Eindhoven University of Technology

MASTER

Opportunities for energy saving in the Dutch household sector

van der Beek, E.

Award date:
2010

Eindhoven, August 2010

……….

Opportunities for energy saving in the Dutch household sector

by Ewout van der Beek

identity number: 0497279

in partial fulfillment of the requirements for the degree of

Master of Science
in (Energy) **Technology & Policy**

Supervisors:
dr.ir. G.P.J. Verbong, TU/e
dr.ir. A.J.D. Lambert, TU/e

Project Mentor:
ir. P. van Gennip, Ecofys/Plugwise

Table of Contents

Preface

> *"Energy and power are not terms within the natural language of mainstream householders. Gas and electricity operate at the level of the subconscious within the home... Whilst there does seem to be some latent cultural guilt about the notion of waste... there appeared to be virtually no sense of being able to actively and significantly reduce energy consumption in the household."*
>
> [Dobbyn and Thomas, 2005, p6]

Since the beginning of my quest for energy saving opportunities for my M.Sc. Thesis, there have been many interesting events. The journey began at the sustainable energy company Econcern. While meeting very nice people, getting more and more interest in the research, reaching the black belt for judo, getting a job offer at Econcern and visiting a marvellous conference at Malta, the tide turned…

The world suffered of the credit crunch, the Econcern ship was threatened to sink and job losses were on their way. There seemed to be so many justified and unjustified reasons not to finish this thesis immediately at that time, with a hospitalisation as its peak (or depth). Fortunately, I have been blessed by the many people around to encourage me, in many ways, to finish this investigation eventually.

Therefore I would like to thank my encouraging friends (especially René, Robin, Peter, Gijs, Bob, Jappe & Alexander), my supporting and critical colleagues (especially Vincent, Vera & Rob) and always faithful family members (specially my parents: Mijndert & Anneke). Finally, I would like to thank my project mentors Geert Verbong & Pim van Gennip for giving constructive feedback and suggestions.

Hopefully the next pages will give you a growing interest and more insight in the broad topic of energy saving within the household sector and its opportunities. Enjoy!

Ewout van der Beek

Summary

This research is set up to study energy saving opportunities within the Dutch household sector. With the help of literature a conceptual framework is constructed. After finding drivers of energy consumption and saving an Energy Saving Potential Model (ESP-Model) is explored to answer the main research question: "What are the technological, behavioural and political opportunities of energy saving in the Dutch household sector?".

The amount of energy consumption reduction within a sector is influenced by technological development, societal changes and the political climate. Perspective on promising drivers of energy consumption reduction, in these different multi-disciplinary directions, is investigated by literature studies, data collections and interviews with experts. The indicated drivers distinguished are divided in three directions. Technological drivers investigated are developments in (enabling) technologies as energy monitoring, energy efficient and energy saving equipment. Societal drivers for energy consumption or consumption reduction studied are demographic factors, cultural development, psychological and economic aspects. Driving policies examined are institutional (reinforcing) factors as taxes, subsidies and regulations.

After that, the (ESP-Model) is constructed to investigate the energy saving potential in the different areas and to compare different scenarios for energy consumption reducing opportunities. Subsequently, recommendations about changes needed in these areas, to increase the potential of energy saving, are done. These changes needed are mainly found in the development of technologies complementary to technological drivers, adjustments in feedback supporting changing in behaviour, more effectiveness of political measures and services an energy service company could provide.

Largest energy saving potential according to this investigation is in the use of more energy efficient and energy saving equipment supported by feedback on electricity consumption. However, the success of energy consumption reduction within the Dutch household sector ultimately is considered to be dependent on an well-organized combination of changes in technological, societal and political factors enforcing each other.

1 Introduction

Until some decennia ago the amounts of used energy in households was no source of concern, hardly any inhabitants were aware of their energy consumption. One did not really care about energy consumption, since it represented only a minor part of all daily expenses. Nowadays high energy prices and concerns about the environment ask for saving of energy.

To reach a more sustainable energy system in the future, it is essential to reduce or limit the total energy requirement. Energy consumption will not only have to be limited or reduced by improving the energy efficiency, but also by changing consumption patterns. The IPCC (2001) holds change in consumption patterns as a possible response option to the treatment of climate change, but the option of changing consumption patterns is insufficiently applied. For an efficient consumer energy policy, it is important to know how the energy requirement of consumption patterns is established and why some households require more energy than others [Vringer et al., 2007].

Studies have shown that feedback on energy consumption often has little impact on the motivation to conserve energy except if it is given over the short term and in combination with some other encouragement to save energy, whether to spur competition, set a goal, or attain a commitment from the consumer [McCalley et al., 2005]. For this reason Ecofys, an Energy Service Company (see Appendix A), specialised in research and consultancy on energy saving, sustainable energy sources and climate policy, is convinced that clearness of the energy consumption will help energy saving. Consequently the concept of the *EnergyMirror* has been developed by Ecofys from 1994. Such a ‘mirror’ shows easily whether the energy consumption of a building is below or above a reference value. Consequently, considerable energy awareness is realised by the encouragements stated above, which is the beginning of energy savings. Ecofys is looking for possibilities to expand their activities to households in Europe. However, little information about the effectiveness of energy feedback on households is available to them and specific services for the consumer market have yet to be developed. In this research the perspective on promising energy saving mechanisms, within the household sector, is investigated with a focus on the effects of feedback on energy consumption.

1.1 Final Objective

The final objective of this investigation is to find opportunities for energy consumption reduction within the Dutch household sector. Furthermore this research points towards service opportunities for ESCOs advising on energy consumption and energy consumption reduction to obtain more energy saving potential. In addition percentages on saving potentials of different energy saving measures are given to give recommendation on the opportunities. Another objective of this investigation is to construct an empirical model to structure the research and to illustrate the implications of several energy consumption reducing measures by energy saving scenarios.

1.2 Problem Definition

The Dutch government is committed to the national energy consumption reduction plan and has ambitious targets aimed at reducing national CO_2 emissions in the residential sector. They will shortly develop a new energy efficiency strategy for existing homes which will consider how to deliver increased savings. The reduction plan enhances sustainable development[1] by reducing both the consumption of fossil fuels and the emission of carbon dioxide and other polluting substances to the air. Additionally, the consumption of less energy will reduce energy costs, so energy saving will support ecological as well as economical sustainability.

The amount of energy consumption reduction within a sector is dependent on technological changes, behavioural changes and the political climate. The opportunities of energy saving in the Dutch households within these areas are unclear; the main research question therefore is:

“What are the technological, behavioural and political opportunities of energy saving in the Dutch household sector?”

---

1 “Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” [UN, 2008]

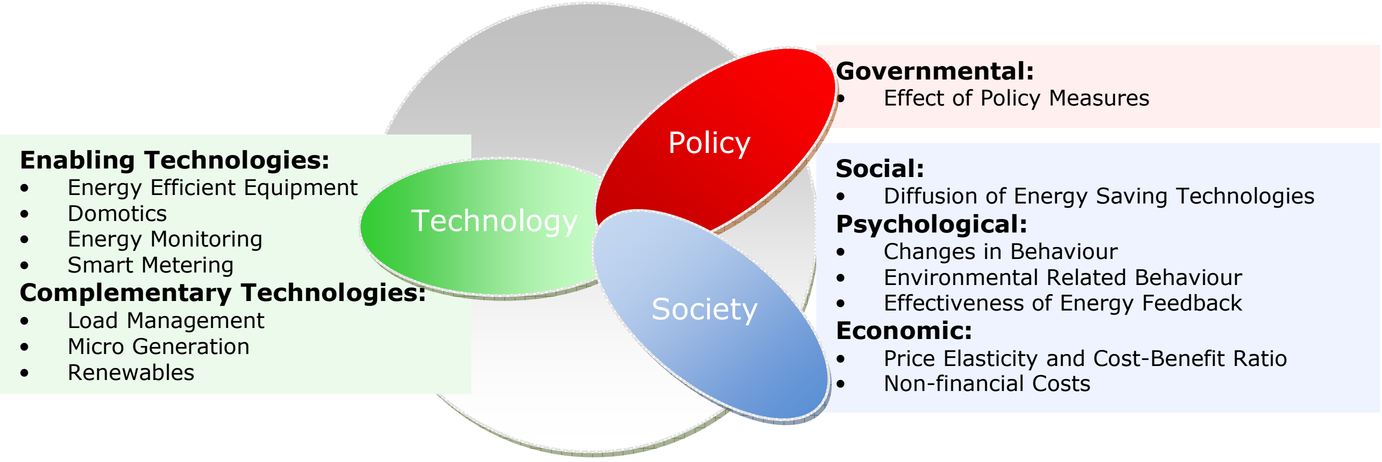
In this investigation the following sub-questions to answer the main research question are answered:

- "What are the main drivers for households to save energy?"
- "Will households save more energy when they get feedback on their consumption?"
- "Will households save on energy consumption on just feedback?"
- "Which changes in technology, behaviour or policy will be most effective and how will they interact?"
- "Which services will be provided to increase the energy consumption reduction in the Dutch household sector?"

1.3 Approach

1.3.1 Conceptual Framework

To find answers on the questions stated earlier a systematic investigation of knowledge is undertaken in the different multi-disciplinary directions: Technology, Society & Policy. This section contains a division of different concepts that are examined in this assessment. These interconnected concepts will be utilized as building blocks for the scenario model that is constructed in this research.



Governmental:
- Effect of Policy Measures

Enabling Technologies:
- Energy Efficient Equipment
- Domotics
- Energy Monitoring
- Smart Metering

Complementary Technologies:
- Load Management
- Micro Generation
- Renewables

Social:
- Diffusion of Energy Saving Technologies

Psychological:
- Changes in Behaviour
- Environmental Related Behaviour
- Effectiveness of Energy Feedback

Economic:
- Price Elasticity and Cost-Benefit Ratio
- Non-financial Costs

Figure 1: Conceptual Framework

Different kinds of technological developments offer possibilities to reduce the consumption of energy with help of feedback on energy use. These possibilities can be divided by enabling and complementary technologies. Enabling technologies in this investigation are required to make energy savings and effective energy feedback possible. Complementary technologies facilitate new functionalities when feedback of energy consumption is put into operation.

