Microgeneration in the domestic sector in the Netherlands

An agent-based model set-up for technology diffusion among households in owner occupied dwellings

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Date: May 2010

Abstract

This research has examined the potential for micro-generation in the domestic sector in the Netherlands, focussing on three technologies: micro-CHP, solar PV and micro-wind turbines. In order to gain insight into the restrictions and possibilities of micro-generation, firstly, a literature study is performed to identify the actors involved in the introduction of the technologies and to describe their role and interests in the subject. From the description, insight is gained in the possibilities and constraints for a large scale introduction of micro-generation from a socio-economic and technological macro-level. Secondly, in order to gain quantitative insight in the potential for micro-generation, a set-up was created for an agent-based computer model (ABM) that simulates the purchase decision of households in the category of owner occupied households for a specific micro-generation technology.

In the ABM set-up, the agents are households who are given the decision to purchase a micro-generation technology (the micro-level behavior). The level of diffusion of a technology (the emergent properties of the system) is determined from the number of households that decide to purchase that technology under a specific set of conditions. The model set-up exists of three parts: (1) A division of households into different agent categories based on their type of ownership, physical properties (type of house), energy demand and purchase decision making behaviour, (2) A description of the technologies (3) A decision making algorithm that simulates a high involvement, rational purchase decision of the agents.

The theory of planned behaviour is used as a framework to describe the decision making of the agents, assuming that the purchase of micro-generation technologies is preceded by a deliberate decision. According to the main principles of this theory, the purchase decision making of the agents is determined by the attitude regarding a product, the experienced perceived behavioural control and a subjective norm. These three determinants have been elaborated using existing consumer research concerning micro-generation technologies.

In the model set-up, the *attitude* of an agent is formed by the preferences it has regarding specific characteristics of a technology. Four attributes are selected to determine the attitude formation of an agent: the payback period, the environmental performance, independency from an external supplier and the performance (comfort level, noise production, visibility, predictability of production). The preferences for specific characteristics of the technology that determine an agents' attitude formation towards a technology are dependent on its type of value pattern.

Technological attributes that are taken to influence *the perceived behavioral-control*, are the investment costs, the compatibility of a specific technology with the existing infrastructure and the bureaucratic barrier associated with micro-generation in general. Two types of agent characteristics are set to influence the perceived behavioral control: (1) the housing type and (2) the level of income. The first relates to the compatibility of the technologies with the existing infrastructure of a house. Given the physical properties of households in stacked dwellings, PV and micro-wind are not purchased individually by this group of households. The second relates to the investment cost of the technologies. Micro-generation technologies are associated with high investment costs, which are identified by households as an important barrier to purchase.

The subjective-norm reflects the communication between the agents and its effect on the diffusion dynamics in the model. In this study it is taken as a function of the market-share of a product, reflecting the popularity of a product which may change an agents' perception of it. An agents' sensitivity to a subjective norm (whether its purchase decision is strongly guided by the consumption behaviour of other agents) is dependent on its value orientation.

Following the TNS-NIPO WIN™ model, the agents are classified based on eight value patterns. These value patterns are subdivided into three income categories (a high, a middle and low income category), resulting in 24 consumer types. From statistics of the residential housing stock of the Netherlands and energy use statistics, the Dutch households are differentiated into 900 household categories with the same type of house, equal heat and electricity usages and the same type of house ownership. By taking the income level as mediating variable, a distribution of the 24 consumer types over the 900 household categories is determined. As a result the households are differentiated into agent categories that are classified based on their consumer behaviour, type of ownership of a house, heat and electricity use, and housing type.

Together with a description of the technologies and a decision making algorithm, the agent categories form the basis for the ABM model set-up. To illustrate what dynamics may be expected from the agent-based conceptual model created, it has been used to calculate the diffusion of PV-systems in the owner occupied households in the Dutch domestic sector. In the calculation examples the agents are given the choice to purchase a PV-system of 1 kWp or to remain using only grid electricity. The modeling exercise was performed in excel, no agent-based simulation software was used.

The experiments have indicated that the model set-up is able to simulate findings form consumer research regarding PV-systems. Furthermore the experiments illustrate that different types of agents are motivated to purchase the technology under different conditions (e.g. grid electricity prices, investment costs, changing environmental concerns in society). In more general terms, the ABM model set-up is able to simulate the expected number of buyers of a specific micro-generation technology in the Netherlands under different conditions. Also, it is able to identify these buyers in terms of their purchase behaviour, housing characteristics and electricity and heat use. The sensitivity of the agents to the variables in the model (e.g. investment cost, market-share) gives insight in the factors that are likely to determine the potential for diffusion in the future. This may provide insight in what policy measures are effective to stimulate specific groups of households to purchase a micro-generation technology (e.g. targeting the group of households with the highest shares of electricity and heat use), or to increase the diffusion of a specific technology in the domestic sector as a whole.

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1 Introduction

1.1 Background

The Dutch energy sector faces many challenges that will affect its functioning in the coming decades. The worldwide energy demand is bound to increase. Fossil fuel reserves, partly located in political unstable countries will become limited. And environmental concerns, most notably climate change, are on top of the political agenda. It is agreed that the energy sector in the Netherlands needs to be transformed in order to adapt to the new environment it finds itself in (EZ, 2008)

In the Energy Report (EZ, 2008), published by Dutch Ministry of Economic Affairs, the goals and strategies for the adjustment of the Dutch energy system in the near future are presented. In line with the developments described above, national policy making is geared towards the security of the energy supply, its affordability and environmental friendliness. In the report, three possible scenarios for the Dutch electricity sector are described which may fulfill these requirements: (1) 'The Netherlands as Power house of Europe' providing a base load in a European market in which the production is predominantly based on coal. In this scenario a reduction of CO_2 emissions is primarily obtained by means of novel Carbon Capture and Storage technologies. (2) 'The Netherlands as Flex worker within Europe' with an electricity system based on gas, taking into account the present Dutch gas reserves and an increasing demand for flexible back-up on a European level because of the introduction of wind and solar power on a large scale. (3) 'The Netherlands as Smart Energy City' focusing on locally based infrastructures with the help of decentralized small scale electricity generation systems (EZ, 2008). The latter scenario is very interesting for a number of reasons. Contrary to the first two scenarios, it emphasizes the importance of distributed generation systems and control at the local level. However, such a localized and decentralized system would demand much further reaching changes from the present electricity system (Verbong et al., 2007).

The opportunities for a far going decentralization of the electricity system depends on many institutional and technological developments. One key development is the introduction of micro-generation in the domestic sector (EZ, 2008). Micro-generation refers to the production of heat and electricity on a small scale where the energy produced is used directly on site, or is fed-back to the local distribution network (Alanne. et al, 2006). The concept includes a range of technologies. Some of these technologies are based on efficient use of fossil fuels (e.g. micro-CHP), while others are based on renewable energy (e.g. solar Photo Voltaic (PV) systems and solar boilers).

This study[1] focuses on the potential for micro-generation in the domestic sector in the Netherlands. In order to better understand and gain insights in of the potential of different micro-generation options and their potential for diffusion in Dutch households, *Agent Based Modeling* (ABM) is applied. The aim is to create a set-up for an agent-based computer model that simulates the purchase decision of households for a specific micro-generation technology. By taking an agent-based approach, the behavioural rules of the individual agents[2] and the rules of their interaction are specified (Srbljinovic et al, 2003). In this research the agents are households who are given the decision to purchase a micro-generation technology (the micro-level behavior). The level of diffusion of a technology (the emergent properties of the system) is determined by the number of households that decide to purchase that technology under a specific set of conditions. Three different technologies will be considered: micro-CHP, micro-wind turbines and small-scale PV installations

This research subject falls within the scope of modeling technology change in energy systems. In traditional optimization models such as MARKAL and TIMER, technological change is measured as the decision making of one representative actor, which purchase-decision is solely determined by cost minimization (Seebregts et al., de Vries et al., 2001). However the model set-up created in this study will differ in a number of important aspects from the traditional optimization approaches. Firstly, it considers the influence of individual differences between (potential) buyers, characterizing households as a heterogeneous group of decision makers, classified in the model set-up by their housing type, energy usage, type of house ownership and their consumption behaviour. Secondly, it takes into account that the decision making of the agents is not only determined by profit maximization, but also by other characteristics of the offered product (e.g. the environmental benefits). Thirdly, the model set-up considers communication between the agents, which is included through the market share of a technology, reflecting its popularity and the effect on an agents' perception of the product.

In comparison to traditional optimization approaches, simulating the purchase decision making process of a large heterogeneous group of interacting agents based on a variety of technology characteristics may give more insight in the factors determining the diffusion level of micro-generation technologies in the future. Also, it allows for the identification of particular niches of users of whom the personal preferences match the specific characteristics of a certain technology.

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[1] This research is performed as part of the LETSGO (Locale E-TranSitie in de Gebouwde Omgeving: Nederland 2020) research proposal, that is to be carried out within the Copernicus Institute at the Utrecht University. The LETSGO research aims to investigate a possible transition towards more locally oriented, sustainable ways of energy use and supply in the built environment in the Netherlands in the near future.

[2] An Agent refers to a representation of a real-life person or group of people (for example an organization) in computer language. It is the virtual entity described according to a set of behavioural rules.

But, apart from the willingness of consumers to purchase the micro-generation technologies, a large scale diffusion of the technologies in the coming decades beyond specific niches of users will be largely determined by socio-economic and technological factors on a macro-level (Faber et al. 2009 b). In the agent based model, technological change is taken as a function of individual decision making on the demand side. However, such a demand driven approach to technological change may overlook the restrictions and possibilities of a large scale introduction of the technologies that stem from a macro-level. In order to gain insight into the restrictions and possibilities of micro-generation from a macro-level, the associated actors[3] on the demand (e.g. public housing organizations, local authorities) and supply side (e.g. technology producers, fitters) of the technologies and in the existing electricity sector (e.g. electricity distribution companies, the national government) will be mapped, and their interest in and influence on the introduction of micro-generation shall be described.

1.2 Research question

The purpose of this study is described by the following two research goals:

I. The identification of possible constraints and opportunities for a large scale introduction of micro-generation in the Dutch domestic sector in the coming decade. In doing this, the associated actors on the demand and supply side of the technologies and the actors in the existing electricity sector will be identified, and their function and interest with respect to micro-generation is described.

II. The construction of a set-up for an agent-based model on the demand side. With the agents as the households in the role of technology consumers that are given a set of possible decision variables to respond to changes in their environment and to proactively change their behavior.

In an attempt to meet these research goals, the following research questions will be answered:

Main Research Questions:

What opportunities and constraints for a swift, large-scale diffusion of the technologies can be identified from a macro-level perspective? And how can the demand for micro-generation technologies in the domestic sector in the Netherlands be modeled taking an agent-based approach?

In answering these questions, the following sub-questions will be investigated:

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[3] The term actor refers to a real-life decision maker or group of decision makers, which decisions may influence the outcome of a specific process.

- *What actors play a role in the diffusion of micro-generation technologies in the domestic sector in the Netherlands? What is their function and what are their main interests with respect to micro-generation?*

- *What household (agent) categories can be distinguished in the domestic sector, based on the following four characteristics of the agents and the houses they live in: 1) type of ownership of a house, 2) physical properties of a house, 3) household energy use, 4) behavioral characteristics of the agents*

- *What characteristics of micro-generation are considered by (potential) consumers in their decision making? How do the selected technologies perform on these characteristics?*

- *What determines the purchase behavior of households in respect to a specific micro-generation technology?*

1.3 Report outline

This report consists of four chapters. In the next chapter (chapter 2) a description of the actors involved in the introduction of micro-generation can be found. Here the actors at the supply side of the technologies, actors at operating in the existing electricity sector and actors at the demand side of technologies are described. In Chapter 3 the set-up for the ABM is created. This chapter exists of four parts. Firstly, a division of households into agent categories based on the ownership type of a house, the energy use and the physical properties is presented. Secondly, a classification of households is given based on the behavioural characteristics of the inhabitants. Thirdly, the technologies are described, presenting their main working-principles, techno-economic characteristics and a qualitative description of the status of their development. And fourthly, a decision making algorithm is presented that simulates the purchase-decision of different types of households related to the selected micro-generation technologies. Next, in chapter 4, the obtained ABM set-up shall be used to perform an illustrative simulation example in which the agents are given the choice to purchase a PV system or to remain using only grid electricity. This is done in order to give insight in the implications of the approach taken in this research. Finally, Chapter 5 will present the conclusions of this study. The conclusion contains an identification of the most important actors involved in the introduction of micro-generation on a macro-level. Also, a reflection on the ABM set-up will be given, as well as recommendations for further research on the development of a future model.

2 Description of the actor field

The opportunity for a large scale introduction of micro generation in the domestic sector in the Netherlands depends on a wide variety of developments stemming from the interaction of economic social and technological factors. In the ABM set-up created in the next chapter, technological change is explained from a micro-level, focusing on individual decision making on the demand side. Such a demand driven approach to the diffusion of micro-generation technologies may overlook the restrictions and possibilities to a large scale introduction of the technologies originating from the socio-economic macro-level. Therefore, before investigating household purchase decision making, the actors involved in introduction of micro-generation are mapped and described according to their role, their function, objectives, strategic interest, influence and relation to other actor groups. These criteria are derived from formal actor analysis methods (Grimble et al. 1997; Hermans et al. 2009). But it should be noted that in the actor description in this research no formal theory (such as described in Grimble et al. 1997; Hermans et al. 2009) is applied. Instead, an open approach was taken aimed at identifying the possibilities and restrictions for a large scale introduction of micro-generation on a macro-level. A schematic overview of the actors that are described in this chapter can be found in Appendix 1.

The actor description is subdivided into three parts. In the first part, the supply side of the technologies is examined. In order to meet demand of the technologies considered (micro-CHP, micro-wind turbines and small-scale PV), an adequate supply system is needed. In the ABM set-up the production of micro-generation technologies is assumed to be able to meet the demand, which is not necessarily the case in real markets. Also, the degree of activity on the supply side may influence the demand, for example through increasing product awareness. The second part focuses on the electricity system of the Netherlands. A large scale introduction of micro-generation in the domestic sector asks for far-going changes in the existing practices in the Dutch electricity sector as it changes the relationship between distribution companies and households (as households also become a producer of electricity), it reduces the demand from centralized production facilities and presents technical challenges to the existing electricity transport system. The opportunities for such changes are bounded by the restrictions from the present transmission network and the embedded activities and interests of the actors in the field (Van Vleuten et al., 2006; Schenk et al., 2007). Thirdly, a closer look is given to the actors on the demand side of the technologies. Besides the house-owners that will be modelled in chapter 2, there are other groups of actors that play a role on the demand side. A large share (around one third) of the Dutch housing stock is owned by public housing organizations, which are responsible for the investment in micro-generation in their properties. Besides, micro-generation can also be applied in utility buildings which form another segment of the building stock. Furthermore, the technologies maybe integrated in the building projects for newly built houses or neighbourhoods. In these projects, a range of actors is involved (e.g. local authorities, architects) which may all stimulate demand.

2.1 Identification of actors on the supply side of the technologies

A range of actors is involved in the introduction and implementation of the micro-generation technologies on the supply side. According to Wah (2008) five groups of actors can be distinguished that are directly related to the supply side of the technologies: (1) The manufacturers and suppliers of the technologies, (2) Fitters (3) Lobby groups (4) Knowledge institutions/ R&D facilities and (5) Intermediary parties aiming to enhance communication between the different actors on the supply and demand side. The following is a description of these different types of actors.

2.1.1 Production and supply of the micro-generation technologies

For micro-CHP and PV a number of producers and suppliers are active in the Netherlands. Micro-CHP installations are primarily developed by the traditional producers of domestic heating systems such as Bosch/Nefit, Vaillant, Remeha and Daalderop (microwkk.nl, 2009). Also, energy companies such as Gasterra, Eneco and Nuon have taken an interest in the development of micro-CHP. It should be noted that micro-CHP is an immature technology. So far, it is only applied as part of field tests in the Netherlands. Therefore the (limited number of) suppliers are mostly the same companies involved in the development of the systems. The production side of PV exists of two separable parts: PV panel producers and the producers of Solar cells. Most important producers of PV panels are Scheuten and Ubbink. Together with NUON-Helianthos and AST, Scheuten is also one of the major producers of solar cells in the Netherlands. There are a large number of PV suppliers in the Netherlands[4]. Also, PV systems are offered as an additional service by the large energy companies Essent, Eneco and Nuon.
From the three technologies considered in this study micro-wind turbines receive the least amount of attention from commercial actors. Numerous companies are working on the development of Micro-wind systems applicable in urban environments, such as the Turby which is developed in the Netherlands (allsmallwindturbines.com, 2009)[5]. The technology is commercially available, but is so far only applied in a limited number of field tests.

2.1.2 Fitters

[4] An overview of Dutch PV panel suppliers can be found on www.zonne-energie.startpagina.nl
[5] Allsmallwindturbines.com (2009): This website contains an overview small wind turbines and their techno-economic specifications, including a link to all the manufacturers.

In between supply and demand, fitters play an important role in the introduction of the new technologies. Fitters exist in different forms: as (non-specialized) independent installation companies, as part of an integrated company that is also active in the production and supply of the technology or as part of an energy distribution company (e.g. Nuon, Essent or Eneco). In general, the innovativeness of fitters is regarded as low; they are risk avoiding and often lack the expertise and knowledge needed in the installation of the new products (Wah, 2008).

2.1.3 Lobby groups

On a national level, the policy making is influenced by several interests groups, advocating the view of actors involved in or influenced by the introduction of micro-generation. Broadly, three categories of lobby groups can be distinguished: Technology specific branch organizations, EnergieNed / Netbeheer Nederlandand and environmental NGO's.

Each of the micro-generation technologies is represented by their own branch organization(s), advocating the interests of producers and suppliers aiming to stimulate the introduction of the specific technology. These are Holland Solar for solar PV, Cogen and the Smart Power Foundation for micro-CHP and the NWEA for micro-wind turbines. A resourceful and influential stakeholder in the lobby groups for micro-CHP technologies is GasTerra. GasTerra is the trade and distribution part of the former Dutch national gas company, which has the national government as its main shareholder. On this moment, most heating applications in households in the Netherlands are based on central boiler systems that run on natural gas. However, increasing attention is being paid to alternative technologies that do not directly use gas as a fuel, such as heat-pumps and solar collectors. The active involvement of GasTerra in the promotion of gas-based micro-CHP to become the dominant successor of existing boiler systems, is aimed at continuation or an expansion (as micro-CHP system have a higher intake of gas than high efficiency boilers per unit of heat) of gas demand in households for heating applications.

EnergieNed is a representative body of the energy producers and suppliers Netherlands. Netbeheer Nederland represents the interests of the national and regional network operators (EnergieNed.nl, 2009). The influence of these organizations on national policy making is very high. Their attitude towards micro-generation can be described as conservative. In their opinion the introduction of sustainable micro-generation alternatives should only be stimulated on a large scale if the electricity produced with the technologies is cost competitive with existing practices, suggesting that the focus in policy making should be directed on technology development as opposed to (premature) implementation [6] (Beerda, 2008).

[6] The opinion of EnergieNed / Netbeheer on the introduction of micro-generation is based on an interview with a spokesman of these organizations included in the study of Beerda (2008).

The third category of lobby groups exists of Environmental NGOs, most notably Greenpeace, 'Stichting Natuur en Milieu', 'Milieu Defensie' and WNF. These organizations support the use of sustainable micro-generation technologies as part of their lobby for the use of sustainable energy in general. Besides, they strongly oppose the plans for building new coal based power plants in the Netherlands.

2.1.4 Knowledge institutions and R&D

Several actor groups are involved in generating knowledge and conducting research from which micro-generation technologies can be developed or improved. Most noticeable are knowledge institutions such as universities and other research organizations such as TNO and ECN (Energy research Centre of the Netherlands). But also the micro-generation technology producers invest and contribute to development of the technologies.

2.1.5 Intermediary parties

Intermediary parties are active in between the supply and demand side of micro-generation technologies. Most important are research institutes such as MNP and SenterNovem (an agency of the Ministry of Economic Affairs) for the communication between government and the public, consumer organizations such as 'Milieu Centraal' and organizations related to a specific technology such as the solar power consumer organizations (ZPV) and the foundation for efficient heating equipment including micro-CHP systems (EPK).

In table 2.1 below, a schematic overview is presented of the actor groups involved on the supply side of the micro-generation technologies.

Table 2.1 Overview of the description of actors on the supply side

Actor	***Function***	***Objectives***	***Strategic interest***	***Influence***	***Related to***
Technology producers and suppliers	Supply of the technologies Creation of supply side of the market for micro-generation technologies	Entrepreneurs driven by the creation of a business, profit maximization	It is a business opportunity. They anticipate on possible developments in the energy system towards sustainable practices in which micro-generation technologies	Important in the creation of a supply side of the technologies Strong competition/ many different suppliers may have positive influence on the	Potential customers/ the demand side Fitters Producers to suppliers and vice versa

			may play a role	price of the technologies	
Fitters	Installation of the technology Creation of supply side of the market for micro-generation technologies	Entrepreneurs driven by the creation of a business, profit maximization. As division of an existing, integrated company, also responsible for production and supply of the technology	Expansion of services by offering the opportunity of the installation of specific micro-generation technologies	Fitters are typically not innovative, and the absence of skilled personnel may negatively influence the introduction of the micro-generation technologies	Suppliers
Industrial R&D departments **Universities** **TNO, ECN**	R&D organizations	Product development Creating scientific knowledge	-	Supportive, stimulating technological developments in the field of micro-generation	The government Industrial actors
Technology branch organizations	Lobby groups	Representing the interests of producers and suppliers of specific micro-generation technologies	Influencing investment conditions/policy settings that stimulate micro-generation	The influence of these actors on policy making is low	The government Suppliers/producers of the technology
Environmental NGOs	Lobby groups	Conservation of the environment; Creating awareness of environmental issues; Pressurizing policy makers, companies	Supporting sustainable electricity generation including micro-generation based on wind and sun. Opposing the plans for building new coal based power plants in the Netherlands.	The influence of these actors on policy making varies per subject, but they are important for creating awareness in society	The government Consumers Existing energy companies
EnergieNed / Netbeheer Nederland	Association of energy producers, suppliers, network operators - Lobby group	Advocating the collective interests of Energy Producers, Traders and suppliers, network operators	Protecting the interests of the actors in the existing energy sector. Only in support of micro-generation if electricity produced is cost competitive	The influence of these actors on policy making is high	The government Energy producers, traders, suppliers, network operators
MNP, SenterNovem, Milieu Centraal, ECN	Intermediary parties, knowledge institutions	Communication to potential consumers, society Policy analysis in the field of energy and environmental	-	Supportive, informative to different stakeholders	The government, Consumers, Industrial actors

		related topics			

2.2 Identification of actors in the existing electricity system in the Netherlands

Broadly six types of activities can be distinguished in the Dutch electricity system: production, transport, trade, supply, regulation and consumption. An overview of the actors involved in the chain of activities is given in figure 2.1 below. Because the domestic sector is the main topic of research, it represented as the only electricity consumer category in the figure.

