands, the problematic market introduction of renewable energy techniques – and especially renewable heat production techniques – is largely due to the abundant availability of natural gas stocks; renewable energy techniques have a weak economic and competitive basis compared to the available fossil fuel energy sources. In this article, we claim that heat is the renewable energy carrier with the highest potential, and we aim to provide a competitive economic model for the introduction of renewable heat in the Netherlands, using the principles of asset valuation.

Keywords: Renewable heat, Market Introduction, Asset Valuation, Net Present Value Method

### 1. Introduction

The worldwide energy demand is enormous – about 500 EJ per year – and is expected to increase strongly in the next decades, mainly because of an increasing energy demand in BRIC-countries. In the Netherlands, 3,495 PJ was used in 2010 [1]. In the last ten years, this energy use increased with 12%, from an initial energy use of 3,065 PJ in the year 2000, and according to recent predictions [2], the energy demand in the Netherlands will slightly increase under all policy scenarios.

A large share of the Dutch energy supply is based upon the combustion of fossil fuels. Of the total energy demand in the Netherlands, 9.1% is generated with coal, 37.2% with oil, and 47.1% with natural gas [1]. However, numerous problems occur as a result of the large scaled fossil fuel combustion in the conventional energy sector, like climate change – due to an increasing level of greenhouse gas (GHG) emissions – and international conflicts concerning the ownership over stocks of oil, coal or gas. In order to reduce the negative effects of the current conventional way of generating energy, it is important to increase the share of renewable energy.

Therefore, the Dutch government entered into a binding agreement with the European Union in the beginning of 2009, in which it was recorded that the Netherlands has to cover at least 14 percent of its total energy use with renewable energy sources by 2020. However, the share of renewable energy in the Netherlands is small and hardly increasing. In 2010, renewable energy in the Netherlands accounted for only 3.8% of the national energy demand, a decrease of 0.4% compared to 2009 [3]. In the years before 2009, the renewable energy share grew on average with 0.5% annually. Especially the production of renewable heat stagnates, covering only 2% of the total heat demand; the renewable heat share grew annually with 0.1% in the last five years [3].

A major cause of the stagnating renewable energy generation in the Netherlands is the absence of a clear and consistent long-term policy on the introduction of renewable energy, which results in the lack of long-term contracts and political obligations for purchasing renewable energy. Eventually, this uncertainty in the renewable energy market reduces the attractiveness of renewable energy investments. Furthermore, renewable energy sources are seemingly unable to compete economically with conventional fossil-fuel based energy sources. They require governmental steering and stimulation, and the current Dutch subsidy system on renewable energy is not effective [4,5,6]. The currently viable SDE subsidy is very complicated and bureaucratic, and the available budget is not enough to realize substantial investments and to close the ‘renewable’ gap on many surrounding countries like Germany, Denmark and Sweden. An additional cause is the availability of large amounts of natural gas in the Netherlands. The Dutch governmental annual budget reports thrive strongly on the revenues of this natural gas, which reduces the government’s incentives to invest consistently and firmly in renewable energy.

This article aims to provide a stronger economic basis for renewable energy generation in the Netherlands. The authors claim that the energy carrier heat has the most potential for a large scale introduction, because of the large share of heat in the total Dutch energy demand and the relative low investment costs for renewable heat technologies. Especially shallow geothermal energy applications like Aquifer Thermal Energy Storage (ATES) and Borehole Heat Exchangers (BHE) appear to be able to become an economically successful renewable energy generation methods. Therefore, this article provides a competitive economic model for the introduction of shallow geothermal heat and cold systems in the Netherlands, making use of the principles of asset valuation.

## 2. Natural gas in the Netherlands

In 1959, the Dutch Petroleum Company (Nederlandse Aardolie Maatschappij, NAM) discovered the first natural gas field in Groningen, a northern Dutch province. In the years following, the girth of the gas field was determined, and in 1961 the NAM requested a gas concession. One year later, the Dutch Ministry of Economic Affairs published its Natural Gas Policy (Aardgasnota). This policy document appointed the exploitation of the natural gas field in Groningen to a special purpose company, in which the State had an interest of 50%, and Esso and Shell were both allocated a share of 25%. In the same policy document, the foundation was laid for the establishment of the Dutch Gas Union. Finally, on May 30 1963, the concession was granted to the NAM.

The discovery of the gas field in Groningen elicited the decision to connect all Dutch energy consumers to a natural gas network. This resulted in a national, very dense network, which is unique in the world. Within ten years, 75% of all Dutch households were connected to the natural gas network, decreasing the importance of oil and coal strongly and quickly. To date, almost all households have a central heating system and warm tap water supply based upon natural gas combustion. Also in electricity production, natural gas is employed as fuel on a large scale.

At the end of the 1960’s and the beginning of the 1970’s, the Dutch government aimed to sell the natural gas to foreign buyers as quickly as possible, because of the presumed increase in the role of nuclear energy. Therefore, the production of natural gas increased strongly, from almost nothing in 1960 to approximately 90 billion $m^3$ in 1975. Due to the first oil crisis and the large societal resistance against nuclear energy, this policy was revised; as a result, the so-called ‘Small Fields Policy’ and the related Gas Law were introduced. In the Gas Law, it was recorded that all independent natural gas producers have the opportunity to sell extracted natural gas against market prices to the Dutch Gas Union. The Gas Union was required to buy the gas and to transport it. This way, the government stimulated the quest for other gas fields, aiming to prolong the exploitation period of the gas field in Groningen. Even today, the government mandated a production maximum for the gas field in Groningen; in the period between 2006 and 2015, the NAM is allowed to extract maximally 425 billion $m^3$ from this specific field. This production maximum ensures the extraction of gas from smaller fields. To date, this policy has been very successful; over the last decade, approximately 40 billion $m^3$ of gas is annually extracted from the fields in Groningen, while all Dutch gas fields together yield averagely 70 billion $m^3$.

## 3. Renewable energy in the Netherlands

Opposed to the successful introduction of natural gas in the Dutch energy system, renewable energy covers only 3.8% of the total Dutch energy demand. The most important sources for Dutch renewable energy are wind energy (30%), the use of biomass as fuel in electricity power plants (18%), waste incineration (12%), and the use of bio-fuels in road transport (12%). In total, biomass covers 66% of the whole renewable energy production in the Netherlands. When regarding the share of different energy carriers in renewable energy production, electricity is the most dominant carrier (67%), followed by heat (20%) and transport fuels (13%) [3].

### *3.1. Future developments*

When aiming to increase the share of renewable energy in the Netherlands, a choice arises between the two important possible energy carriers: heat and electricity. When considering both, one has to regard the share of the specific carrier in the total energy demand and the investment costs per effective kilowatt. An average Dutch household uses yearly 1,800 $m^3$ of natural gas for heating, and 3,500 kWh (= 12,705 MJ) for electricity. The energetic value of standard natural gas in the Netherlands is approximately 9.8 kWh per $m^3$, resulting in an annual use of 17,640 kWh (= 63,504 MJ) for heating. The total energy use of households sums up to 21.140 kWh (= 76,209 MJ), of which 83% is employed for heating. On national scale, 3,495 PJ is used, of which 38% is used for heating with $T > 100^0$C, 30% for heating and cooling with $T < 100^0$C, 20% for transport, and 12% for lighting (electricity). Concluding, 68% of the total Dutch energy use is employed for heating and/or cooling.

Secondly, the investment costs per effective kW are an important parameter. The investment in high efficiency gas boilers is approximately €70 per kWh, which is the most effective investment. Furthermore, heat pumps require an investment of €250 per kWh, and seasonal thermal storage systems require approximately €1,000 per kWh. Systems producing renewable electricity require much larger investments: wind energy demands €6,000 per kWh, photovoltaic systems €7,500 per kWh, and biomass €15,000 per kWh. The large differences between the necessary investments of heat and electricity generating systems can be explained using basics of physics: it is easier to create heat than it is to create electricity (or labor). Combined, the figures on the share of heat in the total energy demand and the relative low investment costs per effective kilowatt for heating systems are considered as a *Quod Erat Demonstrandum* for the use of renewable heat.

### *3.2. The case of shallow geothermal energy*

Shallow geothermal energy applications [7,8], like Aquifer Thermal Energy Storage (ATES) and Borehole Heat Exchangers (BHE), have developed into one of the most economically independent and competitive renewable energy generation methods [9]. Already in 1984, the first Dutch ATES system was developed. The cost efficiency and the high comfort of these renewable energy systems resulted in an increase of ATES system implementation of 25% per year; currently, more than 1,000 systems are installed in the Netherlands, with a total capacity of 121 MW [3]. Important is the fact that ATES systems can compete economically with electric compression cooling systems. An ATES system can realize COP20 (it needs 1 $kWh_e$ for 20 $kWh_{cold}$), while electric compression cooling systems only realize COP3. Oppositely, ATES systems require larger initial investments; investments for heat pumps and shallow geothermal applications for individual houses lie between €10,000 and €15,000, and for collective systems between €5,000 and €10,000 per house. Depending on the heat and cold demand and on the scale of the application, a project has a payback time of about 3-10 years. However, with innovative financing mechanisms – like special energy mortgages – and smart governmental stimuli [10-15] on for instance fixed and low rises in heat prices, ATES systems can become a standard for heating and cooling.

Shallow geothermal applications use the heat and cold that is stored in the subsurface for the heating (in winter) and cooling (in summer) of buildings. The ground water is located on depths diverging from 10 to maximum 300 meters, and has a regular constant temperature of approximately 10 $^0$C. An ATES system (figure 1) contains two wells. During winter, with a relative large heat demand, heat is distracted from the ground water, after which the water is heated to 35-40 $^0$C with an electric heat pump. After heating the intended spaces, the cooled down water is re-injected in the ground. In summertime, with a demand for cooling, this process is reversed and the excess of heat is cooled with cold water from the cold source. The heat and cold production is independent of weather conditions, and is continuously available. After several years, the ground water surrounding the heat source is gradually heated (15-25 $^0$C), and the water surrounding the cold source is colder than average (5-10 $^0$C). By assuring that annually no heat is distracted from or transferred to the ground, the environmental impacts for the soil are minimal; this balance can be maintained for a long time, which is an important condition for long-term contracts. Effective legislation concerning the soil temperature balance is available in for instance Denmark and Sweden [16].

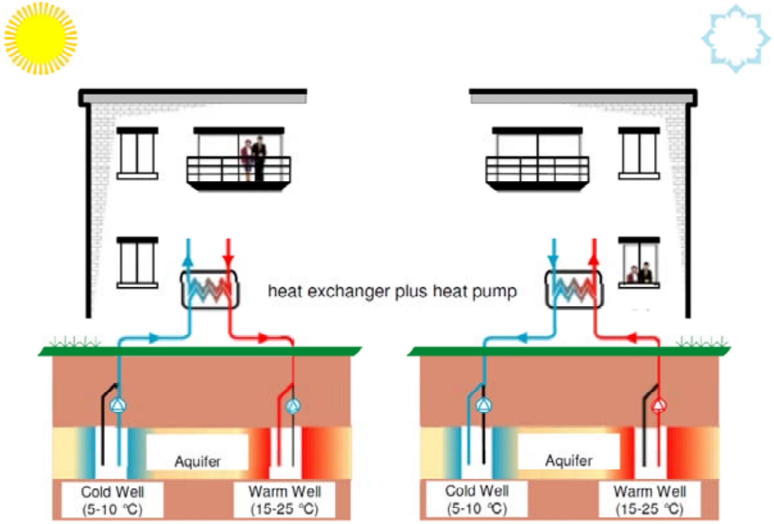

Figure 1: ATES system in the summer (left) and winter (right)

Besides the already mentioned advantages of shallow geothermal systems (e.g. the relative short payback time of 3 to 10 years, the stable price levels because of the possibility of long term contracts, and a continuous, flexible and secure energy supply), these systems also deliver a high level of indoor comfort. When using low temperature floor or wall heating systems, consumers experience heating and cooling with geothermal systems as more comfortable than high-temperature natural gas heating or cooling with air from air condition systems. This is caused by the more evenly spreading of heat through spaces, and by the decrease of air flows and draught. Furthermore, the use of floor or wall heating systems makes radiators unnecessary, which increases the effective spaces in dwellings and reduces dust accumulation. Other advantages of applying shallow geothermal systems are the absence of local combustion of fossil fuels and the possible reductions of 50-80% in greenhouse gas emissions. Therefore, such geothermal systems are recognized as high-potential renewable technology in many countries all over the world [9,16]. In 2010, there were quantified records of geothermal utilization in 78 countries in the world, with a total installed thermal power for direct utilization of 48,493 MWt [17].

### *3.3. Heating efficiencies*

In the Netherlands, policy on heating is predominantly aimed at combustion of natural gas. To date, there is no economic or financial model of heating alternative available for government and consumers; the successful implementation of the current system reduces the necessity for such an alternative. For instance, current gas boilers have an efficiency of almost 100%, which seems difficult to beat. However, by employing geothermal energy from ground water, heating with a low temperature heat source can achieve efficiencies of 160-200%, based on primary energy input. Here, we suppose an efficiency of 40% for the generation of electricity which is necessary for running the heat pumps and water pumps. This efficiency is defined as the used energy divided by the primary energy (in the form of natural gas, coal, or oil). The efficiency rates of heat and cold storage systems is higher than

100% because a lot of produced energy is already provided by the subsurface, which can be subtracted with relative little extra energy. This is illustrated in figure 2, showing that there is relatively little extra heat needed to reach the required temperature for a low temperature heating system (40°C) and for a high temperature heating system (60°C).

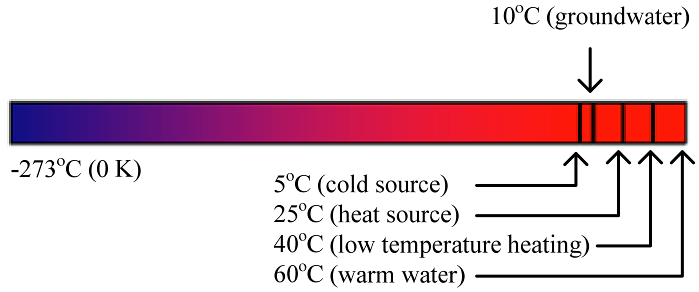

Figure 2: Kelvin temperature scale showing the temperatures of a heat and cold producing aquifer and the little extra energy needed for heating houses at 40°C or 60°C [18].

Even more spectacular are the efficiency rates for cooling. Considering the current efficiency of electricity generation, the regular rate of an electric compression cooling system lies between 80-120%. When using geothermal systems for cooling, this efficiency rate rises to more than 800%. This efficiency increase occurs because the consumer only has to pay for the electric energy of the water pumps. On a yearly basis, this results in a financial saving of 50-80% compared to conventional heating and cooling, and also translates in a similar $CO_2$ emission reduction.

## 4. Economic competitiveness

Geothermal heating and cooling systems have several advantages over conventional gas-based systems. However, there is yet no economically attractive and competitive basis for the introduction of renewable heat in the conventional Dutch system. The current system with combustion of natural gas in individual gas boilers is an efficient system and delivers large financial gains for the Dutch government and industry. Until the economic competitiveness of shallow geothermal applications is enlarged, the introduction of for instance ATES and BHE systems will remain small-scaled. The principle of asset valuation can play a role in increasing the economic competitiveness of these systems.

The stock of natural gas in the Netherlands represents a certain asset value. Currently, the Dutch subsurface contains approximately 1,300 billion $m^3$ of natural gas [19]. On average, 70 billion $m^3$ is annually extracted, of which 40 billion $m^3$ is used for own purposes. Out of this internally used 40 billion $m^3$, approximately 25% is used by households, 25% by offices, 20% for electricity power plants, and 30% for industrial activities [1]. When assuming the extraction rates presented in the report of TNO [19], the Dutch stock of natural gas will almost be depleted after 25 years. Additionally, Veldhuizen *et al.* [20] calculated the value of the Dutch gas reserves in the period 1990-2005, employing the Net Present Value method. According to their calculations, the Dutch gas reserve had a net present value (measured at the stock closing) of between 60.7 and 99.8 billion Euros in the studied period. On 1 January 2010, the value of the remaining natural gas reserves amounted to 164 billion Euros, or 29% of the Dutch GDP [21]. The growing trend in value, largely due to rising prices of oil and gas since 2005, stopped due to a severe cut in oil and gas prices in 2009. For the first time since

1998 the remaining physical reserves at the end of the year, in this case 2009, were higher than at the beginning of a year. This was primarily the result of an upward re-evaluation of remaining expected reserves in 2009 that more than compensated for the extraction in 2009 [21].

We expect that this remaining asset value of natural gas influences the attitude of the Dutch government towards the introduction of renewable energy – and thus the governmental effort so support an increasing share of renewable energy – strongly. It seems that the effect of specific energy sources on the national economy is a major predictor of the level in which such energy sources are successfully introduced in a society, at least in the Netherlands. This leads to the conclusion that – when aiming to increase the level of renewable energy sources – the economic value of renewable energy sources should be considered. Although there are recent examples of technological renewable energy asset studies [22], the economic asset value of renewable energy sources is unknown and uninvestigated to date. When the introduction of renewable energy sources is to be stimulated, it is evidently important to represent the value and remuneration of these energy sources. In the next section, the asset value of shallow geothermal energy is assessed, applying the similar Net Present Value (NPV) Method as used by Veldhuizen *et al.* [20] in their calculations of the value of Dutch gas reserves, since this method is recommended by the Handbook on Measuring Capital (OECD), the System of Environmental and Economic Accounting (SEEA) and the System of National Accounts (SNA) for the monetary valuation of subsoil assets [20].

### *4.1. The asset value of shallow geothermal energy*

Because the Netherlands is positioned in the delta of big rivers like the Rhine and the Meuse, large sedimentary deposits and sand aquifers developed in the Netherlands (figure 3). These sand aquifers are the reason why the greater part – approximately 90% - of the Netherlands is suitable for ATES systems. In the less suitable areas, heat can be mined from the subsurface through BHE systems. It seems that the Netherlands is not only blessed with the wealth of a large stock of natural gas, but also with a widespread availability of groundwater. According to estimations from De Mulder *et al.* [23], the total stock of fresh groundwater comprises about 800 billion $m^3$. Only for the extraction of drinking water, the stock represents an economic value of €100 billion [23]. Additionally, brackish and salt water – which can also be used in shallow geothermal applications – comprise an additional capacity of several times the fresh water capacity. Finally, where these sand aquifers are not available (mainly in the South-Eastern part of the Netherlands) it is possible to apply ground heat exchangers. In fact, 100% of the Dutch surface can be used for shallow geothermal applications.