Within the area of society a distinction between social, psychological, economic aspects of energy consumption reduction is made. Social aspects contain diffusion of innovation and the effectiveness of feedback on societal behaviour. Psychological aspects contain the mental processes and individual behaviour concerning feedback on energy consumption. Economic aspects contain the relationship between energy consumption and monetary factors.

The field of policy contains intentions, to conduct decisions and achieve reasonable outcomes, of the implementation of the energy saving technologies for energy consumption reduction. In this case policy applies to objectives of government to reduce energy consumption and of ESCOs to offer innovative services.

1.3.2 Energy Saving Potential Model

With help of the outcomes of the systematic investigation above an energy saving potential model (ESP-Model) is constructed. This ESP-Model is needed to show the correlation between energy saving measures and to give recommendations to support energy saving in the Dutch household sector. The model, constructed in Excel, contains general historic data on housing and energy consumption derived from different data sources. With numbers on growth and predictions on changes in energy demand is modelled what the energy demand in 2020 for Dutch households would be and how the energy demand could be reduced best.

The outcomes of the model are figures on energy saving potential in different scenarios. In the model energy saving potential is forthcoming by a combination of socio-economic trends, energy saving activities as well as feedback mechanisms and policy options to influence energy consumption. Accordingly the model contains data from the three stated areas of investigation. From the outcome of the ESP-Model, constructed in Excel, the correlation between the several areas of investigation and drivers of energy consumption and savings are illustrated to support the answers on the research question. The outcomes of the different scenarios can be applied by the ESCOs to identify the service opportunities and by governments and industries to identify the most effective measures for energy savings.

1.3.3 Methods of Research

The underlying research sub-questions are investigated by means of a study of literature and interviews with external experts. Together with this study, different data analyses are prepared to examine the impacts of feedback on energy use, technological changes and political changes on energy consumption. Based on this assessment the opportunities and threats for energy consumption reduction are investigated. The empirical analysis is based on existing information and gathered data on energy feedback, and on energy consumption reducing changes in technology, society and policy. Subsequently, a model has been made to discuss the relation between the several drivers of energy consumption and saving. This conceptual model consists of the three stated areas of investigation which are connected with socio-economic trends, energy saving activities as well as feedback mechanisms to indicate drivers of energy consumption and potentials for energy saving.

The empirical analysis, which is the fundament of the ESP-model, is based on the theories this conceptual model contains. The theories of changes in society are primarily based on papers of for instance W. Abrahamse (behavioural change) and S. Darby (feedback on energy use). Figures on changes by policy are modelled earlier by P.G.M Boonekamp (2005). For developments in technology different data sources on best practice gas and electricity appliances are used [Darby, 2006; Abrahamse, 2007]. To investigate energy saving potential quantitatively general historic data until 2009 on housing and energy consumption are derived from sources as CBS and VROM.

Based on the ESP-model, scientific literature on changes in energy consumption and on interviews with experts in the field of energy, different scenarios to 2020 are constructed. Data analyses have been done to examine the impact of the changes on energy consumption reduction and to consider the likely impact of services to be provided to increase energy saving potential. Based on this assessment the opportunities and threats are investigated further. Summarised the investigation to answer the research questions consists of:

- A literature study in the different areas as stated above
- Interviews with energy experts: consultants, policy organisations, consumers
- Data collection and analyses of data gathered from energy monitoring projects
- Construction of an energy saving potential model for the Dutch household sector
- Applying this model by calculating different energy saving scenarios

1.3.4 Limitation

In order to start the investigation the position of this study must be determined. The study has to be broad enough to cover the desired answers within the multidisciplinary scope, however not too broad for the relevance of the outcomes of this project. The target group within the scope of this research is: European occupants, paying their own energy bills with marginal costs per unit of gas and electricity. The actors important in this investigation are the energy consumers, government, energy companies, manufacturers of energy consuming equipment and energy saving service companies.

Boundaries	**Within scope**	**Out of scope**
Market	Households	Companies
Pay Mechanism	Contribution, Pay-as-you-go	Inclusive in rent
Resources	Electricity, Heating	Water
Regions	Netherlands, EU	Other regions
Technology	Smart Metering, Domotics, Design	ICT
Services	Energy Saving, Load Management, Renewables	Other services

Table 1: Position of the project

1.3.5 Structure of the report

After this introduction, in which the final objective, problem definition and approach have been explained, the different research concepts concerning energy saving theories and drivers of energy consumption and saving in general will be introduced in Section 2.

In Section 3, 4 & 5 drivers of energy consumption and savings in the areas technology, society and policy are further described. This investigation together with the constructed conceptual framework will lead to the conceptual model on energy saving and ESP-Model in Section 6. The next step in this research is to identify in which of the areas (technology, society and policy) the main developments should take place, to save on energy consumption optimally by considering different scenarios to 2020 in Section 7.

Section 8 consists of a summary of the drawn conclusions, answers on the sub-questions and recommendations for further investigation. Finally opportunities and threats for the implementation of new services are derived.

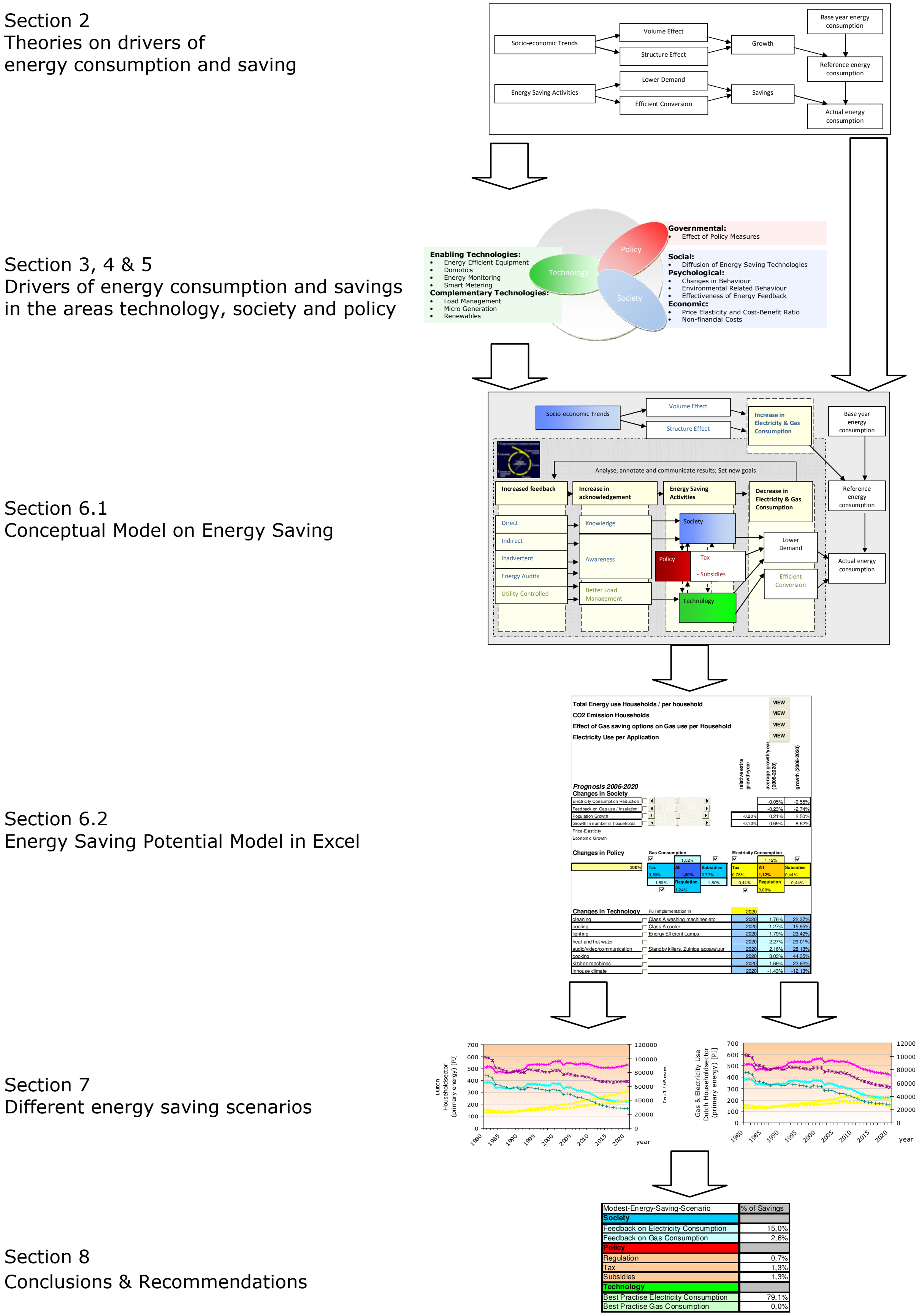


Figure 2: Graphical representation of the structure of the investigation

2 Literature Review

2.1 Energy saving

Household energy use and conservation are related to a broad range of different concepts. In this section the role of energy savings and a general description of saving from energy management by creating awareness is given. Major policy issues related to the energy system are security of energy supply, high cost of energy carriers and environmental problems. Potential solutions to these problems are substitution between fossil fuels or with nuclear energy, increased use of renewables, enhanced savers on energy consumption, and implementation of advanced technologies to capture the harmful emissions. In energy policy the problems mentioned have been summarised into three goals: the energy supply system should be reliable, affordable and clean. Energy savings is one of the potential solutions contributing to each of the goals in competition or cooperation with the other solutions [Boonekamp, 2005].