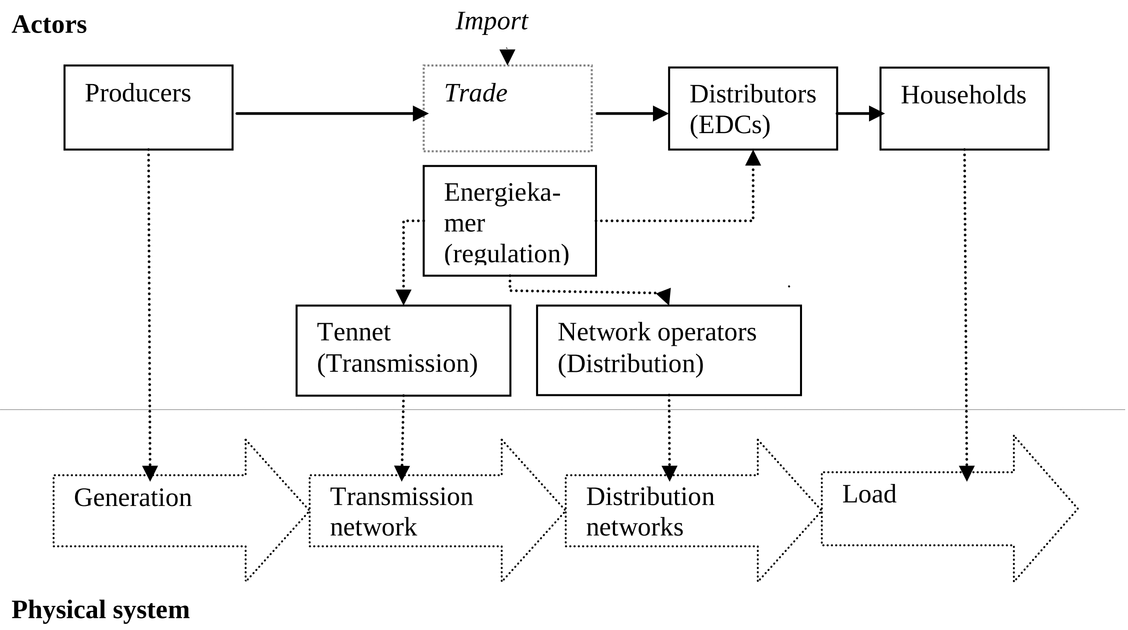


Figure 2.1 Overview of the actors (above the doted line) and the chain of activities (below the dotted line) in the electricity system in the Netherlands, (Composed from Houwing et al.(2006) and Energiekamer.nl)

2.2.1 Production and distribution

Electricity production in the Netherlands is partly centralized (around 60% of the installed capacity) with the use of large fossil fuel-based generators, and partly decentralized with a large share of industrial CHP installations and smaller applications of CHP in horticulture and utilities such as hospitals. The fuel mix is dominated by gas (CBS, 2009). Co-firing of biomass (around 60%) and wind power (around 40%) are the largest contributors to the share of sustainably produced electricity which is around 7% of the total national production (IEA, 2009).

Currently, there are five main producers of electricity in the Netherlands: Essent, NUON, Electrabel/Suez, E.ON Benelux and Delta which together account for more than 90% of the total electricity produced. These firms are primarily driven by profit maximization and continuation of business in the long run. In order to sustain or expand their market share, they have the option to built new generation capacity. The decision for building new centralized production sites is guided by expectations concerning future electricity demand and electricity and prices of CO2 permits, which determine the payback period of the investments made. Building plans require legal approval from local authorities, which are concerned with environmental legislation and infrastructural plans. Furthermore, production companies depend on the cooperation of Tennet, the transmission system operator and administrator of the national high-voltage grid, for connection to the high current, transport network.

All five producers mentioned above have their own Energy Distribution Company (EDC). EDCs Emerged as an actor in the electricity sector after the national government introduced a new electricity law in 1989, imposing the division of formerly integrated companies into a separate production and distribution company (Verbong et al., 2007). The EDC is the intermediate party between production and end-use and its primary responsibility is the deliverance of electricity according the conditions agreed on with the end-use party. EDCs purchase the electricity directly from the producer (often the case in the old vertically integrated firms), on the market (the APX) or imported from international producers (energiekamer.nl, 2009). Since the liberalization of the market in 2004, households are free to choose their distribution company. At the moment there are approximately thirty different EDCs, but concentration on the market is high as Essent, Eneco and Nuon (which are also the major gas suppliers) together account for around 75% of all customers (NMa, 2009). It should be noted that, in contrast to the other large distributors, Eneco is not a large producer of electricity. From 1999 onwards Essent, Eneco, and Nuon followed different strategies. Where the other two became vertically integrated energy companies, Eneco focused solely on the distribution side (Van Damme, 2005).

An overview of the largest producers and EDCs and their production shares and number of clients is presented in table 2.2. The numbers are partly based on data form 2005 and partly on companies' websites. Little is known about the effects of the switching behavior of households on the customer shares of the large EDCs that already existed at the beginning of the market liberalization in 2004. Therefore the table is indicative, as the exact distribution of customers on this moment is unknown.

*Table 2.2 Overview of the share in production capacity and client shares of energy companies in the Netherlands. The numbers are partly adapted from Kovalenko (2005) and * are based on the companies' websites*

Producer + Distributor	Share in total installed production capacity(%)	Client share (%)
Essent	34%	28%
Nuon	24%	23%
Electrabel/Suez	23%	0%
E.ON Benelux	9%	3%
Delta	7%	3%
Only Distributor		
Eneco	-	23%
Oxxio*	-	9%
Greenchoice*	-	3%
Nederlandse Energie Maatschappij*	-	6%

Thus, on the production and distribution side of the electricity sector, two types of actors can be distinguished: integrated firms that are both producer and EDC, and non-integrated EDCs without production facilities. Most important difference with EDCs without production facilities is that integrated firms have an incentive to offset their centrally produced electricity. On this moment there are plans for another 15 GW new capacity to be installed in the form of fossil fuel based plants (equipped with an option for integration of carbon capture and storage in the future), in the coming decade. Existing production companies have taken these initiatives under the notion that part of the current production plants in the Netherlands is relatively old and needs replacement in the near future, while at the same time electricity demand is expected to rise. The strong growth of production capacity in the short run is likely to turn the Netherlands from net importer into a net exporter of electricity, as the new capacity will exceed the growth in national demand (Seebregts et al. 2008; Rooijers et al. 2009). However, due to physical limitations of the network, but also because of the expected lack of demand of foreign countries, there may be limitations to the amount of electricity that can be exported (Rooijers et al. 2009). As the household sector is responsible for around 25 % of the national demand (IEA, 2009), a large scale integration of micro-generation in the household sector may lift the demand of centrally produced power. Thus, an active involvement of integrated firms in the promotion of micro-generation on the supply side may contradict their interests on the production side, as the profitability of the investments made in centralized production facilities is dependent on the grid demand of households.

Just as Eneco, newly emerged EDCs do not have their own production facilities, as the high capital costs of these facilities form a market boundary. But, despite the absence their own production section and the limited number of possibilities for product differentiation (green or grey electricity, the duration of a contract and between fixed or variable costs over the contract period) new distributors such as OXXIO, Greenchoice and De Nederlandse Energie Maatschappij have successfully entered the distribution market (energiekamer.nl, 2009). Market research has revealed that the price of energy contracts has been the main incentive for households to change to another distributor, explaining the market shares of the new entrants. On the other hand, reliable service, resulting in a high level of confidence in their present distributor and the perceived hassle involved with switching, are given as the main reasons not to change (NMa, 2009).

Besides price, in the deregulated market, other aspects such as brand imaging and the relationship between company and customers become important. One possible way in which EDCs may strengthen their relationship with customers or distinguish themselves from other companies is by providing additional energy related services. Observed examples are the advising of customers on their possibilities for energy savings and the providing of new, smart metering systems, which give more detailed insight in a households' energy use and the related costs over time (Sectorakkoord Energie, 2008). Also, all three biggest electricity suppliers offer solar PV and solar boiler installation packages and Eneco offers households the opportunity of Micro-CHP on a trial basis (websites of EDCs, 2009).

In line with these developments, in the future, the focus of EDCs may shift from supplying energy to providing energy services. In such a service based market, energy packages based on micro-generation technologies can form a strategic asset of EDCs. This idea is central to the company driven deployment model of micro generation, as described by Sauter et al. (2007). Besides the 'Company Driven' model, Sauter et al. (2007) distinguish between two other deployment models: 'Community Micro-Grids' and the 'Plug and Play' model. The following is a brief elaboration of these three models.

In the 'Company Driven' model, households play a passive role as the initiative for implementation is taken by the EDC. In the most extreme version, the EDC may us a group of micro-generation devices as a back-up or alternative for a centralized production facility. In this situation, households provide the site, while the technologies are controlled remotely by the companies as a 'virtual power plant'. This could avoid the need for a new power station, or the need to purchase electricity from third parties. However, in the short run, this deployment model is seen unlikely. In the alternative version of the 'Company Driven' model, the EDC provides the technology and the knowledge and expertise needed for the installation, while the household is in control of the system. The up-front capital can be supplied either by the company or the household.

'Community Micro-Grids' comprise energy systems that exist of small production facilities (on a household level) and distribution systems on a local scale, islanded or in connection to the grid. In this model, communication exists essentially between households, based on a 'peer to peer' structure with little or no interference of an external company. The local energy system may be partly owned and controlled (in cooperation with an EDC) by the community.

Under 'Plug and Play', households take the initiative for purchase of a specific micro-generation technology. In this model they are financer, owner and in control of the system, changing the relationship between the consumer and the distribution company. As households become producer, (grid) demand decreases and the EDC has to give a financial compensation for the excess electricity that is fed back into the grid. Presently, in the Netherlands, micro-generation devices are distributed in the domestic sector according to this model. The agent-based model set-up, created in the second part of this thesis will be based on this deployment model. An active involvement of EDCs in the promotion and implementation may induce the diffusion of micro-generation technologies, as it increases the awareness of the products and reduces uncertainty in the decision making of households.

In table 2.3 below, a schematic overview is presented of the actors involved in the production and supply of electricity.

Table 2.3 Overview of the description of actors on the production and distribution side of the electricity sector

Actor	***Function***	***Objectives***	***Strategic Interest***	***Influence***	***Related to***
EDC + Prod.	Generating electricity and the supply of electricity to consumers. The companies have the responsibility for affordable and reliable services, and more recently environmental concerns have become part of this responsibility.	-On the production side: gaining or sustaining production capacity shares - On the distribution side: gaining or sustaining client shares	On the distribution side, service packages based on micro-generation technologies are a strategic asset. But a large scale integration of micro-generation may counteract the interests of integrated companies on the production side. Investments in conventional, centralized production plants are guided by expected market prices of electricity and CO2 permits.	EDC's may stimulate the diffusion of micro-generation by affording hassle free micro-generation installation packages. They may provide the technology, knowledge and capital needed for installation. Investing in new centralized production facilities may create congestion in the transport network, which (depending on the legal framework in place) may put constraints on the amount of decentralized produced electricity that can be fed-back.	- Ministry of Economic Affairs long term sector agreement 2008-2020, under the policy act 'Schoon en Zuinig' designed to stimulate sustainable energy. - Tennet - Energiekamer: - Local network operators - Consumers:

EDC without production facilities	The supply of electricity to consumers. The companies have the responsibility for affordable and reliable services, and more recently environmental concerns have become part of this responsibility	Gaining or sustaining client shares	Service packages based on micro-generation technologies are a strategic asset for these companies in their relation to (potential) customers. Micro-generation may increase the independency of non-integrated firms from third parties.	EDC's may stimulate the diffusion of micro-generation by affording hassle free micro-generation installation packages. They may provide the technology, knowledge and capital needed for installation.	- Producers Ministry of Economic Affairs - Energiekamer - Local network operators - Consumers

2.2.2 Electricity transport

On the transport side two types of actors can be identified, both created following the electricity law adopted in 1998: Tennet and regional network operators. Tennet is the national Transmission System Operator (TSO), which is a state owned company falling under the Ministry of Economic Affairs, formally responsible for the high current (110 kV - 380 kV) or transmission network between producers and suppliers, securing the physical conditions for reliable transport of electricity. Its primary tasks are the creation of adequate transport capacity and the balancing of supply and demand. Producers need a contract from Tennet for the connection of new capacity to the transmission lines. They pay a tariff for connection and transport to the company (Tennet.nl, 2009). These tariffs are determined by the 'Energiekamer' a body of the Dutch Competition Authority (NMa)

The Regional network operators are in charge of the low voltage or distribution side between EDCs and households. There are 14 operators in the regional distribution market under which Liander Enexis and Stedin, which are part of respectively Nuon, Essent, and Eneco. Network operators have the responsibility for delivery of electricity and maintenance of the low current network and exist as a natural monopoly in a certain region. Their primary task is to facilitate the balance between demand and supply in the network. Prices charged for transport and connection in the low current network, are also set by the Energiekamer (Energiekamer.nl, 2009).

A far going decentralization of the electricity system requires changes to existing practices in the transport system. Biggest challenge is the balancing between supply and demand on a local scale in the presence of a large quantity of micro-generation facilities. Micro-generation technologies are characterized by strong fluctuations in supply over short periods of time. Power supply of solar PV and micro-wind turbines varies (on a minute, hourly, daily, seasonal basis) according to variation in sun irradiation levels and wind speeds. Electricity production of micro-CHP installations is dependent on the heat use of households, which differs per type of household and on a daily and seasonal basis.

To anticipate on variations in demand, short-term adjustments in supply are needed. One possible solution to this problem is electrical storage, as back-up to provide electricity in time of shortage in supply. Electricity can be stored on a physical or electro-chemical basis. Storage systems based on a physical basis are characterized by large capacities and are typically unsuitable for micro-generation applications. Small scale electrical storage is likely to take place in different types of batteries. However, so far, there are technological boundaries to the maximum storage capacities and discharge rates of batteries. Other factors, such as high costs and a short lifetime, are also impeding a large scale introduction in the short run (Faber et al, 2009 a).

Apart from electricity storage, in times of overproduction, micro-generation technologies may be decoupled from the local grid. This can be controlled remotely by EDCs in case of a 'virtual power plant', or directed by households themselves in the presence of local 'micro-grids' (Sauter et al. 2007). In order to manage communication and control of electricity loads between different small users and suppliers, on a community scale, ICT related innovations are needed. One of these is smart-grids, which encompass the idea of networks in which balancing between supply and demand occurs autonomously. Furthermore, new metering systems are requested to accommodate a two way flow of electricity and information. On this moment already a new type of meter is needed for feed-back into the grid. This system is able to communicate a households' electricity feed-back and use with a distributor over a distance, but does not have the option of real-time communication of local electricity production and demand and electricity prices (Faber et al., 2009 a).

Innovations in the transport system, needed to accommodate a large scale integration of micro-generation, fall under the direct responsibility of the network operators. Network companies (both Tennet and regional operators) are fully regulated; their income exists of tariffs for transport and connection which are determined by the Energiekamer, which indirectly falls under the supervision of the Ministry of Economic Affairs. In the present institutional setting, there is no apparent incentive for network companies to invest in innovation, as there are no financial regulations compensating for the investments done in the first stages of product development (Künneke, 2008). Besides, the profits of operators are a function of the throughput of electricity in their network, consequently, a decrease in grid-demand associated with an increase of micro-generation might decrease their income. A recent report published by the EnergieRaad on behalf of the network operators, confirms these adversary investment conditions. The report proposes a national infrastructural plan to be composed by the Ministry of Economic Affairs, including a regulatory frame to guarantee that capital investments made for innovation by operators can be translated into the transport costs in the future, thereby improving the investment conditions (energieraad.nl, 2009).

These adjustments to the transport system needed in case of a far going decentralization will be conducted in parallel to other developments in the centralized production system. In its ‘capacity plan 2008-2014’, Tennet highlights the complexities arising from the deregulation of investments of electricity producers and the large quantity of recent initiatives of companies for the building of new plants (Tennet.org, 2009). It recognizes the impacts of these developments and the impacts of the potential growth of decentralized produced power on the scarcity of transport capacity in the present system in the near future. Congestion problems have already occurred at the Eemshaven site in connecting two new large fossil fuel based power plants and in absorbing excess electricity of CHP installations of greenhouses in the Westland region. In the latter case, a sudden growth in decentralized produced electricity, indirectly connected to the high-voltage transmission lines, could not be fed in to the local distribution network as there was shortage in transport capacity and priority was given to centralized produced electricity. Following these events, recently, a new regulatory system is proposed by the Ministry of Economic Affairs, enforcing the precedence of sustainable produced electricity in case of transport capacity shortage, including electricity produced in households.

Following this review of the transport sector, it can be concluded that innovation of the present physical transport system is needed to be able to facilitate a far going decentralization of energy production. The question arises whether network adjustments will be made on forehand, paving the way for micro-generation, or that developments on the production side will be dominant in the development of a new transport infrastructure.

In table 2.4 below, a schematic overview is presented of the actors involved in the production and supply of electricity.

Table 2.4 Overview of the description of actors on the transport side of the electricity sector

Actor	***Function***	***Objectives***	***Strategic Interest***	***Influence***	***Related to***
Tennet	In control of the high voltage transmission lines: -Balancing supply and demand -Providing sufficient transport capacity -Maintenance of the physical infrastructure	- A reliable electricity supply - Development of the integration of the Northwest electricity market - Facilitating the transition to a (desired type of) sustainable energy system	Is guided by the interests of the national government. Tennet emphasizes its role in the development of a Northwest European energy system.	No direct influence, however, households/small producers are indirectly connected to the high voltage grid. Changes in electricity throughput in the distribution lines will affect the balance between supply and demand in the transmission system.	The Energiekamer: High voltage power producers.
Regional	In control of the	-Continuation of	Under the present	Developments in	The Energiekamer

network operators	local distribution lines between consumer and EDC: -Balancing supply and demand -Maintenance of the physical infrastructure	business and profit maximization - Safeguarding a reliable electricity supply	regulatory conditions operators are not compensated for investments in the early stages of product development, which counteracts their willingness to innovate However, recently the network operators have created a plan of action, as part of the transition platforms initiated by the national government, formulating their tasks in assisting the developments towards a decentralized infrastructure (Senternovem.nl, 2009).	the regional distribution networks are essential to accommodate a large scale integration of micro-generation in the household sector.	EDCs Households

2.2.3 Regulation

In the present electricity system, three regulatory actors can be distinguished: (1) the Energiekamer (formerly Dte), (2) the national government and (3) local governments. The Energiekamer is part of the Netherlands Competition Authority (NMa), falling under the direction of the Dutch Ministry of Economic Affairs and is formally responsible for observing the 'Elektriciteitswet 1998'. Its primary tasks are related to the transmission side of the system, determining the prices for transport and tariffs for connection to the grid on both low and high current side, and controlling the functioning of the regional operators and Tennet (energkamer.nl). Furthermore, it aims to enforce fair competition in the energy supply market.

While the responsibility for the reliability and affordability of supply have explicitly been delegated to the Energiekamer, the central government has taken a direct role in the creation of a more sustainable energy system by stimulating the development of clean production technologies and discouraging the use of old, polluting technologies (EZ, 2008). Since the liberalization of the sector the national government has lost its direct control; developments are now increasingly led by the initiatives of individual energy companies. Its present role can be described as to steer future developments of the system in a desirable direction. Historically, this direction has been determined by costs, reliability and a European agenda. More recently environmental criteria have become a factor of increasing importance (Verbong et al., 2007).

The ‘energy report 2008’, published by the Ministry of Economic Affairs, gives insight in the vision, strategy and plans of the national government in facilitating developments in the energy system. Three global developments are recognized as being the most important factors to anticipate to in the coming decades. These are (1) scarcity of fossil fuels as a consequence of rapid increasing demands, and related to this the concerns of an increasing dependency on political unstable countries, (2) climate change and the reduction of CO2 emissions and (3) the likelihood of increasing energy prices as a consequence of the first two developments. In response to these threats, the government aims to make the energy system cleaner through efficiency increases and the use of sustainable sources, more diverse by the use of multiple fossil fuels and sustainable resources, and more intelligent especially on the transport and supply side of the system by new products, such as smart meters and intelligent networks (EZ, 2008).

The government has created three scenarios for the electricity system in the year 2050: (1) ‘The Netherlands as Power house of Europe’; The Netherlands as the provider of a base load in a European market in which the production is dominantly based on coal. (2) ‘The Netherlands as Flex worker within Europe’; An electricity system based on gas, which is possible with the present Dutch gas reserves and an increasing demand for flexible back-up on a European scale because of the introduction of wind and solar power on a large scale. (3) ‘The Netherlands as Smart Energy City’; a focus on locally based infrastructure by decentralized small scale electricity generation with the help of micro-generation technologies (EZ, 2008). These images point out the different ways in which a sustainable energy system can be realized, highlighting the role of market initiatives and technological developments in the formation of a future system.

It should be noted that the first two scenarios reveal a strong European orientation, while in the third scenario developments are guided by local interests. Several current events point towards a further integration of the Dutch electricity system into a European system; two of the biggest electricity producers and distributors (Essent and Nuon) are taken over by large European enterprises (Vattenfall and Rwe); a high capacity transport cable between Norway and the Netherlands has set into operation; a transmission link is constructed between the UK and the Netherlands, which is to be commissioned in 2010; Tennet has purchased a part of the German transmission network. Along with these developments, in the short term, a significant expansion of the centralized gas and coal-based production capacity is expected. Furthermore, the national government aims to stimulate an increase of wind based capacity on land (1600MW in 2007, 4000MW is set as a target) and 450 MW off-shore before the year 2011 under the ‘Schoon en Zuinig’ policy program (Seebregts et al. 2008). A steep increase in production capacity in the Netherlands, possibly followed by overcapacity, together with the ongoing integration of the European transport system, may hint towards one of the first two scenarios pointed out by the Ministry of EZ.

Besides these developments towards a further Europeanization of the electricity system, there are a few identifiable initiatives of the central government aimed at stimulating micro-generation in the built environment. These include the SDE subsidy program (described in more detail in the description of actors on the demand side) and the establishment of the innovation platforms. The national government has created so called ‘Transition Platforms’, which are collaborations between the government, businesses, knowledge-centres and societal organizations, in which these stakeholders exchange knowledge, aiming to assist and speed up the transition to a more sustainable energy system in the Netherlands. Seven platforms have been created and three of them (‘Nieuw gas, Duurzame Elektriciteit en Gebouwde omgeving’) are involved in investigating the opportunities for micro-generation in the built environment. There are plans to create an eighth (‘werkgroep decentrale infrastuctuur’) platform, specifically addressing the development of local, intelligent networks (Senternovem.nl, 2009).

Next to the centrally organized regulatory programs, several local authorities have taken the initiative in greening the electricity system locally by means of extra financial compensation on top of national subsidies for domestically generated electricity by use of PV panels (Senternovem.nl,2009). But, just as the national government, regional authorities have experienced a decreasing influence on the developments of the energy system since the privatization and liberalization of the market. Until recently provinces were the main shareholders of the large energy companies (of both the production and distribution firms) in the Netherlands that existed before the opening of the market. While Eneco is still in the hands of municipalities and provinces throughout the country, the shares in Nuon and Essent will are sold to international energy companies (Vattenfall and RWE). As a result, the steering power of local governments as shareholders on the decision making in these companies ends. But the provinces remain shareholder in the low current distribution networks.

Furthermore, cooperative structures exist between the national and local governments. A contract has been signed by the central government and the twelve provinces, articulating the responsibilities of the local authorities in reaching national climate targets. This ‘Klimaat-Energieakkoord’ states that all provinces invest at least 200 million euros in local climate and energy projects till the end of 2011(Senternovem.nl, 2009).

In 2.5 below, a schematic overview is presented of the actor groups that act as regulators in the electricity system in the Netherlands.

Table 2.5 Overview of the description of actors active as regulators in the Dutch electricity system

Actor	***Function***	***Objectives***	***Strategic Interest***	***Influence***	***Related to***
The National Government	Securing the public interests involved in electricity supply	- A reliable and affordable electricity supply - Development of the integration of the Northwest electricity market - Facilitating the transition to a (desired type of) sustainable energy system - Diversifying the system/ increasing the flexibility of the system	Guided by: -A European agenda -Scarcity of fossil fuels as a consequence of rapid increasing global demands, and related to this the concerns of an increasing dependency on political unstable countries - Climate change and the reduction of CO2 emissions - The likelihood of increasing energy prices A decentralized electricity system with the use of micro-generation technologies is seen as possible future to secure the objectives	The creation of the right conditions for a large scale implementation of micro-generation: - These include financial stimulations such a subsidies on micro-generation technologies or produced electricity (possibly a feed-in tariff structure) - The physical possibilities; by stimulating innovations in the transport infrastructure - Information campaigns/informing the public on the possibilities of micro-generation - Bringing together/aligning the interests of the different stakeholders involved in micro-generation	EDCs and producers: The Energiekamer Households Local Authorities
The Energiekamer:	Supervising body under control of the Ministry of Economic Affairs, securing the quality of the physical transport system, determining transport and connection tariffs and	- A reliable and affordable electricity supply - Creating the conditions for fair competition in the market	- Determined by the national government	-Determined by the national government	EDCs Network operators (Both Tennet and local operators) The Ministry of EZ

	looking after the functioning of the market, protecting consumers from overprizing.				
Local Governments	Securing the local public interests involved in electricity supply	- A reliable and affordable electricity supply - Facilitating the transition to a (desired type of) sustainable energy system on a local level	Micro-generation may be an important technological option in the creation of a sustainable energy system on a local level	May take the initiative for a local sustainable energy system with the use of micro-generation technologies. May take the initiative to integrate micro-generation in newly build neighbourhoods; have the capability to bring the different stakeholders together and to create adequate financial and physical boundary conditions.	The National governments: Energy companies Local network operators Households

2.3 Identification of actors on the demand side

Here, a description is given of the actors influencing the demand for micro-generation technologies. The actors on the demand-side can be separated into three categories: the different types of building owners in the built environment, the group of actors involved in the implementation of micro-generation technologies in newly built houses and neighborhoods, and the government.