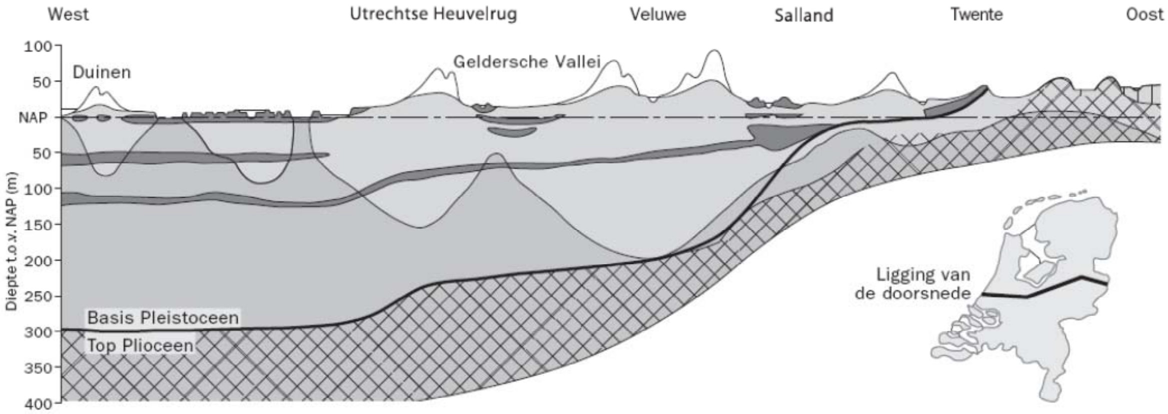

Figure 3: availability of sand aquifers in the Netherlands (white = unsaturated zone; light grey = freshwater; medium grey = brackish and salt water; dark grey = separating layer (peat, clay, loam); boxed = poorly permeable basis) [23]

Theoretically, the complete heating and cooling demand of all households, offices and factories can be covered by shallow geothermal resources. The total Dutch potential is roughly 2.2 EJ/yr for ATES systems and 1.2 EJ/yr for BHE systems [24]. When utilizing this potential, a coordinating role of the government is necessary; the increased use of groundwater for geothermal systems should be fitted in all other uses of the surface. According to Novem [25], a minimum surface of 17 $m^2$ is needed for generating 1 GJ per year; this ensures a maximum change in surface temperature of $1^0$C.

### 4.1.1 NPV method

Differently to the case of oil and gas reserves, for which it is commonly expected that the level of annual extractions will decline when reserves are gradually exhausted – strongly influencing the annual opening and closing stock value of the oil and gas reserves – the use of geothermal heat is not subjected to exhausting reserves. Therefore, the NPV of future income from geothermal reserves at the beginning of year *t* is calculated using the basic model of Veldhuizen *et al.* [20], leaving the different revaluation models out of the equation:

$$NPV^{t} = \sum\nolimits_{\tau=t}^{\infty} \frac{RR_{t-1}^{\tau}}{(1+r)^{\tau-t+1}} = \sum\nolimits_{\tau=t}^{\infty} \frac{rr_{t-1}^{\tau} Extr_{t-1}^{\tau}}{(1+r)^{\tau-t+1}}$$

Where,

$RR_t^{\tau}$ = resource rent in year $\tau$ as expected at the end of year *t*

$rr_t^{\tau}$ = unit resource rent in year $\tau$ as expected at the end of year *t*

$Extr_t^{\tau}$ = extraction in year $\tau$ as projected at the end of year *t*

$(1+r)^{\tau}$ = discount rate for discounting extractions in year $\tau$ to prices of year *t*

### 4.1.2 Extraction: future use scenarios

In the Netherlands, the total housing stock contained 7,172,436 dwellings at the end of 2010 [1]. Currently, 80% of all dwellings are constructed before 1992. Households living in dwellings built before 1992 (5,737,949 in total) have an average heating demand of 69.4 GJ annually. When applying geothermal heating systems for supplying the heating demand, we assume that 70% (48.6 GJ) will be serviced by the geothermal heating system; 30% of the heating demand will be supplied by the use of so-called peak boilers that are situated at the geothermal plant site. Additionally, households living in new dwellings (1,434,487 in total) have an average heating demand of 40 GJ annually. In case of geothermal heating system application, 28 GJ will be delivered by this system. Furthermore, new dwellings have an average cooling demand of 7.5 GJ per year, which can be supplied by a geothermal system.

Over 2010, 59,999 new dwellings have been added to the stock, and 15,110 dwellings were distracted [1]. These figures have been more or less constant over the last five years. Furthermore, demographic scenarios from Poelman and Van Duin [27] show that there will be a linear growth of the Dutch population until 2035, and so there will be a continuing increase in the demand for dwellings the period until 2035. Therefore, we assume that until 2035, an annual amount of 60,000 dwellings is added to the stock, and that 15,000 dwellings are distracted per year. This results in a growth of the housing stock of 45,000 dwellings per year. After 2035, the population will decrease, and so will the housing demand; we expect that only the annual distraction of 15,000 dwellings will continue after 2035.

Finally, a geothermal heat introduction scenario is used as input for the projection of geothermal heat usage in the Netherlands; this scenario is based upon the product diffusion model of Rogers [26] (figure 4). The connection rate of all individual Dutch dwellings is distributed over eight years; in the first four years, 20% will be connected (5% per year), in the two years after the major part of the households (60%) will switch (30% per year), and in the last two years, the remaining households (20%) will be connected (10% per year). After 2018, all newly built dwellings are immediately connected to the geothermal system.

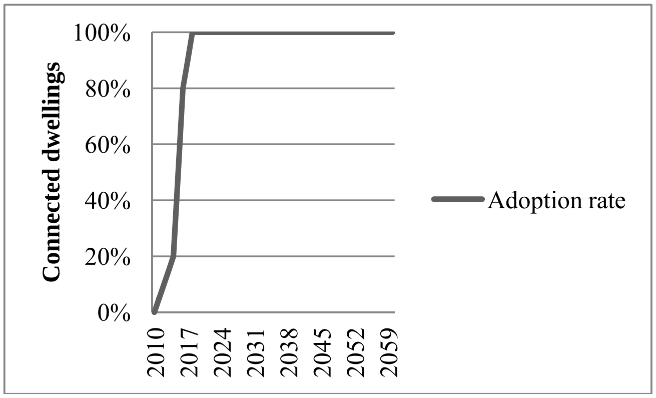

Figure 4: Adoption Rate (based upon Rogers [26])

Using the introduction rates of Rogers [26] and the abovementioned household and dwelling figures, we can calculate the outcomes of our scenario about the annual energetic extraction from the subsoil. In table 1, the assumptions underlying our annual extraction scenario are summarized.

Table 1: future use scenario

| | 2010 | 2011-2035 | 2036-2060 | Heating demand p/dwelling | Cooling demand p/dwelling | Subsoil heating extraction per dwelling | Subsoil cooling extraction per dwelling |
|---|---|---|---|---|---|---|---|
| Old dwellings | 5,737,949 | -15,000 /yr | -15,000 /yr | 69.4 GJ | 0.0 GJ | 48.6 GJ | 0.0 GJ |
| New dwellings | 1,434,487 | +60,000 /yr | +0 /yr | 40.0 GJ | 7.5 GJ | 28.0 GJ | 7.5 GJ |
| Total | 7,172,436 | +45,000 /yr | -15,000 /yr | - | - | - | - |

### 4.1.3 Resource rent

The resource rent (RR) is the net income from extraction defined as total revenue from sales less all costs incurred in the extraction process including user cost of produced capital; the resource rent represents the returns from the resource only [20]. Let us assume an exploitation period of geothermal heat systems of 50 years. The newly built dwellings (>1992) can be heated with a geothermal system with a depth of averagely 2 kilometers, since the temperature at which the water can be extracted from the aquifer is too low for the existing building stock. A geothermal system with a drilling depth of 3 kilometers allows for providing the old building stock (<1992) with geothermal heat, because the inflow temperature is high enough for high temperature systems. The depth of the drill hole influences the necessary investment; in table 2, the costs of both system solutions are presented.

Table 2: characteristics of two geothermal heat solutions

| | Solution for new dwellings (>1992) | Solution for old dwellings (<1992) |
|---|---|---|
| Depth (meters) | 2,000 | 3,000 |
| Costs of the plant (€) | 8,000,000 | 12,000,000 |
| ΔT (°C) | 27 | 33 |
| Capacity (MWth) | 4.7 | 5.8 (x 3.6 levert GJ) |
| Production per year (GJ) | 67,878 | 103,703 |

Additional costs are associated with the network; it is required to construct a network for transporting the water from the geothermal plant to the individual end users. The total network costs per dwelling are estimated at 4,000 Euros; 1,000 Euros for the main heating grid, and 3,000 Euros for the individual connections. Furthermore, each dwelling needs an individual heat pump; since the dwellings are jointly connected to the network, we assume scalar advantages, and an investment of 5,000 Euros per dwelling.

Revenues can be expected from selling GJ's for heating and cooling. As mentioned earlier, supplying cooling to dwellings using geothermal systems is cost-efficient. Assuming the current stock of new dwellings (>1992), and the average cooling demand of 7.5 GJ per dwelling, the total cooling demand for 2010 is estimated at 10.8 PJ. We assume that 1 GJ for cooling is equal to €15. This incurs that – only for cooling – the Dutch surface can yield 161 million Euros on a yearly basis; this amount will increase in the years after 2010, since the number of new dwellings increases annually. For heating, the heating demand using the 2010 figures is 318.9 PJ, and the price of geothermal heat is approximately three times as high as the price for cooling; on average, 1 GJ for heating costs around €35. This equals annual potential revenues of 11 billion Euros.

#### 4.1.5 Discount rate

The real discount rate that was used for calculating the net present value was set at 4 percent, the same value as used by Veldhuizen *et al.* [20]. The sensitivity analysis (section 5) will give information about the influence of a changing discount rate on the NPV of geothermal energy.

### *4.2 Asset value of geothermal energy in the Netherlands*

Using the stated assumptions, the net present value of geothermal energy for cooling and heating is 118 billion Euros, equaling 21% of the Dutch GDP. When only revenues from heating are included, the NPV is 113 billion Euros. The application of geothermal energy systems for only cooling proved to be unfeasible; the NPV of geothermal cooling is -6 billion Euros. The cooling demand is too low to generate enough revenues. Interestingly, the extraction of geothermal energy from the subsoil does not result in an exhausting reserve, as it does in case of natural gas extraction. This results in steady future NPV values for geothermal energy, which might rise due to general energy price increases. In figure 5, the NPV's of natural gas, geothermal heating, geothermal cooling, and a combination of geothermal heating and cooling are displayed. It shows that – on the long term – the subsoil can be of great value for the Dutch economy when applying geothermal systems for heating and cooling.

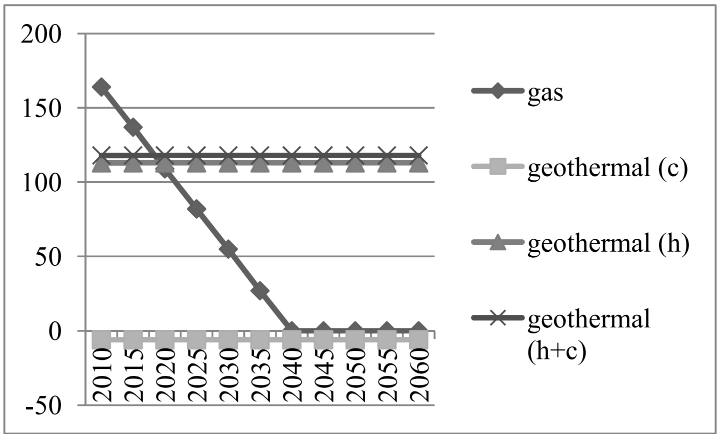

Figure 5: Net Present Values of Gas and Geothermal Energy Systems.

#### 4.2.2 Gas prices

Still, the cost-efficiency of geothermal heating is relatively low compared to heating with natural gas. The only way to make renewable heat economically competitive with natural gas is by manipulating the gas prices for end consumers. The currently prevailing Dutch prices for gas are relatively low, for Dutch consumers as well as for the countries that buy Dutch gas. This becomes apparent when comparing gas prices with prices of gasoline. One liter of gasoline has the same calorific value as one m$^3$ of natural gas. Gasoline costs approximately €1.50 per liter, indicating that the natural price segment of natural gas lies above the current level of €0.50/m$^3$, also regarding the fact that natural gas is delivered at the consumers' homes.

If gas prices rise from the current level (€0.50/m$^3$) to between €0.75 and €1.00, for instance by introducing tax measures, heat costs approximately €30 - €40 per GJ. This is the boundary value on which individual renewable heat networks become profitable (figure 6). Furthermore, gradually raising the gas price increases the asset value of the available stock of natural gas and the possible gas-related revenues from export. And the higher costs for heating create an incentive for investments in energy saving measures in the existing housing stock, eventually resulting in a higher value of the dwellings. However, despite the advantages of higher gas prices, it is important to perform this price transition gradually, in order to reduce the risks on negative side-effects.

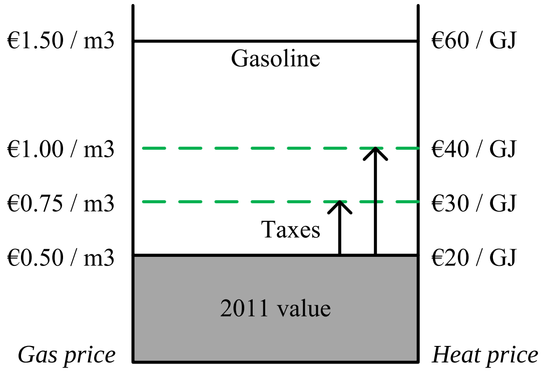

Figure 6: necessary gas price increase

### 4.2.2 Organization

The most appropriate institutions for organizing the proposed heat transition are sustainable local or provincial energy companies. End consumers should be able to buy shares of these renewable energy companies, in order to profit from the heat transition. Furthermore, the proposed additional taxes on natural gas should flow into these energy companies. The most important advantages of this institutional solution are (a) creating local employment; (b) creating prosperity; (c) creating value, of which many people can profit through the share structure.

## 5. Sensitivity analysis

The created NPV model is based upon several assumptions, which are discussed in section 4. In this section, the effects of possible changes in these assumptions are studied. The four assumptions that are subjected to a sensitivity analysis are: (a) the discount rate; (b) the introduction rate of geothermal energy in Dutch households; (c) the exploitation period; and (d) the heating price. Four possible scenarios are calculated: -50%, -25%, +25%, and +50% of the originally assumed values. In table 3, the results are summarized.

Table 3: sensitivity analysis results

| | **-50%** | | **-25%** | | **+25%** | | **+50%** | |
|---|---|---|---|---|---|---|---|---|
| Discount rate | 2% | € 223 billion | 3% | € 163 billion | 5% | € 86 billion | 6% | € 62 billion |
| Introduction rate | 4 yrs | € 136 billion | 6 yrs | € 129 billion | 10 yrs | € 117 billion | 12 yrs | € 113 billion |
| Exploitation period | 25 yrs | € 48 billion | 38 yrs | € 93 billion | 63 yrs | € 135 billion | 75 yrs | € 143 billion |
| Heating price | 18€/GJ | € 18 billion | 26€/GJ | € 65 billion | 44€/GJ | € 171 billion | 52€/GJ | € 218 billion |

The model is most sensitive to discount rates and heating prices, and this is interesting since these are aspects that can be influenced by the Dutch government. If the heat transformation is organized by the government – either on a local or on a provincial scale –

they have the key to maximizing its success. Furthermore, the effects of decreasing the introduction rate on the NPV are very little; the investments are also spread over a longer period, making the larger revenues less influential on the value. Increasing the introduction rates seems interesting but difficult to achieve. Finally, the exploitation period is an influential factor. Since current geothermal systems are constructed with a life-expectancy of >50 years, and the sector is characterized by a high level of innovation, we do not expect exploitation periods to decline in following years.

## 6. Conclusions

The introduction of renewable energy in the Netherlands stagnates. In 2010, renewable energy covered only 3.8% of the total Dutch energy demand. Most important causes for this stagnation are the absence of a clear long-term policy on renewable energy, the ineffectiveness of the Dutch renewable energy subsidy system, and the availability of a large stock of natural gas in the Dutch subsurface. Concluding, renewable energy sources are economically unable to compete with conventional fossil-fuel based energy sources.

When considering the potential of the available carriers for renewable energy, the authors claim that heat is the most promising carrier for renewable energy production. The main reasons for this claim are the large share of heat in the total Dutch energy demand (68%), and the relative low investment costs per effective kilowatt for renewable heat production. Specifically, shallow geothermal energy applications, like Aquifer Thermal Energy Storage (ATES) and Borehole Heat Exchangers (BHE), are regarded as potentially suitable technologies for a short term market introduction, because of their relative economic independence and competitiveness, the maturity and efficiency levels of the technologies, the high level of resulting indoor comfort, and the high possible reductions in GHG emissions.

Despite the advantages of geothermal heating and cooling systems over conventional gas-based systems, there is yet no economically attractive and competitive basis for the introduction of renewable heat in the conventional Dutch system. The current system with combustion of natural gas in individual gas boilers is an efficient system and delivers large financial gains for the Dutch government and industry. For the Dutch government, the stock of natural gas in the Netherlands represents an asset value of €164 billion, which will eventually decrease strongly because of reserve exhaustion.

In order to stimulate the introduction of renewable heat sources, and geothermal heating and cooling systems specifically, the asset value of the Dutch subsurface is determined. For heating and cooling, the Dutch subsurface represents an asset value of €118 billion when assuming an exploitation period of 50 years. Interestingly, the asset value of this renewable energy source does not decrease. Additionally, if prices per GJ heating will increase in the future, due to gas price increases, the asset value of geothermal energy can be as high as the current value of the natural gas reserves in the Netherlands. This requires a gas price increase of 50% - 100%, from the current level of €0.50 per $m^3$ to between €0.75 and €1.00 per $m^3$. Additional advantages of gas price increases are the increasing asset value of the remaining natural gas reserves, and the higher income on taxes, which can be used to organize the renewable heat transition.

Concluding, the proposed economic approach results in the valuation of an asset that does not devaluate, despite using it. The Netherlands possesses a unique and very valuable stock of thermal reserve in the subsurface, which can be used as asset value from an accounting perspective. Furthermore, this asset value increases with a growing use and increasing price of fossil fuels. This valuation approach should primarily be integrated in our economy, after which the knowledge can be exported to other countries. The Dutch government successfully implemented a similar approach in the transition from coal to natural gas; they are able to introduce a new transition, but now with renewable sources of which many generations will be able to profit from.

## 7. Discussion

Although the created value model shows that the introduction of geothermal energy can be interesting for the Dutch government, there are some aspects that can be improved in the model. First, the running costs of the institutions that will be in charge of executing the heat transition are not included in the NPV calculation. As this depends strongly on the organizational choices, additional research is required. However, we propose to finance these institutions with additional tax incomes from gas price increases; therefore, the influence on the net present value might be relatively low. Furthermore, additional revenues can be realized by selling emission rights in case emission trading becomes standard. Since the proposed heating and cooling system reduces the emission of GHG drastically, large gains can be made by selling the non-used emission rights. This influences the asset value of the Dutch thermal reserve positively. Finally, there might be some parts of the Netherlands in which the population density is too low for geothermal heating and cooling systems and networks to be efficient. However, since the Dutch population density is relatively large, the expected consequences of these areas being difficult to connect on the total geothermal heating demand are low.