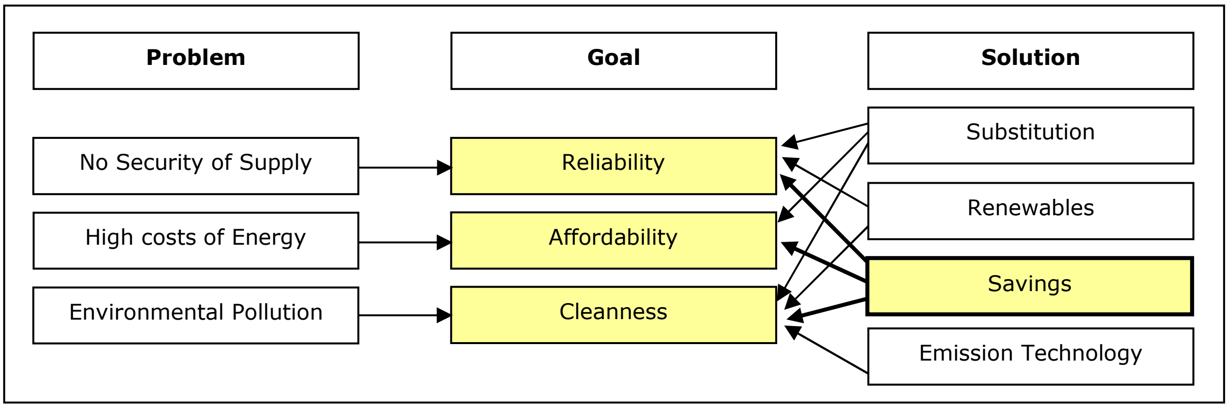


Figure 3: Role of energy savings as solutions to problems and policy goals for the energy system

To reach these goals, a strategy, known as *Trias Energetica*, has been introduced by Novem, the Dutch energy agency, in 1996. The strategy consists of three consecutive steps to conserve and clean the energy demand.

1. Limit the energy demand (insulated buildings, change behaviour)
2. Use sustainable energy sources (rest heat, solar energy, wind, etc.)
3. Efficient use of fossil fuels efficiently and clean (high efficiency) [SenterNovem, 1996]

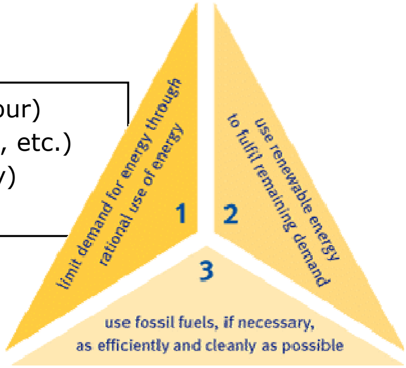


Figure 4: Trias Energetica

Within the principle of this Trias Energetica the logical first step is limiting the energy demand, since a decrease in energy consumption will also limit the demand of more renewable energy or cleaner use for the amount of saved energy. This supports the thesis' main focus on energy consumption reduction. There are different approaches to limit the demand for energy. One of the ways to achieve energy consumption reduction is by energy management. Here a commitment to continuous improvement is needed in order to achieve a dynamic energy consumption reduction cycle. The steps needed for this continuous energy management cycle are shown in Figure 5 [van Gennip, 2007].

1. Arrange commitment to continuous improvement
2. Assess baseline and goals
3. Action
4. Analyse
5. Annotate and communicate results
6. Acknowledge
7. Achieve energy consumption reduction

Figure 5: The seven A's of Energy Management

In general energy management takes place in companies; the underlying principles however will give support to create awareness for consumers in households as well and will therefore be useful for energy conservation in dwellings too. According to Abrahamse (2007) the provision of information about energy-saving measures at home is presumed to lead to an increase in households' knowledge of energy conservation, which in turn might result in the adoption of energy saving behaviours. Wilhite and Ling found that the most effective way to increase energy consumption reduction was to higher the frequency and accuracy of energy bills. They set out what they called *chain of causation from bimonthly, accurate bills with historic feedback to savings*. Additionally other studies have shown that historic feedback is likely to be more effective than comparative feedback. This is investigated in Section 4.2.3 [Wilhite & Ling, 1995; Roberts et al., 2004].

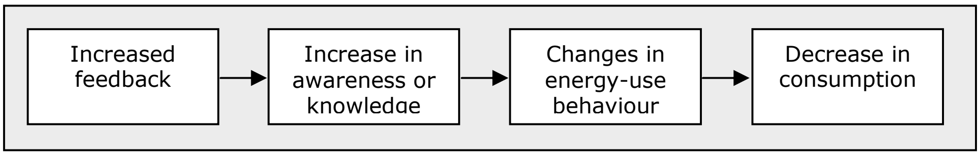


Figure 6: Chain of Causation from frequently accurate bills with historic feedback

Changes in total energy consumption, from one year to the next, are influenced by socio-demographic-economic developments. In an advanced economy the amount (volume) of socio-economic activities (represented by GDP) normally increases over a period of time, while all other factors remain equal, energy consumption then will increase too. A changing composition (structure) of economic activities may further increase energy consumption, but could diminish the volume related increase as well, depending on the energy intensity of the various economic activities. The trend for fewer people per household increases energy consumption, since more dwellings are needed for the same amount of people. The net effect of volume and structure effects normally result in higher energy consumption from one year to the next. Energy saving activities will result in a lower energy demand and to more efficient energy conversion. Those activities can be the result of policy measures or of energy saving technological developments.

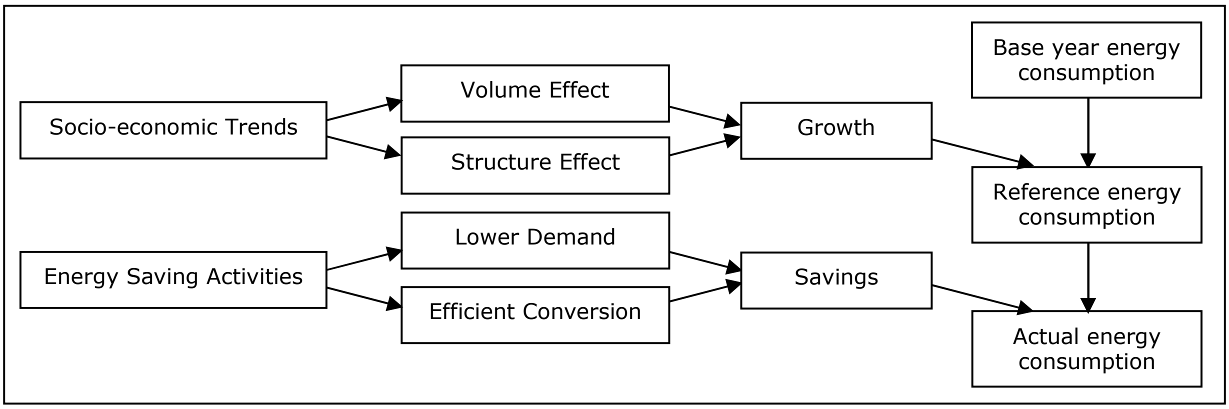


Figure 7: General framework for determining energy trends and energy savings

2.2 Drivers of Energy consumption and saving

In this thesis, the main drivers and opportunities for households to save energy are investigated. However to investigate drivers to save energy, it is convenient to consider factors causing the increase household energy consumption first. One way of categorise these factors may be referred to as *the TEDIC factors* [Abrahamse, 2007]:

○ **Technological developments**	- e.g. energy-intensive appliances;
○ **Economic growth**	- e.g. increase of household incomes;
○ **Demographic factors**	- e.g. population growth;
○ **Institutional factors**	- e.g. governmental policies;
○ **Cultural developments**	- e.g. emancipation

Furthermore Green and Kreuter (1991) in their *PRECEDE-PROCEDE* model describe three general categories of factors that make up the determinants that affect behaviour and environment. The categories they distinguish are predisposing, enabling and reinforcing factors. Each of these factors has a different influence on behaviour:

- **Predisposing factors** are especially internal drivers to motivate behaviour such as knowledge and attitudes in the target group.
- **Enabling factors** are the external drivers to behaviour, belonging to the situation, such as capacity, resources and the availability of services
- **Reinforcing factors** are different kinds of feedback on behaviour and moreover opinions and behaviour of others [Green, L.W., & Kreuter, M.W., 1991]

The described *TEDIC* and *PRECEDE-PROCEDE* factors are divided in the three stated areas of investigation as follows:

Technology	- Technological developments *(mainly enabling factors)*
Society	- Economic growth, demographic factors & cultural development (mainly predisposing factors)
Policy	- Institutional factors *(mainly reinforcing factors)*

The success of energy consumption reduction is considered to be dependent on technological, societal and political factors as stated earlier. Within those areas there can be distinguished two categories of strategies to obtain energy consumption reduction. The psychological intervention strategy reduces the consumption by reducing the energy demand, while the structural intervention strategy by improving the systems and appliances [Steg, 2003].