2.3.1 House and utility building owners

The built environment can be separated, roughly, into two sectors; the utility and domestic sector. This study focuses on the demand for micro-generation in the domestic sector, therefore only a very brief description of the utility sector is given. Several categories of utility buildings are distinguished in the Dutch built environment: Office buildings, education buildings, hospitals, shops, sporting facilities and business premises. By far the biggest categories, both in number and in energy use are office buildings, shops and business premises (SenterNovem, 2006). Already in a large share of hospitals heat is being produced with CHP systems. These are so called ‘mini-CHP’ systems with significant higher heat and electricity production capacities than the micro-CHP systems considered in this research. Furthermore, schools and offices are showing an increasing interest in the application of PV panels and sun boilers as their energy production system (around 3 % of all schools and shops in 2006) (SenterNovem, 2006).

The domestic sector in the Netherlands exists of approximately 7 million dwellings, which are divided over three types of ownership. Each represents a different type of decision maker with respect to the purchase of micro-generation technologies.

- The private rental sector, in which private landlords make the investment decision;
- The public rental sector, in which housing associations[7] make the investment decision;
- The Owner-occupied sector, in which the residents themselves are the decision makers.

The distribution of ownership types as a proportion of the total residential dwelling stock in the Netherlands, is presented in table 2.6 below. For this study, most data regarding the residential dwelling stock is taken from the Dutch woOn research, held under supervision of the Dutch Ministry of VROM (ABF, 2009). Because the database only contains data for the year 2006, this is in most cases the year of reference.

Table 2.6 The distribution of ownership types over the household stock in 2006, both in absolute numbers and as a percentage (Citavista, 2009)

Year: 2006	**Social Rent**	**Private Rent**	**Owner**	**Total**
Abs. Numb	2,394,700	609,200	3,796,690	6,800,590
Percentage	35%	9%	56%	100%

[7] Housing associations are non-profit organizations which are active in public housing, with the responsibility to create affordable housing for specific parts of the Dutch population. Formal activities of the associations are buying, building, selling and letting, as well as the maintenance of the buildings and the residential area's (Vrom.nl, 2009). The associations fall under the supervision of the Dutch ministry of VROM and the CFV (Central Fonds voor Volkshuisvesting). It should be noted that the associations own large groups of houses, meaning that if a certain association decides to implement a micro-generation technology, it is installed in multiple houses at once.

2.3.2 Newly built houses

Besides the existing housing stock, newly-built houses and larger building projects, such as newly constructed neighborhoods, provide an opportunity for the implementation of micro-generation technologies. Observed examples in which PV systems were applied on newly built neighbourhoods are the ‘HAL project’ in three Dutch cities and the 1 MW project in the Nieuwland district in Amersfoort. Also micro-CHP systems have been installed in larger projects e.g. the field test with 200 micro-CHP installations in Apeldoorn.

Crucial in bringing about these projects are local authorities; they are the initiator and have the ability to bring the different stakeholders together. Besides the municipalities and provinces other actors involved are energy companies (distribution companies and network operators), building companies and architects (SenterNovem, 2008). The collaborations between these actors on a local scale can be regarded as technological niches i.e. the protected spaces in which learning processes in the early stages of product development can take place.

2.3.3 The Government

Also the central government is an important actor on the demand side. The domestic sector, as part of the built environment, forms a sector in which two policy domains overlap. On the one hand the use of micro-generation technologies in households contributes to the goal of an increasing share of renewable energy in the energy mix; on the other hand the sector is regarded as an important domain for achieving the overall national energy saving targets.

A policy program in place, stimulating the demand for micro-generation is the ‘Stimulering Duurzame Energieproductie’ (SDE) subsidy scheme. Under this program, households can apply for a financial compensation on every kWh of electricity produced on-site with PV panels. The financial reward is dependent on the grid electricity price and the installed capacity; if the installed capacity is in between 0.6-15 kWp, the producer receives € 0.562 minus the grid electricity price per kWh produced. The program is however constrained to a limited budget (an estimated maximum of 15 MW of total installed capacity for small scale PV) which is on this moment insufficient to meet all applications of small producers (senternovem.nl, 2009). Electricity generated with Micro-wind turbines is also subsidized under the SDE program, by the same amount as electricity generated with large wind turbines (0,118 €/kwh, category ‘wind op land’). Micro-CHP is included in the subsidy program for sustainable heat applications (‘subsidie duurzame warmte’), offering a purchase subsidy of 4000€ per installation for individual households. This budget is limited to an amount of 10.000 installations (SenterNovem.nl, 2009).

Next to the stimulation of micro-generation technologies, a wide variety of policy measures are aimed at reducing energy demand in the built environment. One is the energy labelling scheme for buildings, which falls under the 'Schoon en Zuinig' policy program intending to encourage owners to take additional energy saving measures (VROM.nl, 2009). Another is the performance norm (EPN) for newly built houses, which is part of the 'Lente Akkoord', a covenant between the building sector and the Dutch national government (VROM.nl, 2009). Apart from these instruments, one of the transition platforms ('Gebouwde Omgeving') created by the government, specifically addresses energy reduction in the built environment. Because the economic performance of micro-CHP degrades with a decreasing heat demand, it should be noted that, as these policies are aimed at reducing heat demand, they counteract the demand for micro-CHP installations.

In table 2.7 below, a schematic overview is presented of the actor groups involved on the demand side of the micro-generation technologies.

Table 2.7 An overview of the description of actors on the demand-side of micro-generation technologies

Actor	***Function***	***Objectives***	***Strategic Interest***	***Influence***	***Related to***
House owner	Responsible for the households' energy use; decides if the electricity used is taken from the grid or produced with the use of micro-generation technologies	Is described in detail in the model set-up when classifying the agents	Is described in detail in the model set-up when classifying the agents	Directly determine the demand for micro-generation technologies	Technology suppliers Fitters EDC Central government
Housing association	Responsible for the households' energy use; decides if the electricity used is taken from the grid or produced with the use of micro-generation technologies Important property developer	Creation of affordable dwellings for specific segments of the population. Letting prices are the primary objective when deciding for an energy system in a dwelling.	[8] Micro-generation technologies are applied on a experimental basis for two reasons: (1)Cost savings (2)Support of the micro-generation technologies/ creation of a green image, which applies to the 'visible' technologies such as micro-turbines and PV	Directly determine the demand for micro-generation technologies	Local governments National government Building companies Architects

[8] The strategic interest of housing associations is based on the interviews with multiple associations included in the thesis of Wah (2008). The description in the table above is meant to be indicative, there is no detailed account given of the strategic decision making of these associations.

			But associations are risk avoiding and their main objective is the letting price		
Local governments	Local spatial planning Securing the local public interests involved in energy supply	A reliable, affordable and sustainable electricity supply on a local level electricity supply In achieving sustainability goals in the built environment, increasing energy efficiency is the prime objective	Micro-generation may be an important technological option in the creation of a sustainable energy system on a local level	Are important in the implementation of micro-generation in newly built properties; as initiator and manager	National government Housing associations Private households Energy companies Contractors & Architects
Architects and contractors	Intermediary parties in the building process May include micro-generation technologies as architectonical element (PV, wind-turbine) in the building plan	Satisfying customers' needs	Offering the opportunity for the implementation of micro-generation in newly built properties as an extra service, by which the companies distinguishes itself from others	Stimulating customers to implement micro-generation technologies in their newly built properties	Fitters Technology suppliers Housing associations Private households Local governments
Central government	See table 2.5	See table 2.5	See table 2.5	SDE subsidy program Support for energy savings in the built environment, which counteracts the possibilities for micro-CHP	National government Housing associations Private households Energy companies Building companies & Architects

2.4 Identification of barriers and opportunities for micro-generation

From the description in this chapter, a selection of most important actors is made: (1) energy distribution companies, (2) existing electricity production companies, (3) network operators, (4) the central government, and (5) local governments (6) building owners. The interests and influence of these parties give an indication of some important opportunities for, and barriers to the diffusion of the selected micro-generation technologies on a larger macro (socio-economic and technological) level.

Firstly, energy distribution companies (EDCs) show an increasing interest in micro-generation technologies. Since the liberalization of the market the working field of EDCs has gradually extended from supplying energy to providing energy services. In such a service based market, energy packages based on micro-generation technologies can form a strategic asset for EDCs. An active involvement of EDCs in the promotion and implementation may induce the diffusion of micro-generation technologies, as it increases the awareness of the products and technical help reduces uncertainty in the decision making of potential adopters.

Secondly, the vested interests of existing electricity producers, secured by influential lobby groups such as EnergieNed, may form an important barrier to the introduction of micro-generation on a large scale. Energy companies in the Netherlands produce electricity mostly with large (de)centralized production facilities. Besides, on this moment a large number of new large centralized production facilities are being built. The use of micro-generation technologies on a large scale will likely decrease the demand for grid electricity. Therefore, the existing energy companies are interested in influencing policy-making for reasons of supporting the offset of electricity produced with their production facilities. On the other hand, GasTerra, the largest gas supplier in the Netherlands and an influential actor, is actively involved in the promotion of gas-based micro-CHP installations. The promotional activities of GasTerra are aimed at continuation (or expansion) of gas demand in households for heating applications, as increasing attention is being paid to alternative heating technologies, which do not (directly) work on gas.

Thirdly, the possibility for a large scale integration of micro-generation in the built environment is bounded by physical restrictions from the transport network. Innovations in the transport system fall under the direct responsibility of the network operators. Network companies (both Tennet and regional operators) are fully regulated; their income exists of tariffs for transport and connection which are determined by the Energiekamer that indirectly falls under the supervision of the Ministry of Economic Affairs. Because in the present institutional there are no financial regulations compensating for the investments done in the first stages of product development, there is no apparent incentive for network companies to invest in incremental network innovations

Fourthly, the national government plays an important role in the introduction of micro-generation technologies. In the national energy plan, the extensive use of micro-generation technologies in a decentralized electricity system is presented as one of three possible systems to meet the future objectives of the government. In developing the present system towards a decentralized system the central government has a steering role; she is a central actor influenced in its decision making by other actors such as the existing electricity producers, network operators and producers of micro-generation technologies. The government is able to stimulate the adoption of micro-generation technologies directly through policy measures such as subsidies on the electricity generated by users (e.g. the SDE subsidy scheme) investment subsidies or by creating awareness/informing the public about micro-generation.

Fifthly, local governments have shown to be an important actor in the early stages of the diffusion of micro-generation. Local stimulation plans in the form of subsidies and information campaigns have proven effective measures to create a purchase incentive among households. Also, local authorities are very important for the implementation of micro-generation technologies in newly-built houses and larger building projects, such as newly constructed neighborhoods. They are in most cases the initiator and have the ability to bring the different stakeholders in the building process together.

The last group of actors consists of building owners. Besides developments in the existing electricity sector and policy intervention on a national and local level, a large scale introduction of micro-generation technologies is dependent of the willingness of consumers (the building owners) to purchase the technologies. In the actor description three groups of consumers have been indicated: private house owners, public housing associations and owners of utility buildings. The willingness of these consumers to purchase micro-generation technologies is depended on a large number of factors, such as the functioning of the existing electricity system (reliability of supply, grid electricity prices, and integration of renewable options e.g. biomass and wind parks), social developments (Europeanization vs. localization, increasing environmental concerns) and developments in the micro-generation technologies (e.g. decreasing investment prices) (Verbong et al., 2008). In the following chapter, in creating the agent-based model (ABM) set-up, a closer look is taken at the demand for micro-generation in the domestic sector (the utility sector is disregarded). The set-up provides the basic input for an ABM that is able to simulate the purchase decision of a heterogeneous group of households for three specific micro generation technologies: PV panels, micro-CHP and micro wind turbines. Simulating the decision making of a heterogeneous group of households under different conditions with the ABM, may give insight in the factors determining the demand for micro-generation technologies in the future.

3 The model set-up

In this chapter, the set-up for an ABM is created that simulates the diffusion of micro-generation technologies in the domestic sector in the Netherlands. This set-up will exist of a number of rules that capture the essential mechanisms describing the purchase-decision of different types of households (the agents) for a specific micro-generation technology. The levels of diffusion of the technologies in the domestic sector (the emergent properties) result from the sum of these purchase-decisions.

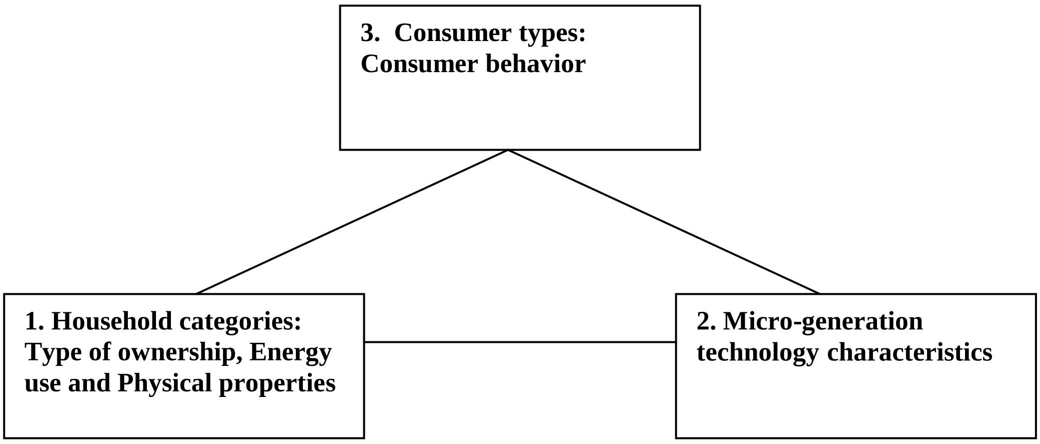


Figure 3.1 The general structure of a set-up for the ABM

In figure 3.1 the underlying structure of the model set-up is presented. This chapter is built up from the three components that make-up the model set-up. Firstly, the domestic sector is differentiated into specific groups of households (agent types), based on the type of ownership of a house (social rent, private rent and owner occupancy), electricity and heat use, housing type (e.g. free-standing, stacked) and behavioural characteristics (e.g. level of income, personal preferences). Secondly, the selected technologies (micro-CHP systems, PV panels, micro-wind turbines) are evaluated, which includes a description of the main working principles and an assessment based on a number of characteristics that are likely to play a role in the purchase decision of households. Thirdly, a simple utility function is used to describe the deliberate purchase decision of different types of agents for a certain micro-generation technology in comparison to technological options already in place i.e. grid electricity, and a combination of grid electricity and condensing boilers in case of micro-CHP.

3.1 Differentiating the domestic sector into agent types

In this section the domestic sector is differentiated into agent categories. This is subdivided into three parts. Firstly, the households will be classified based on the type of house ownership and the electricity and heat use. Because the type of house is an important determinant for the electricity and heat use of a household, in differentiating households according to their energy usages already a distinction is made between different types of houses (freestanding, stacked etc.). Secondly, households will be classified according to the behavioural characteristics that play a role in their purchase decision. The theory of planned behaviour (Ajzen, 1991) is used as a framework to describe the decision making of households according their behavioural characteristics. Thirdly, the first two parts are combined. The result is a differentiation of the domestic sector into agent categories with the same type of ownership of a house, the same type of house and roughly equal electricity and heat use, which are likely to show the same purchase behaviour related to a specific micro-generation technology.

3.1.1.1 House ownership

In the Dutch Domestic sector three types of house ownership occur; social rent, private rent and owner occupancy. Each type of ownership represents a different agent type related to the purchase of DEG technologies.

- Social rent; Housing organizations
- Private rent; Landlords
- Owner occupancy; The residents

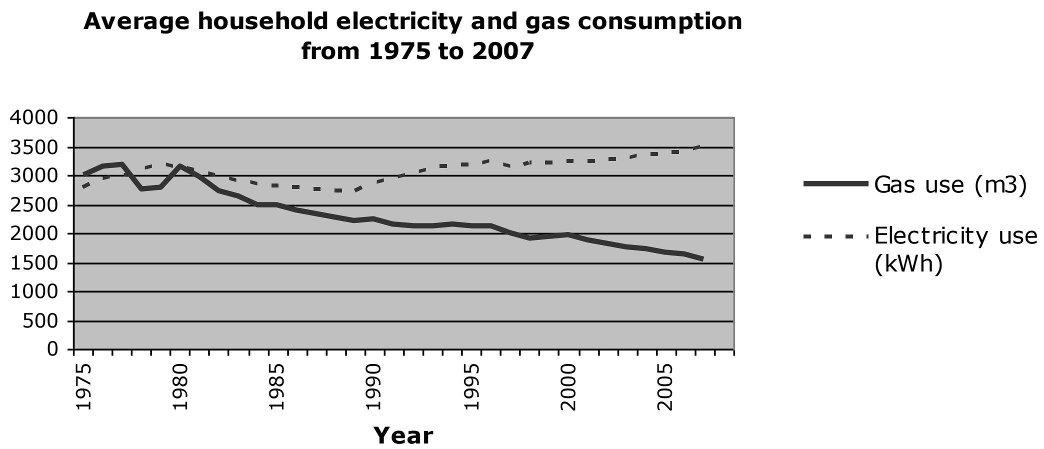
Only the decision making in the owner occupancy sector is modeled. It is assumed that the decision making in the private and public rental sector[9] deviates too much from decision making in the owner occupancy sector to be described by the same set of rules.

3.1.1.2 Energy use

[9] The application of energy saving measures such as high efficient boilers or double glazing is often taken as an indicator of the willingness of households to invest in micro-generation technologies. Research reveals that the penetration of these energy saving measures in the private rental sector is lacking behind on the owner occupied sector (CE, 2007; Element Energy, 2008). This can be explained by the fact that the energy bill is transferred to the tenants, therefore the direct incentive for reducing cost is missing. In correspondence to this, it is assumed that households in the rental sectors do not decide to purchase a micro-generation technology individually, as this will most likely fall under the responsibility of the property owner. Therefore it is assumed that the purchase of decision making of households in the private rental sector deviates too much from the decision making of households in the owner occupancy category to be explained by the same set of rules.

The energy use of households for heat and power is taken as a second point of focus to divide the dwelling stock into agent categories. The average electricity and gas consumption of Dutch households between 1975 and 2007 is presented in Figure 3.2. The aim is to discriminate between household categories that differ in their energy demands and to determine the number of households in each category. This has several implications.

Figure 3.2 Average yearly electricity and gas consumption of Dutch households (EnergieNed.nl, 2009) [10]



Firstly, the study aims at modeling micro-generation technologies as a component that determines the electricity and gas grid-demand of a household. If a household purchases a micro-generation technology it will lower its demand of electricity from, and will likely increase the amount of feed-back into the grid. Furthermore, a gas fuelled micro-CHP system will increase the demand for gas when it replaces a high efficiency boiler due to the lower thermal efficiency of existing boilers. The consequences for grid demand of electricity and gas and feed-back of electricity in the domestic sector is a function of the diffusion of specific micro-generation systems in relation to the energy demands of specific types of households. By discriminating between types of households with different energy demands, the effects on an aggregate level are modeled in more detail.

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[10] Average gas use per household nearly halved over the last 3 decades from around 3000 m^3 in 1975 to 1560 m^3 in 2007, while the average electricity use increased with 720 kWh over the same period. Gas is used in households for three different applications: Space heating, hot water use and cooking, from which the first is responsible for approximately three quarters of the use. Gas use for cooking and water heating were approximately constant in recent decades. The decline in gas use results from an increasing level of insulation measures and the penetration of high efficiency heating equipment in existing and new dwellings. An increase of electrical equipment for domestic services explains the growth in electricity use over this period.

Secondly, the possibilities of households to adopt micro-generation are limited by physical constraints. The categorization of households with respect to energy usages includes a distinction between different types of households with clearly different physical properties. Broadly five types of dwellings can be distinguished in the Dutch domestic sector: Free standing, apartments, middle of a row, corner of a row and semi-detached dwellings. Given the selected technologies in this study, one physical barrier can be identified: *If a household is situated in a stacked building it is assumed that they do not consider the option of solar PV panels or micro-wind turbines individually.*

Thirdly, it is assumed that a micro-CHP system replaces the existing heating system and therefore must be able to fulfill the entire heat demand of a household. Furthermore, the generated electricity with micro-CHP, and subsequently the economic performance, depends on the heat demand of a household. The economic performance is one indicator that determines the likelihood of purchase of the technology. By discriminating between categories of households with different heat demands, the diffusion potential for micro-CHP systems is described in more detail.

Here, a short description of the model is given, describing the aggregate energy use of the domestic sector from the energy use of different categories of households. A more detailed description can be found in Appendix 2. The model is built up in three steps. Firstly, the most important determinants for electricity and heat use are selected from literature.

The most important determinants for electricity use are:

(1) The size of the dwelling

(2) The number of occupants (BEK,1993; SenterNovem, 2007).

The factors that have the biggest influence on the heat use of a household are:

(1) The dwelling type[11]

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[11] The Dutch domestic sector comprises five types of dwellings: free standing, apartments, middle of a row, corner of a row and semi-detached dwellings. The latter two are combined into one category because they have almost equal heat uses (SenterNovem 2007). The heat use is a function, among others, of the volume and contact surface with the surroundings. The type of house is determinant for the heat use in two ways; certain types of houses are on average larger than others, and certain types of house (e.g. situated in the middle of a row) have a smaller contact surface than another type of house with the same volume (e.g. free standing house). To be able to identify the effect of the size on heat use independently from the type of house, a distinction is made between three different sizes for each dwelling type.

(2) The size

(3) The construction period of the dwelling (SenterNovem, 2007).

Secondly, the heat use and electricity use per category are determined. The heat use is based on a data-set containing measurements retrieved from 'Kompas monitoring - Cijfers & tabellen', a study published by SenterNovem. Electricity usages are based on the 'Basisonderzoek Elektricteitsverbruik Kleinverbruiker' (BEK) from 1993, assuming that the relative impacts of the size and number of occupants has not changed.

Thirdly, the number of households per category is calculated based on data taken from the Dutch woOn research held under supervision of the Dutch Ministry of VROM, and the Bureau of Statistics Netherlands (CBS) (ABF, 2009; CBS, 2009). With these numbers, the total electricity and heat use of the household sector can be calculated.

The model is used to reproduce measurements of the average household heat and electricity use performed by EnergieNed (2009). In table 3.1 these numbers are presented. The measurement and calculation of electricity use almost match, while there is a (small) difference between the calculated and measured average heat use. However, there are a lot of uncertainties involved in the built up of the model, reflected by the large number of assumptions underlying the calculations. Therefore the correspondence of the calculated averages to the measurements of EnergieNed is not necessarily a measure of the quality of the model; the quality of the model is primarily a function of the validity of the assumptions made. The numbers are compared to indicate that the calculation generates an average within a corresponding order of magnitude as the measurements performed by ErnegieNed. The model should be treated as a robust methodology to identify the energy use of certain categories of households, and their relative share in the total sector.

Table 3.1 The calculated and measured average heat and electricity use per households in the Netherlands. The year 2006 is taken as the reference measurement because the dwelling stock data dates back to 2006 (ABF,2009)

Average uses (p/hh)	***Calculated***	***Measured (EnergieNed,2006)***
Electricity kWh/yr	3403	3402
Heat m3/yr	1727	1643

3.1.1.3 Household categories according to the type of ownership of a house, housing type and the energy use of households

[11]The construction period is an indicator for the degree of insulation of a dwelling.

As a result, together with the three types of ownership, the dwelling stock is differentiated according to eight variables. The end product is a model including 900 household categories with different energy usages. A schematic overview of the categorization is presented in figure 3.3. This is the basis for the categorization of the domestic sector into agents-categories. Next, a description is given of the purchase-decision behavior of households in respect to the selected micro-generation technologies.