## References

[1] CBS Statline, Industry and Energy Use, The Hague, The Netherlands www.statline.cbs.nl, 2011.
[2] ECN, Reference Projection Energy and Emissions 2010–2020, Energy Research Centre of the Netherlands (ECN), Petten, the Netherlands, 2010.
[3] CBS (Netherlands Central Bureau for Statistics), Hernieuwbare energie in Nederland 2009 (*Renewable Energy in the Netherlands 2009*), CBS publication, The Hague, The Netherlands, 2010.
[4] Reiche, D., Bechberger, M., Policy differences in the promotion of renewable energies in the EU member states, Energy Policy 32 (2004) 843-849.
[5] Rooijen, S.N.M. van, Wees, M.T. van., Green electricity policies in the Netherlands: an analysis of policy decisions, Energy Policy 34 (2006) 60-71.
[6] Beurskens, L., Assessment of the effectiveness and economic efficiency of selected support options for the Netherlands, IEE, Policy development for improving RES-H/C penetration in European Member States, 2011.
[7] Barbier, E., Geothermal energy technology and current status: an overview, Renewable and Sustainable Energy Reviews 6 (2002) 3-65.
[8] Omer, A.M., Ground-source heat pumps systems and applications, Renewable and Sustainable Energy Reviews 12 (2008) 344-371.
[9] Fridleifsson, I.B., Geothermal energy for the benefit of the people, Renewable and Sustainable Energy Reviews 5 (2001) 299-312.
[10] Fischer, C., Newell, R., Environmental and Technology Policies for Climate Change and Renewable Energy, Resources for the Future, Discussion Paper 04-05, 2004.

[11] Haas, R., Eichhammer, W., Huber, C., Langniss, O., Lorenzoni, A., Madlener, R., Menanteau, P., Morthorst, P.E., Martins, A., Oniszk, A., Schleich, J., Smith, A., Vass, Z., Verbruggen, A., How to promote renewable energy systems successfully and effectively, Energy Policy 32 (2004) 833-839.
[12] Jacobsson, S., Bergek, A., Transforming the energy sector: the evolution of technological systems in renewable energy technology, Industrial and Corporate Change, 13(5) (2004) 815-849.
[13] Toke, D., Lauber, V., Anglo-Saxon and German approaches to neoliberalism and environmental policy: The case of financing renewable energy, Geoforum 38 (2007) 677-687.
[14] Lesser, J.A., Su, X., Design of an economically efficient feed-in tariff structure for renewable energy development, Energy Policy 36 (2008) 981-990.
[15] Fischer, C., Preonas, L., Combining Policies for Renewable Energy: Is the Whole Less than the Sum of Its Parts? Resources for the Future, Discussion Paper 10-19, 2010.
[16] Haehnlein, S., Bayer, P., Blum, P., International legal status of the use of shallow geothermal energy, Renewable and Sustainable Energy Reviews 14 (2010) 2611-2625.
[17] Lund, J.W., Freeston, D.H., Boyd, T.L., Direct application of geothermal energy: 2005 worldwide review, Geothermics 34 (2005) 691-727.
[18] Van Hoegaerden, V., Thermische Energie uit de Ondergrond, Comfort en Duurzaamheid door gecertificeerd gebruik van de ondergrond, TNO, 2004.
[19] TNO, Natural Resources and Geothermal Energy in the Netherlands, Annual review 2010 – A review of exploration and production activities and underground gas storage, TNO, Dutch Ministry of Economic Affairs, Agriculture and Information.
[20] Veldhuizen, E., Graveland, C., Bergen, D. Van den, Schenau, S., Valuation of oil and gas reserves in the Netherlands – 1990-2005, Statistics Netherlands, the Hague.
[21] CBS, Environmental Accounts of the Netherlands 2009, Statistics Netherlands, The Hague, The Netherlands, 2010.
[22] Burns, R.K., Afghanistan: Solar assets, electricity production, and rural energy factors, Renewable and Sustainable Energy Reviews 15 (2011) 2144-2148.
[23] De Mulder, E.F.J., Geluk, M.C., Ritsema, I., Westerhoff, W.E., Wong, T.E., De ondergrond van Nederland, TNO, 2003.
[24] Van Hoegaerden, V., Hagedoorn, S., Accelerating the deployment of shallow geothermal heat and cold resources in Europe, Proceeding of the Europe Geothermal Congress, Unterhaching, Germany, 2007.
[25] Novem, Milieu effecten en afwegingen, Fase 2, Bijlagen: Bepaling van preventieve maatregelen voor de milieueffecten als gevolg van de toepassing van grondwatersystemen en bodemwarmtewisselaars, BEB Project (Bodem als Energiebron en Buffer), 2003.
[26] Rogers, E.M., Diffusion of Innovations, Glencoe, Free Press, 1962.
[27] Poelman, B, Van Duijn, C., Bevolkingsprognose 2009-2060, Statistics Netherlands, the Hague, the Netherlands, 2010.

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Han, Q., Nieuwenhijsen, I., de Vries, B., Blokhuis, E., Schaefer, W.F. Optimal Intervention Strategies to Simulate Energy Saving Behavior of Residents, Energy Policy, 1st round review, major revisions.

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# OPTIMAL INTERVENTION STRATEGIES TO STIMULATE ENERGY SAVING BEHAVIOR OF RESIDENTS

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**Abstract:**
This study investigates optimal intervention strategies in stimulating energy saving behavior of residents to achieve energy natural urban development. A tree structure overview of potential intervention strategies classified into three categories is revealed. An integrated behavior model is developed reflecting the relations between behavior and influence factors. A latent class model is used to identify segments of residents who differ regarding their preferences for intervention strategies. Data are collected from a sample of residents in the Eindhoven region of the Netherlands in 2010. The results indicate that social-demographic characteristics, knowledge, motivation and context factors play important roles in energy saving behaviour. Specifically, four segments of residents in the study area were identified that clearly differed in their preferences of intervention strategies: cost residents, conscious residents, ease residents and environment residents. These findings emphasize that the intervention policies should be focused on specific target groups to have effective results in stimulating them to save energy.

**Keywords:** Energy saving behavior; intervention strategy; latent class model

## 1 INTRODUCTION

Sustainable urban development has developed in the past a few decades in the Netherlands to a mature subject of policy, research and innovation with various titles, such as low carbon city, energy neutral city, etc. The strategy of the local government to realize the energy-neutral target is based on the Trias Energetica: reduce energy demand, use renewable energy resources and use fossil fuels efficiently. The first step in this approach is to save energy because energy saving is the cheapest way to reduce $CO_2$ emission (IEA, 2008). The reduction of energy demand in the existing housing stock contributes for 25% to the energy-neutral strategy. Despite all efforts currently being undertaken, the energy-saving rate of the residents is still very low. Therefore, it is important to investigate how residents can be encouraged to save energy.

There are two different types of energy-saving behaviors: investment behavior and curtailment behavior. Investment behavior is spending money on the improvement of dwellings in terms of energy efficiency and the purchase of energy efficient appliances. Curtailment behavior is about reducing energy usage by behavioral changes. Contextual factors, knowledge, motivations, abilities and socio-demographic variables may influence such energy saving behavior. There are certain intervention strategies that local government can apply to promote residents to change their behavior in energy saving, such as providing information, demonstration, offering free products, commitment with goal setting, giving feedback, rewards, and financial support.

This paper is about the research that has been done to investigate the optimal intervention strategies to stimulate energy saving behavior of residents. We collected our sample data with an online questionnaire, and the residents at Eindhoven, the Netherlands, are invited to participate. Based on the literature analysis, an overview of potential intervention strategies is revealed in a tree structure. With the survey data, an integrated energy saving behavior model is developed. With the use of the latent class model, four segments of residents are distinguished, each possessing specific characteristics with different preferences and dislikes for the intervention strategies. Consequently, the recommendations are given to the local government of the study area that different segments of residents are in demand for different (combination of) intervention strategies. The intervention policies should be focused on specific target groups to have effective results on stimulating them to save energy.

## 2 ENERGY USE BEHAVIOR

Households use energy directly in forms of natural gas and electricity and indirectly through the energy that is used to develop the products and foods that households consume (Vringer and Blok, 1995). The amounts of electricity and natural gas use per household are comparable to a total energy of about 73,4 GJ/yr on average. The amount of electricity and natural gas use per household slightly changed over the past ten years. In comparison to former years more electricity and less gas is used per household.

Van Arkel et al. (1999) distinguished energy use into two categories, namely dwelling related energy use and user behavior related (or appliances related) energy use. The dwelling related energy use consists of heating, insulation, ventilation and the heating of tap water. The user behavior related energy use consists of using all kinds of appliances related to cleaning, cooling and preparation of food and audio-, video- and telecommunication. Lighting is conditioned by the design of the house together with the lifestyle of the residents. Therefore, it is part of both dwelling related energy use and user behavior related energy use. In this research, energy demand is assumed to depend on both the behavior of the residents and the characteristics of the dwelling. Accordingly, energy saving are related to both the investment and curtailment behavior of the residents

Since the energy use for heating covers more than 50% of the total energy uses of a household (Itard, et al. 2009), technical characteristics of dwellings – energy label – are important factors when determining energy demand and consequent energy saving potentials. Dwelling technical characteristics such as constructional measures, insulation measures and method of heating and lighting are important factors. Ownership of the housing, duration of the residence may influence the maintenance of the dwelling and indirectly impact the energy efficiency.

Recent studies have shown that residents' behavior has a significant impact on the energy demand of households (Guerra, et al. 2009). Such behavior has a strong association with the characteristics of the user. The study conducted by Leidelmeijer and Cozijnsen (2010) shows that age is an important factor in energy consumption. Age of the residents influences thermostat settings, frequency and length of showering, and the number of used appliances (Groot, et al. 2008). Moreover, age of the residents may imply the strength of the habitual behavior, since the behavior is likely to be repeated when outcomes are satisfactory. Habitual behavior may involve misperceptions and selective attentions: people tend to focus on information that confirms their choices, and neglect information that is not in line with their habitual behavior (Steg, 2009). People only accept a change in information when there is a sufficient deviation, and such habitual behaviors are commonly observable in elderly people.

The household-size and composition, which represents the total number of people living in the same dwelling, determines the frequency of activities over the week, such as washing, dishwashing, tumble drying and refrigeration (Groot, et al. 2008), therefore direct related to the total energy demand (Abrahamse and Steg, 2009). Furthermore, other socio-demographic factors, such as income, education level, work status and etc, may serve as barriers or opportunities for energy usage and saving.

Consequently, there are two types of energy saving behaviors: investment behavior and curtailment behavior. Investment behavior is about investment in the measures to increase the quality of dwellings in terms of energy efficiency (e.g., change the old single glass window to the double HR glass), or the purchase of energy efficient appliances to reduce energy usage (e.g., LED light). Curtailment behavior is about the decrease in energy usage by behavioral changes, such as shortening shower duration, lowering thermostat setting. However, with the energy saving behavior there is a risk for rebound behavior (Berkhout, et al. 2000).

Contextual factors, knowledge, motivations, abilities and socio-demographic variables are the important factors that could influence residents' energy usage and saving (Steg, 2008). Although people often seem to be aware of the environmental and energy problems, they often do not act in line with their concerns, because they rarely make a conscious decision to use energy, and total household energy demand is still rising. This seems to be partly caused by a lack of insight in the relation between user behavior and energy usage, and partly caused by the perceived obstruction of regulation and public opinion.

Government has few (financial and legal) means to push the energy neutral target forward in the public sphere. Despite all the effort being undertaken, the energy saving rate is still very low. The current governmental financial incentives appear to be inadequate because household energy demand keeps rising (Abrahamse, 2007). The local government is dependent on the voluntary participation of their residents to save energy.

## 3 INTERVENTION STRATEGIES

In the literature (Abrahamse, 2007; Abrahamse, et al., 2005), several types of intervention strategies for stimulating energy saving are introduced. We can classify them into three main categories: antecedent, consequence and structural interventions. However, a systematic overview of all possible intervention strategies and its subtypes did not exist in the literature yet. In this section, first a brief description of the intervention strategies is given, and then a tree structure is developed to provide a clear overview (shown in figure 1).

Antecedent interventions increase people's knowledge and strengthen their concern with energy problems in order to encourage energy saving behavior. There are different types of antecedent interventions, such as providing information, giving demonstration, building commitment, setting a goal, offering free products, and etc. Providing information aims to increase people's awareness about energy problems and enrich their knowledge about the way to solve these problems. Information campaigns are commonly used to promote energy saving. There are different possibilities to provide people with information, to name a few: workshops, mass media campaigns, and website. In contradiction to the general belief, mass media campaigns appeared not to be very effective. Providing specific information that is tailored to a particular type of household is essential and seems to be effective (Abrahamse, et al. 2009). Demonstration provides examples of recommended behavior. In general, people will follow these examples when they are understandable, relevant, meaningful and rewarding. Free products offer people knowledge and strengthen their concern for saving energy in a passive manner by giving them the possibility to try out. Commitment strategies contain a promise to change behavior, in this case to save energy. If the promise is pledged to oneself it may only activate a personal norm (i.e., a moral obligation). When the promise is made public (e.g., by leaflets), social norms (i.e., expectation of others) also play a role in influencing the energy saving behavior (Lucas, et al. 2008). The promise to save energy can be linked to a specific goal such as reduce energy consumption by 5% within 5 years. The commitment strategy of goal setting is often used in combination with other interventions (e.g., feedback).

Consequence interventions are based on the assumption that the presence of positive or negative consequences will influence behavior. Feedback and rewards are two incentives that associate with the positive or negative outcomes. The study conducted by Abrahamse (2007) reveals that providing feedback about the reached saving rate is very effective, and appeared to be more effective when such feedback was given more frequent and related to a specific saving goal. Rewards seem to have a positive effect on reducing energy usage, but it appeared that effects of rewards are short-lived (Geller, 2002)

Structural intervention strategies are aimed at changing the contextual conditions to facilitate behavior changes (Steg, 2008). Changes in the circumstances of energy usage may be used to make pro-environmental behavior more attractive. The costs and benefits of behavioral alternatives may be adjusted in various ways through financial support (Steg and Vlek, 2009). Changes in physical, technical and organizational systems can alter the availability in products and services. High energy consuming products and services can be made less attractive or even unavailable by policies, while energy efficient products and services may be promoted by subsides (e.g., LED lights and other energy efficient appliances). Legal regulations can be implemented (to prevent split-incentive for example). Pricing policies can be used to set higher prices for conventional energy intensive products/options via taxation (e.g., higher tax for using fossil fuel energy).

The tree structure in Figure 1 shows the different main types and subtypes of intervention strategies identified in the literature. The owner-residents-panel (Vereniging Eigen Huis, 2009) has been used to validate the tree structure. As it appears, there are three categories with seven main intervention strategies recognized: information; demonstration; free products; commitment with goal; feedback; rewards and financial support.

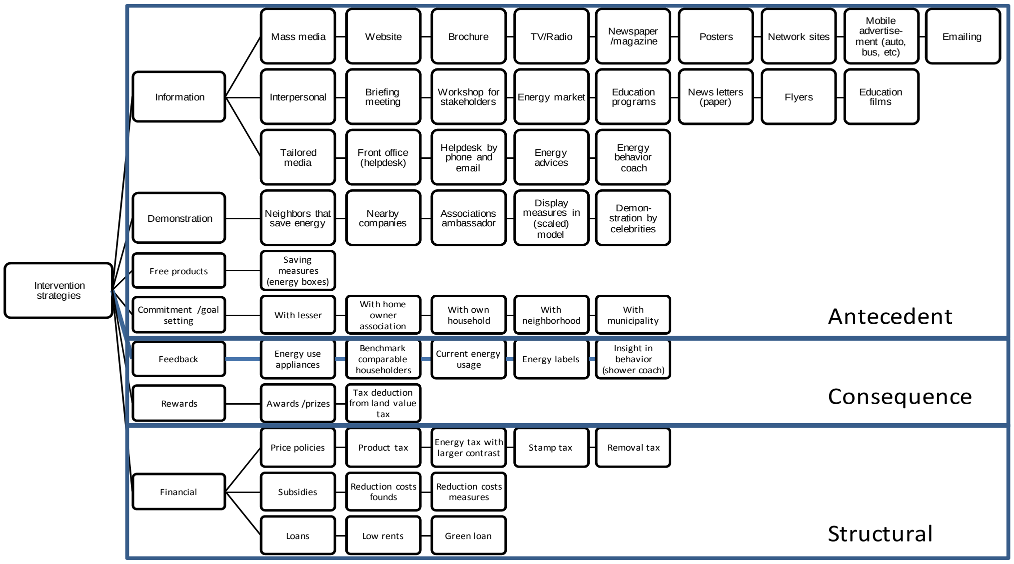

**Figure 1: Tree structure of all possible intervention strategies**

## 4 LATENT CLASS MODEL ANALYSES

A latent class model (Greene and Hensher, 2002; Swait, 1994) was used to segment the respondents regarding their preference in intervention strategies. Latent class model (LCM) involve characterizing segments from observed measures and permit choice attributes data and individual characteristics to simultaneously explain choice behavior. The advantage of the latent class segmentation approach over other segmentation approaches using socio-demographics is that the segments are behavior based and are therefore more actionable and more directly relevant to management and planning decision making (Greene, 2001). Regardless of its potential, the latent class model has not been widely used in the field of urban sustainable development research especially in policy making. In our study, a latent class formulation is proposed that simultaneously groups residents and estimates a separate set of utility parameters for each segments.

Formally, the model can be described as follows: an individual resides in a latent class, *c*, which is not revealed to the researcher. The existence of a fixed number of *C* classes in a population is assumed. The utility underlying individual *i*'s choice among *J* intervention packages at choice situation *t*, given that he/she belongs to latent class c, can be expressed as:

$$U_{jit} = \beta_c^{'}\mathbf{X}_{jit} + \varepsilon_{jit} \qquad (1)$$

Where, $\boldsymbol{X_{jit}}$ is a union of all attributes that appear in all utility functions, and $\boldsymbol{\beta_c'}$ is a class specific parameter vector. The $\boldsymbol{\varepsilon_{jit}}$ indicates the unobserved heterogeneity for individual *i* and package *j* in choice situation *t*. The number of choice situations and the size of the choice set may vary by individual with the assumption that the same individual is observed in several choice situations (i.e., makes one or more choices). Within the class the choice probabilities are assumed to be generated by the multinomial Logit (MNL) model:

$$P(y_{it} = j \mid class = c) = \frac{\exp(\beta_c^{'}\mathbf{X}_{jit})}{\sum_{j=1}^{J_i}\exp(\beta_c^{'}\mathbf{X}_{jit})} \qquad (2)$$

As noted, the class is not observed. Class probabilities are specified by the MNL form:

$$P(class = c) = Q_{ic} = \frac{\exp(\theta_c^{'}\mathbf{Z}_i)}{\sum_{c=1}^{C}\exp(\theta_c^{'}\mathbf{Z}_i)}, \quad \theta_c = 0 \qquad (3)$$

where $\boldsymbol{Z_i}$ is an optional set of observable individual, choice situation invariant characteristics. If no such characteristics are observed the class specific probabilities are a set of fixed constants that sum to one. For individual *i*, the model's estimate of the probability of a specific choice is the expected value (over classes) of the class specific probabilities:

$$P(y_{it} = j) = E_c\left[\frac{\exp(\beta_c^{'}X_{jti})}{\sum_{j=1}^{J_i}\exp(\beta_c^{'}X_{jti})}\right] = \sum_{c=1}^{C}\Pr(class = c)\left[\frac{\exp(\beta_c^{'}X_{jti})}{\sum_{j=1}^{J_i}\exp(\beta_c^{'}X_{jti})}\right] \qquad (4)$$

The model is estimated by direct maximization of the log likelihood (Greene, 2001).