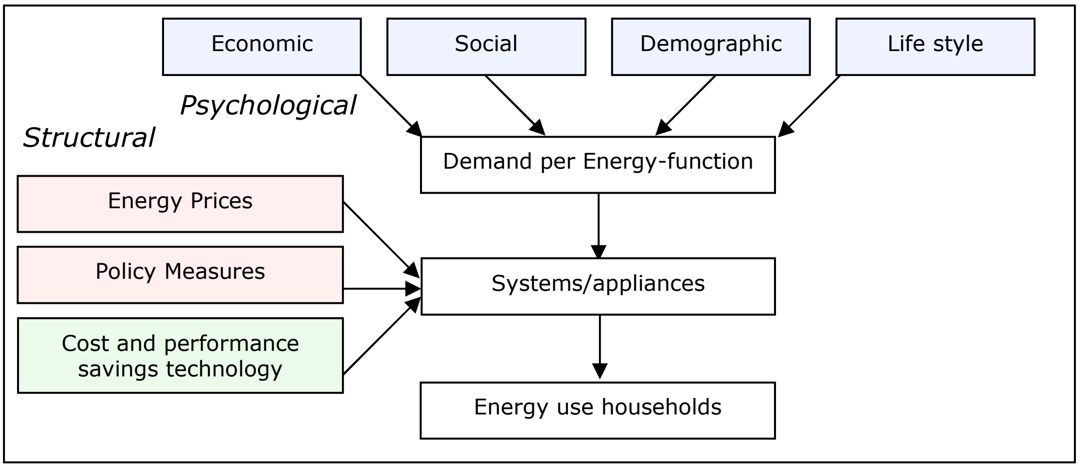


Figure 8: Structural and Psychological strategies to change household energy consumption

Within the structural interventions some strategies for energy consumption reduction are distinguished and can be divided over the areas of technology and policy. Psychological interventions are aimed at developments in the field of society.

3 Technology Drivers

Energy consumption reduction caused by technology drivers will only take place when new energy efficient or energy saving equipment is diffused in society. Within this field a distinction is made between enabling and complementary technologies. Enabling technologies are required to make energy savings by effective energy feedback possible. Complementary technologies can facilitate new energy saving functionalities when home energy monitoring is put into operation. Both enabling and complementary technologies described in this section are considered to be the technological drivers of energy savings.

3.1 Enabling Technology

3.1.1 Energy Efficient & Saving Equipment

Consumers often fail to account for energy costs when purchasing equipment, even though more energy-efficient equipment with comparable features and performance is available for the same price. In this section is examined what the effect would be on energy consumption if more energy efficient equipment would be used. By means of numbers on electricity consumption of individual appliances in the Dutch households, their penetration grades and average yearly consumption an overview of sources of electricity consumption is constructed as shown in Appendix B [Senternovem, 2008; VROM, 2007]. From this overview and energy saving potential estimations for the individual appliances, calculations for the average Dutch household have been done. *Top10*, an initiative from foundation “natuur en milieu”, offers an independent overview of the most energy efficient equipment for the Dutch household sector. The website of *Top10* can be visited to find the best practice applications in different appliances like TV, washing machines or cooling equipment and lighting. The data on this website has been used to determine the total energy saving potential by switching to energy efficient equipment [Top10, 2009].

In *Table 2* below electricity use of different appliances in Dutch household sector are shown. The expected average electricity use per appliance per year is compared with the energy saving potential of best practice equipment. Energy saving potential is based on the switch between regular appliances to A/A+/A++ label machines. The table below shows that by the use of this energy efficient equipment the average energy consumption of a Dutch household in 2009 goes from 3632 kWh to 2146 kWh per year, which is a saving of 41%.

One can see that a large amount of electricity within a household is used for cleaning appliances. The washing machine, dryer and dishwasher together use 21 % of all electricity use within a household; whereas large savings could be done when best practice equipment would be used (+/- 55%). Furthermore large savings (75%) can be achieved by lighting when light bulbs are replaced with energy saving lamps. This type of structural energy saving can be seen as long term saving not depending on the change of behaviour. Within the average Dutch households about 10% of all electricity consumption is used by equipment using standby power. The impact of avoiding this standby power use is also taken into account. Switching of these appliances or using standby killers would save approximately 333 kWh in an average household.

	Yearly Electricity Use Average Household		Yearly Electricity Use Best Practice Average Household		Electricity Savings
	Kwh/year	%	Kwh/year	%	%
Total	3632	100,0%	2146	100,0%	40,9%
Lighting	584	16,1%	146	6,8%	75,00%
In House Climate	127	3,5%	121	5,6%	5,00%
Cooling Equipment	395	10,9%	168	7,8%	57,62%
Dish Washer	168	4,6%	98	4,6%	41,63%
Wash Dryer	359	9,9%	119	5,5%	66,91%
Washing Machine	219	6,0%	116	5,4%	47,02%
Television	214	5,9%	145	6,8%	31,90%
Rest Equipment	1566	43,1%	1233	57,5%	21,26%

Table 2: Energy efficient equipment

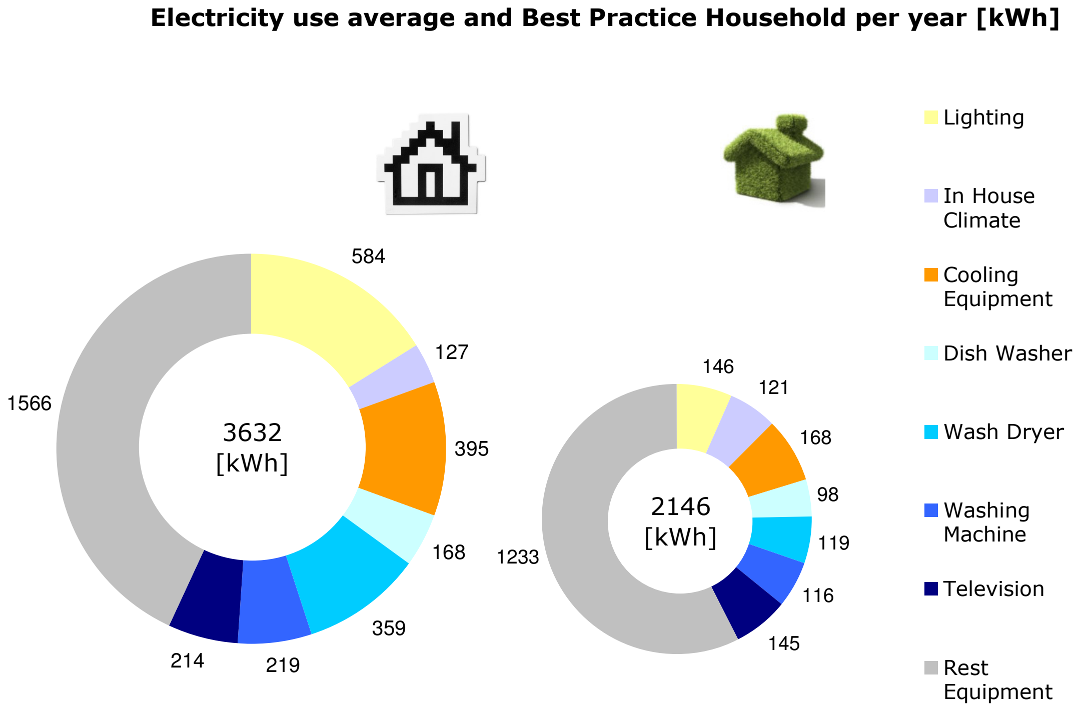


Figure 9: Electricity use average and best practice appliances per household

Besides energy efficient equipment there are also measures to save on gas use by installing insulating materials and energy efficient heating systems. These insulating materials are used to reduce the rate of heat transfer within the households to decrease the use of gas. These energy efficient heating systems and insulating measures with the highest potential for energy savings (wall, glass, roof and floor insulation) are investigated in this research. When these energy saving measures would be installed in all Dutch households the gas savings could be approximately 39%.

	Average Gas Savings measure	Penetration Grade in 2007	Maximum Penetration
	m^3	%	
double glazing	500	69,6%	100%
roof insulation	450	92,0%	100%
wall insulation	420	75,1%	100%
floor insulation	350	54,8%	100%
HE Heating System	315	59,9%	100%

Average Gas Consumption (m^3)	1472	895
Gas Savings (%)		39,2%

Table 3: Gas saving measures and penetration grades

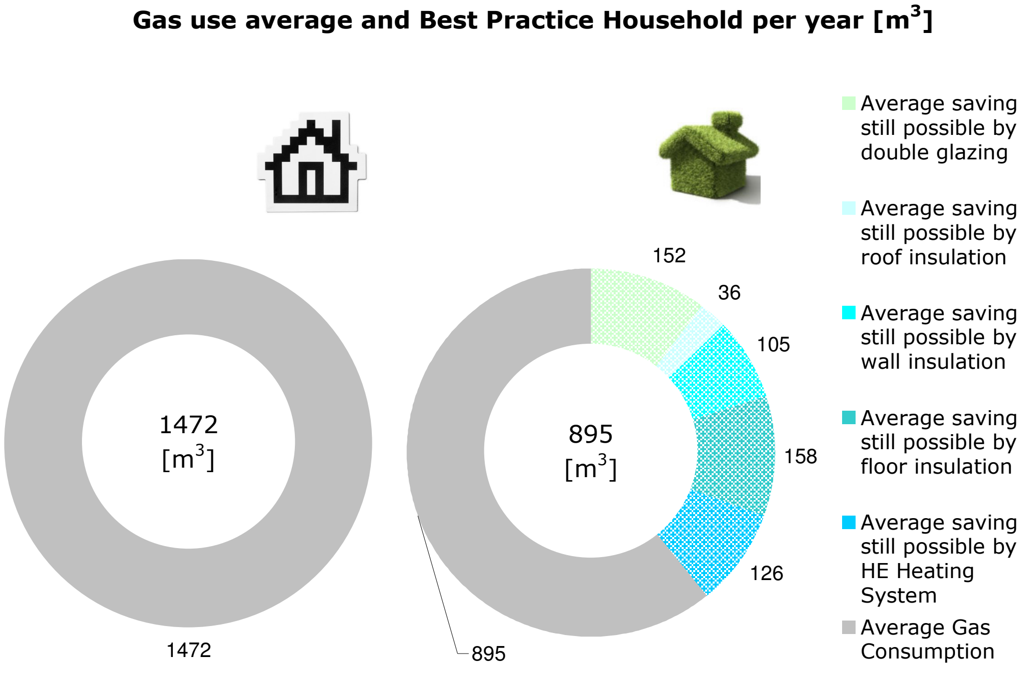


Figure 10: Gas use average and best practice measures per household

It has been acknowledged that efficiency improvements are necessary for sustainable development [Hinterberger, Kranendonk, Welfens, & Schmidt-Bleek, 1994]. However, technological innovations can only offer partial solutions, as the effectiveness of technological measures centres upon the adoption of new technology by consumers (see Section 4.1) and the extent to which consumers know how to use these technologies efficiently. Moreover, even when one acquires energy efficient equipment, there evidently still has to be a minor change of behaviour. For instance a smaller cooler asks for different ways of buying grocery, the colour of light from a light bulb is different as from an energy saving bulb and the installation of gas saving measures can be time and money consuming.