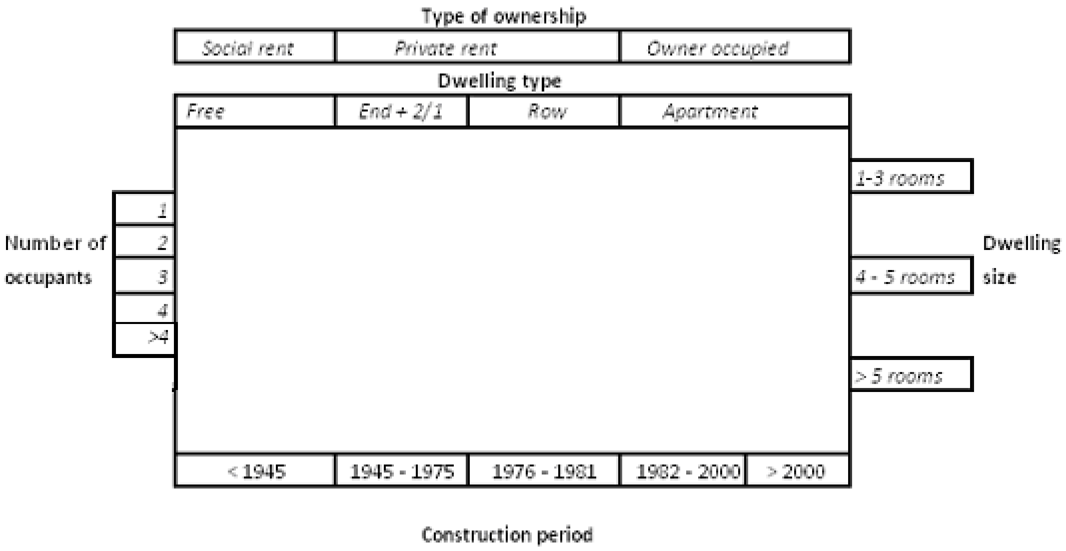


Figure 3.3 Categorization of the residential dwelling stock based on ownership, electricity and heat use

3.1.2 Behavioural characteristics

In this section the households are classified according to their behavioural characteristics. This is structured as follows. Firstly, a short introduction is given of the theory of planned behaviour. Secondly, based on existing consumer research, an inventory is made of the arguments that are used by (potential) buyers of micro-generation technologies in their purchase decision. Thirdly, the arguments are linked to the theory of planned behaviour, resulting in a model set-up which gives a description of the purchase decision making of households in relation to micro-generation technologies. According to this set-up, the domestic sector is differentiated into agent categories which are likely to show the same purchase behaviour related to a specific micro-generation technology.

3.1.2.1 The theory of planned behavior

In this study the theory of planned behavior (Ajzen, 1991) is used as an overall framework to describe the purchase decision of households in respect to micro-generation technologies. The analysis of the behavioural characteristics of households that play a role in the decision making is structured according to the main principles of this theory. The theory of planned behaviour states that the intention underlying the decision-behaviour of individuals is a function of three determinants:

- The *attitude* towards the behaviour, which refers to the degree 'a person has a favourable or unfavourable evaluation or appraisal of the specific behaviour' (Ajzen, 1991, page 188). In the case of the decision to purchase an technology this is tailored to the preferences or condemns an individual has regarding specific attributes of the technology.

- A *subjective norm*, which refers to 'the perceived social pressure to perform or not perform the behaviour' (Ajzen, 1991, page 188). The role of a subjective norm in the diffusion of products is extensively discussed in innovation literature (Rogers, 2003; Faiers et al., 2006 A; Jager, 2006). In this study the subjective norm is taken as a function of the market-share of a product, reflecting the popularity of a product which may change an individual's perception of it.

- The *perceived behavioural control,* which refers to 'the perceived ease or difficulty of performing the behaviour' (Ajzen, 1991, page 188). In respect to the purchase decision of individuals for a specific product, the perceived behavioural control is assumed to be a function of: (1) the properties of a technology, such as the compatibility with existing infrastructure, or investment costs and (2) the individuals' abilities, such as the level of income or the physical abilities of a households (if a household is situated in a stacked building it does not consider the option of solar PV panels or micro-wind turbines individually).

The relation of these three determinants to the expected behaviour is defined by the following rule: 'the more favourable the attitude and subjective norm with respect to a behaviour, and the greater the perceived behavioural control, the stronger should be an individual's intention to perform the behaviour under consideration' (Ajzen, 1991, page 188).

The theory gives a description of expected behaviour in general terms. In order to apply the theory for the purpose of this study, the three determinants (attitude, subjective norm and perceived behavioural control) are elaborated using arguments from existing consumer research concerning micro-generation technologies.

3.1.2.2 The arguments used by individual households in their purchase decision

In this section, an inventory is made from existing consumer research, of the arguments that are used by individual households in their purchase decision for a specific micro-generation technology. The inventory is based on four researches containing surveys in which the respondents were asked to indicate (and prioritize) the motives that played a role in their decision making process (Adachi, 2009;: Element Energy, 2008; Faiers et al., 2006 B; Jager, 2006). The respondents are both individuals that have decided to purchase and individuals that have decided not to purchase a specific micro-generation technology. An overview is given in table 3.2. A distinction is made between arguments that either function as a driver for, or barrier to purchase. These drivers and barriers are separated into four categories: monetary, social/environmental, technological and institutional (this categorization is based on Hadachi, 2009).

Table 3.2 An overview of drivers for, and barriers to micro-generation technologies, given by (potential) consumers. The arguments are retrieved from (Adachi, 2009;: Element Energy, 2008; Faiers et al., 2006 B; Jager, 2006)[12].

	Drivers	***Barriers***
Monetary	Worthy investment Saving/producing money A reduction in the energy bill in the long run (payback period) Increasing value of the house	Payback period High investment costs Running costs
Social/ Environmental	Climate change / CO2 reduction Reduction of other pollutants such as NOx Energy security issues Independence from electricity supplier A political statement	

[12] The list of arguments given is based on four researches containing surveys in which the respondents were asked to indicate (and prioritize) the motives that played a role in their decision making process (Adachi, 2009;: Element Energy, 2008; Faiers et al., 2006 B; Jager, 2006). One of the studies (Element Energy, 2008) has considered the whole range of micro-generation alternatives, with a focus on Micro-CHP, while the others (Adachi, 2009; Faiers et al., 2006 B; Jager, 2006) have solely focused on Solar PV. This can be explained by the fact that PV is a relatively more mature technology with a larger group of adopters which allows for the surveys to be held. Three of the four studies (Element Energy, 2008; Hadachi, 2009; Faiers, 2006 B) have also included the arguments of the group of next, likely adopters. Both Hadachi (2009) and Jager (2006) have taken the survey in the light of a policy program, aiming to indicate the effect of the program on the purchase behavior. Only the survey of Jager is held in the Netherlands. Therefore the arguments given in the other researches must be verified on their validness within a Dutch context.

	Lead by example	
Institutional	Presence of a program (financial support) Administrative assistance Central organization of the request for a grant Grant on offer Technical support	Administrative bother in the case of a subsidy program The level of grant available
Technological	Reliability of the technology in addition to grid electricity	Reliability/predictability of performance Inadequate roofing Little solar exposure Noise production Aesthetics and space considerations (unattractive) Capacity/ability to meet the full needs with one technology The perceived complexity of the technologies Perceived hassle with installation Compatibility with the existing situation

The arguments given in the different researches are very similar. High investment costs and a long payback period are generally given as the most important barriers to purchase a micro-generation technology. The most important drivers for purchase are related to environmental concerns and self-sufficiency. Self-sufficiency can either refer to independence from politically instable regions in an international context, or to independence from an external distributor. Also economical arguments are identified as a driver. A reduction in the energy bill in the long term is repeatedly noted as a motive for purchase.

One of the households' primary needs is that it has electricity on command. Much of the functioning of a household is dependent on electricity; therefore the most important attribute considered is *the reliability* of the system. It is assumed in this study that all households remain connected to the central grid, so the reliability of the micro-generation systems is of little importance. The reliability of the central grid on the other hand is no issue at stake because the Dutch grid has proven to be solid and not sensitive to major drop-outs in recent history. If for some reason the central grid becomes unreliable in the near future and a continuous flow of electricity to the households can no longer be guaranteed, this will automatically have to be made an important driver for micro-generation in the model.

Some of the arguments given in the researches are technology specific. It is stated that Micro-CHP is reviewed in comparison to the existing heating system it replaces (Element Energy, 2008). This way the old system directly functions as reference material i.e. the micro-CHP technology has to outperform the system in place. The capacity of the heating part of the CHP system is singly required to meet the full heat demand of a household. Also, comfort level and noise production are given as possible barriers to the uptake of the technology.

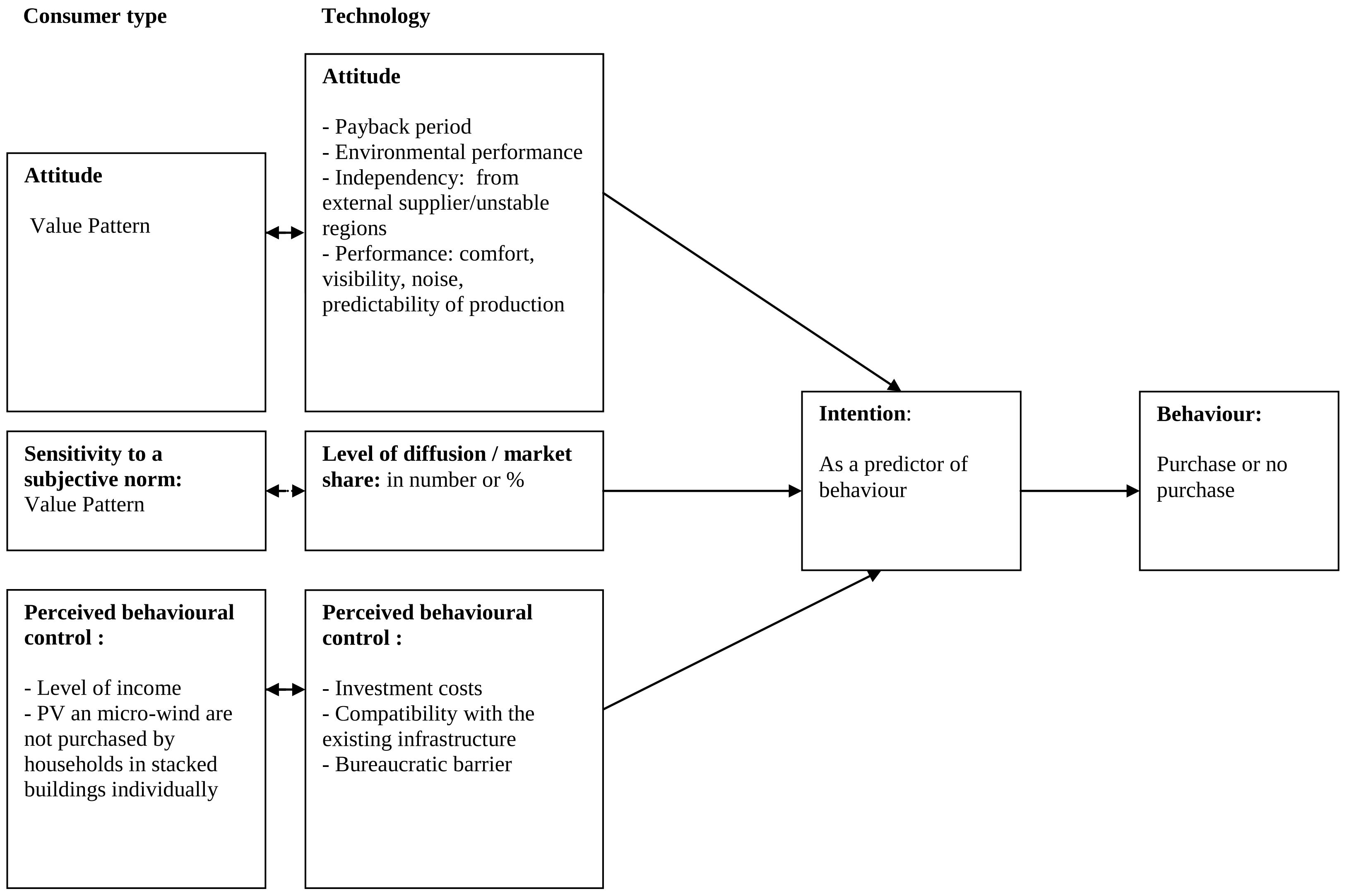
In the case of solar PV systems, other characteristics play a role. The visual aspects of a set of panels are repeatedly noted by the interviewed. Because of the visibility of the technology it can function as a status symbol or serve as a symbol to communicate a certain identity or value orientation. But the technology is also regarded as visually intrusive.

Little can be concluded about micro-wind installations from these studies. The newness of the technology and, consequently, the low uptake so far, make that there is little known about the aspects that are regarded as important by the (potential) adopters. Similar to PV installation, micro-wind turbines are visible to bystanders. More so, test results reveal considerable noise production and a low predictability of the average generated power on a specific location. These may be important factors impeding the uptake of micro wind-turbines in the future.

3.1.2.3 The theory of planned behavior applied to the purchase decision making process of households

Next, the theory of planned behavior is applied to describe the purchase decision making process of households for a specific micro-generation technology. A schematic overview of the variables that play a role in the decision making process of households is presented in figure 3.4. The three determinants (attitude, subjective norm and perceived behavioural control) are elaborated using arguments from existing consumer research presented above in table 3.2. The following is an explanation of figure 3.4.

Figure 3.4 Schematic overview of the components that are expected to determine the purchase decision-behaviour of households in respect to microgeneration technologies



The Attitude; Technology

In the case of deciding to purchase a technology, the attitude is determined by the preferences or condemns an individual has regarding specific characteristics of a technology. Below, a selection of characteristics is presented which determine the attitude formation of the agents towards micro-generation technologies.

Table 3.3 The technology attributes that play a role in attitude formation of the agents towards micro-generation technologies

Technology characteristics that determine the attitude formation of the agents	***Operationalization***
Saving money in the long run	- Payback period in years
Environmental performance	- The level of CO_2 avoidance
Independency (From political unstable countries as well as from an external distributor)	- The production capacity
Performance	- The level of heating comfort in the case of micro-CHP - The Predictability of the amount of power generated - The Visibility of a technology, when considered as a negative property - The noise production

The Attitude; Agent type

Different individuals will have different preferences for specific characteristics of the micro-generation technologies e.g. some may buy a micro-generation technology because of its contribution to a cleaner environment while others may buy it because it gives a reduction in the energy bill in the long term. In this study the preferences of an agent are assumed to be determined by its *value pattern*. An individual's value pattern denotes a certain social-cultural group with specific preferences expected to describe the motivations underlying consumer behavior (Aalbers et al. 2006). According to the value patterns described in the TNS-NIPO WIN-model[13] (Aalbers et al. 2006; Mulder, 2009), 8 different consumer types are distinguished. Below in table 3.4 the consumer types are described according to their preferences, by giving a score for each technology characteristic presented in table 3.3. These

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[13] The WIN-model is a segmentation of the Dutch population according to their values and socio-demographic characteristics, based on extensive research including surveys conducted among 200.000 participants (Mulder, 2009).

scores represent the relative importance a specific type of consumer gives to a specific technology characteristic in comparison to the other types, and in comparison to the other characteristics. The score of each consumer type per variable is based on the descriptions of the value patterns in Aalbers et al. (2006).

Table 3.4 Overview of the scores of the selected agent types on the different parameters that determine the attitude formation. The consumer types are based on the value patterns of the WIN-Model from TNS-NIPO (Mulder, 2009).The scores range from 0 (not important) to ++ (important).

Consumer type	***Distribution***[1]	***Attitude***[2]			
Type; value pattern	*Percentage (%) of the population*	*Environmental concerns*	*Independence from external suppliers*	*Performance*[3]	*Payback period (benefits)*
Caring Faithful	15	0	0	+	0
Conservatives	16	0	0	+	+
Hedonists	11	0	0	++	++
Materialists	11	0	0	++	++
Professionals	8	0	0	++	++
Broad minded	7	++	++	+	0
Socially minded	11	++	++	+	0
Balanced	21	+	+	+	+

1 The distribution of value patterns over the Dutch population is based on Mulder (2009).

2 The score of each consumer type per variable is based on the descriptions of the value patterns in Aalbers et al. (2006).

3 Hedonists, Materialists and Professionals are described by Aalbers et al. (2006) to be driven by the performance of technologies. For all other consumer types the performance is assumed to be of medium importance.

The subjective norm; Technology

The subjective-norm reflects the communication between individuals and its effect on the diffusion dynamics in the model. In this study it is taken as a function of the market-share of a product, reflecting the popularity of a product which may change an individual's perception of it. By taking this approach, communication is taken implicitly in the model as a function of the number of others that have adopted a specific technology. No detailed account is given of communication networks as they exist in real life. Because of this, in contrast to empirical findings (Rogers, 2003), communication is not modelled as a selective process, wrongfully suggesting that the chance that two comparative individuals (for example with respect to their value orientations or socio-economic status) effectively exchange information is equal to the change that two dissimilar individuals do. Furthermore no distinction is made between different technologies based on social compatibility. For example, the diffusion dynamics of visible products and products that are not directly observable to bystanders are expected to differ because status and identity needs are expected to play a more important role in the market of directly observable products.

The subjective norm; Agent type

The study of Rogers (2003), one of the most cited publications in the field of innovation diffusion research, states that new ideas enter a community through the people who are least dependent on others of that particular community for their information and opinion forming. According to this, in the ABM set-up in this study some agents are more strongly guided by the consumption behavior of others in their purchase decision making than others. The agents' sensitivity to a subjective norm is assumed to relate to its *value pattern*. In the study of Aalbers et al. (2006) the sensitivity of the consumer types to the behavior of others is explicitly described.

Table 3.5 Overview of the scores of the selected consumer types on the sensitivity to a subjective norm. The scores range from 0 (least sensitive) to ++ (most sensitive).

	Distribution	***Subjective Norm***
	Percentage (%) of the population	*Sensitivity to the behaviour of others*
Caring Faithful	15	++
Conservatives	16	++
Hedonists	11	++
Materialists	11	+
Professionals	8	0
Broad minded	7	0
Socially minded	11	+
Balanced	21	+

The perceived behavioral control; Technology

The perceived behavioral control in a purchase-decision for the selected micro-generation technologies is assumed to be a function of both the decision maker and the specific technology. Technology attributes that are expected to influence the perceived behavioral-control are the investment costs, the compatibility of a specific technology with the existing infrastructure and the bureaucratic barrier associated with micro-generation in general. The bureaucratic barrier reflects the perception of the administrative hassle involved in the application for a grant, suggesting that (institutionally arranged) administrative assistance may increase the perceived behavioral control (Jager, 2006). It is assumed that the bureaucratic barrier experienced does not depend on the type of agent but is equal for all agent types.

Table 3.6 The technology attributes that determine the perceived behavioral control in the investment decision of the agents

Technology characteristics that influence the perceived behavioral control of the agents	***Operationalized***
Investment costs	Costs in €
Compatibility with the existing infrastructure	Qualitative description of the compatibility with the existing infrastructure
Bureaucratic barrier	Qualitative description of the administrative hassle related to the application for a grant

The perceived behavioral control; Agent type

Two types of household characteristics are expected to influence the perceived behavioral control; (1) the housing type and (2) the level of income. The first relates to the compatibility of the technologies with the existing infrastructure of a house. As noted before, given the physical properties of households in stacked dwellings, PV and micro-wind are not purchased individually by this group of households. The second relates to the investment price of the technologies. Micro-generation technologies are associated with high investment costs, which are identified by households as an important barrier to purchase. It is assumed that a household with a high income level can afford the high investment costs more easily. Therefore, the perceived barrier to purchase, raised by the invest costs, is assumed to be negatively related to the income level of an agent.

In the model set-up the income level is taken as a separate variable that is directly linked to the perceived behavioural control of the consumer types (independently from the value segment). This way, every value segment is subdivided into three categories; a high, a middle and low income category, resulting in *twenty-four consumer types*. A distribution of the consumer types over the Dutch population of households is presented below in table 3.7. This distribution is based on Aalbers et al. (2006, page 220). The numbers from Aalbers et al.(2006) are adjusted such that the total number of households per income category match the data of the number of households per income category retrieved form Citavista.nl (2009).

Table 3.7 The distribution (%) of the (24) agent types over the Dutch population of households. This distribution is based on Aalbers et al. (2006, page 220). The numbers from Aalbers et al. are adjusted such that the total *number of households per income category match the data of the number of households per income category retrieved form Citavista.nl (2009) (last three rows in the table).*

Agent Type (value pattern + income level)		***Distribution:*** *Percentage (%) of all households*
Caring Faithful	**Low**	8%
	Middle	5%
	High	2%
Conservatives	**Low**	8%
	Middle	5%
	High	2%
Hedonists	**Low**	6%
	Middle	4%
	High	2%
Materialists	**Low**	4%
	Middle	4%
	High	2%
Professionals	**Low**	1%
	Middle	3%
	High	4%
Broad minded	**Low**	1%
	Middle	3%
	High	3%
Socially minded	**Low**	4%
	Middle	4%
	High	2%
Balanced	**Low**	8%
	Middle	8%
	High	5%
Total *(Citavista.nl, 2009)*	**Low**	40%
	Middle	37%
	High	23%

3.1.3 The agents in the model set-up

The agents in the model set-up are described according to the 900 household categories illustrated above in figure 3.3 as well as the 24 different types of consumers presented in table 3.7. As a result, each agent is described according to the type of ownership of a house, the type of house, the size of a house, the number of occupants, the building period of a house its expected purchase behaviour related to a specific micro-generation technology.

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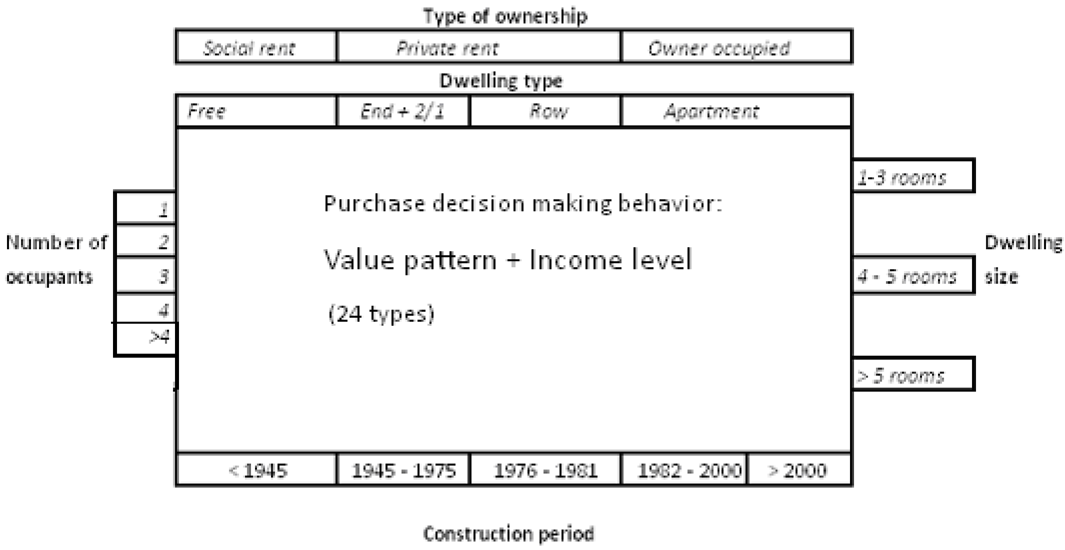

Figure 3.5 An illustration of the agents in the model set-up

The income level is used as a mediating variable in order to find a distribution of the 24 consumer types (value pattern + income level) over the 900 household categories (figure 3.3). From the distribution of income levels over the three categories of house ownership, the distributions of households over the categories of house ownership, within each consumer type, are calculated. The category of house ownership then determines the change that a type of decision maker falls within one of the other categories (e.g. free standing, <1945, 4-5 rooms, and 3 occupants).

As a result, the number of households of each consumer type per type of house ownership can be determined. Furthermore, an indication can be given of the share of a specific consumer type of the total domestic electricity and heat use. Also, the number of households per consumer type which live in stacked dwellings can be calculated. These results are presented in table 3.8 below. The calculations from which these numbers were obtained are presented in Appendix 3.