## 5 DATA COLLECTION

Data for this study were obtained using an online questionnaire. With the help from the municipality of Eindhoven, the survey has been distributed to a sample of 1500 households in Eindhoven in 2010. Each head of a household in the sample received a letter with a request to participate in the survey. In total 309 respondents filled in the questionnaire and 265 were valid to be used in the analysis. The lower respondents' rate might be caused by that it was not possible to send the respondents in the sample an email with a direct web link to the survey on the internet.

The choice experiment is designed using fractional factorial design with the seven intervention strategies as described in the previous section. Each intervention strategy has two levels about whether or not it is present in the package. Respondents were asked to make several choices between two intervention packages and a baseline option of none of the two. In addition, there are many other questions in the survey about the current energy saving behavior such as investment in HR glass, knowledge of energy problems, motivation for energy saving, experienced obstruction by regulation and public opinions, and etc. Finally, personal information such as age, household composition, education level, employment status, duration of current residence and income level was collected.

To test the questionnaire for its clarity and ambiguity, it was first presented to 20 respondents for a pilot test. Taking into account their comments and suggestion, unclear questions such as lifestyle were excluded, some open questions were changed to semi-structured and other too ambiguous questions were adjusted. Also the presentation of the choice sets of the experiment is improved in an attempt to avoid flat lining answer as much as possible.

## 6 RESULTS

The results of the analysis included a description of the distribution of the respondents in the sample on a series of socio-demographics, an integrated energy saving behavior model of casual relations, the result from the estimation of the LCM model including the relation between preference for intervention strategies and the characteristics of the residents, and the policy implication of the results.

### *6.1 Sample descriptions*

The profile of the respondents is presented in Table 1. The results showed that about 44% of the respondents were in the age group of 27–45 years and 20% in the age group of 46–58, with 21% over 59 years of age and about 15% younger than 27 years of age. More than half (69%) of the respondents had a university level education, and another 13% had a professional education level. The largest group of households had monthly income between €2500 and €5000, but 18% belonged to the high level income group (i.e., more than €5000), and about 31% had a below €2500 income.

The work status results indicated that 38% of the respondents did not provide information and may not work, while 10% worked less than 12 hours per week and 52% had a more than 12 hours work weekly. Most of the respondents were couples, which was the most common type of household in the study region. 39% were a single person household and 33% of the households consisted of a family with children. More than half the households lived in a private housing, while 41% had a rental house.

The respondents in the sample were compared with census data of the residents of the region according to some selected characteristics including age, household type, income, education level, housing ownership type and the number of working hours. Several observations were made. First, slightly more high educated people were willing to participate in our study. Further, and not surprisingly, the younger than 27 years of age category participated less in our study. For household type and income, no significant differences between the sample and the residents of the region were found.

**Table 1 Characteristics of respondents**

| Variables | Levels | % |
|---|---|---|
| Age | <27 | 15 |
| | 27—34 | 21 |
| | 35—45 | 23 |
| | 46—59 | 20 |
| | >59 | 21 |
| Education level | Primary level | 3 |
| | Medium level | 15 |
| | Professional education | 13 |
| | University level | 69 |
| Income level | Below €2,500 | 31 |
| | Between €2,500 and €3,750 | 23 |
| | Between €3,750 and €5,000 | 18 |
| | More than €5.000 | 18 |
| | No answer | 10 |
| Work status | No information | 38 |
| | Less than 12 hours | 10 |
| | More than 12hours | 52 |
| Household type | Single | 39 |
| | couple | 28 |
| | Family with children | 33 |
| Housing ownership type | Private owned house | 59 |
| | Private rental house | 10 |
| | Rental house from housing corporation | 31 |

### *6.2 The energy saving behavior model*

There are multiple papers about behavior models with causal relations between influence factors and behavior. The MOA-model is often used and it visualizes the theory of reasoned action (Ajzen and Fishbein, 1980). According to this model, behavior is caused by three main influence factors (motivation, ability and opportunity). Motivation includes beliefs, attitudes, intention and social norms. Habits and knowledge are part of the ability factor. Considering our specific topic about energy consumption behavior in residence, the social-demographic factors and the dwelling characteristics are added as influential factors in the model. As such, the model consists of both contextual factors (macro level) and individual factors (micro level). Since social-demographic characteristics influence all three psychological factors, it is shown as a layer below the factors knowledge, motivation and ability. The main intervention strategies are also included to show the potential influences.

With the survey data, an integrated energy saving behavior model was developed and represented in figure 2. The causal relations between different factors are indicated by arrows. However, the model should not be visualized as a strict flowchart since the relations are sometimes not strictly only one direction. There is no beginning in this model since behavior does not result from one particular process through successive phases. A factor can have more than one arrows (and relations with other factors).

The model revealed that energy saving behavior has strong associations with some main influence factors such as motivation, knowledge, financial ability and context opportunity. The various intervention strategies could influence different factors directly and/or indirectly, which consequently impact the energy saving behavior. For example, structural strategies (such as legal regulations, pricing policies, subsidies and etc) influence the context conditions not only in terms of energy saving possibilities but also public opinion and regulation. Consecutively it modifies both financial ability and motivation of the residents, and in sequence influences their energy saving behavior.

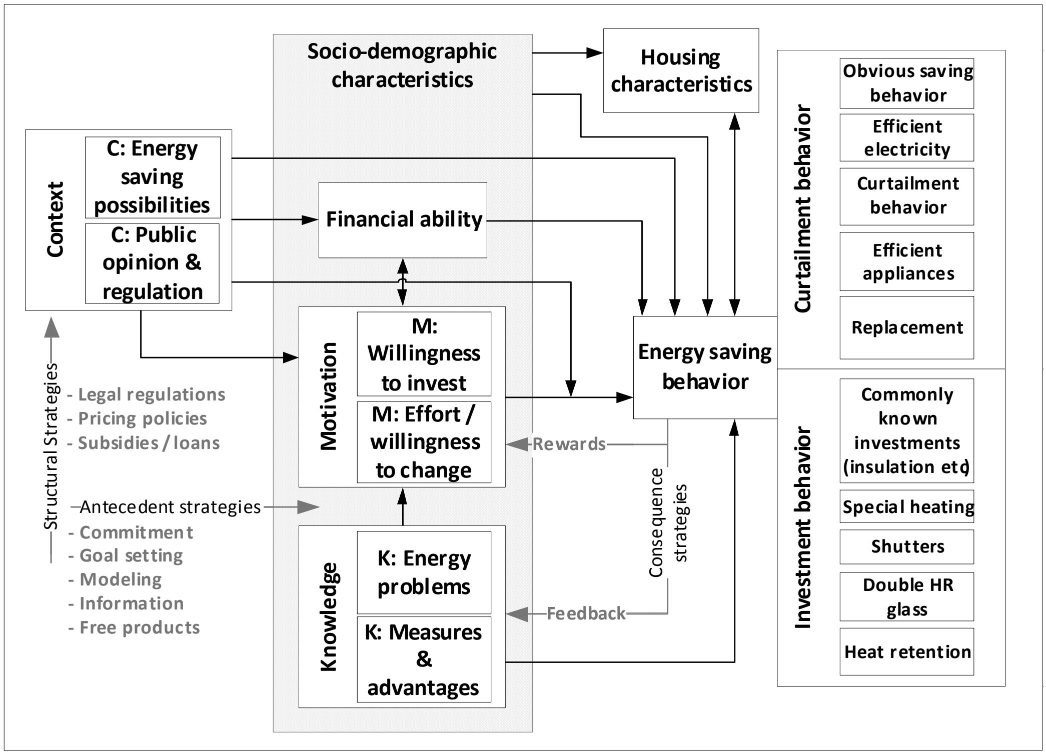

Figure 2: **The energy saving behavior model**

### *6.3 Segments in preference for intervention strategies*

The latent class models were estimated using maximum likelihood estimation. Specifically, latent class models from one up to 4-segment solutions are estimated. Also 5-segment model was estimated, but it became unstable. Table 2 presents the number of segments, the corresponding log-likelihood values at convergence (LLB), rho-squares, Akaike Information Criteria (AIC) and Bayesian Information Criteria (BIC). The log-likelihood values at convergence and rho-squares showed improvement in model fit as the number of segments increased. This finding confirmed heterogeneity in preference and suggested the existence of latent segments.

To determine the optimal number of segments, the AIC and BIC statistics were inspected together with the corresponding estimates. The AIC kept decreasing with an increasing number of segments that suggests a 4-class model, while the BIC values deviated slightly among 2-segment, 3-segment and 4-segment model. Since our goal of the latent class analysis is managerial relevancy of the segmentation solution, therefore the most important aspects to consider when choosing a solution for segmentation purposes are its interpretability and stability (reproducibility). On the basis of these considerations, the 4-segment model was selected as the best model in this particular case.

**Table 2 Statistics for the Latent Class Model**

| Number of classes | Number of parameters (p) | Log likelihood at convergence (LLB) | Log likelihood evaluated at 0 (LL0) | ρ² adjusted | AIC | BIC |
|---|---|---|---|---|---|---|
| 1 | 8 | -1492.42 | -1616.94 | 0.1605 | 2.0167 | 2.0452 |
| 2 | 17 | -1263.47 | -1616.94 | 0.2227 | 1.7211 | 1.7817 |
| 3 | 26 | -1241.89 | -1616.94 | 0.2336 | 1.7042 | 1.7969 |
| 4 | 35 | -1197.29 | -1616.94 | 0.2588 | 1.6563 | 1.7811 |

The results of the 4-segment latent class model are presented in Table 3. For reasons of comparison, the results of the one-segment model are also shown in this table. For each segment, the parameter estimates and their significance are presented with significant values indicated in bold with a superscript star. Most parameter values are significant at the 95% confidence level. The segment probabilities also are presented in Table 3.

**Table 3 Results for the Latent Class Model Estimation**

| | | | 4-segment model | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | 1-segment model | | Segment 1 Cost residents | | Segment 2 Conscious residents | | Segment 3 Ease residents | | Segment 4 Environment residents | |
| | Para-meter | (t-value) | Para-meter | (t-value) | Para-meter | (t-value) | Para-meter | (t-value) | Para-meter | (t-value) |
| Constant | **-1.17*** | -8.34 | **-1.94*** | -3.90 | **-0.64*** | -2.10 | -0.16 | -0.68 | **3.03*** | -8.99 |
| Information | **0.29*** | 3.48 | -0.38 | -1.15 | **1.03*** | 7.13 | **0.85*** | 5.29 | **-0.51*** | -2.06 |
| Modelling | **0.27*** | 3.52 | -0.22 | -0.72 | **0.41*** | 3.82 | **0.49*** | 3.23 | -0.1 | -0.42 |
| Free products | **0.40*** | 4.88 | -0.18 | -0.48 | **1.63*** | 11.10 | **0.38*** | 2.38 | 0.27 | 1.13 |
| Commitment | -0.11 | -1.31 | 0.70 | 1.88 | **0.80*** | 6.24 | **-1.69*** | -9.16 | -0.42 | -1.78 |
| Feedback | **0.45*** | 5.88 | **0.54*** | 1.96 | **0.9*** | 9.72 | -0.004 | -0.03 | **0.49*** | 2.09 |
| Rewards | **0.82*** | 8.63 | **2.16*** | 4.48 | **2.11*** | 11.57 | **0.40*** | 2.19 | **0.61*** | 2.66 |
| Financial | **0.83*** | 10.33 | **3.14*** | 6.51 | **1.42*** | 10.88 | 0.12 | 0.79 | **0.67*** | 2.88 |
| Segment probabilities | | | **0.20*** | 7.98 | **0.43*** | 12.65 | **0.18*** | 6.85 | **0.19*** | 7.13 |

*Significant at $p < 0.05$ level.

In Figure 3 the preferences and dislikes of residents in the four segments for the seven main intervention strategies are pictured.

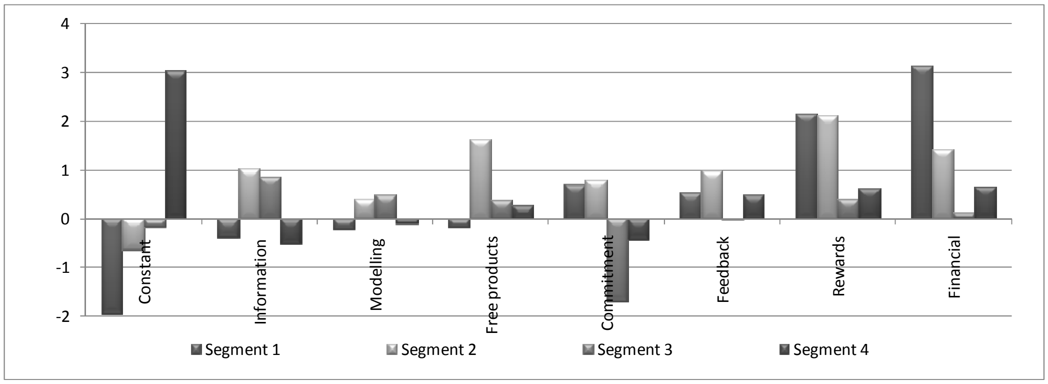

**Figure 3 Preference in intervention strategies per segment**

Further, for each respondent, individual preference parameters and segment probabilities were estimated. Based on these individual parameters respondents were classified into the four segments. Cross-tabulations, chi-square tests and analysis of variances were used to test and explore the relations between the four preference segments and the socio-demographic and current energy saving behavior. The results are show in table 4.

Segment 1 is labeled cost focused residents (46 respondents, 20%). Respondents in this segment are mainly about 27 till 35 years old and have medium knowledge about energy problems. In this segment, the degree of education is average and the main daytime activity is work for more than 12 hours per week. Respondents in this segment have the relative low average income and experience medium obstruction by governmental regulation and public opinion to save energy. Many of them live in their current residences for less than two years and a few of them live in their houses for more than 10 years. Quite a few of them live in rental houses with a lower energy label of E/F. They are highly aware of cost and basically save energy to reduce costs.

Especially, respondents in segment 1 score high on the current curtailment behavior comparing with other segments. This probably has to do with the fact that curtailment behavior of energy saving involves the lowest money cost. They also scores high on the investment in HR glass, and it is most likely because there are a lot of financial supports currently implemented like the subsidy on investment in double glass (see: www.subsidie-dubbel-glas.nl). This segment shows the least initial interests in the pro-environmental interventions. They generally are not interested in any antecedent interventions, but highly sensitive to financial structural interventions and consequence interventions such as rewards. The main reasons of not save energy for this segment are the perceived expensive investment and the long payback time.

**Table 4 Main characteristics of four segments of respondents**

| | Segment 1 Cost residents | Segment 2 Conscious residents | Segment 3 Ease residents | Segment 4 Environment residents |
|---|---|---|---|---|
| Age | many 27-35 | many >35 | many 35-59 | average |
| Income monthly | <2500 | <2500 | 2500-3750 | >3750 |
| Education level | high | medium | medium | high |
| Housing ownership type | many public rental | many rental | many private | many private |
| Housing energy label | many E/F | average | many C/D | many A/B |
| Duration of current residence | Many < 2yrs<br>A few > 10yrs | Many >10yrs | 2-5 yrs and<br>Many >10yrs | Many >10yrs |
| Current curtailment energy saving behavior | high | medium | low | high |
| Current investment behavior | low | medium | low | high |
| Experienced obstruction by regulation and public opinion | medium | medium | low | high |
| Knowledge of energy problem | high | medium | low | high |
| Motivation | low | medium | low | high |

Segment 2 is described as conscious residents (43%, 129 respondents). These residents prefer comfort, but also take into account cost and environment. Respondents in segment 2 have a medium level of knowledge about the energy problems and do not experience high obstruction by governmental regulation and public opinion. They like all types of intervention strategies. Furthermore, many respondents in this group are above 35 years old and live in a rental house. The main duration of current residence is long (i.e., most are more than ten years). Respondents in segment 2 save energy not only for the purpose of saving money, but also for environmental concerns. They prefer to get well informed of the new technology and new products. They are the group of residents that like to try out the free products most. Financial intervention strategies are highly preferred by this segment as well.

Respondents belonging to segment 3 are ease residents (18%, 43 respondents). Residents in this segment act to enjoy comfort and have less sense or interest in energy or environment problem. Majority of the respondents in this segment are between 35 and 59 years old with just above average monthly income. They have a low level knowledge of energy problems and experience a low degree of obstruction by governmental regulation and public opinion. There are many respondents in this segment that live in their current residents for about two to five years. The score for investment in HR glass in this segment is very low. Respondents in this segment show least motivation and involvement in energy problem. They like to know a bit about pro-environmental behavior, but they definitely dislike commitment. It is probably because they belief that making commitments will decrease their freedom in comfort seeking. They are the only group of residents that are not sensitive to financial interventions. It is likely that due to the relative high average age in this segment, these respondents show more of a habitual behavior and less willing to modify their behavior to save energy.

Segment 4 was described as environment residents (19%, 47 respondents). These residents act mainly from the viewpoint of environment. Respondents in segment 4 have a high level of knowledge about the energy problems and already invest sufficient (assessed by themselves) in energy efficient products. They have on average the highest education level and monthly income among the four segments. 70% of them live in private houses with a high energy label of A/B, and the main reason for them to save energy is environmental concern. They show the high initial interests in the involvement of energy saving behavior and moderate sensitivity regarding interventions. They are the only group that dislikes information interventions. This is probably has to do with the fact that they consider themselves already well informed and being experts on this topic.

### *6.3 Policy making recommendation*

Our results indicated that it is best to distinguish four different segments of residents in the study area and use different intervention strategies accordingly. Therefore, the local government, in this case study the municipality of Eindhoven, should target these different segments with the intervention strategies they prefer in order to get optimal effect in stimulating them to save energy. We now interpret our empirical results to provide policy making recommendations.

20% residents in the study area were in segment 1 that is cost focused. The respondents belonging to segment 1 are highly sensitive for rewards and financial (structural) interventions. Subsidies are a very good financial incentive to encourage residents in this segment to invest in the improvement of their houses in terms of energy efficiency.

Providing feedback is another good intervention strategy for this group, since it provides the consequence of their behavior (in relation to cost).

A relatively large segment of the residents (43%) in the study area was in segment 2 that is conscious. The respondents belonging to segment 2 are highly sensitive for all interventions especially regarding rewards. However, the short-lived effect of rewards should be taken into account when using this method. Providing free products is another good intervention strategy for this group, since it influences both knowledge and motivation. In practice, these products are presented in a gift box with small test examples of various energy saving behavior categories, and it services as an incentive for energy saving behavior in general. These residents are aware of their own energy use but still welcome more knowledge about their opportunities to save more energy. These residents are highly sensitive for information. The best approaches to provide them information are through websites, TV and radio and workshops. Information should be provided very clearly and unambiguously and tailored. Residents in segment 2 are also appealing for demonstration of energy saving. They like to visit a model house with all types of new measures and get a real life experience with these measures. Demonstration by neighbors and acquaintances also prompt them to follow up. Regarding the financial intervention strategy, residents in segment two highly prefer the adjustment of removal tax on appliances. Apparently they consider this incentive as a good opportunity to invest in energy efficient appliances. Financial supports, such as subsidy, loan with low interests, pricing policy are all useful intervention strategies for this group.