Furthermore, reducing energy consumption does not always have the desired effect in terms of energy saving impact, because of so-called rebound effects. A rebound effect refers to a counterbalancing or even a complete disappearance of initial energy efficiency gains. One type of rebound effect occurs when households spend the money they saved on energy use on energy-intensive goods and services. A second type of rebound effect is related to the implementation of energy efficient and saving equipment. When using energy-saving light bulbs for example, it may be that energy consumers leave them always on. Hereby initial efficiency gains are counterbalanced. Rebound effects are therefore important to take into consideration [Berkhout, Muskens, & Veldthuisen, 2000]. The changes in behaviour needed for or caused by these technological developments are further elaborated on in Section 4.2.1.

3.1.2 Domotics

Domotics stands for electronic communication between all kinds of electric applications in the house and its environment in favour of households and service providers. The expression *domotics* is derived from the words *domus* (house) and *telematics*. It has been introduced in 1994, on the Dutch market by Domotica Platform the Netherlands. Domotics is a continuation of the electrification of the house and the first production in the Netherlands of domestic equipment in 1908.

In a domotics house care tasks, communication, entertainment and other home activities have been made easier by many electric equipment and networks. It includes all electronic applications in the house to control (heat, ventilate, relieve, etc.) and external services (internet, telephone, television, etc.). This happens at preference in a flexible way: on each spot and at each time that it is appropriate, with ease of use if required controlled on distance. Domotics is particularly about consumers' electronics, mutually linked by an electronic network. It contributes to the pleasure, the value and sustainability of living in an efficient manner. In the Dutch world of domotics, the development has not truly started yet. The solutions for savings on energy consumption provided by domotics are mostly integrated in full home management systems and other applications for domotics. In consequence these systems are very expensive [Domotica Platform.nl, 2007].

Plugwise, a dutch company founded in 2006, developed a wireless energy management system which is a step in the direction of domotics for energy saving. Their product is a plug to put in between equipment and the contact box. This plug is able to measure electricity use, configure the electricity circuits and to gives a household the possibility to switch equipment remotely and save on energy-bills.

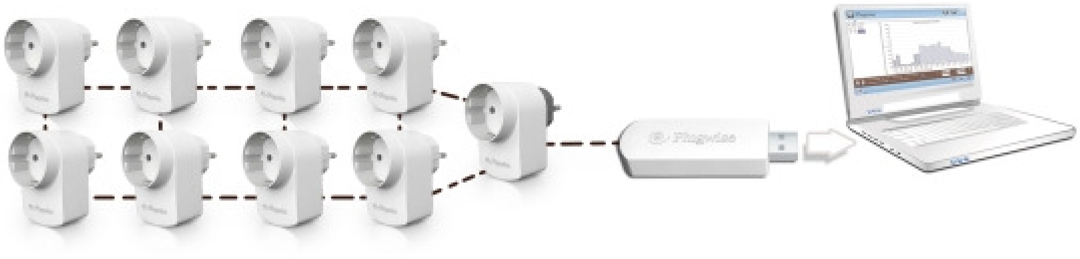


Figure 11: Plugwise: wireless energy management system

It is hard to estimate at what speed the diffusion of domotics or comparable energy management systems will take place in the coming years until 2020. Nevertheless the use of domotics can play a major role in more balanced energy consumption and in feedback on energy use of specific appliances. Therefore the ESP-Model doesn't describe this variable as a single variable but it is part of the energy consumption feedback system scenarios discussed in Section 7.4.

3.1.3 Energy Monitoring

Energy Monitoring is a way to monitor the various flows of energy. Feedback on energy consumption is given through either linked display units or by the use of media, such as internet or television. This will raise awareness about the cost of power and encourage consumers to reduce energy consumption during times especially when the price is high.

Since there is a growing societal awareness that the energy consumption contributes to environmental issues, that fossil fuels are not infinite and that this shortage leads to geopolitical tensions. Therefore the demand for more economic ways to use energy rises to contribute to a solution of the problems mentioned earlier. The planned rollout of the smart meter (see Section 3.1.4) and regulation towards providers of energy-using products and services to give the user insight into their consumption, will lead to more monitoring. There are many examples of feedback analysis and presentation in the industrial sector. They are often designed for use by an energy manager and tailored to suit the clients' need. Within Ecofys already several projects on energy monitoring have been taken place. For example there are two generations of the EnergyMirror which is an energy monitor for the build environment [Priva, 2010].

Figure 12: First and Second Generation of the EnergyMirror

Another example is the Eclipse, a monitor of solar-generated energy. In the domestic setting however there are fewer examples, although some energy monitoring devices are available.

Figure 13: Eclipse

3.1.4 Smart Metering

The smart meter is the name of a new type of advanced meter that is introduced in the Dutch household sector since January 2008. This smart meter allows the local energy distributors to track how much energy is consumed and what time it is consumed. One of the objectives is to be able to monitor energy consumption which might eventually lead to energy saving. Given that the measured energy consumption data is communicated to the energy suppliers and feedback is given to households, energy consumption reduction could be achieved by creating awareness by consumers. In September 2007, the Dutch government proposed that all seven million households of the country should have a smart meter by 2013, as part of a national energy consumption reduction plan. On April 7th 2009 the Dutch government had to stop the plans to implement the smart meter in Dutch households after consumer groups raised privacy concerns. Instead of a mandatory role out smart meters will now be discretionary [European Parliament, 2006].

The smart meter identifies consumption in more detail than a conventional meter and communicates that information via a network back to the local utility for monitoring and billing purposes [CBC, 2005]. These meters can be controlled from a distance and subsequently can be used for load management or new forms of contracts (in- or decrease consumption by certain taxes, pay-as-you-go) which is a convenience for energy suppliers. Furthermore, the collected information could be used to get understanding of the users profile and opportunities for energy saving. Finally the smart meter should be able to communicate with machinery in the house, like the washing machine or dryer. Automation within houses (see Section 3.1.2) could be utilised in the house to realise energy saving on moments in which the prices are high or when certain norms are exceeded. Smart meters have communication capability, which allows energy suppliers to communicate directly with their customers, removing the need for meter readings and ensuring accurate bills with no estimates.

Summarised advantages the smart meter could offer:

- More accurate estimated bills;
- Information assisting consumption of less energy and energy efficiency;
- Lower costs through reduced peak consumption;
- New contract forms (pay-as-you-go);
- Increased security of supply.

On the other hand there are some difficulties with smart metering:

- Less privacy for the smart meter users;
- The smart meter itself will have to be paid;
- Hard to decide who has control over the smart meter

[Siderius et al., 2006; Energy Saving Trust, 2007]

The introduction of the smart meter came with high expectations. However, the smart meter might not be able to meet these expectations. A workgroup focussed on the technical lay-out of the smart meter. The result is a typically compromised product, in which the price of production of the meter was important. The possibilities for communication with the meter are unsatisfactory. The smart meter might ultimately be not so “smart”, with little opportunities to reduce energy consumption. Smart metering and energy monitoring in itself won't lead to energy savings without relevant feedback. The effects of feedback on energy consumption via monitoring and its position within the ESP-Model are further discussed in Section 4.2.3 [CBC. 2005; Smith et al.,2007].

3.2 Complementary Technologies

3.2.1 Load Management

Losses in transmission and distribution networks represent the single biggest use in any electricity system. In the Netherlands, average network losses currently are around 7% of total electricity use. These network losses mainly depend on factors as network design, operation and maintenance. The higher loads on power lines, the higher the networks' variable losses. This means that a trade-off between load and losses should be made. Since investment costs to decrease losses in the network are high, the optimal balance from cost point of view is obviously not the most energy efficient one.

The current tariff systems on networks in most European countries are not favouring network efficiency. In some European countries a price cap on the network tariff discourages investments in network efficiency. The price cap prevents operators from saving enough cash for efficiency investments, while the lack of a price cap on network losses would make such investments unattractive since the losses would be paid by the customers anyway. In other European countries maxima are set for the amount of network losses that can be charged through. This forces network operators to prevent losses from increasing, but it does not yet stimulate them to reduce losses [Targosz, 2008]. However, without investments in the network itself there are still means to lower the network losses. System-wide savings can be accomplished by better load management through reduced demands in peak hours. This can be achieved by time-of-use pricing. Within the well-known concept of time-of-use pricing electricity prices are set for specific time periods. Prices for electricity consumed during the different time periods are pre-established and known by consumers in advance. This will allow them to vary their consumption pattern in response to the changing prices by shifting usage to a lower cost period [Sargent, 1985].

The two prominent time-of-use tariff systems are the two-part pricing system[2] and peak load pricing[3]. The first alternative is well-known in the Netherlands and it gives consumers the opportunity to save money by using relatively more electricity during the nights and weekends. The second option might be an option when smart metering and domotics or comparable energy management systems will be implemented in a large number of households. These kind of systems provide possibilities to manage network load in an efficient way dividing consumers energy consumption smoothly over times when there is a low electricity demand [CBC, 2005]. By efficient load management network losses could be much lower. However, the probability that lots of households until 2020 will have implemented an efficient domotics system, as been stated before, is very unpredictable as well. Additionally the amount of kilowatts consumed by appliances that can be used overnight (dish washer, washing machine, dryer) is very low, and so is the effect of this on load management. So therefore the ESP-Model doesn’t describe this variable as a single variable.