Value pattern → Income level→ Type of house ownership, electricity use, heat use, share of stacked dwellings

Table 3.8 The distribution (%) of the (24) agent types over the types of ownership of houses, the share of energy use of each agent type of the total energy use of the domestic sector, and the distribution of the share of stacked dwellings of the total housing stock (32%) over the agent types.

Agent type		***Distribution (%)***[1]					
Value pattern	*Income level*	**Soc. Rent**	**Pr. Rent**	**Owner**	**Elec. use**	**Heat use**	**Stacked**
Caring Faithful	**Low**	5%	1%	2%	7%	7%	3%
	Middle	1%	0%	3%	5%	5%	1%
	High	0%	0%	2%	2%	3%	0%
Conservatives	**Low**	5%	1%	2%	8%	7%	4%
	Middle	1%	0%	4%	6%	6%	2%
	High	0%	0%	2%	3%	3%	0%
Hedonists	**Low**	3%	1%	1%	5%	5%	2%
	Middle	1%	0%	3%	4%	4%	1%
	High	0%	0%	1%	2%	2%	0%
Materialists	**Low**	3%	1%	1%	4%	4%	2%
	Middle	1%	0%	3%	4%	5%	1%
	High	0%	0%	2%	2%	2%	0%
Professionals	**Low**	1%	0%	0%	1%	1%	1%
	Middle	1%	0%	2%	3%	3%	1%
	High	0%	0%	3%	4%	4%	1%
Broad minded	**Low**	1%	0%	0%	1%	1%	0%
	Middle	1%	0%	2%	3%	3%	1%
	High	0%	0%	3%	3%	4%	1%
Socially minded	**Low**	3%	1%	1%	4%	4%	2%
	Middle	1%	0%	3%	4%	5%	1%
	High	0%	0%	2%	2%	2%	0%
Balanced	**Low**	5%	1%	2%	7%	7%	3%
	Middle	2%	1%	5%	8%	8%	2%
	High	0%	0%	5%	6%	6%	1%
Total (share of all households)		35%	9%	56%	100%	100%	32%

Notes:

[1] The numbers presented are rounded; therefore the sum of the percentages of all the agent categories does not exactly match the percentages of the total of households presented in the last row of the table.

It should be noted that the shares of electricity and heat use of the consumer types is almost identical to their shares of households of the total housing stock. This indicates that, in contrast to what is expected, the values of the average electricity and heat usages of the consumer types are almost similar. In the model set-up, the heat and electricity use of a consumer type is dependent on its level of income, not on its value pattern. The relation between the level of income and the heat and electricity use is determined indirectly through the relation between income level and ownership type. Below the average heat and electricity usages per type of ownership of a house are presented.

Ownership type → Electricity and heat use

Table 3.9 Average energy use per type of ownership of a house

	Electricity use (kWh/yr)	***Heat use (m^3/yr)***
Social rent	3085	1342
Public rent	3066	1403
Owner occupancy	3659	2023

From the distribution of income levels over the types of ownership of houses, the average heat and electricity use per income level is determined (appendix 3).

Income level → Electricity and heat use

Table 3.10 The average energy use in each income level

Income level	***Electricity use (kWh/yr)***	***Heat use (m^3/yr)***
Low	3238	1534
Middle	3460	1794
High	3594	1950

Table 3.10 shows that in going from a distribution in electricity and heat use over the type of ownership of a house to a distribution over the income level, the spread in electricity and heat use decreases significantly. The most important explanation for this is given by the relatively large share (27 %) of households with a low income that are owner their house. An important determinant for the electricity and heat use of a household is the size of the house. The average size of houses is the largest in the owner occupancy category (appendix 2). Because the size of a house and the income level are indirectly related in the model set-up through the type of ownership of a house, and a relatively large share of low income households are owner of their house, the spread in the distribution of household size over the income level is lower than what is expected. Consequently the spread in electricity and

heat use over the income levels is lower than expected. Using a more detailed distribution of income categories over the household categories, for example the distribution of income over the size of a house in each ownership category, would give a more in-depth description of the relationship between a specific consumer type (value segment + income level) and its energy use. But no such data were available by the time this research was conducted.

3.2 Technology descriptions

Here, the three micro-generation technologies considered in this study - micro-CHP, Photo Voltaic (PV) systems and micro-wind turbines - are described. It consists of a short explanation of the working principles, a techno-economic analysis and a qualitative description of the status of development of the technologies.

The techno-economic performance of the micro-generation technologies is determined in respect to a reference scenario where households use electricity from the grid. For µCHP the reference situation is grid electricity in combination with a condenser boiler. It is assumed that households remain connected to the central grid. If electricity demand exceeds the production from micro-generation, shortage is compensated with grid-electricity. The numbers used for the reference situation are presented in table 3.11. In the analysis the environmental impact is reduced to one dimension; the level of CO_2 emissions avoided by applying one of the technologies. A thorough investigation into other environmental costs and benefits of each type of technology, such as the level of other emissions avoided (for example NOx), would ad quality to this assessment.

At a household level, the electricity produced can either be sold back to the distributor or used directly on-site. The share of electricity fed-back to the grid is dependent on the match between the energy load curves of households and the production profile of the micro generation technologies over time. The energy demand for heating and electricity may vary during the day and on a seasonal basis and also between households, for example as a function of the number of residents. In the case of (heat-led) µCHP, the proportion of feedback is determined by what extend the heat and electricity load profiles of a household match over time, and the heat-to-power ratio of the system. In the case of micro-wind and solar PV the percentage of feed-back is a function of the wind speed distribution and the intensity of solar radiation over time. In further analysis, the feedback price and grid price are assumed equal. In this way the share of electricity fed-back to the grid does not influence the economic performance of the micro-generation technologies.

Table 3.11 Overview of the numbers that determine the economic and environmental performance of the reference situation

Caloric value CH4 (MJ/m3)	***Gas price (€/m3)*** [1]	***Electricity Price (€/kWh)*** [1]	***Feed-back price of electricity*** [3]	***Price of electricity produced*** [3]	***CO2 emissions in kg per kWh grid electricity*** [2]
31.65	0.61	0.24	0.24	0.24	0.566

[1] *The gas and electricity price are estimates for the year 2009, retrieved form milieucentraal.nl (2009).*

[2] *This number is adapted from Senternovem, 'cijfers en tabellen' (2007)*

[3] *The feedback-price equals the electricity price up till a limit of 3000kWh or 5000kWh produced per year, depending on the distributor. For every kWh above this limit, and if the yearly production exceeds the yearly consumption, the feedback price becomes 9,1 €ct/yr. A selection of PV users receives a subsidy funded by the national government, on every kWh of electricity produced. Including this subsidy households receive 0,526 €/kWh electricity produced (senternovem.nl, 2009).*

3.2.1 Micro-CHP

Micro Combined Heat and Power technologies (µCHPs) are small energy conversion units, simultaneously producing power and heat on a household level. The simultaneous production may lower the use of primary fuels compared to the situation when both products are being produced separately, which may result in lower CO2 and NOx emissions (Elzenga, et al., 2006; Pehnt 2008). This is illustrated in a calculation example given below in figure 3.6. Three types of micro-Combined Heat and Power systems (µCHPs) are considered for application in the Dutch domestic sector: (1) The Stirling engine (external combustion engine) (2) Gas engines and (3) Fuel cell based technologies (Proton Exchange Membrane Fuel Cell (PEMFCS) and The Solid Oxide fuel cell (SOFCS)) (Elzenga et al., 2006). In table 3.12 an overview is given of the characteristics determining the techno-economic performance of the different types of µCHPs. The technologies vary, among others, on their conversion efficiencies and heat-to-power (HPR) ratio. The total efficiency is given as the sum of the electric and thermal efficiency of the technology. All technologies have the ability to use natural gas as a primary fuel.

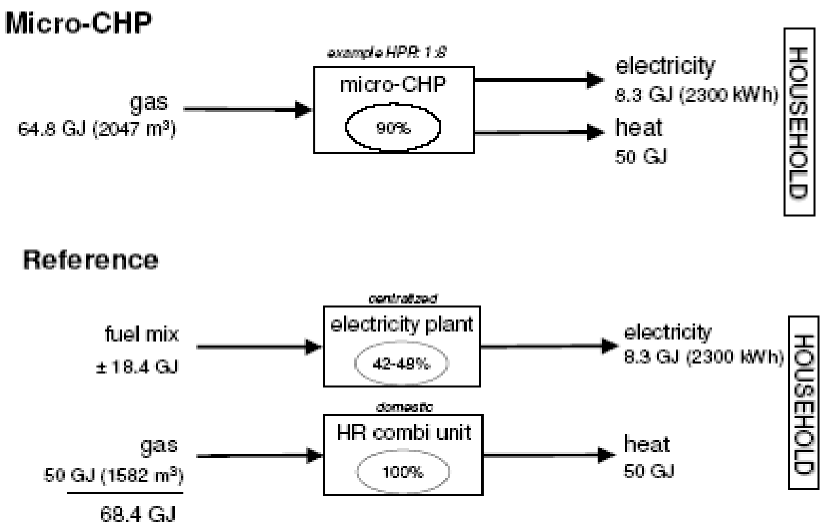

Figure 3.6 Schematic overview of a calculation example, in which the central idea and benefits of micro-CHP are explicated. The leading principle is a household with a heat demand of 50 GJ (Faber et al., 2009 b). The primary energy saved in comparison to the reference case is 3.6 GJ.

Stirling engines are external combustion engines in which mechanical work is transformed into electrical power. µCHPs based on this working principle, are characterized by low electric efficiencies and relatively high thermal efficiencies and low HPRs. Furthermore, these systems require little maintenance and produce little noise (Kuhn et al., 2008). Gas engines are a type of internal combustion engine that work according to the same principle as most car engines. This technology is already applied in larger CHP systems in the Netherlands, for example in greenhouses. Gas engines, typically have a higher electrical, and a lower thermal efficiency than Stirling engines (Phent, 2008).
The working principle of fuel cells is an electrochemical reaction in which a primary fuel and oxygen react to produce electricity and heat. Fuel cells have the ability to run on hydrogen. These technologies are characterized by low thermal and high electric efficiencies, and high heat-to-power ratios in comparison to the other two options. Furthermore, fuel cell based µCHPs require little maintenance and produce little noise (Kuhn et al., 2008).

From these three alternatives, the Stirling engine is closest to the point of market penetration. Gas fired Stirling based Micro-CHP is in between its demonstration phase and the early introduction in the Netherlands. While some pilot projects are still running, there are already signs of introduction in the Dutch residential sector (Eneco.nl, 2009). From the beginning of 2010, gas-based Stirling engines will be the most likely option considered for usage by households (Jong, de et al., 2008, Elzenga et al., 2006).

Several developments are counteracting the prospects for µCHP in the domestic sector. Energy use in households for heating is decreasing in recent decades, due to increasing insulation measurements in the existing stock and increasing energy efficiencies of newly built houses. Below a certain heat demand, µCHP systems may no longer be a cost competitive alternative from a policy, consumer and an environmentalist perspective. This is depending on the HPR of the µCHP system considered (Pehnt, 2008).Furthermore, the usage of alternative heating systems such as solar water heaters and heat pumps, is in competition with µCHP (Elzenga, et al. 2006).

Techno-economic performance

In further analysis, the produced electricity is treated as a co-product (a heat-led system). The reference situation is a conventional boiler in combination with electricity from the grid. In this configuration, µCHP installations are assumed to replace the central heating systems currently installed in households. The techno-economic performance of µCHP systems is dependent on the specific energy demand characteristics of a household. The thermal efficiency of a system is, among others, a function of the amount of full thermal load hours and the amount of start/stops procedures over a certain period of time (Pehnt, 2008).

Table 3.12 Overview characteristics of different types of µCHP systems. The overall efficiency is calculated as the sum of the electric and thermal efficiency based on the lower heating value (Jong de, et al. (2008) Faber et al., (2009a), Pehnt (2007).

	Stirling based micro-CHP	***ICE***	***Fuelcell***	***Reference: Grid electricity + condensing boiler*** [3]
P Electric (kW)	1	1	1	
η electric (%)[1, 2]	10-20	18-25	28-35	45 %
HPR[1, 2,3]	4 -9	3 -4	1 - 3	
η Total (%)[1, 2]	85-105	85-95	85	
Upfront Costs[3,5]	€ 6000 (4500–6500)	-	-	2500 €
Lifetime[4]	15	15	15	15
Availability 2010[1]	available	demo	demo	
η Thermal [3]				100%

The numbers are based on: [1]Jonge, de et al. (2008), [2]Pehnt (2008), [3] Faber et al.(2009a), [4]Paepe et al.(2006) [5]Kuhn et al. (2008).

Calculation Example: Stirling, gas-based micro-CHP

In this example the HPR is assumed 9, the overall efficiency is 90%, the costs of the Stirling-based micro-CHP technologies are €6500, the gas demand of a household is 2000 m3/yr and the efficiency of the condensing-boiler in place is 100% and its price is €2500. In the case of heat-led systems, the costs of micro-CHP are calculated in comparison to the costs of a condensing-Boiler. The costs function is a composition of the upfront and running costs. The running costs include the costs for energy input and the maintenance costs associated with both type of heating devices. It is assumed that households perform a simple payback-period calculation, in which the concept of discount rate is neglected.

The simple payback-period of a micro-CHP system is calculated as follows:

- Payback period in years = Difference in investment costs / (Yearly Benefits – Yearly Costs)
- Difference in Investment costs (€) = Price µCHP - Price Conventional Boiler (€)
- Yearly Costs (€/yr) = Difference in maintenance costs (€/yr)
- Benefits (€/yr) = [Gas price (€/m3) * [Gas demand Boiler (m^3/yr) - Gas demand CHP(m^3/yr)]] + [E.price (€/kWh) * [Eprod. Used domestically (kWh/yr)] + [E. feedback price (€/kWh)*E.prod. fed-back (kWh/yr] (€/yr)

This generates the following outcomes:

- The electricity produced = 1955 kWh/yr.
- The additional gas demand of a household = 469 m^3/yr.
- The yearly benefits = 182.72 €/yr
- The payback period = 19 yr
- The avoided CO_2 emissions = 0.14 (kg/kWh) (271 kg/yr)

Remarks:

- Maintenance costs an lifetimes of Stirling based systems are the same as those of condensing boilers (Paepe. et al. 2006)
- The feedback price of electricity is assumed to equal the grid price of electricity.

3.2.2 PV panels

Photo Voltaic (PV) systems produce electricity from sunlight. Small scale PV systems are applied in the residential area in connection to the central gird or as autonomous units with an electricity production capacity between 1 to 10 kWe. The technology is in most cases applied to the roof of houses. Other examples are the integration of solar cells in façades or in sun-blinds. Three types of technologies are in use in the Netherlands. (1) Multi crystalline silicon: (efficiency 12-16 %), (2) Mono crystalline silicon (efficiency 14-20 %), (3) Thin film solar cells (efficiency 6-12%) (SenterNovem, 2008; Montfoort et al., 2008). On this moment, approximately 10% of the total installed capacity of PV panels in the Netherlands exists of thin-film solar cells, and 90% of crystalline silicon based cells. Due to lower production cost (lower material use), the market rate of thin film solar cells shows an increase and this trend is likely to continue in the future (Jol, J.C. et al., 2008).

So far, of the three micro-generation technologies considered, solar PV panels are the most mature technology in terms of usage. They are commercially available and there is approximately 50 MWp installed in the Dutch residential area (including commercial buildings) (Montfoort et al., 2008). This amount is however stagnating in recent years. While the knowledge and production side of this technology can be regarded as strong in the Netherlands, market formation is weak. Most of the products and expertise are transported to foreign markets, particularly the German market (Wah, 2008). This year as part of a larger subsidy scheme (SDE), a subsidy was offered for every kWh produced by small producers over a period of 15 years. The budget level is limited, and the number of applications quickly exceeded the available grants (SenterNovem.nl, 2009).

Techno-economic performance

The performance of a PV panels depends on numerous factors such as the sun irradiation level (which is different in different areas among the country), the level of incline of sun irritation, the north/south orientation of the system and efficiency loses in cables and converter (SenterNovem, 2008). Due to these loses the actual production of a system is only a fraction of the theoretical maximum obtained under test conditions. This fraction is the Performance Ratio (PR) of a PV system. On this moment the PR of PV panels in the Netherlands lies between 0.7 and 0.8.

In table 3.13 an overview is given of the characteristics determining the techno-economic performance of crystalline silicon PV panels (HollandSolar,2005). The upfront costs for 2009 are based on a market research among Dutch PV manufacturers which gives an indication of the price of solar PV panels in the Dutch market on this moment (Duurzameenergiethuis.nl, 2009). A significant part of the costs (30 -50 %) of solar PV systems are to the account of the Balance of System (BOS) equipment. The BOS consists of material for mounting the modules and a system for converting the electricity from DC to AC (Holland Solar, 2005). The prices in table 3.13 include the costs of the BOS system but it excludes installation costs. Installation costs are estimated around a minimum of 250 € per system (Milieucentraal, 2008). Maintenance costs are estimated around 2% of total investments costs per year (Montfoort et al., 2008).

Table 3.13 Overview Techno-economic characteristics of Solar PV systems

	PV Panels
Turn-key system price (€/Wp)	4.5 -7.5 [1]
Performance Ratio	0.75 (0.70-0.8)
Simple Payback Period (yr)	25 – 42

[1]*Referencce: Duurzameenergiethuis.nl, 2008, these prices include 250€ installation costs.*

A calculation example

The product of the PR, the irradiation level of sunlight (kWh/yr) and the total installed peak capacity (Wp) gives an indication of the yearly electricity production of a PV system (SenterNovem, 2008). The peak capacity is defined as the maximum produced capacity of a system given an irradiation level of sunlight of 1000 W/m^2.

Assumptions:

- Payback period in years = Investment costs / (Yearly Benefits – Yearly Costs)
- 1000 hours of (full) sunlight (1000 W/m^2) per year on average in the Netherlands.
- The installed peak capacity is 1 kW/peak
- An optimal orientation to the south and an optimal angle of incline
- The PR is 0.75 and the price of the system is 5000 €/kWp
- The electricity feedback price equals the grid electricity price which is 0.24 €/kWh

This generates the following outcomes (if the yearly maintenance costs are ignored):

- The electricity produced per year = 750 kWh/yr
- The yearly benefits = 180 €/yr
- The payback period = 27.8 yr
- The avoided CO_2 emissions = 0.566 kg/kWh (424.5 kg/yr)

3.2.3 Micro wind turbines

Micro-wind turbines are small scale turbines converting kinetic energy from wind into electricity, applicable on the domestic level with a maximum production capacity, typically between 0.1 and 3 kW. In general, there are 2 different types of micro-wind turbines; turbines with a horizontal and turbines with a vertical rotor axes. Systems based on a vertical rotor axe, are specially designed for the built environment. Horizontally based turbines have difficulty reorienting with changing wind directions, which is an important aspect in the built environment. So far, in the Netherlands, most micro-wind turbines are applied as stand alone units or mounted on top of larger buildings (Cace et al., 2007).

Of the micro generation technologies considered, micro wind turbines are the least far in terms of product development. Several aspects can be indicated, that may affect the decision making of potential adopters. Firstly, the predication of the performance of micro-wind turbines is very low, due to site specific elements such as the average wind speed and possible turbulence (Peacock et al., 2008). Also, information given by manufacturers is hard to verify because the methodology by which the numbers are attained (such as the average yearly power production for a certain average wind speed), are often unspecified (allsmallwindturbines.com, 2009). Because manufacturers may apply different methodologies, the performances of turbines are difficult to compare. Uncertainty about the expected performance of wind turbines may increase the purchase of the technologies. Secondly, micro wind turbines come as stand alone units or as systems that are attachable to the house. The complexity of integrating a system in, or on top of an existing building (roof top) is an important criterion from a consumer perspective. In respect to this the rotor diameter/height and weight of the system are crucial aspects of the technology. Thirdly, noise production and visual impacts are likely to be taken in consideration by potential adopters. Fourthly, because wind turbines consist of free moving parts, the safety of the system is an important issue at stake when integration in the built environment is considered (Peacock et al., 2008).

Apart from these obstacles noted on forehand, an interview-round among early adopters revealed disappointing first experiences with micro-wind turbines. From the thirteen persons interviewed only one was mildly positive, all the other were negative about the performance of the technologies. Most important drawbacks were high maintenance because of failures in the system, lower electricity production than was expected from manufacturer’s numbers (up to 1/3 of what was expected) and significant noise pollution (Groenerekenkamer, 2009).

Techno-economic performance

To be able to compare this technology with the other micro-generation options, a specification is needed of its techno-economic performance. In general, the performance of wind turbines is described according to its power curve, which is the power output over a given wind speed range. Every type of system has its own power curve, which means that every turbine has different energy yields given a set of wind speed data (Peacock et al., 2008). However, the power curves of are not always presented by manufacturers. Furthermore, the methodology underlying other technological specifications is often lacking, which makes the numbers presented by manufacturers hard to validate. Besides this, in the built environment, average wind speeds and wind speed fluctuations depend on the specific location. For these reasons, giving a general estimation of the techno-economic performance of different types of micro-wind turbines is complicated.

In table 3.14, an overview is given of the parameters of four types of micro-wind turbines. It should be noted that two of these (the Montana and the Ropatec) are unsuitable for application on rooftops of households because of their size. A possible application is on larger buildings, or as stand alone units. The numbers are partly attained from manufacturer's websites. The costs and annual yield are taken from a field test at Schoondijke in the Netherlands (provincie.zeeland.nl.2009). Te numbers serve as an indication for state of the art in the micro-wind turbine market. No conclusions or generalizations should be drawn from these numbers. Also, the test conditions are not representative for the built environment, because the test location in Schoondijke is situated in the open field.

Table 3.14 Techno-economic parameters of 4 types of small wind turbines

	Fortis Montana	***Turby***	***Energy Ball***	***Ropatec WRE030***
Hor./Vert. Rotor Axis[1]	Horizontal	Vertical	Horizontal	Vertical
Stand alone/ Attached[1]	S.A.	Both	Both	Both
Rotor diameter[1]	5	2	1.1	3.3
Costs[3]	18.508 €	21.350 €	4.324 €	29.512€
Maximum Capacity[1]	5800 kWh/yr	2500 kWh/yr	500 kWh/yr	3000 kWh/yr
Lifetime	20 yr	20 yr	20 yr	20 yr

Annual yield (Test results) [2]	2691 kWh/yr	247 kWh/yr	73 kWh/yr	404 kWh/yr
€ / kWh [3]	0,34	4,32	2,96	3,65

Notes:

[1] *Adapted from manufacturer websites, the conditions under which these performances are reached are unknown.*

[2] *Adapted from provincie.zeeland.nl (2009). These numbers include installation costs. The energy yields were measured given an average yearly wind speed of 3.7 m/s.*

[3] *Prices per kWh are calculated using the field test performances and assuming a life time of 20 yrs.*

3.3 A decision making algorithm

In the model set-up the deliberate purchase decision of the agents is described with a utility function. According to this utility function, for each agent a numerical value is assigned to every technological option, representing the level of satisfaction an agent will receive from purchasing the technology. The utility function integrates the effects of attitude, perceived behavioral control and subjective norm on the purchase decision. With the formula below, the utility of a technology for a specific type of agent is calculated. Each agent purchases the technological option with the highest utility.

- The utility of technology (j) for agent (i) is calculated with the following purchase decision making algorithm (adapted from Schwarz et al. 2009):

$$\text{Utility}(i,j) = [\text{attitude}(i,j) \cdot \text{imp}_{\text{attitude}}(j) + \text{control}(i,j) \cdot \text{imp}_{\text{control}}(j)] \cdot (1 - \text{imp}_{\text{sub.}}(i)) + \text{sub.}(j) \cdot \text{imp}_{\text{sub}}(i)$$

$$\text{attitude}(i,j) = \sum_{1}^{k} \text{imp}_{k}(i) \cdot \text{value}_{k}(j)$$

$$\text{control}(i,j) = \sum_{1}^{k} \text{imp}_{k}(i) \cdot \text{value}_{k}(j)$$

$$\text{subjective}(j) = \text{percentage of buyers}_{j}$$

With agent type *i*, technological option *j*, technology characteristic *k* and importance of decision factor *imp*.