18% residents in segment 3 cannot be urged with feedback and financial interventions, although they have a preference for information, modeling and free products interventions. They can be labeled ease residents as enjoying comfort is their main focus. Residents in this segment generally do not bothered by financial intervention strategies and have less interest in saving energy, probably because they believe that it is too much effort and/or less comfort to save energy. Especially they dislike make any commitments, which is corresponding to early findings that energy policies are more acceptable when they increase (e.g., purchase energy-efficient new appliances) rather than limit the freedom of choices (Steg, 2008). Therefore the best intervention strategy for this segment is to show them that the energy saving can also be achieved without discomfort or restricting freedom.

On average residents in segment 4 are more interests in environment problem. It seems as if they consider themselves experts in this filed as they dislike information interventions. They know a lot of information and examples about how they can save more energy and already executed in their behavior. Contrast with the majorities that is more cost focused as in segment two, this segment is a relative small group and likely to be innovators and the early adopters. They mainly react to their own principles and the technological or other contextual innovations.

## 7 CONCLUSIONS AND DISCUSSION

The aim of this study was to investigate the optimal intervention strategies of the local government to stimulate residents to save energy. Specifically, the relationship between the segments and preferred intervention strategies and between current energy behavior of residents and their characteristics are explored. The findings of studies such as this can inform local governments about the impact prospect of intervention strategies for various segments of the population and provide the support of energy neutral development. The preference of intervention strategies would be useful in developing and employing optimal and effective policies.

The strategy of the local government, such as the municipality of Eindhoven, to realize the energy-neutral target is based on the Trias Energetica. One of the three components is to reduce energy demand. Based on the survey results, it appeared that the respondents currently invested only a small amount of money in the improvement for their dwellings in terms of energy efficiency. The limited amounts they do spend are mostly invested in HR glass. It indicates that this type of investment behavior deserves the more attention of the intervention policy. Besides the current focus of the municipality on the investment behavior of energy saving, it is also possible to realize a significant reduction in energy usage through curtailment behavior. For example, studies show that 9% of the total gas usage can be saved through changes in heating behavior. From the results of the survey it can be concluded that residents do not save a lot of energy by changes in behavior yet. Therefore, it is interesting for the municipality to add the focus on stimuli of curtailment behavior changes to the intervention strategies for saving energy.

Remarkable is that different segments of residents were found in this research that are in demand for different intervention strategies. This contributes to the current literature that municipal intervention policies should focus on specific target groups, and utilize the intervention strategies accordingly that are appreciated and effective for each target group. Therefore an optimal combination of intervention strategies can be structured and applied to encourage energy saving behavior.

Our results revealed that the estimates of feedback, rewards and financial interventions are most significant and positive for almost all four segments, while information, modeling, free products and commitment are not. In particular, commitment intervention is valued by one segment with positive preference, whereas by the other segment with absolute negative effect. It also provided some evidence for the argumentation that antecedent interventions has less impact compare to consequence intervention, while financial (structural) interventions have the most effects in changing residents’ behavior (Steg and Vlek, 2009). Moreover, an important implication from a policy perspective is that policies aiming to reduce energy use may especially want to target high user of energy through these structural intervention strategies, because of a higher energy saving potential.

Our study had some limitations that worth noting. First, several aspects such as detailed technical characteristics of dwelling features and lifestyle of the residents which might affect energy saving behavior were not included in the study. Second, the respondents’ rate is rather low and may not cover the whole population. It is better in the next step to conduct some cognitive interviews with experts to validate the findings and maybe reweight the data before deploy them in reality. Third, the study was conducted in the municipality of Eindhoven, and it would be interesting to investigate whether or not differences can be found between different municipalities. Municipalities in urban areas may need to focus their strategies differently comparing with municipalities in rural areas. In addition, future research could focus on one of the three types of house ownership (private ownership, private rental housing and rental housing by housing corporations), and explore optimal intervention strategies.

## REFERENCES

Abrahamse, W., 2007. Energy saving through behavioral change: Examining the effectiveness of a tailor-made approach. PhD Thesis, State University Groningen, the Netherlands.
Abrahamse; W., Steg, L., 2009. How do socio-demographic and psychological factors relate to households' direct and indirect energy use and savings? Journal of Economic Psychology, 30, 711-720.
Abrahamse, W., Steg, L., Vlek, C., Rothengatter, T., 2005. A review of intervention studies aimed at household energy saving. Journal of Environmental Psychology, 25, 273-291.
Ajzen, I., Fishbein, M., 1980. Understanding attitudes and predicting social behavior. Englewood Cliffs, NJ: Prentice-Hall.
Arkel, W. van, Jeeninga, H., Menkveld, M., Ruig, G., 1999. Energieverbruik van gebouwgebonden energiefuncties in woningen en utiliteitsgebouwen. ECN-C-99-084, november 1999.
Berkhout, P., Muskens, J., Velthuijsen, j., 2000. Defining the rebound effect. Energy Policy, 28(6-7), 425-432.
Geller, E., 2002. The challenge of increasing proenvironmental behavior. In Bechtel, R., Churchman, A., (Eds.), Handbook of environmental psychology, 525-540, New York: Wiley.
Greene,W., 2001. Fixed and random effects in nonlinear models. Working Paper EC-01–01, Stern School of Business, Department of Economics, New York University.
Greene, W., Hensher, D., 2002. A latent class model for discrete choice analysis: Contrast with mixed logit. Working Paper ITS-WP-02–08, Institute of Transport Studies, the University of Sydney, Australia.
Groot, E. de, Speikman, M., Opstelten, I., 2008. Dutch research into user behavior in relation to energy use of residences. PLEA 2008 – 25th Conference on Passive and Low Energy Architecture, Dublin, 22-24 October 2008.
Guerra Santin, O., Itard, L., Visscher, H., 2009. The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock. Energy and Buildings, 41, 1223-1232.
Itard, L., Meijer, A., Guerra Santin, O., 2009. Consumenten Onderzoek Lenteakkoord. Rapport in opdracht van NVB, Research Institute OTB, Delft, the Netherlands.
Leidelmeijer, K., Cozijnsen, E., 2010. Energiegedrag in de woning: Aanknopingspunten voor de vermindering van het energiegebruik in de woningvoorraad. RIGO Research, Amsterdam, the Netherlands.
Lucas, K., Brooks, M., Darnton, A., Jones, J., 2008. Promoting pro-environmental behavior: existing evidence and policy implications. Environmental Science & Policy, 11(5), 456-466.
Steg, L., 2008. Promoting household energy saving. Energy Policy, 36, 4449-4453.
Steg, L., Vlek, C., 2009. Encouraging pro-environmental behavior: An integrative review and research agenda. Journal of Environmental Psychology, 29, 309-317.
Swait, J., 1994. A structural equation model of latent segmentation and product choice for cross-sectional revealed preference data. Journal of Retailing and Consumer Services, 1(2), 77–89.
Vereniging Eigen Huis, 2009. Eigen Huis Panel, VROM – energie.
Vringer, K., Blok, K., 1995. The direct and indirect energy requirement of householders in the Netherlands. Energy Policy, 23(10).

Han, Q., Kadarpeta, S.S.R., de Vries, B. (2010) Governance Instruments For Energy Neutral Housing Developments, In: Proceedings of the 2011 annual European Real Estate Society Conference (ERES Conference 2011).

# GOVERNANCE INSTRUMENTS FOR ENERGY NEUTRAL HOUSING DEVELOPMENTS

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## ABSTRACT

*Netherlands has set national energy targets for year 2020 following the European Union vision. In this context at the local level Eindhoven Municipality has set its ambition to go energy neutral in housing sector by 2020 and decided to develop new energy neutral housing areas.* ***L****ack of strict regulations and appropriate forms of support aimed at relevant stakeholders involved* ***has attributed to the lack of acceptance for energy*** *neutral housing in the current housing market. Further lack of a defined role for municipality to promote stakeholder participation has affected the realization of energy neutral housing developments. Market research shows that Denmark and UK have introduced several effective regulatory and support instruments to promote their energy ambitions in housing sector. Especially, Danish municipalities have played a unique role to promote stakeholder participation in energy efficient housing developments. These instruments found from Denmark and UK experiences are prioritized for Eindhoven scenario by stakeholder groups of Municipality, project developers, Energy consultants and consumers regarding their preferences using Analytical Hierarchy Process. Using scenario analysis a proactive participatory role is found essential for the Eindhoven municipality to promote stakeholder participation in energy neutral housing development process.*

**Key words:** Energy Neutral Housing, Governance instruments, Analytical Hierarchy Process, Scenario analysis

## INTRODUCTION

The European Union, under the Kyoto protocol, has set ambitious targets for greenhouse gas emissions reduction in order to limit the rising global temperature. At the same time, the EU has adopted equally ambitious targets for its future energy supply. It aims to meet these targets through a range of policy instruments at the Union, Member State and even sub national level. (Böhringer, et al., 2009). To foster the speed of developments to reach the targets EU has adopted certain policies and legislations aimed at the three energy targets: carbon emissions, energy efficiency and renewable energy sources.

In European Union buildings account for 40 % of the energy demand and about one thirds of green house gases of which about two-thirds are attributed to residential and one-third to commercial buildings (EC Green-paper, 2000). The households represent 63% of total energy consumption of the buildings sector. Electricity consumption in the household sector has grown by 12.5% since 2000 (Enerdata, 2007). Further households energy demand is expected to increase by 0.6% per annum between 2000 and 2030. This is attributed to the growing number of households, around 40 million, in this time period.

Member states, as per the EU regulations on Carbon emissions, renewable energy sources and energy efficiency, have outlined their own energy ambitions for year 2020 and set them as national level targets (EU Commission, 2008). The energy ambitions are spread over three layers of governance as observed in EU member states namely the Central government, Regional government and Local government (municipality). The municipalities play an important role in the planning and regulation of built environment as the European spatial planning system outlays certain building performance responsibilities to be fulfilled at the local level (DTU, 2009).

Sustainable urban development has developed in the past a few decades in the Netherlands to a mature subject of policy, research and innovation with various titles, such as low carbon city, energy neutral city, etc. In the same context, at the local level, Eindhoven municipality has expressed its vision for 2040 to become an energy-neutral in all sectors, and aims to go energy neutral in the built environment, specially housing sector, by 2020 (Gemeente Eindhoven, 2009).

Practical realization of energy efficient housing developments requires a transition in existing systems and ways of doing in the building sector. This is currently not happening in the building sector due to a deadlock in supply and demand. The construction companies do not offer developers to build energy efficient buildings as they cannot identify sufficient demand from consumers and thus developers complain about the reluctance of construction companies to come up with viable solutions (Rohracher, 1991). Lack of acceptance for energy efficient homes or buildings in the current market is attributed to lack of strict regulations and appropriate forms of support for the stakeholders involved in housing sector and the end user – customers. Lack of organized and structured process to be followed in the planning, development and realization phases has further lead to poor collaboration and communication between various stakeholders.

The potentiality of municipalities to promote energy efficient buildings through municipal governance is large, since municipalities typically have a powerful local planning role in terms of developing local urban areas and authorizing local building projects. However, short of strict regulations and appropriate forms of support aimed at relevant stakeholders involved has attributed to the poor acceptance for energy neutral housing in the housing market. Further, deficient in a defined role for municipality to promote stakeholder participation has affected the realization of energy neutral housing developments.

This paper is about the research that has been done to investigate what kind of regulatory and support instruments are needed to regulate the interests of various stakeholders towards energy neutral housing developments and what role should municipality play to promote collaboration among stakeholders and realize energy neutral housing developments. The paper is structured as follows. First, Market research shows that local governments in Denmark & UK have introduced several effective regulatory and support instruments to promote their energy ambitions in housing sector. Especially, Danish municipalities have played a unique role to promote stakeholder participation in energy efficient housing developments. Second, the instruments found from these best practices are then prioritized for Eindhoven scenario as per stakeholder group preferences using Analytical Hierarchy Process analysis on the data collected from experts representing Municipality, Project developers, Energy consultants and consumers. Using scenario analysis on a case study of Blixembosch Noord Oost energy neutral housing development project, a proactive participatory role is found necessary for the Eindhoven municipality to promote stakeholder participation in energy neutral housing development process. Consequently, the detailed recommendations on implementation are given to the local government.

## ENERGY NEUTRAL HOUSING DEVELOPMENTS

An energy-neutral housing community is defined as a residential area where the net total energy used in all housing related processes and activities is generated within the district or community using renewable energy sources. The typical features of energy neutral housing community are high energy efficient houses (high levels of insulation, air sealing etc), reduced carbon emissions and production of heat and electrical energy required by the home from decentralized renewable energy sources within or surrounding the community (NAHB, 2006). Energy neutral housing developments are different from other construction projects because of the additional energy issues related to them like the type of technology, design for efficiency, and generation of electricity within the community etc. In energy neutral and efficient housing developments the Local governments (i.e., Municipalities) play an important role in promoting and facilitating the process. Moreover, for employing energy neutral and efficient housing developments other stakeholders such as project developers, energy consultants and prospective owners and customers are also important (ENPIRE, 2009). The development process of energy neutral housing developments is broadly classified into planning, implementation and realization phases.

To promote energy efficient housing development, the municipalities' have to deal with various issues due to the complexity in the governance functioning of the local processes. As a result the municipalities of member states have combined a number of policy instruments and approaches in their planning practices in order to cope with the challenge of mobilizing changes among local stakeholders. Some of the applied instruments are originated within traditional planning frameworks based on the ideas of regulation and support, whereas other instruments represent more innovative methods of facilitation (CONCERTO, 2009). Regulation is the strongest singular means to ensure that specific improved energy requirements are complied with in practice. Certain requirements are made directly binding for stakeholders involved in the building sector through a specific law passed by national government or municipality in its local plans (such as building code). Support instruments are important since developing this new type of building involves some uncertainty of risks and losses to the stakeholders acting as prime movers. With financial support like economic subsidies and facilitation support like information on new technology, demonstration programmes etc the idea is to compensate for the challenges involved in being prime mover and innovator to foster the transition process (Maj-Britt, et al., 2009).

The potentiality of municipalities to promote energy efficient buildings through municipal planning practices is large, since municipalities typically have a powerful local planning role in terms of developing local urban areas and authorizing local building projects. Besides having the authorities to promote energy efficiency at the local level, municipalities also prove to have interests in doing so, since it could promote the local economy. To promote these interests there is a need for strict national level and local level policies and governance instruments which are aimed at regulating and supporting this transition in housing sector.

The Dutch policy instruments have failed to instigate the adoption of energy efficiency and measures for energy neutral developments. The research conducted by Beerepoot (2007) shows that a broad scale adoption of energy efficiency measures fails to occur in the existing Dutch housing sector, which has related to the lack of structural cooperation between different actors in the mainly project-based building sector. The energy neutral housing ambition of Eindhoven is being affected due to lack of strict regulations and support instruments, lack of effective collaboration between stakeholders which has resulted in lack of market demand for energy neutral houses (Bekering, 2009). The research conducted by Hans (2008) on Groningen's $CO_2$ neutral ambitions shows that serious investments and/or collaborations of all stakeholders is necessary for such projects to become practically feasible. Thus the Eindhoven municipality now is aiming to actively cooperate with all actors and stakeholders that can contribute to achieve the goal of energy neutrality between 2035 and 2045. The municipality is looking for the pioneer examples, which are actively taking place as the latest developments, especially the developments proven successful in practice.

Energy neutral homes have proven to benefit residents of lower energy costs, with even better quality and comfort of home (IEEE spectrum, 2010). Despite the advantages of energy saving measures for the house owners and consumers, the steps taken so far by the local government, such as Eindhoven municipality, have not been successful in promoting them. Achieving energy neutral homes is technically proven possible and case study, concerning the development of Blixembosch Noord Oost, has shown that this is also financially feasible (Petra Rovers, et al. 2009). However the role of the municipality involved in the redesign of development process are still needed to actually achieve the realization of energy neutral homes. There is a need for municipality to promote energy neutral ambitions in housing sector through local means. This implies that greater attention is needed towards supporting and encouraging a new role for municipality in planning and regulating practices.

## GOVERNANCE INSTRUMENTS

Market research showed that local governments in Denmark and UK have introduced several effective regulatory and support instruments with diverse characteristics to promote their energy animation in house sector. Danish regulatory and support instruments are focussed on improving the energy efficiency of households and promoting renewable energy usage in housing sector through community owned cooperative farms. UK on the other hand has employed numerous financial support instruments like renewable heat incentive; LCBP grants, reduced VAT and Stamp duty etc. to promote carbon reduction by using micro-generation technology and decentralized energy sources.

Combining the strengths from these practices, we can categorize these successful instruments for energy neutral housing into four main instruments: 1) regulating and supporting energy efficiency measures, 2) carbon reduction and micro-generation measures, 3) promoting usage of renewable energy measures and 4) financial incentives and supports. Each main instruments includes more detailed the sub instruments as described in the following. The tree structure of the instruments is shown in figure 1.

## Energy efficiency

To regulate and facilitate the reduction of energy consumption in households, EU has passed EPBD (EU, 2002) which asks its member nations to impose strict regulations to decrease their energy dependence on fossil fuels. Denmark and UK have implemented the following more detailed instruments in order to decrease the energy consumption (kwh/m$^2$) in house sector. Stricter building codes have enforced stricter energy consumption limits for new housing developments, and aim to increase the energy efficiency of housing. Energy efficiency obligations for energy companies force them to reduce energy consumption in households by providing advice, energy audits, subsidies etc. For example, reduction targets have been set as 2.95 PJ (0.7% of total energy usage) for 2006-09 in Denmark. Mandatory energy labelling/EPC are used to label a house based on its energy efficiency. These labels are generally from A-G, where A means most efficient and G means no efficiency at all. Easements, which are a process where municipality can impose legal regulation on the land it owned. It can be used to make energy performance requirements lawfully binding (compulsory) for those who buying and building on that piece of land. This Instrument is supported by a planning and building regulation act in Denmark. Collaboration with material manufactures and building demonstration houses is both technologically and economically effective. Project developers and municipalities are making collaborations (contracts) with material manufacturers for building demonstration houses. The developers try to show customers the latest technology that can be used in houses to increase energy efficiency or make low energy consumption. Material and appliance manufacturers try to advertise the new products and agree to supply these new technologies for low price. This type of arrangement guarantees very low material/technology costs for developers and also acts as a promotional activity for manufacturers. For example, Velux and Rockwool (manufacturers) have such contracts for a few projects in Denmark.