3.2.2 Micro generation

Micro generation is the generation of zero or low-carbon heat and power by individuals, small businesses and communities to meet their own needs. Micro generation technologies include small scale wind turbines, water turbines, ground source heat pumps, solar thermal collectors, solar electricity and Micro CHP installations. The use of these installations can help reduce net consumption of energy since less energy is demanded from the energy companies.

The two main ways to reduce network losses, as described above, are designing the network system with power lines as direct as possible and to reduce the number of transformation steps. For this reason it is often assumed that micro generation systems reduce network losses in every situation. Reality is not so simple; micro generation systems only reduce network losses if the energy is consumed locally in urban or densely populated areas.

---

[2] With this system, a fixed charge reflects capacity and distribution charges whilst a variable charge is based on on-peak and off-peak costs. This approach eliminates distortions caused by average cost-pricing, enabling customers to face the true costs of additional electricity purchase [Berg, 2006].

[3] With this system, electricity is priced at higher levels during periods of highest demand. Such an approach signals users that continuing high levels of usage are imposing high costs on the system (as when the system capacity must be expanded sooner than otherwise would be the case). Usually, the higher prices are in effect during a specific set of hours [Berg, 2006].

Intelligent control systems for micro generation units could take the energy losses of the involved network cable into account. If the losses would be too high, the control system could switch the micro generation unit off the grid. Such a system would be particularly interesting if the micro generation unit were to be combined with local energy storage. In this case, the micro generation unit could continue to generate power when it went off grid and then inject this power into the grid at later time. On the other hand in this case battery storage losses will have to be taken into account. By implementing micro generation systems on a larger scale in urban areas losses could be much lower. Still, the use of micro-generation systems won’t reduce direct energy consumption.

3.2.3 Renewables

The use of sustainable energy sources such as solar and wind power placed near the households can reduce the net consumption of energy. As the name already reveals renewable energy sources are able to be regrown or renewed. Since they have an ongoing or continuous source of supply they are not finite. For this reason solar and wind power are renewable and coal is not [Darby, 2006; Ecostream, 2007].

The total avoided use of energy by the use of renewables between 1990 and 2009 has grown from 0,67% to 3,44%. The Dutch government aims at 20% in 2020. However, the largest contribution in this sustainability is caused by biomass combustion and large wind turbine parks and the avoided amount of energy holds for the total amount of energy use in the Netherlands. The use of privately owned renewable energy sources is very marginal. Furthermore it would be a separate study to perform Life Cycle Analyses on energy on all different renewable sources. Moreover this investigation focuses on means to decrease energy consumption. The use of renewables however does not centre on energy consumption reduction although it can decrease the negative environmental effects of energy consumption. These motivations considered the use of renewables would not give an extra value in the ESP-Model. Therefore the ESP-Model won't consider the use of renewables [CBS, 2009].

4 Societal Drivers

There are many societal drivers for households to save energy consumption. However, changes in economic growth, demographic factors and trend are also the main drivers to consume more energy. For this investigation common numbers for energy consumption growth are calculated on the bases of reports of RIVM on population growth and average size of Dutch households. According to their estimations the population in the Netherlands in 2020 will be around 16,8 million people and the number of households will be 7,9 million. The average growth of number of households, between 2009 and 2020, will be 0,7% per year. The average growth of size of households between 2009 and 2020 will be -0,5% per year and goes from 2,2 to 2,1 persons per household. The amount of electric appliances per household will grow due to cultural developments. Therefore, the total gas and electricity consumption growth, due to social factors, will be 0,7% compared with an unchanging population size. The gas and electricity consumption per household due to social factors will decline with 0.5% per year compared with an unchanging number of people per household.

In general energy consumers do not give their energy consumption entirely rational thoughts. The majority sticks on in the mainstream routines or imitate the behaviour of other consumers. The societal drivers for energy consumption reduction therefore are hard to investigate since energy saving asks for a restricting change in behaviour. A restriction is experienced negatively because it usually means that one cannot do something that one actually wants to do. Therefore reducing energy consumption is not very popular while it costs people effort and reduces comfort generally. This section contains societal drivers of energy consumption reduction originating from the areas of sociology, psychology and economy.

4.1 Social

4.1.1 Diffusion of energy saving technologies

Everett M. Rogers (2003) theorises that innovations spread through society in an S curve, as the early adopters choose a technology first, followed by the majority, until a technology or innovation is ordinary. The effective use of energy saving technologies and smart metering as feedback system for energy conservation can be seen as such an innovation which has to be diffused in this way [Rogers, 2003]. An innovation or new technology, such as an energy saving measure, slowly spreads within the social system. Not everyone will immediately benefit from a new measure. This section discusses some general theory on leaders, followers and laggards in an innovation process. The theory of adoption by Everett M. Rogers (2003) is used to explain these processes here with a specific focus on the distribution of energy saving measures.

The definition of diffusion according to Rogers is (1962) "the process by which an innovation is communicated through certain channels over time among the members of a social system". The energy saving measures examined in this investigation are relatively new technologies which are not yet spread in the whole Dutch society. Within the process of diffusion, consumers that adopt energy saving measures are divided into five categories concerning the level of ‘innovativeness’ [Rogers, 2003];

(1) *Innovators*; these consumers are characterised as risky. Because of their extreme nature entrepreneurial innovators often travel outside their local network, despite geographical difficulties. They have a reasonable financial ability, technical knowledge and can cope with uncertainty;
(2) *Early adapters;* they are characterised with respect. These consumers serve as examples for other consumers within a social system. They are ‘locals’ and are always consulted by other people for advice on a new idea. They reduce uncertainty by adopting a new idea themselves and proclaim their subjective evaluation through interpersonal networks;
(3) *Early majority*; these consumers are characterised as cautious. They interact regularly with consumers from their own network, but never take the initiative to adopt a new technology. They are an important chain in the diffusion process, because they are in between the relatively early and relatively late adaptors. Early adapters are considering a long time before they proceed to the total adoption of a new idea;

(4) *Late majority*; these consumers are characterised as sceptical. Innovation by this group of consumers are sceptical and cautious approached and will only be accepted if the majority of a social system did it before. So the uncertainty is reduced. They are often under pressure of the social system or economic necessity;
(5) *Laggards*: this final group is characterised as traditional. These consumers often live almost isolated and their reference is the past. Also, these consumers distrust new ideas and their decision-making process is relatively long. This is understandable from their situation: they have relatively little financial capital to cope with the disadvantages of unsuccessful innovations.

In the diffusion process the different kind of adopters follow the S-curve (see Figure 14), according to the difference in adoption rate. In the figure the number adaptors is plotted in time.

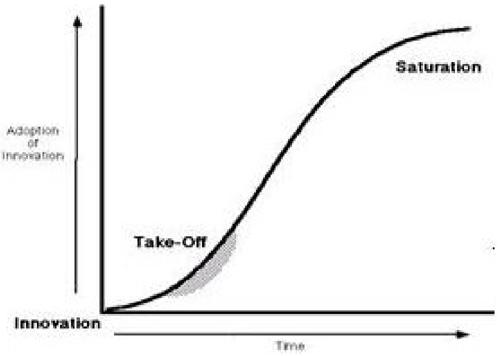


Figure 14: The innovation adaption curve

At first the diffusion rate will go slowly because of the low number of *innovators* and *early adapters'.* The innovators and early adapters must be persuaded first for the energy saving measures to be applied. The innovators are the first consumers to implement an innovation. The early adapters are the consumers that serve as the first large group of consumers that adopt the innovation. Then, faster adoption by the largest group adopters, the 'majority', will adopt the innovation. The last consumer *laggards* that innovation will adopt must be persuaded, because they are much more critical about the innovation. Hence at this point in time the adoption rate is lower.

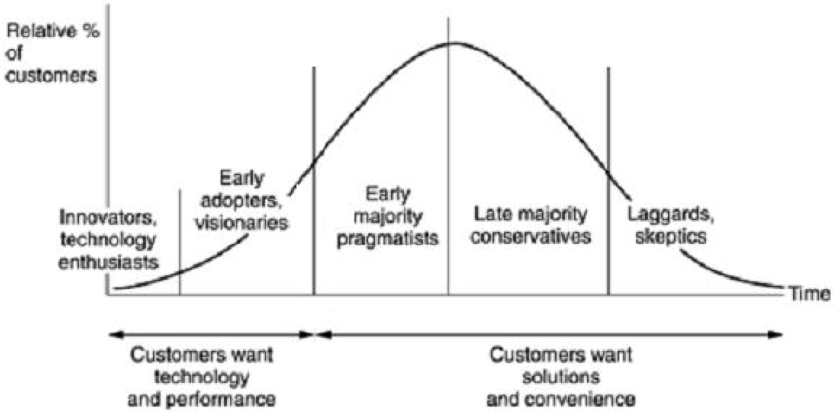


Figure 15: Different Categories of adapters

The five categories of Rogers can be divided into two groups: the early market and the mainstream (Moore, 2002). The early market contains people characterized as visionaries when it comes to migrating to innovations. The mainstream can be regarded as pragmatists. Consumers that have not been convinced of the benefits of the energy saving measures might follow the good example of the early market in this way. Uncertainty will be reduced and more consumers will switch to energy saving options.

The early market for the taken measures within the ESP-Model could be people with altruistic, bio-centric or egoistic behaviour. Longing for personal benefits as status, comfort or more money by energy savings or demanding a good feeling by serving the common good. Therefore the theory of diffusion is used for several energy saving measures. Since historic data on the implementation of insulating and energy saving measures follow the innovation adaption curve, predictions have been done for the future. Growth curves based on the theory of diffusion will be estimated for diffusion of the implementation of the different types of insulation, high efficiency heating systems and best practice energy efficient equipment. From this future scenarios for energy use within the households are calculated.