Attitude (i,j)

The attitude (i,j) refers to the preferences of agent type (i) for specific characteristics of the technological options (j). Different individuals will have different preferences for specific characteristics (k) of the micro-generation technologies (e.g. some may buy a technology because of its contribution to a cleaner environment while others may buy it because it gives a reduction in the energy bill in the long term).In this study the preferences of an agent are assumed to be determined by its *value pattern*. Table 3.15 below gives a schematic overview of the preferences of the selected agent types for the different technology characteristics that determine the attitude formation.

Table 3.15 Overview of the preferences of the selected agent types for the different technology characteristics that determine the attitude formation (0 = regarded as unimportant, ++ = regarded as important).

Attitude: $\mathrm{imp}_k(i)$					
Agent type (i)		**Technology characteristic (k)**			
Value pattern	*Income level*	*Environmental concerns*	*Independence*	*Performance*	*Payback time (long term benefits)*
Car.	**Low**	0	0	+	0
	Middle	0	0	+	0
	High	0	0	+	0
Cons.	**Low**	0	0	+	+
	Middle	0	0	+	+
	High	0	0	+	+
Hed.	**Low**	0	0	++	++
	Middle	0	0	++	++
	High	0	0	++	++
Mat.	**Low**	0	0	++	++
	Middle	0	0	++	++
	High	0	0	++	++
Prof.	**Low**	0	0	++	++
	Middle	0	0	++	++
	High	0	0	++	++
Broad.	**Low**	++	++	+	0
	Middle	++	++	+	0
	High	++	++	+	0
Social.	**Low**	++	++	+	0
	Middle	++	++	+	0
	High	++	++	+	0
Bal.	**Low**	+	+	+	+
	Middle	+	+	+	+
	High	+	+	+	+

Table 3.16 below gives a schematic overview of the performance of the selected technological options on the different technology characteristics. The numerical values are derived from the technology descriptions in the preceding part.

Table 3.16 Overview of the performance of the selected technological options on the different technology characteristics. The numerical values are derived from the preceding chapter in which the technologies have been described.

Attitude: $\text{value}_k(j)$						
		Technological option (j)				
Technology characteristic (k)		**Grid electricity**	**Boiler**	**PV**	**Micro-wind turbine**	**Micro-CHP**[1]
Payback time(yr)		0	0	25	37	19
Environmental performance(kg/kWh)		0	0	0,57	0,57	0,14
Independence (kWh/yr)		0	0	750	500	0
Performance	*Comfort*	(-)[2]	++	(-)	(-)	(U)[3]
	Noise (db)(0=high noise level)	++	+	++	0	+
	Visible (0 =not visible)[4]	0	0	++	++	0
	Predictability of performance(++ = high predictability)	++	++	+	0	+

1 Micro-CHP is compared to the combination of grid electricity and a conventional boiler. The independency gained from applying micro-CHP is set to 0 because in the case of gas-fuelled micro-CHP the household remains dependent for its electricity from an external supplier of fossil fuels.

2 (-) Means that the performance of the technology on the specific characteristic is not evaluated by the agents (because the households remain connected to the central electricity grid the comfort level for electricity use is dependent on the performance of the central grid).

3 (U) Means that the performance of a technology on the specific characteristic is unknown.

4 It should be noted that the visibility of a micro-generation technology can be interpreted by the potential buyers as negative or positive: Because of the visibility the technology can function as a status symbol or serve as a symbol to communicate a certain identity or value orientation (drive for purchaser). But the technology can also be seen as visually intrusive (barrier to purchase). In this research only the latter argument is taken into account.

Perceived behavioral control (i,j)

The perceived behavioural control refers to ‘the perceived ease or difficulty of performing the behaviour’ (Ajzen, 1991, page 188). In respect to the purchase decision of individuals for a specific technology, the perceived behavioural control is assumed to be a function of the characteristics (k) of a technology (j) and the agents’ (i) abilities with regard to these technology characteristics.

In the model set-up, an agent's ability to purchase a specific micro-generation technology is dependent on its housing type and level of income. The housing type relates to the compatibility of the technologies with the existing infrastructure of a house. Given the physical properties of households in stacked dwellings, it is assumed in this study that PV and micro-wind turbines are not purchased individually by this group of households. This means that in each category of agents (i) the number of buyers of PV panels and micro-wind turbines is bounded by the percentage of agents in that group that live in stacked dwellings. The level of income relates to the investment price of the technologies. Micro-generation technologies are associated with high investment costs, which are identified by households as an important barrier to purchase. It is assumed that, on average, a household with a high income level can afford the high investment costs more easily. Therefore, within each value pattern (agent types with the same attitude formation), the perceived barrier to purchase, raised by the invest costs, is assumed to be negatively related to the income level of an agent.

Table 3.17 The importance of technology characteristic (k) for the perceived behavioral control in the purchase decision of agent type (i) (0 = more important, ++ = less important).

Perceived behavioural control: $\mathrm{imp}_{\mathrm{k}}(i)$		
Agent type (i)		**Technology characteristic (k)**
Value pattern	*Income level*	*Investment costs*
Caring Faithful	**Low**	0
	Middle	+
	High	++
Conservatives	**Low**	0
	Middle	+
	High	++
Hedonists	**Low**	0
	Middle	+
	High	++
Materialists	**Low**	0
	Middle	+
	High	++
Professionals	**Low**	0
	Middle	+
	High	++
Broad minded	**Low**	0
	Middle	+
	High	++
Socially minded	**Low**	0

	Middle	+
	High	++
Balanced	**Low**	0
	Middle	+
	High	++

Table 3.18 below gives a schematic overview of the performance of the selected technological options on the technology characteristics that relate to the perceived behavioural control. The bureaucratic barrier refers to the administrative hassle involved in the application for a grant on the electricity that is fed-back. This is the same for all three micro-generation technologies. The perceived compatibility of the technologies with the existing infrastructure is unknown, but is expected to vary across technologies. So far, in this study the compatibility of the technologies is only included by assuming that PV and micro-wind turbines are not purchased individually by agents that live in stacked dwellings.

Table 3.18 Overview of the performance of the selected technological options (j) on the different technology characteristics (k) that determine the perceived behavioural control in the purchase decision of the agents. The numerical values are derived from the preceding chapter in which the technologies have been described.

Perceived behavioral control: Value$_k$ *(j)*					
	Technological option (j)				
Technology characteristic (k)	**Grid electricity**	**Boiler**	**PV**	**Micro-wind turbine**	**Micro-CHP**
Investment costs (€)	0	0	2500	5000	6500
Compatibility with the existing infrastructure (U = unknown, ++ = high compatibility)	++	++	(U)	(U)	(U)
Bureaucratic barrier (0 = high, ++ = low barrier)	++	++	0	0	0

Importance of the attitude and the perceived behavioural control: $imp_{attitude}$ (j), $imp_{control}$ (j)

The *imp* in the decision algorithm above denotes the importance of each of the three determinants (attitude, perceived behavioural control and the subjective norm) in the purchase decision. Schwarz et al. (2009) have applied the decision algorithm above to water-saving technologies. Based on empirical data collected from questionnaire surveys among households, Schwarz et al. have found that the importance of the attitude and the perceived behavioural control vary across technologies. According to these findings, the importance of the attitude ($imp_{attitude}$) and the perceived behavioural control ($imp_{control}$) in the purchase decision of the agents in my model set-up is dependent on the type of technology (j).

However, an empirical foundation for the relative importance of the attitude and behavioural control in the purchase of each of the micro-generation technologies considered in this study is missing. In their study, Schwarz et al. (2009) have considered three types of water-saving technologies: showerheads, toilet flushes, and rain harvesting systems. Similar to the rain harvesting system and in contrast to the other two technologies, the micro-generation technologies selected are large, expensive systems that require considerable installation efforts. Therefore, in correspondence to the empirical based weight factors for rain harvestings systems found by Schwarz et al (2009), the importance of the attitude is assumed to be relatively low and the importance of the perceived behavioural control is assumed relatively high in the purchase decision making for micro-generation technologies.

Table 3.19 The importance of the attitude ($imp_{attitude}$) and the perceived behavioural control ($imp_{control}$) in the purchase decision of the agents per type of technology (j).

	Technology (j)		
	Micro-CHP	**Micro-wind turbine**	**PV**
$imp_{attitude}$ → Purchase	low	low	low
$imp_{attitude}$ → Control	high	high	high

Subjective norm (i,j)

In this study the subjective norm is taken as a function of the market share of a technological option (j). The market share is measured as the percentage of all households that have purchased technology (j). In the model set-up, some agent types (i) are more strongly guided by the consumption behavior of others in their purchase decision making than others. The agents' sensitivity to a subjective norm ,*$imp_{sub.}(i)$*, is assumed to relate to its *value pattern*.

Table 3.20 The importance of the subjective norm ($imp_{subjective}$) in the purchase decision of agent type (i) (0 = least sensitive to the purchase behaviour of others, ++ = most sensitive to the purchase behaviour of others).

$Imp_{subj.}$ → Purchase decision		
Agent type (i)		**Subjective Norm (i)**
Value pattern	*Income level*	*Sensitivity to*
Caring Faithful	**Low**	++
	Middle	++

	High	++
Conservatives	**Low**	++
	Middle	++
	High	++
Hedonists	**Low**	++
	Middle	++
	High	++
Materialists	**Low**	+
	Middle	+
	High	+
Professionals	**Low**	0
	Middle	0
	High	0
Broad minded	**Low**	0
	Middle	0
	High	0
Socially minded	**Low**	+
	Middle	+
	High	+
Balanced	**Low**	+
	Middle	+
	High	+

4 An illustrative experiment

In this part, the model set-up is used to calculate the diffusion of PV-systems in the owner occupied households in the Dutch domestic sector under different conditions. These experiments are conducted to illustrate what dynamics may be expected from the agent-based conceptual model created. In this example the agents are given the choice to purchase a PV-system of 1 kWp or to remain using only grid electricity. The modeling exercise is performed in excel, no agent-based simulation software is used. Complexity is reduced by limiting the number of technology attributes that influence the agent's choice. The PV-system is compared to grid electricity according to the *payback-period*, *environmental performance*, *the investment costs* and *the market-share*.

The numerical values of the weight factors that are used in this example are *not* based on empirical data. The values were chosen such that the model, in this simulation example, generated sensible outcomes. For example, given the high payback period of PV panels and a zero market share in the beginning, the first likely group of adopters will be the agents that are motivated by environmental concerns, have a high income and are least guided by others in their purchase decision. In this example the weight factors do only discriminate between 'more and less important' for a particular technology and agent type. In building the actual model, it is suggested that the verification of weight factors and scores is based on empirical data conducted through a questionnaire survey among households (both buyers as non-buyers of the products).

4.1 Input data

Below a schematic overview of the input data of this simulation are given. In table 4.1 the weights of the decision variables used in the simulation experiments are presented. This table gives a schematic description of the agents according to a set of numerical values.

Table 4.1 The weights of the decision variables used in the simulation experiments. The numerical values of the weight factors that are used in this example are not based on empirical data. They only give an indication of the degree of importance.

	Techn. (j)	**Agent type (i)**											
		Caring - Faithful			**Conservatives**			**Hedonists**			**Materialists**		
	PV (1 kWp)	**Low**	**Mid.**	**High**	**Low**	**Mid.**	**High**	**Low**	**Mid.**	**High**	**Low**	**Mid.**	**High**
Imp (j) attitude→ purchase[14]	0.35												
Imp (j) control → purchase	0.65												
Imp (i) subj. → purchase		0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.1	0.1	0.1
Payb.Per. (k_1) → attitude		0.15	0.15	0.15	0.3	0.3	0.3	0.45	0.45	0.45	0.45	0.45	0.45
Env.perf. (k_2) → attitude[15]		0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001
Invest.costs (k_3) → control		0.5	0.25	0.1	0.5	0.25	0.1	0.5	0.25	0.1	0.5	0.25	0.1
	PV (1 kWp)	**Professionals**			**Broad minded**			**Socially minded**			**Balanced**		
		Low	**Mid.**	**High**	**Low**	**Mid.**	**High**	**Low**	**Mid.**	**High**	**Low**	**Mid.**	**High**
Imp (j) attitude→ purchase	0.35												
Imp (j) control → purchase	0.65												
Imp (i) subj. → purchase		0.001	0.001	0.001	0.001	0.001	0.001	0.1	0.1	0.1	0.1	0.1	0.1
Payb.Per. (k_1) → attitude		0.45	0.45	0.45	0.15	0.15	0.15	0.15	0.15	0.15	0.3	0.3	0.3
Env.perf. (k_2) → attitude		0.001	0.001	0.001	0.3	0.3	0.3	0.3	0.3	0.3	0.15	0.15	0.15
Invest.costs (k_3) → control		0.5	0.25	0.1	0.5	0.25	0.1	0.5	0.25	0.1	0.5	0.25	0.1

[14] The empirical findings for the relative importance of the attitude and perceived behavioural control in the purchase decision for rain harvesting systems (Schwarz et al. 2009) is used as an indication for the relative importance of these indicators in the purchase decision for PV systems (given the high investment costs and construction efforts of both technologies).
[15] The value 0.001 suggests that agent type (i) regards the specific technology characteristic (k) as very unimportant. It is only meant to generate a difference when two technologies have exact the same utility for a specific agent type (i), based on the other technological characteristics.

Below, a description is given of the implementation of the technology attributes (k) and the market share (j).

Table 4.2 Overview of the characteristics by which the PV panel (j) is described. .

PV : Technology (j)	
Attitude	k_1: Payback period (yr)
	k_2: Env. Perf.; Avoided CO_2 (kg/kwh)
Control	k_3: Investment costs (€)
Subjective Norm	Market share (%)

k_1 The effect of the payback period is included by the following rule:

- If the payback period of technology (j) < 10 years, the score of technology (j) = 1-(payback period / 10); If the payback period > 10 years the score is 0. This implies that none of the agents perceives a payback period higher than 10 years as beneficiary.

k_2 The effect of the environmental performance is included by the following rule:

- If environmental performance of technology 1 > environmental performance technology 2, the score of technology 1 on the environmental performance is 1.

k_3 The effect of the investment costs is calculated as follows:

- The score of technology (j) for the investment costs = - (investment costs (€)/10,000)) (ignoring the maintenance costs). The investment costs form a barrier for all agent types and technologies, but the height of the barrier perceived, is negatively related to the income level of an agent. The height of the barrier decreases for all agents with decreasing investment costs.

The market share of PV is a function of the level of diffusion (%) in the last round. The effect of the market-share on the utility of agent (i) for PV panels (j) is calculated as follows:

- Effect of market share $(i, j) = [\text{imp}_{\text{sub}}(i) \cdot$ ((% of buyers of PV panels *(j)* – (1 - (0.3 + % of buyers of PV)) $]$ But if (1- (0.3 + % of buyers of PV)) < 0.35, then = 0.35.

The effect of the market share of PV systems is measured relatively to the market share of electricity grid connections. The factor 1 stands for the market share of grid electricity, which is assumed 100% in the beginning of the experiments. In the model set-up, the market share is taken as a measure for the popularity of a product. Because PV systems are new in comparison to grid electricity, it is assumed that a certain market share of PV systems is more apparent than the same market share of grid connections. Therefore the factor 0.3 is built in. Because of this factor, when PV reaches a markets hare of 35 % (instead of 50%) a PV system is regarded as more popular option than to remain using only grid electricity by all agent types.

According to the minimum value of 0.35 for grid electricity, the effect of the popularity of PV systems on the utility of the agents after a market share of 35% is reached, is lower than the effect of popularity of grid electricity before PV systems reach a market share of 35%. This is built in to correct for the fact that households remain connected to the central grid when purchasing a PV system. In contrast to the beginning of the diffusion of PV systems when this technology is unknown, grid electricity remains a known technological option.

Although, the diffusion of PV systems is only determined for the owner occupancy category, the market-share that is weighted in the utility function is taken as the percentage of all (6.8 million) households in the Netherlands. It is assumed that the level of diffusion in the other two ownership categories keeps pace with the level of diffusion in the owner occupancy category.

The market share that is used in calculating the Utility (i,j) is determined as follows:

$$\text{Market share \%} = [(\text{market share PV in owner occupied households (exl.share of stacked dwellings)} \\ (\%)) \cdot (1 - \text{share of stacked dwellings in the total stock (\%)})]$$

4.2 The experiments

4.2.1 The influence of a changing market share on utility (i,j)

Using these settings, a number of experiments are performed. Firstly, the influence of a changing market share on the utility of the agents is determined by calculating the utility for a number of agent types (i) at a market share of PV ranging from of 0 – 100 %.

In this calculation example the following input data are used:

Table 4.2 input data for the calculation example

Technology (j): PV (1 kWp)			
	Characteristic k	**Input**	**Factor**
Attitude	k_1 : Payback period	12.7 yr (Including subsidy: Price electricity produced = 0,525 €/kWh)	- 0.27
	k_2 : Environmental perf.	0.57 kg/kWh	1
Control	k_3 : Investment costs	€ 5000	- 0.5
Subjective Norm	Market share	0 % ; 100 %	- 0.7 ; 0.65
Imp (j) attitude→ purchase			0.35
Imp (j) control → purchase			0.65

To give insight in the derivation of the utility (i,j) , a schematic overview is given of the calculation of the utility(i,j) of a PV system (in comparison to grid electricity) for the *caring and faithful* - *high income*, *Broad minded* - *high income* and *Balanced* - *high income* agent types.

Calculation Example: The effect of a changing market share

$$\text{Utility}(i,j) = [\text{attitude}(i,j)\cdot \text{imp}_{\text{attitude}}(j) + \text{control}(i,j)\cdot \text{imp}_{\text{control}}(j)]\cdot(1-\text{imp}_{\text{sub.}}(i)) + \text{sub.}(j)\cdot \text{imp}_{\text{sub}}(i)$$

If utility (i,j_1) - utility (i,j_2) > 0, agent (i) purchases technology j_1.

Agent ($i_{1,2,3}$) = Caring Faithful, High income (i_1), Broad minded - high income (i_2), Balanced - high income (i_3).

Attitude (i,j) = $\begin{bmatrix} -0.27 & 1 \end{bmatrix} \begin{bmatrix} 0.15 & 0.15 & 0.3 \\ 0.001 & 0.3 & 0.15 \end{bmatrix} = \begin{bmatrix} -0.04 & 0.26 & 0.07 \end{bmatrix}$

Control (i,j) = $\begin{bmatrix} -0.5 \end{bmatrix} \begin{bmatrix} 0.5 & 0.5 & 0.5 \end{bmatrix} = \begin{bmatrix} -0.25 & -0.25 & -0.25 \end{bmatrix}$

Utility (i,j) = $[\text{attitude}(i,j)\cdot 0.35 + \text{control}(i,j)\cdot 0.65]\cdot(1-\text{imp}_{\text{sub.}}(i)) + \text{sub.}(j)\cdot \text{imp}_{\text{sub}}(i)$

$\text{Imp}_{\text{sub.}}$ ($i_{1,2,3}$) = $\begin{bmatrix} 0.25 & 0.01 & 0.1 \end{bmatrix}$

Utility ($i_{1,2,3}$,j) if market share 10 %: $\begin{bmatrix} -0.16 & 0.06 & -0.06 \end{bmatrix}$ (Only broad-high income purchase)

Utility ($i_{1,2,3}$,j) if market share 90 %: $\begin{bmatrix} 0.10 & 0.06 & 0.05 \end{bmatrix}$ (All 3 purchase)

In figure 4.1 the effect of a changing market share on the utility of the three agent types is presented. It can be seen that the broad-minded-high income agent group purchases the PV under all market shares. Because they are set to be almost indifferent to the purchase behavior of other agents, their utility stays almost constant. Under these conditions, the caring-faithful high income agents purchase a PV system around a 50% market share and the balanced- high income agents purchase a PV system when it has gained a market share of 40 %. Under lower market shares these agents remain using the old technological option (grid electricity). Because the group of caring faithful agents is set as most sensitive to the purchase behavior of others, at a market share of 100%, under the present settings of the model set-up, their utility for PV systems is higher than the utility of the other agent categories. After PV systems have gained a market-share higher than 35 % the slope of the line decreases a little. This shows that the effect of the popularity of PV systems on the utility of the agents after a market share of 35% is reached, is lower than the effect of the popularity of grid electricity before PV systems reach a market share of 35%. This is built in to correct for the fact that households remain connected to the central grid when purchasing a PV system. In contrast to the beginning of the diffusion of PV systems when this technology is unknown, grid electricity remains a known technological option.

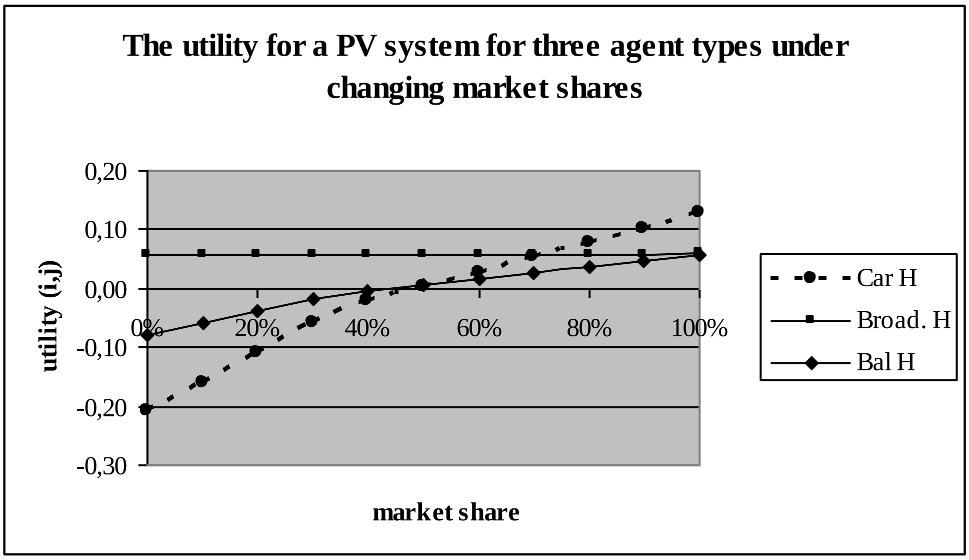

Figure 4.1 The effect of a changing market-share on the utility of three agent types

4.2.2 The effect of changing electricity prices and investment costs

Two other experiments have been conducted to simulate the impact of decreasing investment costs (either by subsidy or by technological developments e.g. lower production costs) and growing electricity prices (either growing grid prices or a subsidy on the electricity generated with the PV system) on the level of diffusion. The other variables remain the same as in experiment 1. The results of these experiments are presented below in figures 4.2 and 4.3 and tables 4.3 and 4.4. The range of electricity prices and investment costs and their sudden increases are not intended to represent possible scenario’s or expected events; the experiments are performed to highlight the relative impact of these two variables on the level of diffusion and the order of purchase moments of the different agent categories.

The methodology applied in both experiments is the same; the chosen independent variable (investment costs, electricity prices) is first adjusted in every simulation round using rounded large relative changes. After a new group or groups of agents have decided to adopt a PV system, the independent variable is kept constant and the effect of the increase in market-share on the purchase behaviour of other agent types is measured. This is repeated until the automatic purchase (without changing the investment cost/electricity prices) stops.