## Carbon reduction and micro-generation

Renewable energy sources have been found to be the most efficient way to reduce carbon emissions in energy production. UK has employed several regulatory and support instruments and at the same time promoted a micro-generation approach to curb its carbon emission and head for carbon free from 2020. Micro-generation means the small-scale production of heat and/or electricity (generation of a capacity of less than 50 kW) from a low-carbon source. These sources are very close to the final consumption points (households), generally on roof-tops or backyard, in order to reduce the losses from energy transport. The stricter building code for sustainable buildings makes it mandatory to use decentralized micro-generation technology for building zero carbon/low energy buildings. Obligations for households make sure that housing communities are required to generate electricity from onsite renewable. Merton rule (2003) in UK has set 10% renewable generation obligation for developments larger than 1000m$^2$. Obligations for energy suppliers ensure them to reduce carbon emissions. For example, UK's carbon emission reduction target (CERT) requires energy suppliers to reduce carbon emissions in households by providing subsidies for energy saving measures for consumers. Eased out planning permit certifies that strict planning/building regulations normally required for installing domestic micro-generation technologies in households are removed. Under certain fixed conditions there is no need to get permission for installations. This has avoided the planning costs for owners and therefore indirectly increased the installations. Micro-generation certification scheme and demonstration programs take care of the assurance of quality, and service and products is provided to consumers by certifying the installers through a certificate scheme supported by national commission, which is currently running in UK.

### Renewable energy technology

New forms of energy generation from renewable sources using different technologies are observed in Denmark and UK, which have been highly effective and have proven their worth. Community owned energy generation is promising. Decentralized renewable energy generation in a community by forming cooperatives, e.g., wind cooperatives and district heating plants, are observed in Denmark. Potential for large scale generation is high due to large combined investments from community and low liability for each individual of the community. Grid independence is efficient in case of onsite renewable generation using private wire. Electricity can be sold directly to customers rather than exporting to the grid first and then back to customers. A private wire system simply connects the generation plant located on site with the existing on site electricity network. It avoids unnecessary distribution charges and energy losses. Thus green electricity can be supplied at a cheaper price. Micro-generation technology shows the potential of the small-scale production of heat and/or electricity (generation of a capacity of less than 50 kW) from a low-carbon sources using technologies like solar collectors, photovoltaic cells, micro-wind, micro-hydro, heat pumps, biomass, micro combined heat and power (micro CHP) and small-scale fuel cells. Electronic energy monitoring systems and SMART meters provides control. Different from electronic energy monitoring system where one person with a PC can monitor and control the energy consumption in all buildings, smart meters have a visual display allowing customers to see exactly how much electricity and gas they are using individually and relay the data to energy firms automatically.

### Financial support

Financial support means support in terms of monetary benefits for the households (consumers) to adopt energy saving, carbon reducing and micro-generation techniques. Modified and newly targeted financial schemes that have encouraged households to generate renewable energy and improve energy efficiency are discussed in this section. Feed in tariffs (FIT) with a constant tariff system for producer for a period of 20-25 years is currently used in UK. The benefits from feed in tariff for an average household using 4500kwh/year with 2.5 kW of solar PV have been calculated as £830. Domestic Green Loans are loans attached to properties rather than individual. In UK if a family moves away from the property before payback on the loan, then the next occupants will be responsible for the repayments (as they also enjoy the benefits). As a consequence, more families are willing to utilize the loans for renovation and micro-generation technologies. Reduced VAT and stamp duty exemption are also applied in UK. In UK, VAT on all micro-generation technologies used in households has been reduced from 17.5% to 5% and stamp duty for zero carbon houses with a real estate value below £ 500.000 is exempted. Renewable heat incentive is also introduced in UK. In UK, the Renewable Heat Incentive (RHI) provides financial support for a range of technologies, including air and ground-source heat pumps (and other geothermal energy), solar thermal, biomass boilers etc for new houses.

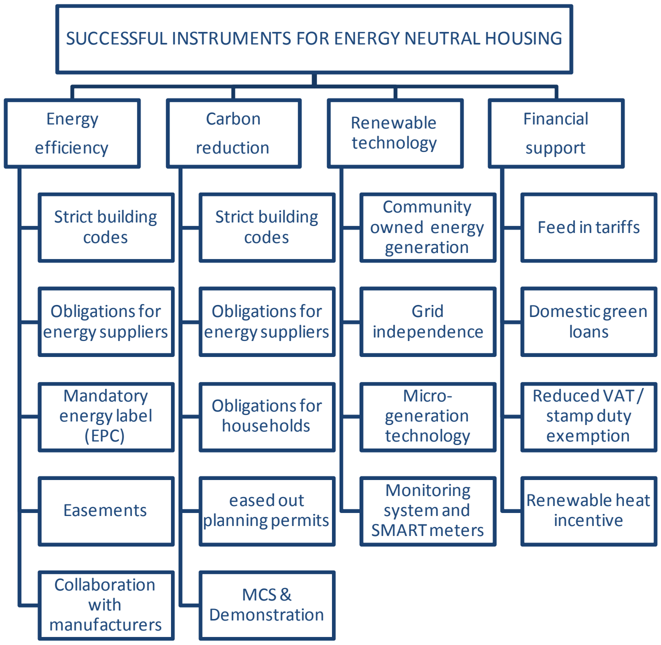

Figure 1, Hierarchical tree structure of instruments

## GOVERNANCE ROLE

Further the Danish municipalities have promoted stakeholder participation in energy efficient housing developments by playing a proactive participatory role in the planning, implementation and realization phases of the projects. By playing a pro-active role and effectively participating in all phases of the project Danish municipalities have helped to successfully realize such developments. By taking a proactive role, the municipalities were able to regulate the developers to build energy efficient homes by bringing the local plans to effect as the owner of the land, planning authority and also as approval authority. By participating in the implementation phase and realization phase the Danish municipalities were able to promote effective collaboration between stakeholders.

They have satisfied the interests of different stakeholders by playing a participatory role i.e. the diverse stakeholders and their interests are engaged together in reaching for a consensus on a plan and its implementation. This was possible since municipality was able to understand the difficulties faced by the developers and customers in relation to the new concepts of energy efficient homes. They have used unique facilitation support instruments like collaboration with manufacturers, micro-generation certificate scheme, and model houses etc. to encourage the project developers and house owner's participation in developments. The highlights of role played by Danish municipalities in all phases are shown in the figure 2. The experiences of Danish municipalities also show that the role played by municipalities has an effect on the type of instruments employed in the development process of the energy efficient housing projects.

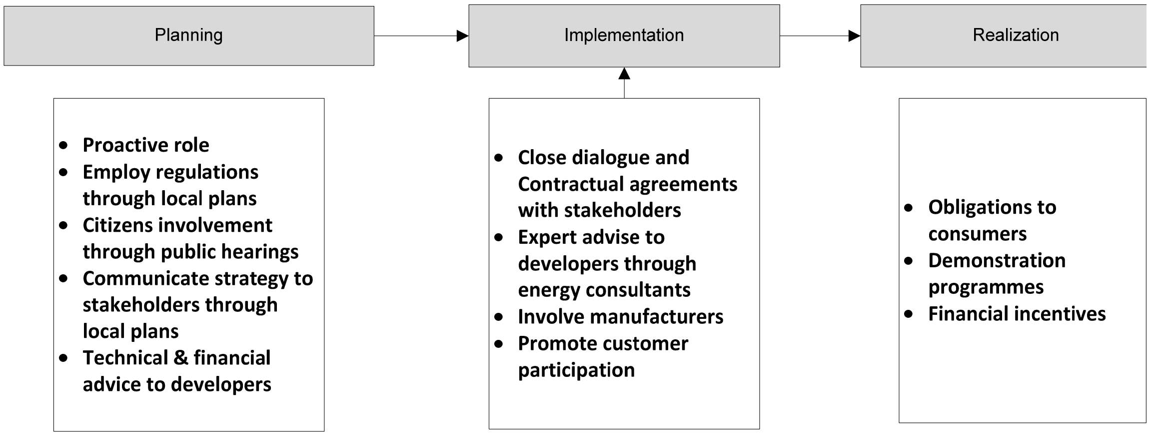

Figure 2 Highlights of participatory role played by Danish municipalities

## PRIORITIZE STAKEHOLDERS' PREFERENCES USING ANALYTICAL HIERARCHY PROCESS (AHP)

The instruments, found from market research on Denmark and UK, are employed to achieve the local energy ambitions successfully in their respective housing sectors. The effectiveness of the instruments may vary widely depending on the contextual condition of local environment and the government in terms of the development and implementation of energy ambitions of different regions. Therefore, when we consider applying those instruments in the Dutch context, especially in the municipality of Eindhoven, we need to get insight of the preferences of various stakeholders that involved in the process in order to compose an effective package of instruments.

Analytical Hierarchy Process (AHP) analysis provides a proven, effective means to deal with complex decision making and can assist with identifying and weighting alternative regarding selection criteria, analyzing the data collected for the criteria and expediting the decision-making process. It offers a way to integrate complexity, set the right objectives, establishes their priorities and determines the overall value of alternative solutions. It uses a multi-level hierarchical structure of objectives, criteria, sub criteria and alternatives. The pertinent data are derived by using a set of pair wise comparisons. These comparisons are used to obtain the weights of the decision criteria, and the relative performance measures of the alternatives in terms of each individual decision criterion.

With the given decision problem of finding the prioritized instruments for energy neutral housing in Eindhoven, AHP can be used to find the preferences of the instruments (performance criteria) found from the research and thus find the relative importance of one instrument over the other regarding the goal of achieving energy neutral housing. This way the optimized package of preferred instruments for Eindhoven case can be found out.

Based on the tree structure shown in figure 1, a survey questionnaire is designed to find the preferences of the instruments using pair wise comparison approach. Pair wise comparisons are used to determine the relative importance of each instrument in terms of its performance towards energy neutral housing development (Fu, 2009). Taking into account the high level 4 main instruments and the low level 18 detailed instruments, in total 38 questions are framed for the questionnaire.

In this survey approach the respondents have to express their opinion about the assessment of one single pair wise comparison at a time. The questionnaire is sent to 50 different experts representing stakeholder groups of Municipality, Project developers, Energy consultants and Consumers. Among them 25 respondents (19 customers, 2 Energy consultants, 3 Project developers and 1 Municipality) completed the questionnaire. The responses made by the respondents are converted into a numerical value determined for pair wise comparisons in the AHP according to the scale of set values: {9, 8, 7, 6, 5, 4, 3, 2, 1, 1/2, 1/3, 1/4, 1/5, 1/6, 1/7, 1/8, 1/9} (Saaty, 1980). The type of question used in the questionnaire and the assigned numerical values used to convert the answers of respondents can be seen in table 1.

| Sample: To achieve energy efficiency in housing developments in Eindhoven how important are the instruments A and B in relation to each other?<br>A. Energy efficiency; B. Carbon reduction | |
|---|---|
| A and B are equally important | (1) |
| A is slightly more important than B | (3) |
| A is absolutely more important than B | (5) |
| B is slightly more important than A | (1/3) |
| B is absolutely more important than A | (1/5) |

Table1 Sample survey question and the assigned numerical value

To find the priority weights of instruments from the responses the mean value of all responses is calculated for each of the 38 questions. Further reciprocal and normal matrixes are used to compute priority vectors i.e. the priority weights of the instruments. The obtained priority weights are used to rank the instruments in the order of descending weights and thus the relative importance of one instrument over another can be determined. The overall prioritized instruments for Eindhoven and the priority weights of the instruments for each stakeholder group (i.e. customers, Energy consultants, Project developers and Municipality) are found out. The various priority weights of regulatory and support instruments as preferred by individual stakeholder group are reported in table 2.

Table 2 Preferred priority weights of individual stakeholder groups

| Main Instrument | Sub-Instrument | Municipality | Project Developer | Energy Consultants | Customer |
|---|---|---|---|---|---|
| Energy efficiency | | **0.541** | **0.414** | 0.247 | 0.282 |
| | Building code | 0.460 | 0.254 | 0.323 | 0.240 |
| | Obligation for supplier | 0.155 | 0.242 | 0.263 | 0.258 |
| | Mandatory E. label/EPC | 0.250 | 0.216 | 0.161 | 0.174 |
| | Easements | 0.044 | 0.129 | 0.139 | 0.170 |
| | Collaboration | 0.092 | 0.158 | 0.114 | 0.158 |

| | | | | | |
|---|---|---|---|---|---|
| Carbon reduction | | 0.260 | 0.107 | 0.134 | 0.198 |
| | Building code | 0.469 | 0.252 | 0.328 | 0.243 |
| | Obligation for households | 0.142 | 0.119 | 0.126 | 0.201 |
| | Obligation for supplier | 0.259 | 0.348 | 0.216 | 0.231 |
| | Planning permits | 0.079 | 0.143 | 0.100 | 0.184 |
| | MCS & Demonstration | 0.050 | 0.138 | 0.129 | 0.141 |
| Renewable technology | | 0.140 | 0.196 | 0.134 | 0.243 |
| | Community generation | 0.058 | 0.357 | 0.573 | 0.330 |
| | Grid independence | 0.499 | 0.181 | 0.099 | 0.220 |
| | Micro-generation | 0.161 | 0.162 | 0.233 | 0.285 |
| | Electronic monitoring | 0.282 | 0.300 | 0.190 | 0.164 |
| Financial support | | **0.059** | 0.283 | **0.486** | 0.277 |
| | Feed in tariffs | 0.081 | 0.181 | 0.262 | 0.257 |
| | Domestic green loans | 0.560 | 0.322 | 0.087 | 0.201 |
| | Reduced VAT/stamp duty | 0.279 | 0.178 | 0.248 | 0.276 |
| | Renewable heat incentive | 0.081 | 0.319 | 0.403 | 0.265 |
| Note that the numbers in bold show a clear diverse, which reflect different interests of the stakeholder groups. | | | | | |

## SCENARIO ANALYSIS FOR THE ROLE OF MUNICIPALITY REGARDING VARIOUS INSTRUMENTS

To find the effect of the various preferences of stakeholder groups and validate the role played by Danish municipalities for Eindhoven municipality a scenario analysis is conducted. This analysis is used to explain the effect of various preferences of different stakeholder groups found from the survey and the possible outcome when the role of Danish municipalities is adopted by Eindhoven municipality and implemented in the Netherlands. The scenarios are developed and reflected on the project context of Blixembosch Noord Oost energy neutral housing development using Global scenario analysis method. Global scenario analysis offers the decision-makers an outlook into distinctive future environments that have different implications for long-term operating decision and options analysis (Ratcliffe, 2000).

The project of Blixembosch Noord Oost located nearby the new road junction A50/A58 (Ekkersrijt), which covers an area of about 18 hectares. The Eindhoven municipality decided to construct energy neutral homes in this area and granted this land to developers to make it an energy neutral community with approximately 450 homes. This project is part of the "Energie Neutral Brainport Wonen". Hurks Vastgoed South and Rabo Bouwfonds are the two project developers involved. The Municipality Eindhoven is the primary promoter for the project and the organization of Brainport Foundation promotes cooperation between companies, knowledge institutions and Municipality (Creative energy, 2009). The objective is to achieve energy-neutral homes with improved living quality and lower monthly energy costs. All the energy needed for living in the new district will be sustainable and generated by facilities within the neighbourhood. Therefore, besides an improved comfort the ambition is also about lower housing costs, less burden on the environment (less $CO_2$

emissions) and less dependence on rising energy prices. The energy targets have been set as: 0.55 of Epc; 45% Carbon reduction and Renewable energy. The project (shown in figure 3 on the right) is still in the planning stage where the final master plan (on the left) is being developed and the municipality will also sell plots for individual construction.

Figure 3 The project of Blixembosch Noord Oost energy neutral housing development

Based on the research on Danish municipalities, an assumption is made for analyzing the scenarios that, the role played by the municipality in the planning, implementation and realization phases, will result in the employment of specific type of instruments. As a consequence, it will promote stakeholder participation and collaboration, which indirectly determine the outcome of the project. Two scenarios are developed in this analysis. The first scenario assumes that the municipality adopts an existing housing development process and used as a benchmark. In the second scenario it is assumed that the municipality adopts the role of Danish municipalities for the development process and employ similar instruments. The outlay of the scenarios is shown in figure 4.

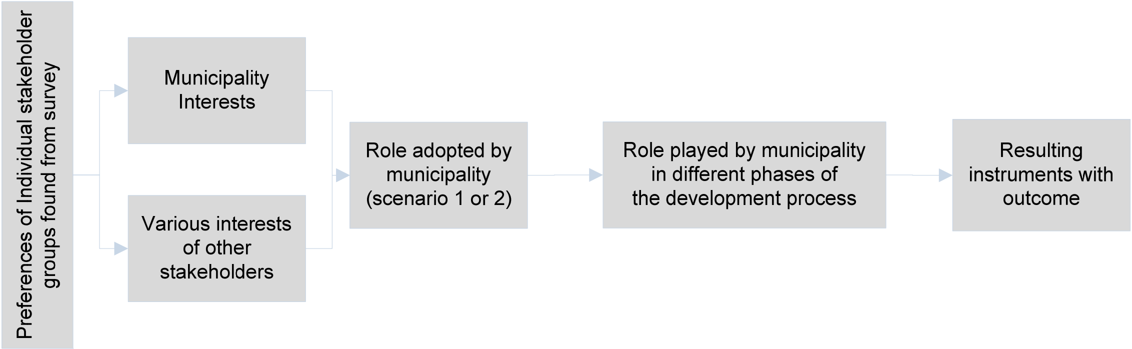

Figure 4 The outlay of scenario analysis

As a consequence of the role played by municipality in different scenario, different instruments are deployed. The outcome of the scenario is determined by adding the weights of the resulting instruments used in the scenario. These weights are the averages of preferred instruments weights of involved stakeholders' group found from the survey (table 2).

The scenario of present governance role showed an appreciation outcome value of 0.457 and the scenario of participatory governance role of the municipality gave an outcome value of 0.731. This clearly suggested that to promote energy neutral housing developments the Eindhoven municipality needs to play a participatory role in terms of actively participating in all the phases of project development.

## RECOMMENDATIONS

The successful instruments found from research are focussed on promoting energy efficient and carbon neutral housing developments. For promoting energy neutral developments in Eindhoven a combination of these instruments is necessary. Though some of these instruments exist already, there is still a need to strengthen or widen their scope to promote energy neutral housing developments effectively.  It is interesting to see how Eindhoven can learn to adopt these instruments following Denmark & UK experiences. Based on the findings, the prioritized instruments that adopted and improved to successfully achieve energy neutral housing developments are shown in the table 3.

The results from the survey scenario analysis revealed that promoting stakeholder interests rather than self-interests should be the main priority for municipalities in energy neutral developments. Such development projects are still in its early realization stages and thus pose great technical and implementation difficulties for stakeholders. To facilitate stakeholders' interests, the municipality should extend their role of governance and fulfil responsibilities using the recommended regulatory and support instruments.