4.2 Psychological

4.2.1 Changes in behaviour

Consumption in identical homes, even those designed to be low-energy houses, can differ a lot depending on the behaviour of the inhabitants [Curtis, 1992-93; Egmond, 2006; Keesee, 2005; McCalley et al, 2005; Sonderegger, 1978]. Within changes in behaviour two types of energy related behaviour are identified. A distinction is made between curtailment behaviours and efficiency behaviours. Curtailment behaviour generally implies reducing the use of existing appliances and asks for a repetitive effort to reduce energy use. These behavioural changes are often associated with increased effort and/or reduced comfort. Here are some examples of curtailment behaviour:

- Turning off the lights when not in the room
- Turning off TV, radio and other equipment when not in use
- Lowering central heating by one degree and wearing warm clothes
- Only turning on washing machine, dryer or dishwasher when completely filled
- Washing at low temperatures when possible
- Shortening shower time
- Keeping coffee hot in a thermo can instead of leaving on coffee maker
- Putting a lit on the pans during cooking time

Gardner & Stern (2002) state that energy consumption reduction by changes in curtailment behaviour just give a small effect on the total energy saving in comparison with behaviour towards the use of more efficient technologies. Efficiency behaviour includes one-off actions as switching to energy efficient equipment, implementing insulation materials or acquiring an energy-efficient domestic central heating system. Efficiency behaviours generally ask for initial investments but can in the long term save costs of energy.

So generally efficiency behaviour is relatively more effective in reducing energy consumption and requires little further attention. In a sense efficiency behaviour, acquiring energy saving equipment, therefore concerns changing buying habits more as it focuses on real behavioural change [Boersema et al., 2009]. Examples of efficiency behaviour are:

- Buying A++ label products
- Replacing incandescent light with energy saving lights
- Central switch at desk
- Central switch to shut off everything unnecessary by absence
- Acquiring insulating measures

4.2.2 Environmental related behaviour

There are several social-psychological theories explaining environmental related behaviour. The theories explained in this section have been applied to behaviours as car use, recycling, environmental activism but are also relevant for energy consumption reduction [Abrahamse; 2007]. The Theory of Planned Behaviour (TPB) states that behaviour is the result of the positive and negative evaluations of the individual (attitudes), the perception of the general opinion of other people (social norm) and the perception of one's capabilities of performing the behaviour (perceived behavioural control) [Ajzen; 1985].

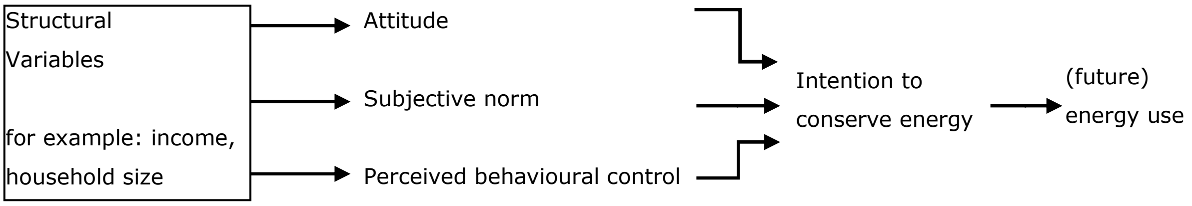


Figure 16: Theory of planned behaviour

Another theory important in energy saving behaviour is the Norm Activation Model (NAM). This theory explains pro-social and altruistic behaviour. Therefore it has been applied to pro-environmental behaviour, as both types of behaviour may involve giving up personal benefits for the communion [Schwartz; 1971]. The more recent Value-Belief-Norm (VBM) combines the NAM with general values and the New Environmental Paradigm (NEP). This theory states that important values are related to a supposed relationship between human and the environment [Stern, 2000].

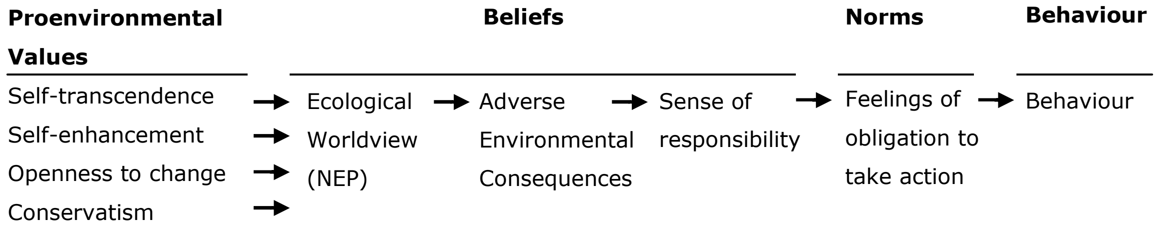


Figure 17: Value-Belief-Norm

In total these theories explain altruistic, bio-centric and egoistic behaviour and show drivers with both personal and collective benefits in relation to energy savings. These theories are used to explain the diffusion of energy saving technologies (see Section 4.1), changes in behaviour and the effect of feedback on energy use (see Sections 4.2.1 & 4.2.3). Understanding these theories is useful to know how to motivate different types of people to conserve energy which are used in the ESP-Model.

4.2.3 Effectiveness of energy feedback

According to Sarah Darby (2006), there are five main categories of feedback on energy consumption with various degrees of immediacy and control by the consumer with various relevant practices within these categories:

Direct feedback - Available on demand. *Learning by looking or paying*

- Self-meter-reading;
- Interactive feedback via a PC;
- Pay-as-you-go/keypad meters;
- Meter reading with an adviser, as part of energy advice;
- Cost plugs or similar devices on appliances

Indirect feedback – Raw data processed by the utility and sent out to customers. *Learning by reading and reflecting*

- More frequent bills;
- Frequent bills based on readings plus historical feedback;
- Frequent bills based on readings plus comparative/normative feedback;
- Frequent bills plus disaggregated feedback;
- Frequent bills plus detailed annual or quarterly energy reports

Inadvertent feedback – *Learning by association*

- With the advent of micro generation, the home becomes a site for generation as well as consumption of power;
- Community energy conservation projects such as the Dutch 'Eco-teams'

Utility controlled feedback – *Learning about the customer*

- Utility-controlled feedback via smart meters, with a view to better load management

Energy audits – *Learning about the 'energy capital' of a building*

- undertaken by a surveyor on the client's initiative;
- undertaken as part of a survey for the Home Information Pack;
- carried out on an informal basis by the consumer using freely available software, eg carbon calculators [Darby, 2006, p 8]

Many studies on energy saving behaviour and effective implementation of energy saving by energy monitoring have shown that feedback on energy consumption with various degrees of immediacy and control can motivate the reduction of energy consumption [Darby S., 2006]. These studies have shown that strategies that take into account factors at all levels are the most successful. This is because in their turn they all influence individual factors such as motivational factors (e.g. preferences, attitudes), abilities and opportunities [Ölander, F., Thøgersen, J., 1995].

With energy supply and consumption, technology and behaviour interact and co-develop with each other over time. It is well established that technological improvements in housing are not enough to guarantee reduced energy consumption. Some researchers state that feedback is part of a learning process, in which people are information processors actively making sense of the world around them [Ellis P., Gaskell G., 1978]. However, measures with a focus on behavioural change should be placed within the systems context containing the areas of policy and technology [Winkler et al., 1982]. In recent studies on behavioural change the focus on money saving shifted to more ecological reasons. These studies funded by energy suppliers, regulators or government were carried out on a longer timescale with a larger number of people. Therefore there was a smaller danger of a 'Hawthorne effect' [when participants behave differently because they know they are being observed].

Van Houwelingen and van Raaij [1989] in their study included interviews on the effect of goal-setting and daily electronic feedback on gas use. Householders used their feedback mainly as a permanent check on the effects of energy conservation measures. Informative billing initiatives, in contrary to traditional billing, proved to be effective in changing energy saving behaviour. Consumers began to read their energy bills more often and with more understanding. These initiatives indicated a reduction in consumption when the information was presented in an easily understood way, such as a pictorial or simple graphic. However, many people choose to pay for their energy in advance by direct debit which often results in people ignoring bills, or reviewing consumption months after it has been used [Roberts et al., 2004].

By getting historic and comparative feedback consumers started to change their behaviour [Wilhite et al., 1999; Kempton et al., 1994]. In general, consumers especially appreciated feedback that compared the consumption with that in previous billing periods. Important with comparative feedback is that consumers will have to trust the validity of the comparison group [Dobbyn et al., 2005].

While consumers' knowledge and attitudes can be influenced effectively, this does not automatically lead to behavioural change. Frequently the desired impact on behaviour soon fades away and in many cases also proves to be quite expensive. Giving people point-of-use feedback has shown to be most effective mainly because it prevented energy saving behaviour to fade away. This kind of feedback has three main functions:

- Learning – Give understanding how behaviour influences energy consumption;
- Forming habits – Using this knowledge to change routines;
- Internalisation of behaviour – Habits change attitudes to suit the new behaviour

[van Houwelingen & van Raaij, 1989]

Within different feedback designs, antecedent interventions (such as commitment, goal setting and giving information) and consequence interventions (giving feedback or rewards) are distinguished. Darby (2006) and Abrahamse (2005) compared different feedback designs exercised in different studies on their effect during the intervention. Table 5 gives an overview of studies on the effect of the different feedback designs on energy consumption reduction, as summarised in Table 4 below.