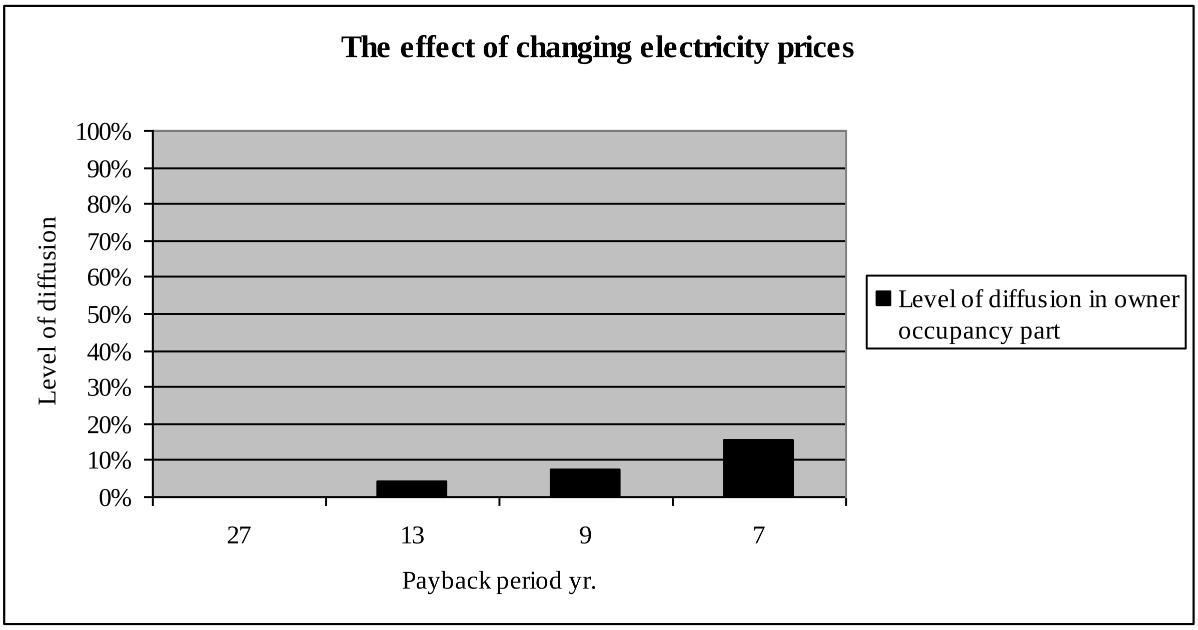

Figure 4.2 The effect of changing electricity prices (growing grid prices or higher subsidies on the electricity generated) on the level of diffusion of PV systems

Table 4.3 Overview of the purchase moments of the different agent types and their contribution to the level of diffusion in the owner occupied category and the total housing stock

Elect. Price	***Payback period***	***Diffusion level (%) owner occ.***	***Agent types***
0,25	27	0%	None
0,5	13	4 %	High broad.
0,75	9	7 %	Middle broad.
0,75	9	7 %	
1	7	16 %	High prof. + high soc.
1	7	16 %	

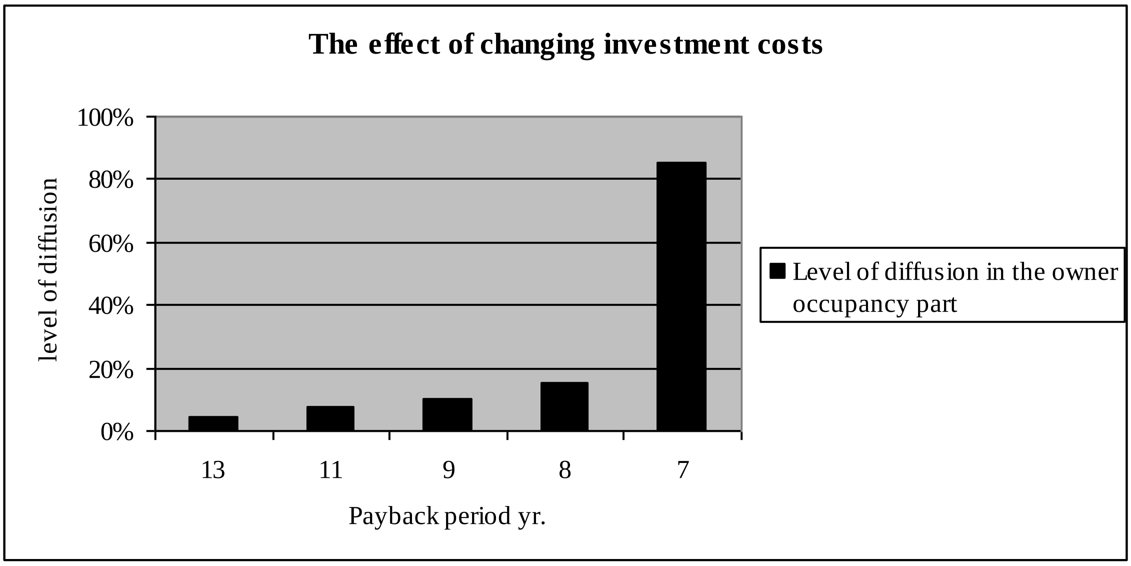

Figure 4.3 The effect of changing investment costs (technological development or investment subsidies) on the level of diffusion of PV systems

Table 4.4 Overview of the purchase moments of the different agent types

Payback period	***The effect of changing inv.costs***	***Diffusion level (%) owner occ.***	***Agent types***
13	5000	4 %	High broad
11	4500	7 %	Middle broad
9	3500	10 %	High Soc.
8	3250	16 %	High prof.
7	2750	31 %	High bal.+ low broad + middle prof. + middle soc.
7	2750	43 %	High mat.+ middle bal.
7	2750	59 %	Low soc.+ middle Mat. + High + middle hed. + High cons.
7	2750	75 %	Low hed. + Middle cons. + high + middle car.
7	2750	85 %	Low balanced + Low Cons + Low Car

These results indicate that the model set-up is able to measure different levels of technology diffusion at a same payback period. While a payback period of around 7 years is the second experiment results in a diffusion level of 85 % in the category of owner occupied households, around the same payback period results in a maximum diffusion level of 16 % in the first experiment.

A common methodology applied energy models, is to simulate the purchase behaviour of individuals or companies as a function of their maximum tolerated payback period. In the conceptual model created in this research, the investment costs are assessed independently from the payback period by the agents. More importantly, the population of agents is differentiated into distinctive categories which are expected to experience the same level of perceived control in respect to the investment costs (income categories). This explains the lower level of diffusion in the first experiment, which is caused by the barrier of the high investment costs which is too high to overcome for the low income groups. The investment costs also determine to some extend the order in which the agent groups adopt. It can be seen that the income categories in the second experiment are strictly separated, indicating the high impact of the investment price on the purchase decision. These results are off course dependent on the relative importance of the perceived behavioural control in comparison to the importance of the attitude and subjective norm. In these experiments the importance of the perceived control is set relatively high. For further research it is suggested that the relative importance per technology is based on empirical data collected surveys.

4.2.3 Changing environmental awareness, a subsidy on the electricity produced and technological development

The last experiment explores the effect of a sudden shift in importance of environmental concerns (the weight factor increases from 0.8 to 1) in year 8, followed by a subsidy increase on the electricity generated from 0.525 to 0.65 in year 10. Furthermore, exogenous technology development is assumed. During the simulation period of 20 years, the investment price decreases with 100 € per year to 3000 € in year 20 and the PR of the PV panels increases with a fraction of 0.005 per year from 0.75 in the beginning to 0.85 in year 20. Again, these settings do not necessarily reflect realistic numbers or reflect expert forecasts, they are chosen such that the experiment would elicit some important dynamics that can be expected from the model set-up.

In this example, every calculation round is assumed to reflect one year. Every round, the chosen independent variables (environmental awareness, performance ratio, investment costs, and electricity prices) are first adjusted before calculating the utility (i,j). Thus, every year, all the agents decide upon to buy a PV panel or not, under a new set of conditions. If, in a certain year, for a specific group of agents, the utility of PV exceeds the utility of grid electricity, the whole group purchases a PV system at once. After a new group or groups of agents have decided to adopt a PV system, the other agents are set to respond to the increasing market share in the next calculation round (year). Furthermore, it is assumed that the lifetime of the PV panels exceeds the simulated period of 20 years. This means that the agents who purchase the technology in the first year do not re-evaluate their decision in the experiment. It should be noted that the high synchronization of decision making assumed here is not expected to occur in reality. Therefore, when building the model, a more realistic representation of time is suggested (more decision moments and diversity within the agent categories).

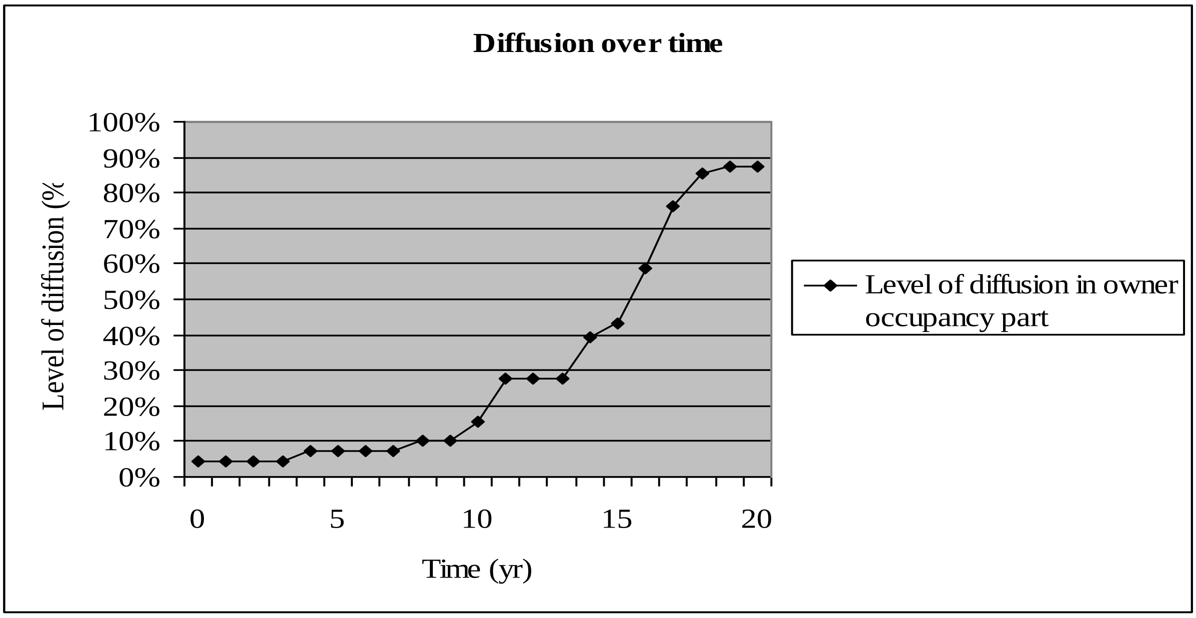

Figure 4.4 The effect of changing environmental concerns followed by a subsidy increase on the electricity generated on the level of diffusion of PV systems in the Dutch domestic sector

Table 4.5 Overview of the purchase moments of the different agent types

Time step	***Payback period***	***Diffusion level (%) owner occ.***	***Agents***
0	13	4%	High income broad minded
1	12	4%	
2	12	4%	
3	12	4%	
4	11	7%	Middle income broad minded
5	11	7%	
6	11	7%	
7	10	7%	
8	10	10%	High income socially minded
9	10	10%	
10	8	15%	High income professionals
11	7	27%	Middle soc. + High bal.
12	7	27%	
13	7	28%	Low broad.
14	7	39%	Middle bal. + High mat.
15	7	43%	High hed. + low soc.
16	6	59%	High cons. + middle prof./mat/hed
17	6	76%	Low bal. + high +middle cons+car/faith.
18	6	85%	Low hed. + cons. + car/faith.
19	6	87%	Low materialists
20	5	87%	

As table 4.5 shows, the first group of adopters exists of 'broad minded' agents with a high income who are willing to purchase PV panels under present conditions in the Netherlands (including a grant offered on sustainable generated electricity around 0.525 €/kWh). This reflects empirical findings in consumer research, which states that the first adopters of PV systems under present conditions have a higher income level than average, higher education [16] than average, are on average more environmentally concerned, and were not socially informed on the possibility of PV panels (Jager, 2006; Keirstead 2007). Technological development, most importantly decreasing investment costs, induces a response of the agents in the broadminded category with an average income. The shift of environmental concerns in time step 8 results in the purchase of the technology by the socially minded agents (guided by environmental concerns and to some extend by the decision behaviour of others) with a high income level. In time step 10, the sudden decrease of the payback period, resulting from an increase of subsidies on the electricity generated, stimulates the agents in the professional - high income category to purchase. For this agent type the payback period plays an important role in the attitude formation. The next step a relatively large increase in the diffusion level can be seen; the large group of 'high income balanced' and 'middle income socially minded' agents are convinced to purchase a PV system by the early adopters. From time step 13 onwards, after a critical mass of agents have adopted the technology, the diffusion rate accelerates. The large group of agent types in this period are primarily motivated by others (the subjective norm) and the lower investment costs (increasing perceived behavioural control). The diffusion level saturates when around 90 % of the households in the owner occupancy category have purchased a PV system. This number excludes the number of households in stacked buildings and the category of 'low income professionals' which are not affected by the behaviour of others and are held back by the high investment costs.

This experiment provides insight in the role of attitude formation, perceived behavioural control and the subjective norm on the purchase behaviour (the moment of purchase) of different types of households. In contrast to classic diffusion research such as the theory of Rogers (2003), the individuals with the highest socio-economic status who are the least guided by others in their decision making do not necessarily fall into the first groups of buyers. Because the 'socially minded high income group' are more environmentally concerned, they purchase the technology on an earlier point than the group of 'high income professionals' who are defined to be less guided by others in their purchase decision. Besides this, the second group to purchase the technology falls outside the high-income group of households (a lower socio-economic status). Also, the group of households that never purchases under these experimental conditions is the group of low income professionals, which are set to belong to the group of households that is least guided by others in their decision making.

[16] According Aalbers et al. (2006) the individuals in the socially minded and professional value pattern have on average completed the highest level of education.

5 Conclusions and recommendations for further research

This research has examined the potential for micro-generation in the domestic sector in the Netherlands, focussing on three technologies: micro-CHP, solar PV and micro-wind turbines. In conducting this research the following questions have been answered:

What opportunities and constraints for a swift, large-scale diffusion of micro-generation technologies can be identified from a macro-level perspective? And how can the demand for the micro-generation technologies in the domestic sector in the Netherlands be modeled taking an agent-based approach?

In answering the first question, '*What opportunities and constraints for a swift, large-scale diffusion of micro-generation technologies can be identified from a macro-level perspective?'* the actors involved in the introduction of the technologies have been identified and their role and interests have been described. From the actor description, insight is gained in the possibilities and constraints for a large scale introduction of micro-generation from a socio-economic and technological macro-level.

In the existing electricity sector, Energy Distribution Companies (EDCs) show an increasing interest in micro-generation technologies. The reason for this is that in the newly created electricity market, that is more service based, micro-generation technologies form a strategic asset for EDCs. An active involvement in the promotion and implementation of EDCs may induce the diffusion of micro-generation technologies. Also, GasTerra, the largest gas supplier in the Netherlands and an influential actor, is actively involved in the promotion of gas-based micro-CHP installations. The promotional activities of GasTerra are aimed at continuation (or expansion) of gas demand in households for heating applications, as increasing attention is being paid to alternative heating technologies, which do not (directly) work on gas.

On the other hand, the vested interests of existing electricity producers, secured by influential lobby groups such as EnergieNed, may form an important barrier to the introduction of micro-generation. The use of micro-generation technologies on a large scale will likely decrease the demand for grid electricity. Therefore, electricity producers in the market are interested in influencing policy-making for reasons of supporting the sales of electricity produced from their existing production facilities. Furthermore, the possibilities for large scale integration of micro-generation in the existing electricity system are bounded by technological restrictions from the transport network. Network operators are responsible for any necessary innovations in the transport system. In the present institutional setting there are no financial regulations compensating network operators for the investments done in the first stages of product development. As a result, network operators are reluctant to invest in innovation of the transport network. Therefore, whether network adjustments will be made on forehand, paving the way for the introduction of micro-generation is likely to be dependent on political intervention.

In the national energy plan, the Dutch government has presented a decentralized and localized electricity scenario with extensive use of micro-generation technologies as one of three possible systems to meet its future energy objectives. In contrast to a localization of electricity supply, the other two electricity systems described highlight a further integration in a European market. Whether the Dutch electricity systems transforms into a locally based, decentralized system and also becomes more integrated in a Northwest European system is dependent on a large number of developments (e.g. policy intervention, the influence and interests of energy companies in the existing sector ,social pressure). The government emphasizes that it does not favour one of the energy systems described. Policy making is both geared towards a further localization of energy supply and a further integration into a (northwest) European system.

At the moment, both Europeanization as localization trends are observed. Recently, two of the biggest energy companies (Nuon and Essent) have been sold to European companies (Vattenfall and RWE), a high capacity transport cable between Norway and the Netherlands has set into operation, and the national TSO (Tennet) has taken over part of the German electricity transport network. These developments indicate that the Netherlands is increasingly becoming integrated in a Northwest European market. At the same time, although having a much smaller impact, there are initiatives taken on a local (province or municipality) level, aimed at stimulating the introduction of micro-generation in the built environment. Examples of these local initiatives are field tests carried out with micro-CHP, the implementation of PV panels in large quantities in newly built neighbourhoods and local subsidies on the production of electricity generated from PV systems. These initiatives are mostly carried out under supervision of local authorities.

Besides developments in the existing electricity sector and policy intervention on a national and local level, a large scale introduction of micro-generation technologies is dependent of the willingness of consumers (the building owners) to purchase the technologies. In answering the second research question, '*And how can the demand for the micro-generation technologies in the domestic sector in the Netherlands be modeled taking an agent-based approach?'* a set-up was created for an agent-based model that simulates the purchase behaviour of households in relation to the micro-generation technologies, aiming to provide a quantitative basis for the estimation of the potential of the technologies. In this research the group of consumers was restricted to households in the owner occupancy category.

Following the *Theory of Planned Behaviour*, the purchase decision making of the agents is described according to the attitude, perceived behavioural control and a subjective norm. These three determinants are elaborated using existing consumer research concerning micro-generation technologies.

In the model set-up, the attitude of an agent is formed by the preferences it has regarding specific characteristics of a technology. Four attributes are selected to determine the attitude formation of an agent: the payback period, the environmental performance, independency from an external supplier and the performance (comfort, noise production, visibility, predictability of production). Depending on the type of value orientation of an agent it evaluates the characteristics either as positive or negative.

Technology attributes that influence the perceived behavioral-control, are the investment costs, the compatibility of a specific technology with the existing infrastructure and the bureaucratic barrier associated with micro-generation in general. Two types of agent characteristics are set to influence the perceived behavioral control; (1) the housing type and (2) the level of income. The first relates to the compatibility of the technologies with the existing infrastructure of a house. Given the physical properties of households in stacked dwellings, PV and micro-wind are not purchased individually by this group of households. The second relates to the investment price of the technologies. Micro-generation technologies are associated with high investment costs, which are identified by households as an important barrier to purchase.

The subjective-norm reflects the communication between the agents and its effect on the diffusion dynamics in the model. In this study it is taken as a function of the market-share of a product, reflecting the popularity of a product which may change an agents' perception of it. An agents' sensitivity to a subjective norm (i.e. whether its purchase decision is strongly guided by the consumption behaviour of other agents) is dependent on its value orientation.

According to the TNS-NIPO WIN™ model, the agents are classified based on eight value patterns. These value patterns are subdivided into three income categories (a high, a middle and low income category), resulting in 24 consumer types. Apart from the decision making behaviour, the agents in the model set-up are described according to the type of ownership of a house, their electricity and heat use and type of house (e.g. free standing, row). From statistics of the residential housing stock of the Netherlands and energy use statistics, the Dutch households are differentiated into 900 household categories with the same type of house equal heat and electricity usages and the same type of house ownership. By using the income level as mediating variable, a distribution of the 24 consumer types over the 900 household categories is determined. The result is a differentiation of the domestic sector into agent categories with the same type of ownership of a house, the same type of house and roughly equal electricity and heat use, which are likely to show the same purchase behaviour related to a specific micro-generation technology.

Together with a description of the technologies (both quantitatively and qualitatively according to arguments given by households in consumer research) and a decision making algorithm describing a high involvement purchase decision making, the agent categories form the basis for the ABM model set-up. To illustrate what dynamics may be expected from the agent-based conceptual model created, it has been applied to calculate the diffusion of PV-systems in the owner occupied households in the Dutch domestic sector under different conditions (e.g. grid electricity prices, investment costs). The modeling exercise was performed in excel, no agent-based simulation software is used, calibration of the model parameters was not based on any empirical data and complexity was reduced by limiting the number of technology attributes that influence the agent's choice. The PV-system was compared to grid electricity according to the payback-period, environmental performance, the investment costs and the market-share.

In all experiments (different conditions), the first group of agents that purchased a PV system were the 'broad minded – high income' agents. These agents, which fall within one of the environmentally concerned categories, are triggered to buy the technology by the environmental benefits that can be gained from producing electricity with it. Furthermore, the 'broad minded – high income' agents have on average completed higher levels of education and are least guided by the consumer behaviour of others. These findings are is in correspondence to empirical based descriptions of the first buyers of PV systems in existing consumer research. With the model set-up, insight is gained in the number of households in this agent group, their household characteristics and electricity and heat use. The 'broad minded – high income' group is estimated to represent 3 % of all households and also around 3 % of the heat and electricity use in the domestic sector of the Netherlands. Furthermore, almost all of these households are owner of their house, and around 15 % live is stacked dwellings (are assumed to do not make the purchase decision for a PV-system individually).

The other groups of early buyers (after 'broad minded – high income' group) existed of agents that were motivated either by the environmental performance and a decrease of the investment costs, or by a short payback period caused by an increase of the grid electricity price in combination with decreasing investment costs. This reflects the arguments given by some of the first buyers of PV systems in consumer literature, who indicated to be motivated in their purchase decision by a decrease in the energy bill in the long run. What these groups of first movers have in common is that they are least guided by others in their decision making. Also, on average, in all experiments the latter groups that purchased the technology were the agents who are most sensitive to the purchase behaviour of others. But, the agents who are least influenced by others in their purchase decision are not necessarily the first to adopt. In one of the experiments it is seen that specific types of agent that belong to the groups that are least sensitive to a subjective norm (low income, professionals) do never purchase a PV system. These findings illustrates that different types of agents are motivated to purchase the technology under different conditions (e.g. different grid electricity price, investment prices, market shares).

In more general terms the ABM model set-up is able to simulate the expected number of buyers of a specific micro-generation technology in the Netherlands under different conditions. Also, it is able to identify these buyers in terms of their purchase behaviour, housing characteristics and electricity and heat use. The sensitivity of the agents to the variables in the model (e.g. investment cost, market-share) gives insight in the factors that are likely to determine the potential for diffusion in the future. This may provide insight in which policy measures are effective to stimulate specific groups of households to purchase a micro-generation technology, e.g. targeting the group of households with the highest shares of electricity and heat use, or to increase the diffusion of a specific technology in the domestic sector as a whole.

But, so far, the model set-up created has some important weaknesses that should be taken in consideration in further research, when developing the model.

- Firstly, the model of the housing stock is a static representation based on numbers from 2006. The model does not include changes over time. Therefore no predictions can be done for the composition of the housing stock and expected energy usages in the future.

- Secondly, the model of the energy use of households does not describe the energy use fluctuations over time e.g. on an hourly, daily, weekly or seasonal basis. The load curve of households is a predictor for the fraction of onsite use and feedback into the grid. Load prediction curves per type of household would allow a more detailed calculation of the effects of the usage of micro-generation technologies on grid demand and the proportion of feedback into the grid.

- Thirdly, the impact of the value patterns on the electricity and heat usages is determined by the number of houses and the properties of the houses (such as the average size, type, number of occupants) in the ownership categories. Using a more detailed distribution of income categories over the households, for example the income per household type and size in each ownership category, would give a more in-depth analysis of the relationship between a specific value segment and its energy demand.

- Fourthly, no detailed account is given of communication networks as they exist in real life. Because of this, in contrast to empirical findings communication is not modelled as a selective process. Besides, no distinction is made between different technologies based on social compatibility. For example, the diffusion dynamics of visible products and products that are not directly observable to bystanders are expected to differ because status and identity needs play a more important role in the market of directly observable innovations. The model set-up chosen in this research is not able to simulate such dynamics.

- Fifthly, so far, the model set-up does not include a realistic representation of space and time. In the set-up the agents represent all households in the Netherlands. Distribution of agent types (value patterns but especially housing types) is dependent on the type of geographical area (e.g. the concentration of stacked dwellings is much higher in a city than in the country side). This means that the market share of the micro-generation technologies, and consequently the utility experienced by the agents, is dependent on the geographical area within the Netherlands. An alternative approach could be to apply the model set-up to a smaller area e.g. at a city or municipality level.

The last experiment considers the diffusion over time. In one every year, all the agents decide upon to buy a PV panel under a new set of conditions. If, in a certain year, for a specific group of agents, the utility of PV exceeds the utility of grid electricity, the whole group purchases a PV system at once. After a new group or groups of agents have decided to adopt a PV system, the other agents are set to respond to the increasing market share in the next calculation round (year). The high synchronization of decision making assumed here is not expected to occur in reality. Therefore, when building the model, a more realistic representation of time is suggested i.e. more decision moments and diversity within the agent categories.