The active participation of municipality in all the phases of the project is necessary to ensure success in energy neutral development projects. In the planning phase, municipality should be proactive and regulate energy neutral requirements effectively through its land allocation plans. Energy neutral ambitions should be propagated to local citizens during the planning stages and prospective customers should be involved in all the project phases. They can provide technical and financial advices to project developers in attempt to reach contract agreement. In the implementation phase, municipality could promote innovative partnership between stakeholders and local businesses, and involve manufacturers as stakeholders. They can provide technical assistance through energy suppliers and promote existing renewable technology by developing model houses for demonstration to attract consumers. In the realization phase, municipality can support obligations with financial incentives and facilitate stakeholder participation through certifying schemes to earn consumer trust.

| Instrument | Situation in Denmark and UK | Present situation in NL | Recommended improvements |
|---|---|---|---|
| **Building code for energy efficiency** | Denmark has a minimum requirement of 85kwh/m$^2$ at present with energy ambition of 75% reduction by 2020.<br>UK has a sustainable building code focused on carbon neutral buildings. | With energy neutral ambitions by 2020, currently an EPC of 0.8 (100kwh/m2) is mandatory. There is still no definition for low/zero energy buildings. | Set the current requirement needs to be lower than EPC 0.8.<br>Set up stricter building code with strict definitions for energy neutral houses/buildings. |
| **Energy obligations for companies** | Energy targets have raised some difficulties in the scope of employment. | Currently focussed on transport sector only | Learn from the drawbacks of Danish obligations. |
| **Renewable Heat incentive** | UK has introduced renewable heat incentive i.e. grants for purchasing renewable heat sources for new and existing households. | Grants are available, but only for houses built before 2008. | Extend RHI to newly constructed houses to encourage installation of more renewable heat sources in the new developments. |
| **Community owned energy cooperatives** | In Denmark wind farms and solar farms owned by community members supply majority of renewable energy. | Though some examples exist in the Netherlands the concept is still not promoted well. | Develop community owned renewable generation concept following Danish share based investment model that can ensure large scale energy generation with low investments for user. |
| **Reduced VAT/Stamp duty** | UK has fixed only 5% VAT on purchase of all micro- generation technologies used in housing and exempted stamp duty for carbon neutral homes worth less than £500.000. | Reduced VAT (6%) on certain energy efficient renovation material only.<br>No stamp duty exemption is possible. | Extend VAT exemption for new houses as well as micro-generation technology to promote renewable energy. Exemption of stamp duty on energy neutral houses can be attractive incentive for customers. |
| **Feed in Tariff & Micro-generation technology** | UK FIT is designed to benefit household owners though generation and Export tariff. | There are still no clear FIT rules for household producers. | Implement FIT to promote micro-generation which indirectly promotes renewable energy and carbon reduction. |
| **Domestic green loans** | UK offers green loans fixed to the property rather than the users. | Low interest loans are available for purchasing green technology and energy efficient renovation. | Set up fix loans for properties rather than individuals to ensure that individuals don't have to think of payback period for their investments. |
| **Easements** | Denmark has successfully reformed its Planning Act and the Building Regulation in 2006 to employ this regulation in its local plan. | No strict enforcement exists to regulate land buyers to build energy neutral buildings. | Make energy neutral requirements mandatory in its land allocation plans when the next revision of local planning comes. This will legally regulate the private developers to build energy neutral houses. |
| **Collaboration with manufacturers** | In Denmark energy efficient construction projects have collaborated with material manufacturers like Velux, Rockwool and Danfoss. | Energy neutral housing development projects are quite expensive and developers don't have good knowledge of the latest technology. | Provide technology assistance, expertise and also costs of construction / renovation can be reduced.<br>They can also market the projects better as it also helps for their advertising. |
| **Grid Independent (Private wire)** | Local councils have implemented private wires to supply electricity at reduced tariffs. | Policies don't grant the freedom to employ private wires. | Allow sale of electricity without distribution charges. Perfectly suitable for degeneration of renewable energy. |
| **EPC** | The laws have made it impossible to get a house without an EPC. | Initially failed in implementation due to improper organization. | More effort in promote modified EPC implementation strategy, for example reducing the costs for getting the epc. |

**Table 3 Implementing the prioritized instruments for Eindhoven**

## CONCLUSION & DISCUSSION

Eindhoven needs to focus primarily on improving energy efficiency in households. There is a need for employing stricter building regulations. This needs to be complemented with strong financial support in terms of renewable heat incentives, feed in tariffs and tax/stamp duty rebates. Further community generation should be prioritized for new housing areas. Stakeholders prefer strict building codes to have clear regulated use of micro-generation at household level to reduce carbon emissions. Good collaboration with technology and material manufacturers is necessary to provide technical support and reduce financial burden for project developers.

Research shows that community owned generation is highly preferred for Eindhoven. This is a compulsory requirement for energy neutral housing developments since it reduces the financial burden on the consumers by allowing cooperative investments. Eindhoven municipality should learn from the Danish wind cooperatives established on share basis investments. Currently financial incentives are available to install micro-generation technology and energy efficiency measure in existing houses. Municipality should consider extending the financial incentives for new houses as well. This study only considers the preferences of stakeholder groups to evaluate the instruments required for Eindhoven scenario. More studies to evaluate these instruments in terms of legal, financial and technical feasibilities are needed to be carried out. The instruments and the role of municipality are discussed with the focus only private energy housing developments. The same research can be carried out in case of social housing or housing renovation projects.

## REFERENCES

1. Beerepoot, M. (2007). Energy policy and technical change in the residential building sector, Delft University Press, ISBN 978-1-58603-811-3, pp.240.
2. Bekering, J. (2009). Presentation: Gemeente Eindhoven, Geïntegreerde Aanpak Koude Warmte Opslag, Nationaal Congres Warmtepompen, Bussum 1, 7 September 2008.
3. Böhringer, C., Rutherford, T. and Tol, R. (2009). The EU 20/20/2020 targets: an overview of the EMF22 assessment, Energy Economics 31 (2009) S268–S273.
4. CONCERTO (2009). Class 1 Cost-effective low-energy advanced sustainable solutions, http://www.concertoplus.eu/cms/index.php?option=com_content&view=article&id=165&Itemid=182&lang=nl, last accessed May 20, 2011.
5. CREATIVE ENERGY, (2009). Op Weg Naar Energieneutraal, www.naarenergieneutraal.nl, last accessed May 20, 2011.
6. EC Green-Paper (2000). Towards a European Strategy for the Security of Energy Supply, Commission of the European Communities, COM 769, Brussels, November 2000.
7. Enerdata (2007). Global energy intelligence, http://www.enerdata.net/enerdatauk, last accessed on May 20, 2011.
8. ENPIRE (2009). Final Guidelines on the Process, http://www.enpire.eu/, last accessed May 20, 2011.
9. EPBD, EU (2002). On the energy performance of buildings. Directive (2002/91/EC) of the European Parliament and of the Council, Official Journal of the European Communities, Brussels.
10. EU Commission (2008). The EU's Target for Renewable Energy: 20% by 2020, Volume I: Report, Published by the Authority of the House of Lords.
11. Fu, H. (2009) Using AHP to analyze the priority of performance criteria in national energy projects. Proceedings of International Conference on Pacific Rim Management, 19th Annual Meeting, San Francisco, California, USA.
12. Gemeente Eindhoven (2009). Programma Wonen 2010-2015- met een doorkijk naar 2020, Gebiedsontwikelling, October 2009.
13. Hans, I. (2008). Groningen energy neutral? A scenario study, http://ivem.eldoc.ub.rug.nl/ivempubs/dvrapp/EES-2008/EES-2008-47M/, last accessed May 20, 2011.
14. IEEE spectrum, (2010). Denmark's Net Zero Energy home. http://spectrum.ieee.org/green-tech/buildings/denmarks-netzeroenergy-home, last accessed May 20, 2011.
15. Maj-Britt, Q., Birgitte, H. et al (2009). Municipalities as promoters of energy efficient buildings : Idea catalogue for proactive planning practices, Kgs. Lyngby, Denmark, Technical University of Denmark (DTU), pp.87.
16. Merton rule (2003). What is the Merton rule? http://www.merton.gov.uk/environment/planning/planningpolicy/mertonrule/what_is_the_merton_rule.htm, last accessed May 20, 2011.
17. NAHB (2006). The potential impact of zero energy homes, NAHB research centre, February 2006.

18. Ratcliffe, J. (2000). Scenario building: a suitable method for strategic property planning? Dublin Institute of Technology.
19. Rohracher, H. (1991). Managing the technological transition to sustainable construction of buildings: a socio-technical perspective. In: Technology Analysis & Strategic Management, Vol. 13, no. 1, pp. 137-150, Taylor and Francis Ltd.
20. Rovers, P., Blokhuis, E.G.J., Han, Q. and Schaefer, W.F. (2009). The price of building energy-neutral residential areas. In Yildiz, H.T. (Ed.), Revitalising Built Environments: Requalifying Old Places For New Uses, (pp. 1-9). Istanbul: IAPS - CSBE.
21. Saaty, T. (1980). The analytic hierarchy process. New York: McGraw- Hill.

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# AGENT-BASED SIMULATION FOR DYNAMICALLY MEASURING ENERGY DEMAND AND PRODUCTION

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## ABSTRACT

Energy neutral city development asks for a thorough insight in the energy demand of households, and in the consequences of potential technological and social measures on energy consumption and generation. In this article, the development of a prefigurative comprehensive agent-based model that simulates the energy use and potential energy production on a district-level stands central. The three main building blocks of this model are individual lifestyles of occupants, technical dwelling characteristics, and the possibility to generate energy. The constructed model takes weather influences, technical and behavioral aspects into account and simulates the energy balance on an hourly resolution scale. The results of sensitivity analyses show the effects for a list of popular measures of energy reduction in case of a real-life district in the Netherlands. Some standard measures – like window and facade insulation – are regarded as very effective. Interestingly, measures related to occupant behavior and energy sharing appear to be almost equally important, showing the added value of the dynamics and the high level of detail of the presented energy calculation method.

*Keywords: Agent Based Simulation, Occupant behavior, Energy network, Decentral energy production*

## 1 INTRODUCTION

Cities are facing a major task to fulfil (inter)national climate ambitions. Fulfilling these ambitions requires a substantial transformation process of the existing building stock. However, the current effort of city councils is principally limited to financially support the house owner when investing in sustainable technologies. Such actions, aimed to motivate individual house owners, only have limited success and do not significantly contribute to realizing the new climate ambitions. In reaction, city councils begin to realize that they have to develop and support large scaled transformation plans at the city level. Such transformation plans should include the process of building renovation, (decentral) energy network extension and exploitation of new energy sources. Transformation projects must be planned in a coherent manner, starting with districts that guarantee a positive cost/benefit ratio, and which can be redeveloped within a reasonable period of time.

Implementing energy transformation on a district level requires insight in the consequences of possible measures – like increasing the insulation, installing photovoltaic panels, or stimulating energy awareness – on the level of energy consumption and energy generation [1]. To date, city councils lack specific knowledge about the effects of the increasing variety of technologies on energy consumption and production on district level. Without this knowledge, finding the right combination of measures is impossible. The current energy decision support systems, lacking a focus on the individual house owner, are inadequate for this purpose.

When considering the energy balance, insight in the energetic effects of technological measures implies fundamental knowledge about the energy demand and possible energy generation. Only when we are able to predict the energy demand and generation of a household at any given time with accuracy, we can redesign houses, districts and their energy networks. In this research, energy demand is assumed to depend on the occupants and the dwelling. Firstly, recent studies have shown that occupant behavior has a significant impact on the energy use of households [2, 3, 4]. However, the influence of individual occupant behavior remains a shallowly explored field of research, although there is much knowledge about the effect of household characteristics on energy use. Secondly, since the energy use for heating covers more than 50% of the total energy use of a household [5], technical characteristics of dwellings – such as thermal insulation of facades, floors, roofs, and windows – are important factors when determining energy demand. The third aspect in this study is the inclusion of decentralized energy generation, combined with the possibility to share overproduced energy on district level. Local production of energy is easier, cleaner and much cheaper in the long run than conventional ways of producing energy.

Incorporation of the individual differences of occupants, the technical characteristics, and the possibility to generate energy requires a fine grained dynamic energy calculation method. This research is aimed at constructing and programming a prefigurative comprehensive model that simulates the energy use and potential energy production on a district-level. The model takes weather influences, technical and behavioral aspects into account and simulates the energy balance in Joules on an hourly resolution scale. The proposed model can be used to run simulations and indicate quantitative effects of potential behavioral and technical measures in achieving a zero energy urban environment.

## 2 CONCEPTUAL MODEL

The constructed conceptual model (figure 1) includes the most important entities that influence the energy balance within a housing district. The model is divided in three parts: energy consumption, energy distribution, and energy production. *Dwelling* characteristics determine to a large extend a dwelling's energy consumption for heating. The *occupant* behavior determines the hourly energy use. A part of this occupant behavior is the lifestyle of the occupant, in which energy using activities are incorporated. The *weather* sets the conditions for both energy consumption (heat demand is influenced by outside temperature) and energy production. *Energy production* at dwelling level in this study is implemented through photovoltaic (PV) cells. The energy balance is controlled for in the distribution network. By connecting dwellings into an *energy sharing* network, they can share their excess produced energy with their neighbors.

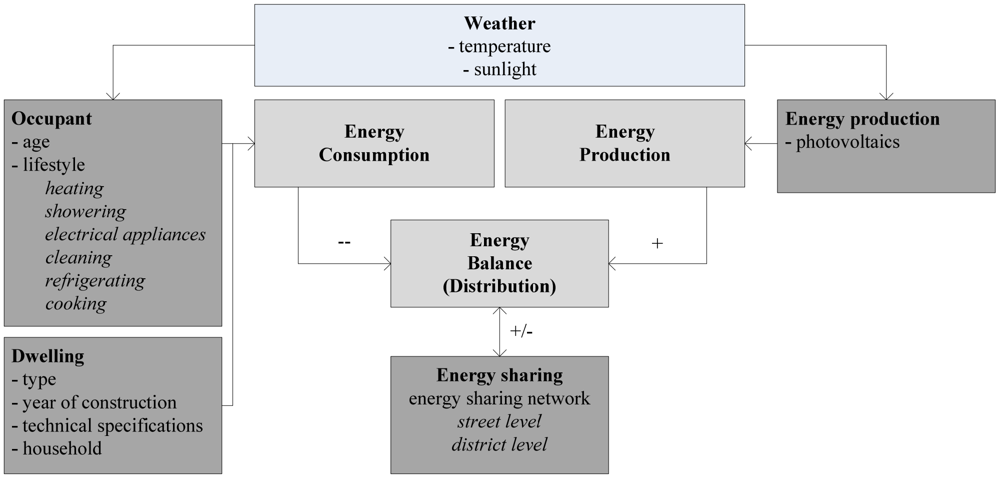


Figure 1: Conceptual model showing the principles of the research model.

From the conceptual model, it is clear that the energy balance of households is maintained by the interplay between dwelling and occupants, energy production, energy sharing and weather influences. These principles are further explained in the following sections.

*Dwelling*

The dwelling's technical specifications are based on reference dwelling data from SenterNovem [6]. This data is categorised according to dwelling type and year of construction and contains specific numerical values for ground floor, roof, facade and glass surfaces [$m^2$] and their corresponding thermal insulation [$W/m^2$]. In total, 9 different dwelling types exist in the model. The dwelling types 'row-house' and 'corner-house' are divided into 6 periods of construction. The dwelling types 'porch-flat', 'flat', 'gallery-flat', 'maisonette', 'semi-detached house, 'large-detached-house' and 'medium-detached-house' are divided into 3 periods of construction. In total, we distinguish 33 unique dwelling types in the model, all having specific technical characteristics.

*Occupant*

A number of occupants reside in a dwelling, which is recorded by the household size value. A household consists of at least one parent and other occupants in specific age ranges. Recent research [3] shows that age is an important factor in energy consumption. Furthermore, all occupants in the model have a lifestyle. This lifestyle contains an occupant's preference temperature during day and night, the showering frequency, length and time, the washing, dishwashing and tumble drying frequency and time, and the cooking time for breakfast, lunch and dinner.

*Weather*

The outside temperature and the sunlight intensity are based on a data-set from the national weather institute (KNMI) which contains data for a whole year on an hourly resolution scale. For the model, we used the data from the year 2009. The average Dutch temperature in 2009 was 10,5$^o$C, which is high compared to the normal average temperature (9,8$^o$C). The total number of hours of sunlight in 2009 was 1838, higher than the average of 1524 hours of sunlight.

*Energy production*
The amount of energy produced depends on the installed area of photovoltaic cells, on the efficiency of the used cells, and on the sunlight intensity. In this research, we assume that all applied photovoltaic cells have the same orientation, and have an efficiency of 15%.

*Energy sharing*
For this study we assumed that excessively produced energy cannot be stored, and if produced energy is not used, it is 'wasted'. Therefore, the dwellings are connected through an energy sharing network, which allows them to share excess produced energy directly. Two types of hubs exist in the energy distribution network: street hubs and district hubs.

## 3 AGENT BASED SYSTEM

Occupant behavior, dwelling characteristics, and the availability of an energy sharing network are central to the modeling approach as opposed to energy transfer in buildings in more classical modelling approaches. The notion of agents representing occupants, dwellings, weather, energy production units and energy sharing networks, gives a new perspective to urban energy modeling [1]. Through the application of an Agent Based System (ABS) we are able to simulate the dynamics of the energy flow between the occupant and its house, between the house and its environment, between the energy production unit and the network, and between the energy network hubs. Occupants trigger the energy demand and thus the drive the energy flow through the network components.

Many ABS platforms (commercial and non-commercial) are available for a large variety of application domains. Since this study does not aim for developing a comprehensive simulation platform, but to present a proof of our concept, we looked for an easy-to-use ABS prototyping system. NetLogo [7] suits this purpose very well. A simple representation of the NetLogo model, the different Agents that exist, and their relation is shown in figure 2.

The Agent Based System is constructed with three main building blocks: occupant behavior, dwelling characteristics, and decentral energy production and sharing. In the following paragraphs, these three building blocks will be described more in detail: the activity patterns of individual occupants, the technical characteristics of dwellings, and the assumptions concerning energy production and sharing.

Figure 2: Agents and their relations in the NetLogo model.

### 3.1 Activity execution

In order to model the behavioral aspects of energy use of households, we regarded individual people as “social atoms” [8]. One of the primary behavioral characteristics of the social atom is that it acts on the basis of simple rules. From literature, nine activities have been identified that cause energy use in households, and the performance of these activities is influenced by five factors. The activities and influential factors, represented in table 1, are based on the ‘activity-patterns’ approach from Papakostas and Sotiropoulos [9] and on the ‘use-patterns’ approach from Widen *et al.* [10].

Certain activities will only be performed if the occupants are at home. Others, such as washing, dish washing, and tumble-drying can also be performed if an occupant is away. A use-pattern of an activity determines on what hour-of-day an occupant may execute that activity. Some activities can be executed at different hours of the day, whilst others have a small range of hours. If an individual occupant is at home, it can perform one or more activities, thereby influencing the energy use. The behavior of individual occupants strongly depends on the age of the occupant [3]; temperature settings, frequency and length of showering, and the number of used appliances are related to the age-related lifestyle. The household-size, which represents the total number of occupants living in the same dwelling, determines the frequency of activities over the week, such as washing, dishwashing, tumble drying and refrigeration. Each activity performed by occupants in a household has a specific pre-set energy use. Finally, the dwelling size influences the volume that has to be heated, and the number of electrical appliances present in a dwelling. Adding up the energy use of different activities will result in the total energy demand of a household.