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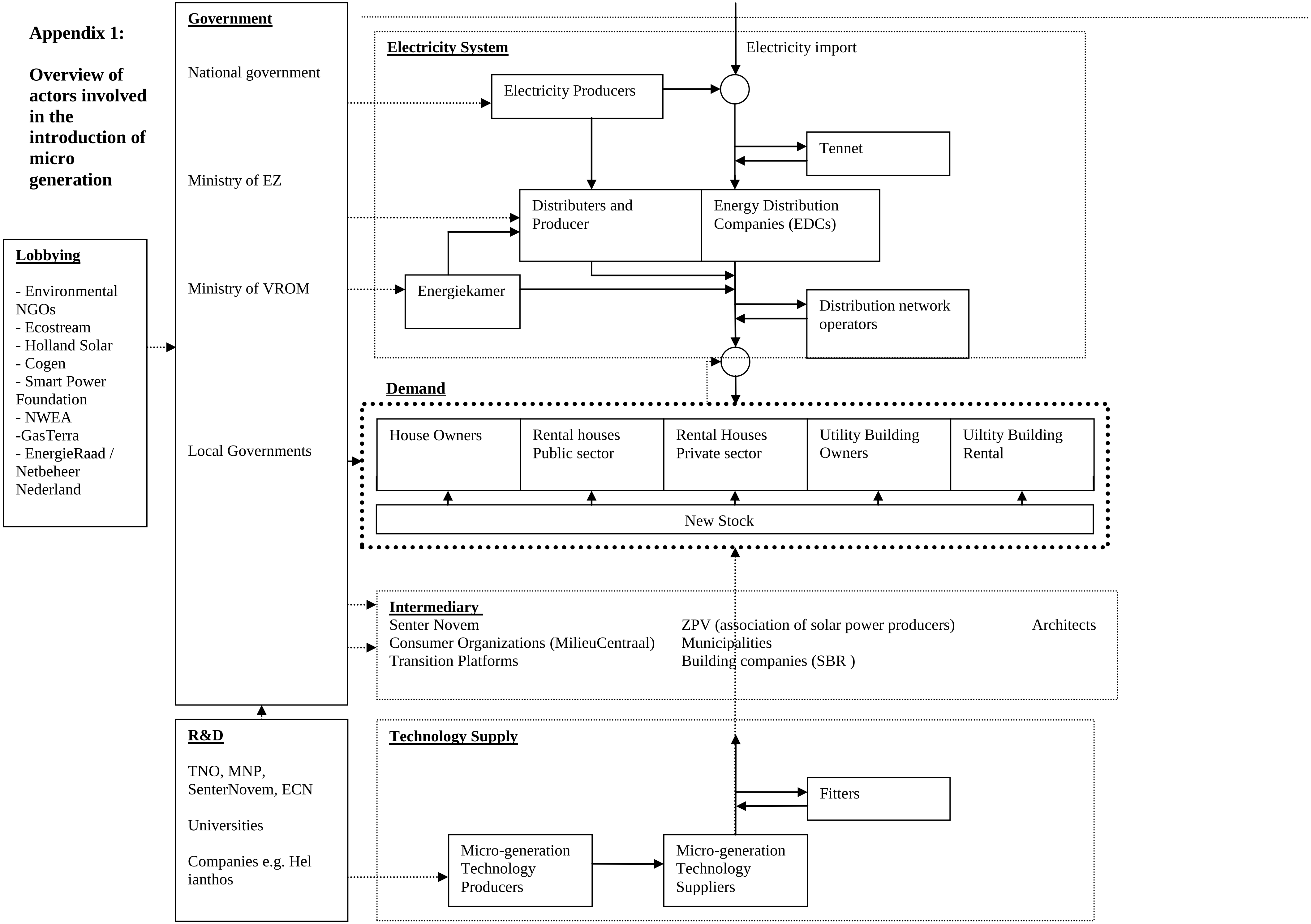
Appendix 1:

Overview of actors involved in the introduction of micro generation



Appendix 2 Modelling heat and electricity use

Modelling Heat use

The factors that have the biggest influence on the heat use of a household are:

(1) The dwelling type
(2) The size and
(3) The construction period of the dwelling (SenterNovem, 2007)

The type of house relates to the volume and the size of the direct contact surface with the surroundings. To be able to identify the effect of size on heat use individually, a distinction is made between three different sizes for each dwelling type. The construction period is an indicator for the degree of insulation of a dwelling. The type of ownership is assumed to have a negligible impact on the heat use.

In table 1 and 2 the heat usages per dwelling type and building period are presented. The numbers are results form measurements performed by SenterNovem under supervision of the Dutch Ministry of Spatial Planning and the Environment VROM (SenterNovem, 2007). The measurements date back from 2004, no updates are available yet. It is assumed that the average heat use per household per category has changed since 2004, because of a wider diffusion of insulation measures and HE-boilers in the household sector and due to compositional changes of the stock.

Table 1 Heat use per type of dwelling

Dwelling type	***Heat Use (m^3/year)***
Free standing (Free)	2,624
End + 2/1	1,878
Row dwelling (Row)	1,560
Apartment (apart.)	1,173

Table 2 Heat use per construction period

Construction period	***Heat Use (m^3/year)***	***Coefficients***
< 1945	1,946	1.17
1945 until 1975	1,810	1.09
1976 until 1981	1,651	0.99
1982 until 2000	1,443	0.87
> 2000	1,485	0.89

For this study the numbers from the study of SenterNovem are adjusted to minimize the amount of household categories. The categories ‘2/1 roof’ and ‘end of a row’ have nearly equal heat usages and are combined by taking the average of the sum of the two under the header ‘end + 2/1’. In the same way the total of nine building period categories is brought back to five categories, with clearly distinctive heat usages. The coefficients in the third column are calculated by dividing the corresponding heat use by the average of the heat uses in the table. The coefficients are used in modeling the heat use of each type of household in the model.

Finally the size of the dwelling is measured in number of rooms. Within each dwelling type category, 3 categories of dwelling sizes are created: (1) 1-3 rooms (2) 4-5 rooms and (3) > 5 rooms. There is no data available on the heat use per dwelling size. The coefficients predicting the effect of dwelling size on heat use in the model are chosen such that the calculated average heat use per household corresponds to existing measurements from EnergieNed (2009).

The model for calculating heat use exists of 60 cells, in which each cell represents a subcategory of households described by the type of dwelling, construction period and number of rooms. The heat use per subcategory is calculated by multiplying the heat use of the dwelling type with the corresponding coefficients of the number of rooms and the construction period. The heat use in (m^3/year) for each category of dwellings is presented below.

Figure 1 Model with the calculated heat use per category of households in (m^3/year)

Heat Use (m^3/year)		***Row***			***End +2/1***		
		1-3 rooms	**4-5**	**> 5**	**1-3 rooms**	**4-5**	**> 5**
	Coefficients	*0.8*	*1*	*1.2*	*0.8*	*1*	*1.2*
<1945	*1.17*	1460	1825	2190	1758	2197	2637
1945 - 1975	*1.09*	1360	1700	2040	1638	2047	2456
1976 - 1981	*0.99*	1236	1544	1853	1487	1859	2231
1982 - 2006	*0.87*	1086	1357	1629	1307	1634	1961
>2006	*0.89*	1061	1326	1591	1277	1596	1916
		Free			**Appart.**		
		1-3 rooms	**4-5**	**> 5**	**1-3 rooms**	**4-5**	**> 5**
	Coefficients	*0.8*	*1*	*1.2*	*0.8*	*1*	*1.2*
<1945	*1.17*	2456	3070	3684	1098	1372	1647
1945 - 1975	*1.09*	2288	2860	3432	1023	1279	1534
1976 - 1981	*0.99*	2078	2598	3117	929	1161	1394
1982 - 2006	*0.87*	1826	2283	2739	816	1021	1225
>2006	*0.89*	1784	2230	2676	798	997	1196

Modeling Electricity Use

Most important determinants for electricity use are:

(1) The <u>size</u> of the dwelling

(2) The <u>number of occupants</u>

The electricity use per household is modeled in a corresponding manner as the heat use. Data on electricity use per household are scarce. The data in this study that serve as an input are retrieved from the ‘Basisonderzoek Elektricteitsverbruik Kleinverbruiker’ (BEK) from 1993. This research contains measurements of the electricity use per household per number of occupants from the year 1987 till 1992. The electricity use per number of occupants as well as the average household use in that year in kWh, is presented in the table below.

Table 3 the average electricity use per number of occupants + the average electricity use per household in the concerning years (BEK’93).

Number of occupants	(kWh/year) **1992**	(kWh/year) **1991**	(kWh/year) **1990**	(kWh/year) **1989**	(kWh/year) **1988**	(kWh/year) **1987**
- 1	1863	1852	1875	1828	1719	1765
- 2	2712	2653	2622	2525	2512	2529
- 3	3265	3210	3164	3049	3106	3184
- 4	3744	3759	3523	3402	3410	3518
- 5	4185	3855	3767	3502	3741	3479
>5	4594	4489	4378	4331	4364	4198
Average Electricity use per household (kWh/year)	3040	2930	2835	2740	2735	2760

From these numbers, coefficients are calculated that indicate the electricity use per number of occupants. The two latest categories of occupant numbers are combined into one category (> 4) in which the use of the two categories is averaged. The coefficients are calculated by dividing the electricity use per number of occupants by the average household electricity use in that year. A rounded average of these coefficients is used to predict the electricity use in the model. The coefficients for the number of rooms are again chosen such that the calculated average use, corresponds to the measured average use in 2006.

The model for calculating electricity use exists of 15 cells, in which each cell represents a subcategory of households, described by the number of occupants and rooms of a dwelling. The electricity use per subcategory is calculated by multiplying the average measured electricity use in a particular year, with the corresponding coefficients of the number of rooms and number of occupants. The electricity use in (kWh/year) for each category of dwellings is presented below.

Figure 2 Model with the calculated electricity uses per household category in kWh/yr

Year 2006	**Average use (measured)** 3402 kWh/yr	**1-3 Rooms**	**4-5 Rooms**	**>5 Rooms**
Number of occupants	**Coefficients**	*0.9*	*1.05*	*1.2*

1	*0.65*	1990	2322	2654
2	*0.95*	2909	3393	3878
3	*1.15*	3521	4108	4695
4	*1.30*	3980	4644	5307
>4	*1.45*	4440	5180	5919

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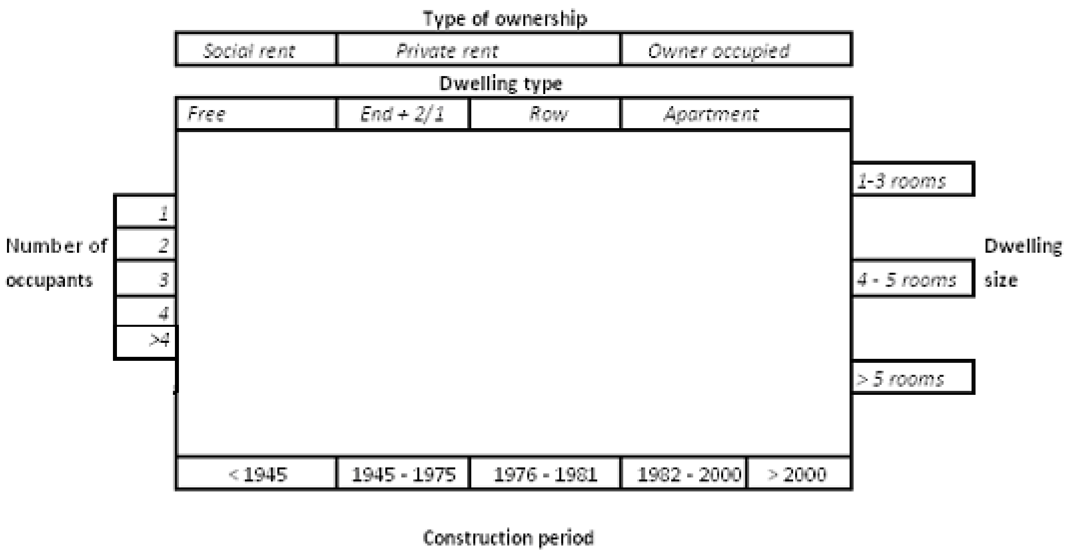
Identifying number of households in each subcategory

Here, the number of households in each subcategory is determined. The dwelling stock is differentiated according to 5 different variables: (1) Type of ownership, (2) the dwelling type, (3) the dwelling size, (4) the building period and (5) the number of occupants. A schematic overview of the categorization is presented in figure 3. A distinction is made between 900 different types of households.

Figure 3 Categorization of the residential dwelling stock, based on their electricity and heat use



There arises a problem in matching the available data of the Dutch residential dwelling stock on the one hand and the household energy use data on the other. In the database of the housing stock used (ABF), there is only made a distinction between stacked dwellings (apartment/flat) and the rest. The numbers do include the size of a dwelling as a variable, measured in the number of rooms. To be able to identify the number of households in the categories free standing, row and 2/1 roof/corner of a row, a relation is assumed between dwelling size and dwelling type. It is assumed that, on average, freestanding houses are the largest in size followed by 2/1 roof and corner of a row as one category, followed by row dwellings and the category flat/apartments.

The distribution of dwelling types over the complete dwelling stock is calculated in three steps. Firstly, the distribution of free standing, row and 2/1 roof/corner dwellings over the Dutch dwelling sector is retrieved from the Dutch Bureau of Statistics (CBS). The proportion of flat/apartments in the total stock is taken from ABF. The numbers of CBS date back from 2002, and for 2006 I have assumed an minor increase in free standing houses and a minor decrease in row dwellings (corner and in between). Secondly, the distribution of dwelling size over the total stock in 2006 is taken from the ABF Database. The distribution of dwelling type and size over the complete stock is presented in table 4. Thirdly, an assumption is made regarding the distribution of dwelling types over the number of rooms. The distribution is chosen such that the fraction of a dwelling type per number of rooms, multiplied by its fraction of the total stock, corresponds to the distribution of dwelling size in the ABF database. The distribution of the category flat/apartment is taken from the ABF database. The distribution of dwelling type over the number of rooms is presented in table 6.

Table 4 The distribution of dwelling types and dwelling sizes over the total sector

Type	***Percentage of the total dwelling stock (2006) (CBS + ABF)***	***Size***	***Percentage of the total dwelling stock (2006) (ABF)***
row dwelling	25 %	*1-3 kamers*	29%
corner of a row + 2/1	26 %	*4-5 kamers*	57%
freestanding	17 %	*6+*	14%
Flat/Apartment	32 %		

Table 5 The assumed distribution of room sizes over the type of building

	< 4 rooms	***4-5 rooms***	***> 5 rooms***
row dwelling	15%	75%	10%
corner of a row + 2/1	10%	75%	15%
freestanding	5%	55%	40%

Table 6 The calculated distribution of dwelling type over the number of rooms

	< 4 rooms	***4-5 rooms***	***> 5 rooms***
row dwelling	3.8%	18.8%	2.5%
corner of a row + 2/1	2.6%	19.5%	3.9%
freestanding	0.9%	9.4%	6.8%
Flat/Apartment	22.4%	9.1%	0.5%
Total Calculated	**29.6%**	**56.7%**	**13.7%**
Total ABF	**29.3%**	**56.7%**	**14.0%**

Now, an error occurs in the distribution of dwelling types in the category ownership. The relation between ownership of a dwelling and the type is, so far, implicitly a function of the dwelling size. This leads to incorrect results when verifying the numbers with CBS statistics. To correct for this in the model, it is assumed that the type of dwelling determines the ownership type; thus the distribution of size per type of ownership is determined by the relationship between dwelling type and ownership category, not vice versa.

The allocation of types of ownership over dwelling types is retrieved from CBS. Again the numbers date back from 2002. It is assumed that no major shifts in the proportion of ownership types have occurred. The number of dwellings per ownership type from the ABF database is used for validating the results. Table 7 shows (1) the distribution of ownership types per type of dwelling used in the model, (2) the calculated number of dwellings in each ownership category and (3) the corresponding numbers from the ABF database.

Table 7 The calculated distribution of dwelling types over ownership categories

	Social rent	***Private Rent***	***Owner Occupied***
row dwelling	40%	6%	54%
corner of a row + 2/1	20%	5%	75%
freestanding	2%	4%	94%
Flat/Apartment	62%	17%	21%
Total Calculated	2,397,246	604,568	3,798,612
Total ABF	2,394,696	609,194	3,796,686

Results

With these numbers, the total electricity and heat use of the household sector can be calculated To test the accuracy, the model is used to reproduce the measurements performed by EnergieNed (2009). In table 8 the calculated and measured heat and electricity use of the domestic sector in the Netherlands are presented. The electricity measurement and calculation almost match, while there is a (small) difference between the calculated and measured average heat use.

However, there are a lot of uncertainties involved in the built up of the model. Each assumption made adds a degree of uncertainty in the calculation. The averages calculated below are not necessarily a measure of the quality of the model. The calculation is performed to indicate that the calculation generates an average within a corresponding order of magnitude as the measurements performed by ErnegieNed. The quality of the model is dependent on the logic behind the assumptions made. The model should be treated as a robust methodology to identify the energy usages of certain categories of households, and their relative share of the total sector.

Table 8 the calculated and measured heat and electricity usage of the domestic sector in the Netherlands. The year 2006 is taken as the reference measurement, because the dwelling stock data are from that year (ABF).

Average usages (p/hh)	***Calculated***	***Measured (EnergieNed) (2006)***
Electricity kWh/yr	3403	3402
Heat m3/yr	1727	1643

Appendix 3

Calculation of the distribution of agent types over types of ownership of a house, the energy use per agent type and the share of each agent type in stacked dwellings

The share of each of the 24 consumer types per type of house ownership is determined from the distribution of the income levels over the house ownership types presented in table 1 (Citavista, 2009).

Income level → Type of house ownership

Table 1: the distribution of income levels over ownership types of houses (Citavista, 2009). The income levels are based on the gross modal income (the income class with the highest number of households); the low income class earns less than the modal income, the middle category earns 1-2 times the modal income and high incomes earns more than two times the modal income (CBS, 2009).

	Social rent	**Private rent**	**Owner occupancy**
Low	60%	13%	27%
Middle	27%	8%	66%
High	7%	4%	89%

Using the distribution over income levels of each agent type from table 2, the distribution agent types (value pattern +income level) over ownership types of house are determined.

Table 2: The distribution (%) of the (24) agent types over the Dutch population of households. This distribution is based on Aalbers et al. (2006, page 220). The numbers from Aalbers et al. are adjusted such that the total number of households per income category match the data of the number of households per income category retrieved form Citavista.nl (2009) (last row in the table).

Agent Type (value pattern + income level)		**Distribution:** Percentage (%) of all households
Caring Faithful	**Low**	7,5%
	Middle	5,3%
	High	2,3%
Conservatives	**Low**	8,0%
	Middle	5,6%
	High	2,4%
Hedonists	**Low**	5,5%

	Middle	3,9%
	High	1,7%
Materialists	**Low**	4,4%
	Middle	4,4%
	High	2,2%
Professionals	**Low**	1,2%
	Middle	3,2%
	High	3,6%
Broad minded	**Low**	1,1%
	Middle	2,8%
	High	3,2%
Socially minded	**Low**	4,4%
	Middle	4,4%
	High	2,2%
Balanced	**Low**	7,8%
	Middle	8,0%
	High	5,3%
Total *(Citavista.nl, 2009)*	**Low**	40%
	Middle	37%
	High	23%

Value pattern → Income level → Type of house ownership

Table 3 The distribution agent types (value pattern +income level) over ownership types of house. The numbers presented are rounded; therefore the sum of the percentages of all the agent categories does not exactly match the percentages of the total of households presented in the last row of the table.

Agent type		**Distribution (%)**		
Value pattern	*Income level*	**Soc. Rent**	**Pr. Rent**	**Owner**
Caring Faithful	**Low**	5%	1%	2%
	Middle	1%	0%	3%
	High	0%	0%	2%
Conservatives	**Low**	5%	1%	2%
	Middle	1%	0%	4%
	High	0%	0%	2%
Hedonists	**Low**	3%	1%	1%

	Middle	1%	0%	3%
	High	0%	0%	1%
Materialists	**Low**	3%	1%	1%
	Middle	1%	0%	3%
	High	0%	0%	2%
Professionals	**Low**	1%	0%	0%
	Middle	1%	0%	2%
	High	0%	0%	3%
Broad minded	**Low**	1%	0%	0%
	Middle	1%	0%	2%
	High	0%	0%	3%
Socially minded	**Low**	3%	1%	1%
	Middle	1%	0%	3%
	High	0%	0%	2%
Balanced	**Low**	5%	1%	2%
	Middle	2%	1%	5%
	High	0%	0%	5%
Total (share of all the households)		35%	9%	56%

Table 3 below is used to calculate the average energy use in each income level and the share of households in each income level that live in stacked dwellings. The values in table 3 are retrieved from the model described in Appendix 2.

Type of house ownership → electricity + heat use + share in stacked

Table 4 Average energy use and share of households in stacked dwellings per type of ownership of a house.

	Electricity use (kWh/yr)	**Heat use (m^3/yr)**	**Share in stacked (%)**
Social rent	3085	1342	54%
Public rent	3066	1403	63%
Owner occupancy	3659	2023	13%

The average energy use in each income level and the share of households in each income level that live in stacked dwellings are calculated by multiplying the distribution of income levels over the ownership of a house in table 1 with the values in table 3.

Income level→ Type of house ownership, electricity + heat use + share in stacked

(Table 1 multiplied by Table 3)

$$\begin{bmatrix} 0.6 & 0.13 & 0.27 \\ 0.27 & 0.08 & 0.66 \\ 0.07 & 0.04 & 0.89 \end{bmatrix} \begin{bmatrix} 3085 & 1342 & 0.54 \\ 3066 & 1403 & 0.63 \\ 3659 & 2023 & 0.13 \end{bmatrix} = \begin{bmatrix} 3238 & 1534 & 0.44 \\ 3460 & 1794 & 0.28 \\ 3594 & 1950 & 0.18 \end{bmatrix}$$

Table 5 The average energy use in each income level and the share of households in each income level that live in stacked dwellings

Income level	**Electricity use (kWh/yr)**	**Heat use (m^3/yr)**	**Share in stacked (%)**
Low	3238	1534	44%
Middle	3460	1794	28%
High	3594	1950	18%

Finally, the values in table 7 are determined from table 5 and the distribution of each value pattern over the income levels presented in table 2. For the calculation of the electricity and heat usages per income level, the fractions of the average usages are used (3402 kWh/yr, 1726 m^3/yr).

Table 6 The electricity and heat usages per income level as a fraction of the average usages

Income level	**Electricity use (kWh/yr)**	**Heat use (m^3/yr)**
Low	0.95	0.89
Middle	1.02	1.04
High	1.06	1.13

Value pattern → Income level→ Type of house ownership, electricity + heat use + share in stacked

Table 7 The share of each agent type of the total energy use of the domestic sector and the distribution of the share of stacked dwellings of the total housing stock (32%) over the agent type

Agent type		**Share (%)**		
Value pattern	*Income level*	**Elec. use**	**Heat use**	**Stacked**
Caring Faithful	**Low**	7%	7%	3%
	Middle	5%	5%	1%
	High	2%	3%	0%
Conservatives	**Low**	8%	7%	4%
	Middle	6%	6%	2%
	High	3%	3%	0%

Hedonists	**Low**	5%	5%	2%
	Middle	4%	4%	1%
	High	2%	2%	0%
Materialists	**Low**	4%	4%	2%
	Middle	4%	5%	1%
	High	2%	2%	0%
Professionals	**Low**	1%	1%	1%
	Middle	3%	3%	1%
	High	4%	4%	1%
Broad minded	**Low**	1%	1%	0%
	Middle	3%	3%	1%
	High	3%	4%	1%
Socially minded	**Low**	4%	4%	2%
	Middle	4%	5%	1%
	High	2%	2%	0%
Balanced	**Low**	7%	7%	3%
	Middle	8%	8%	2%
	High	6%	6%	1%
Total (share of all the households)		100%	100%	32%