Table 1: Activities and influential factors

| **Activity** | **Activity-pattern [location]** | **Use-pattern [hour-of-day]** | **Occupant age [preference]** | **Household size [frequency]** | **Dwelling size [volume]** |
|---|---|---|---|---|---|
| Sleep | x | x | | | |
| Heating | x | x | x | | x |
| Shower | x | x | x | | |
| Electrical appliances | x | x | x | x | x |
| Wash | | x | | x | |
| Dish wash | | x | | x | |
| Tumble-dry | | x | | x | |

| **Activity** | **Activity-pattern [location]** | **Use-pattern [hour-of-day]** | **Occupant age [preference]** | **Household size [frequency]** | **Dwelling size [volume]** |
|---|---|---|---|---|---|
| Refrigeration | | x | | x | |
| Cook | x | x | | | |

In order to introduce variability in the energy demand, some variables are set through a probability function, namely the location of the occupant, the showering behavior of the occupant, the usage of electrical appliances, and the planning of washing, dish washing, tumble-drying, and cooking. The probability distributions of these variables are deduced from the use-patterns found in literature [9, 10].

### 3.2 Dwelling characteristics

The combination between outside temperature and the technical characteristics of a dwelling directly influences the energy use of heating. To calculate the energy use for heating in the NetLogo model, the following formula is employed:

$$Q_{prim;heat} = Q_{loss} - \eta_b * Q_{gain}$$

In which:

$Q_{prim;heat}$ is the heat needed for space heating [MJ]

$Q_{loss}$ is the heat loss through transmission and ventilation [MJ]

$\eta_b$ is a utilization factor of heat gain [-]

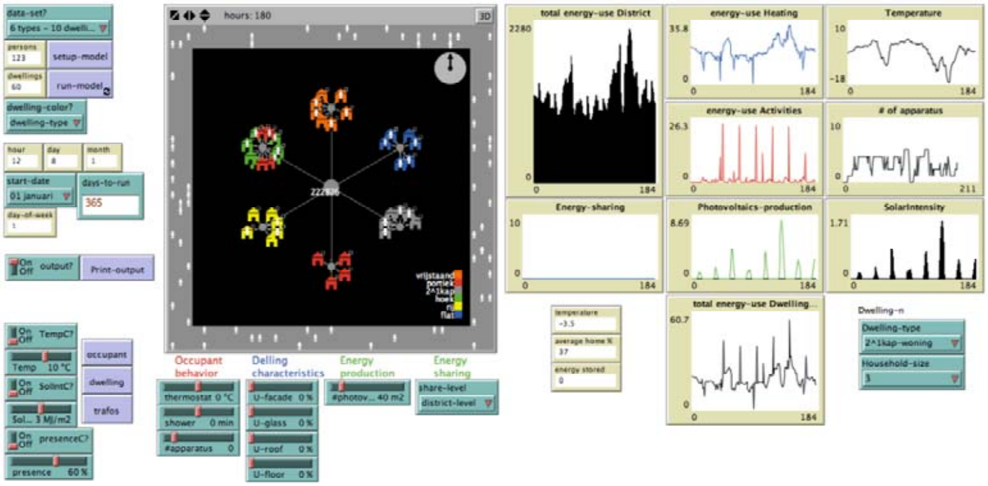
$Q_{gain}$ is the heat gain through sunshine and internal heat [MJ]

The outside temperature is based on a dataset from the national weather institute (KNMI) which contains the outside temperature for a whole year on an hourly resolution scale. There is a heat demand if the outside temperature is lower than the indoor temperature. The specific heat demand is related to the indoor temperature setting, which depends on the occupant’s age. Furthermore, the heat loss through transmission is calculated using the dwellings’ technical characteristics, which are based on data from SenterNovem [6]. For calculating heat losses through ventilation and heat gains through sunshine and internal heat production by electrical appliances, general building physics methods are used [11].

### 3.3 Energy sharing

By subtracting the energy produced by the photovoltaics from the occupants’ energy demand, the excessively produced energy can be calculated. In the NetLogo model, this excess energy production can be shared between dwellings, thereby reducing energy waste. In this research, two different levels of energy sharing are adopted: (1) street-level sharing; and (2) district-level sharing.

The final NetLogo model is represented in figure 3. This figure shows the basic structure of the model, with districts, streets, and dwelling types. On the right, graphs of energy consumption and energy production are given. The most important characteristic of this model is its dynamic character; several variables can be altered, and the consequences of these alterations are directly visible in the output graphs.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days-to-run 365
day-of-week 1
Temp 10 °C
Sol... 3 MJ/m2
presence 60 %
thermostat 0 °C
shower 0 min
#apparatus 0
U-facade 0 %
U-glass 0 %
U-roof 0 %
U-floor 0 %
#photov... 40 m2
share-level district-level
temperature -3.5
average home % 37
energy stored 0
Dwelling-type 2^1kap-woning
Household-size 3

Figure 3: Final NetLogo model

## 4 SENSITIVITY ANALYSIS

Data from the district “De Kruiskamp” in the city of ‘s Hertogenbosch in the Netherlands, containing 3389 dwelling and 8161 occupants, is used for testing the model and for recording the effects of several possible energetic measures (see Table 2). The district contains a large number of row-houses (48%). The dwelling type ‘flat’ covers a share of 23% of the total stock of dwellings, and corner-houses 21%. The dwelling types ‘semi-detached house’ (3%), ‘detached house’ (3%), and ‘porch-flat’ (2%) cover only a small share of the total stock of dwellings in the district. Furthermore, most dwellings (83%) are built in the period 1966-1988. 11% of all dwellings is built before 1966, and 6% between 1989 and 2010. Finally, the household size in the district is generally small; 29% of all households is a one-person household, 36% of all households contain two persons, and 14% of all households contain three persons. Larger household sizes (4 persons (13%); 5 persons (5%); 6 persons (3%)) cover a relatively small share.

Through ten simulation runs, we aim to discover the sensitivity of each of these measures for the energy use in the district. These simulation runs are divided into four categories: (a) occupant behaviour; (b) dwelling characteristics; (c) energy production; and (d) energy sharing.

Table 2: NetLogo model simulations

| **Category** | **Sim. nr.** | **Adjustable variable setting** | **Description** |
|---|---|---|---|
| | s1 | Base case | The base case serves as the reference point for all the other simulations. |
| Occupant behaviour | s2 | Showering -5 min | All occupants in the model shower 5 minutes shorter. |
| | s3 | Thermostat -1°C | All occupants set their thermostat 1°C lower. |
| Dwelling characteristics | s4 | Thermal insulation roof +50% | The thermal insulation for all dwellings' roofs improves with 50%. |
| | s5 | Thermal insulation façade +50% | The thermal insulation for all dwellings' facades improves with 50%. |
| | s6 | Thermal insulation floor +50% | The thermal insulation for all dwellings' floors improves with 50%. |
| | s7 | Thermal quality glass +50% | The thermal quality for all dwellings' glass improves with 50%. |
| Energy production | s8 | Photovoltaics $40m^2$ Sharing: house-only | All the dwellings in the model are equipped with $40m^2$ of photovoltaics, of which the produced energy is used in the dwelling. |
| Energy sharing | s9 | Photovoltaics $40m^2$ Sharing: street-level | All the dwellings in the model are equipped with $40m^2$ of photovoltaics, of which the produced energy is used in the dwelling, and excess energy can be shared with dwellings in the same street. |
| | s10 | Photovoltaics $40m^2$ Sharing: district-level | All the dwellings in the model are equipped with 40m2 of photovoltaics, of which the produced energy is used in the dwelling, and excess energy can be shared with dwellings in the same district. |

The simulation period was 365 days and the weather data used for temperature and solar intensity is from the year 2009. The total absolute energy use for a period of 365 days in the district is 235 TJ. The results for the absolute reduction of the mean energy use (in MJ) of households for all simulation (s2 to s10) from table 2 are shown in figure 4. In addition, figure 5 shows the results for the relative reduction (in %) in the energy use in the district for each of the simulation scenarios.

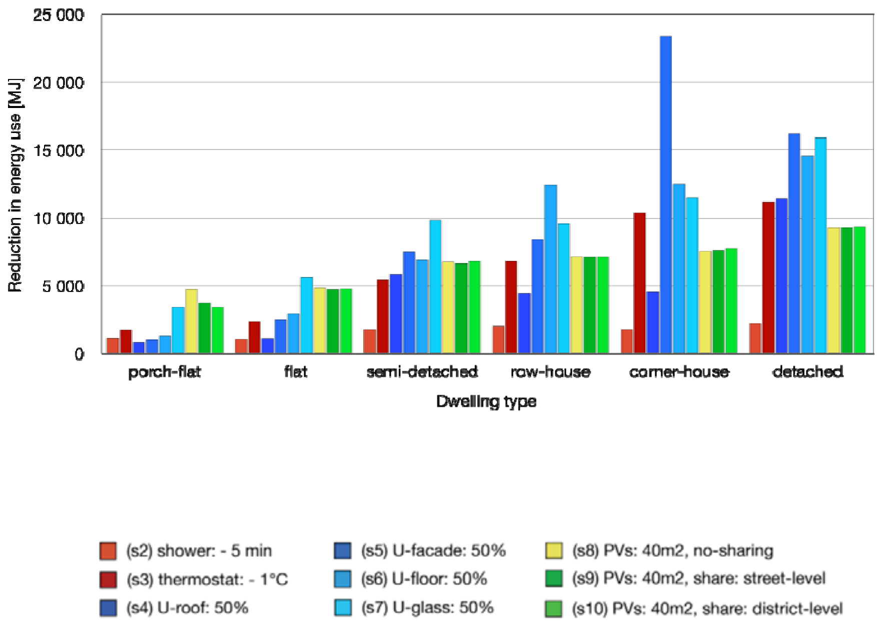

Figure 4: Absolute reduction on the mean energy use of households per dwelling type [MJ].

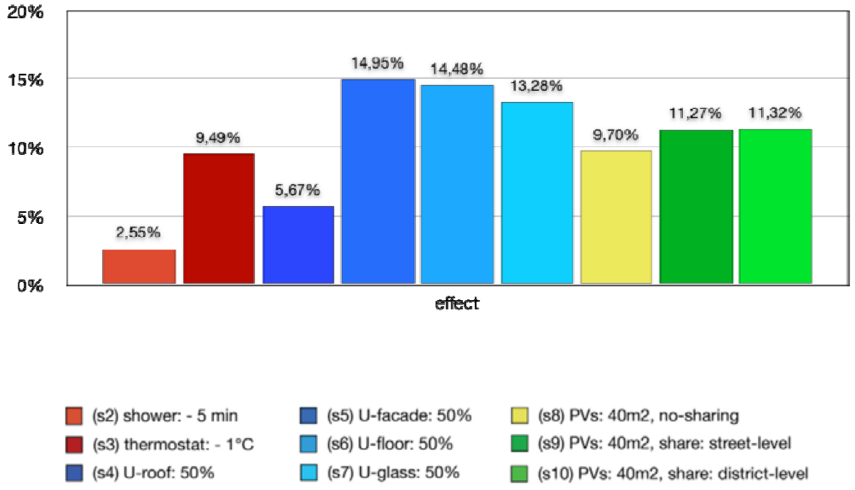

Figure 5: relative reduction of the energy use in the district

### 4.1 Occupant behavior

Age is found to be an important variable for energy use, because it influences the indoor temperature setting and the frequency and length of showering. Setting the indoor temperature 1°C lower can result in an average reduction of more than 9% on the total energy use for a single household. This indicates a reduction of almost 6.800 MJ per household or 22.3 TJ in the district of de Kruiskamp. Although the effects of decreasing the shower length are less significant, it can still cause a considerable amount of reduction in the total energy use of a household on a yearly basis.

### 4.2 Dwelling characteristics

Any improvement in the thermal insulation of floors, facades, and windows will cause a significant reduction in the total energy use, and should therefore always be considered. Improving thermal quality of glass should be especially aimed at the smaller dwelling types with high levels of glass surface, such as 'flat' (21.1%) and 'porch-flat' (13.9%). On a district level this means a reduction of 13.3%. An improvement of 50% in the thermal quality of glass, compared to the existing situation, can be achieved by transforming all existing single glazing into double HR glass; transforming all existing double glazing into triple glazing even gives an even larger thermal quality improvement. In this calculation, the ZTA values of glass are incorporated: improving the thermal quality of glass positively influences the energy losses, but also decreases the heat gain through sunshine.

Improving insulation in facades has the most significant impact on total energy use reduction for households. It should especially be implemented in the dwelling types 'corner-house' (22.1%) and 'detached house' (14.3%), because of the large wall surface, and in older houses, constructed before 1988. On a district level, improving the thermal quality of all facades with 50% compared to the existing situation results in an energy reduction of 15%, equaling 35.2 TJ. Improving facades' thermal quality seems technically possible and there is already a wide variety of products available. However, some older dwellings, especially those built before 1966, might not have a sufficient cavity depth to use these existing methods.

Floor insulation should be realized especially in the dwelling type ‘row-house’ (17.2%), which is by far the most common dwelling type in the Dutch building stock. The total district’s relative reduction of the energy use by applying floor insulation is 14.5%, equaling 34 TJ. However, isolating floors of existing dwellings will most likely pose a practical problem since older dwellings do not have crawl space underneath their foundations.

Finally, roof insulation should be realized especially in the dwelling type ‘detached-house’ (10.1%). It has the smallest effect of all dwelling characteristic adjustments, but is also the easiest to adjust.

### 4.3 Energy production by photovoltaics

Placing photovoltaics on a dwelling roof especially has a significant effect on the smaller dwelling types ‘porch-flat’ (18.2%) and ‘flat’ (19.1%). This difference in effects is caused by the difference in energy demand per dwelling. Basically, 40 $m^2$ of PV cells produce the same amount of energy, irrespective of the dwelling type; however, the model does not incorporate energy storage, so larger households might use more energy from PV cells than others. In this research, we assume that all dwellings have enough space to install 40$m^2$ of PV cells. Generally, the use of decentralized photovoltaics causes a reduction of 9.7% or 22.8 TJ in the district or an average reduction of 6.700 MJ on a yearly basis per household.

### 4.4 Energy sharing network

Sharing excess energy between dwellings on a street-level is about 1.5% more efficient than having photovoltaics on a dwellings roof without the possibility to share energy. An energy sharing network on street-level should therefore be considered a potential measure in districts. However, energy sharing between dwellings on a district-level is only 0.05% more efficient than sharing energy on a street-level, and we pose that the necessary investments do not outweigh the effect. An energy sharing network – without the possibility of energy storage – connecting all dwellings on district level should therefore not be implemented yet.

For the dwelling type ‘porch-flat’, we found that not sharing produced energy results in a higher absolute reduction on the mean energy use. This can be explained by looking at the number of porch-flats in the case; only 2% of all dwellings in the district De Kruiskamp. Because the model randomly asks occupants to set their location at ‘home’ or ‘away’, it is possible that during s8 a relative high number of occupants living in the porch-flat dwelling type were at home, while during s9 and s10 more occupants were away. This small variance might explain the difference between the simulation runs, as the number of porch flats is small.

## 5 CONCLUSIONS

The general conclusion that we can draw is that the ABS approach and the NetLogo platform have resulted in a prefigurative model that simulates energy use of occupants and households on an hourly resolution scale. In the model, dwelling characteristics are complemented with occupant behavior, resulting in quantitative insights into the effects of occupant’s lifestyles, dwelling characteristics, decentralized energy production and energy sharing on energy use.

The most important distinctive factor of the model is the focus on individual occupant behavior; this occupant behavior has a significant impact on households' energy use. This model therefore added a level of detail to already existing models in which household characteristics influence energy consumption; the results of this model are expected to be more realistic. Secondly, the model contains technical characteristics of dwellings in a district, based upon reference figures and building physics calculations, giving insight in the amount of energy needed to control the indoor temperature. These two factors constitute the main building blocks of the presented fine grained dynamic energy calculation method.

Finally, the model allows us to analyze different energy reduction scenarios in real-life situations. The results of several scenario runs show the effects for a list of popular measures of energy reduction in case of a real-life district in the Netherlands. Some measures like window and facade insulation are confirmed as very effective actions. Others, like occupant behavior and street-level energy sharing appear to be almost equally important and thus should not be neglected in the quest for energy neutral city development.

## 6 DISCUSSION

In future research, the urban energy model can be developed into a more comprehensive model through some extensions. First, long periods of absence such as holidays are currently not included in the simulation runs which prevent correct comparison with observed energy uses. However, since most people have holidays during the summer, the influence of holidays on the heating demand is expected to be very small; the major concern is the use of electrical appliances during periods of absence. Second, from an energy perspective it is better to consider renovation projects with a mixture of different building types and building use. Mixture increases the possibility of balancing energy use at the street level or district level. Therefore the model must be extended with other building types such as offices and schools. Third, thermal energy storage at the house, street or district level is not yet included but will have a major effect and energy balancing over time. Existing energy storage technologies like geo thermal energy and thermal storage in soil should be included in the model.

Finally, evaluation of the model in multiple districts is necessary to confirm validity of the results. Therefore, energy consumption data are needed on the house level. Privacy legislation might turn out to be a severe problem. A higher political urgency can solve this in the near future.

## References

[1] Boulanger, P.M., Brechet, T., Models for policy making in sustainable development: the state of the art and perspectives for research, *Ecological Economics*, **55**, pp. 337-335, 2005.

[2] Guerra Santin, O., Itard, L., Visscher, H., The effect of occupancy and building characteristics on energy use for space and water heating in Dutch residential stock, *Energy and Buildings*, **41**, pp. 1223-1232, 2009.

[3] Leidelmeijer, K., Cozijnsen, E., *Energiegedrag in de woning: Aanknopingspunten voor de vermindering van het energiegebruik in de woningvoorraad*, RIGO Research, Amsterdam, the Netherlands, 2010.

[4] Vringer, K., Aalbers, T., Blok, K., Household energy requirements and value patterns, *Energy Policy*, **35**, pp. 553-566, 2007.

[5] Itard, L., Meijer, A., Guerra Santin, O., *Consumenten Onderzoek Lenteakkoord*, Research Institute OTB, Delft, the Netherlands, 2009.

[6] SenterNovem, *Voorbeeldwoningen bestaande bouw 2007: Kompas energiebewust wonen en werken*, publication number 2KPwB0618, the Hague, the Netherlands, 2007.

[7] Wilensky, U., NetLogo http://ccl.northwestern.edu/netlogo/. Center for Connected Learning and Computer-Based Modeling, Northwestern University, Evanston, IL, 1999.

[8] Buchanan, M., *The social atom: Why the rich get richer, cheats get caught and your neighbour usually looks like you*, Bloomsbury, UK, 2007.

[9] Papakostas, K.T., Sotiropoulos, B.A., Occupational and energy behavior patterns in Greek residences, *Energy and Buildings*, **26**, pp. 207-213, 1997.

[10] Widen, J., Lundh, M., Vassileva, I., Dahlquist, E., Ellegard, K., Wackelgard, E., Constructing load profiles for household electricity and hot water from time-use data, *Energy and Buildings,* **47(7)**, pp. 753-768, 2009.

[11] Pennavaire, C., *Comprehensive modeling of energy use in households: an Agent Based case study on potential behavioral and technical measures towards an energy neutral urban environment*, Graduation Thesis, Eindhoven University of Technology, the Netherlands, 2010.