	Electricity		Gas	
	Number of studies	Average Savings %	Number of studies	Average Savings %
Commitment	0	0,0%	0	0,0%
Goal setting	11	10,4%	5	10,2%
Information	28	7,8%	13	8,3%
Prompts	5	6,0%	0	0,0%
Self-monitoring	1	7,0%	1	4,8%
Time of use pricing	7	16,1%	0	0,0%
Feedback	57	10,2%	20	9,7%
Financial	19	11,6%	2	8,6%
Rebate	1	13,8%	1	5,9%
Reward(s)	21	9,3%	4	-1,2%
Tailoring	2	6,0%	1	10,0%
Weighted average	152	9,9%	47	8,2%
Antecedent	52	9,3%	19	8,6%
Consequence	100	10,3%	28	7,9%

Table 4: Average effect of feedback designs on energy consumption

Within the ESP-Model the outcome of this comparison is translated in effect of feedback on electricity and gas consumption. This is further elaborated on within the ESP-Model in Section 6.

Author(s)			Intervention(s)														Target behaviour						Effect during intervention	
	Year	Method Design	Commitment	Goal setting	Incentive	Information	Prompts	Self-monitoring	Time of use pricing	Feedback	Financial	Rebate	Reward(s)	Tailoring	Category of Feedback	Number of Participants	Electricity use	Gas use	Water use	Curtailment	Efficiency	Duration [days]	Electricity use	Gas use
Becker	1978	1		x		x				x					1	20	x			x		31	15,1%	
Becker	1978	2		x		x				x					1	20	x			x		31	5,7%	
Becker	1978	3		x		x									1	20	x			x		31	4,5%	
Becker	1978	4		x		x									1	20	x			x		31	-0,6%	
Bittle et al	1979	1								x	x				2	15	x					42	4,0%	
Brandon & Lewis	1999	1								x					2	17	x	x				61	12,5%	12,5%
Brandon & Lewis	1999	2								x					2	17	x	x				61	6,4%	6,4%
Brandon & Lewis	1999	3								x	x				2	17	x	x				61	12,7%	12,7%
Brandon & Lewis	1999	4								x					2	17	x	x				61	3,4%	3,4%
Brandon & Lewis	1999	5								x					2	17	x	x				61	8,3%	8,3%
Brandon & Lewis	1999	6								x					2	17	x	x				61	12,2%	12,2%
Hayes & Cone	1981	1								x					2	20	x					122	4,7%	
Mc Calley & Midden	2002	2		x						x					1	25	x					0	21,9%	
Mc Calley & Midden	2002	3		x						x					1	25	x					0	19,5%	
Mc Clelland & Cook	1980	1								x	x				2	25	x					335	12,0%	
Mc Clelland & Cook	1980	1				x				x			x		2	250		x				84	6,6%	
Mc Makin et al.	2002	1				x								x	1	1231	x	x				366	10,0%	10,0%
Mc Makin et al.	2002	1				x								x	1	175	x					122	2,0%	
Midden et al.	1983	1				x				x			x		2	18	x	x				84	13,3%	6,8%
Midden et al.	1983	2				x				x			x		2	18	x	x				84	12,8%	-5,8%
Midden et al.	1983	3				x				x		x	x		2	18	x	x				84	13,8%	5,9%
Midden et al.	1983	4				x				x			x		2	18	x	x				84	2,0%	-11,6%
Seligman & Darley	1977	1								x					2	20	x					31	10,5%	
Slavin et al.	1981	1				x	x			x			x		1	55	x					98	11,2%	
Slavin et al.	1981	2				x	x			x			x		1	55	x					84	1,7%	
Slavin et al.	1981	3				x	x			x			x		1	55	x					56	4,0%	
Slavin et al.	1981	2		x		x	x			x			x		1	85	x					77	4,7%	
Slavin et al.	1981	3		x		x	x			x			x		1	85	x					56	8,3%	
Staats et al.	2004	1				x				x					1	75	x	x	x			244	4,6%	20,5%
Van Houwelingen & Van Raaij	1989	1		x		x				x					1	55		x		x		366		12,0%
Van Houwelingen & Van Raaij	1989	2		x		x				x					1	55		x		x		366		7,4%
Van Houwelingen & Van Raaij	1989	3		x		x		x							1	55		x		x		366		4,8%
Van Houwelingen & Van Raaij	1989	4		x		x									1	55		x		x		366		4,0%
Vollink & Meertens	1999	1		x		x				x					1	24	x	x	x	x		153	15,0%	23,0%
Winett et al.	1978	1				x				x			x		2	26	x					56	11,1%	
Winett et al.	1978	2				x				x			x		2	26	x					56	6,7%	
Winett et al.	1978	3				x				x			x		2	26	x					56	-2,6%	
Winett et al.	1978	4				x				x			x		2	26	x					56	-8,2%	
Winett et al.	1979	1		x		x				x					1	24	x			x	x	31	13,0%	
Winett et al.	1979	2		x		x		x							1	24	x			x	x	31	7,0%	
Winett et al.	1983	1				x									1	26	x			x	x	31	21,0%	
Seligman, Darley & Becker	1979	4								x					2	40	x					28	16,0%	
Gaskell, Ellis & Pike	1982	4				x				x					1	160	x					28	9,0%	
Gaskell, Ellis & Pike	1982	4				x				x					1	160		x				28		5,0%
Winett et al.	1982	4				x				x					1	138	x					35	15,0%	
Sluce and Tong	1987	2								x					2	56	x	x				153	13,0%	13,0%
Dobson and Griffin	1992	2				x				x	x				2	100	x					60	13,0%	
Harrigan and Gregory	1994	4				x				x					1	180		x				427		26,0%
Nielsen	1993	2								x					2	1500	x					1096	5,5%	
Staats and Harland	1995	1								x					2	93	x					2192	27,0%	
Staats and Harland	1995	1								x					2	144		x				2922		23,0%
Wood and Newborough	2003	4								x					2	41	x					366	14,0%	
NIE	2002	1								x					2	0	x					0	11,0%	
NIE	2003	1								x					2	26	x					366	4,0%	
Mountain	2006	2								x	x				2	557	x					914	6,5%	
Benders et al.	2006	2								x					2	190	x	x				153	8,5%	8,5%
Seligman, Darley & Becker	1979	2								x	x				2	29	x					21	10,0%	
Seligman, Darley & Becker	1979	5								x	x				2	100	x					28	13,0%	
Arvola et al.	1994	3								x	x				2	700	x					731	3,0%	
Garay and Lindholm	1995	2								x	x				2	1200	x					457	7,0%	
Haakana et al	1998	2								x	x				2	755		x				914		4,5%
Wilhite and Ling	1995	4								x	x				2	1286	x					1096	10,0%	
Wilhite	1997	1								x	x				2	2000	x					609	8,0%	
Henryson et al.	2000	7								x	x				2	1500	x					0	4,0%	
Kasulis et al.	1981	1								x	x		x		2	30	x					0	0,0%	
Sexton et al.	1987	2							x	x	x		x		2	600	x					0	26,0%	
CPUC pilot of DR to CCP	2003	1							x	x	x		x		2	0	x					0	27,0%	
Crossley for IEA	2005	2							x	x	x		x		2	1200	x					0	13,0%	
NIE	2005	1							x	x	x		x		2	200	x					0	11,0%	
Puget Sound Energy	2005	1							x	x	x		x		2	30k	x					0	5,0%	
Gulf Power Company	2005	1							x	x	x		x		2	3000	x					0	22,0%	
SWALEC	2005	1							x	x	x		x		2	100	x					0	25,0%	

Table 5: Effectiveness of feedback designs on energy consumption

A recent project by RED, a developer of new practices on social and economic problems through design-led innovation, considered how effective design principles could facilitate feedback on energy consumption. The RED team especially wanted to design a monitoring system that could become an object of desire. The result is a system giving a choice of graphical representations of energy use for example by showing bubbles moving up a display screen at a speed reflecting total electricity use in a household. A touch-sensitive screen allows the consumer to interrogate the system for cost, carbon emissions, power in real-time or over a number of time periods. The conclusion of this project was that the 'Home Dashboard' concept could make home energy management desirable while energy is saved and useful energy education is given [Lockwood, M. et al., 2005].

This project shows that besides the considerations having to do with the ways to visualise energy consumption an energy saving feedback system could be extra effective if it is an object of desire. To stimulate the reduction of energy demand a positive approach should be taken. For example 'reduction of energy demand' should be formulated as 'energy savings' in energy saving campaigns. This complies with the sustainable product design vision of onsustain.com, a platform marketing sustainable design and designers filled with design products that are both creative and sustainable, and will surely have to be taken into account when one designs such a system [Onsustain, 2007]. The Plugwise system, mentioned in Section 3.1.2, is also an example of the effectiveness of this approach.

Incorporating product design considerations will help ensure people engage with the feedback information and allow them to learn, change habits and eventually fall into new behaviour patterns. There must be given careful thoughts on how feedback information is displayed in order to support energy saving behaviour. To get the most effect of point-of-use feedback, there are a number of considerations to be taken into account on visibility, comprehensiveness and functionality, while designing feedback instruments.

Visibility:

- The display must be situated in a prominent position;
- Large displays/text to enable reading from across a room;
- Sensible use of foreground and background colours;
- Limited number of colours and separate pieces of information at any one time;
- Something which flashes or moves attract attention – this could become annoying, unless used infrequently for warnings or similar;
- It should be attractive – something you would like to have in your kitchen

Comprehensiveness:

- Selecting understandable units – kWh, m^3, € or CO_2;
- Symbols – dashboard style, digital numbers, smiley faces, bar graphs;
- Sensitivity – degree of accuracy which is useful, such at 0.1 kWh, grams of carbon rather than 0.001kWh and tonnes of carbon

Functionality:

- Ability to personalise the display – colours, text size etc;
- Different parameters – to allow switching between types of display. For instance current use, historic use (day, week, month etc.), comparisons with other dwellings/national averages etc.
  [Energywatch, 2006; Lohr, 2000]

Textbox 1: Incorporating product design in energy feedback

4.3 Economic

4.3.1 Price elasticity and Cost-Benefit Ratio

Energy economics is a broad area including topics related to supply and demand of energy in societies. The relationship between energy consumption and the economy provides some interesting issues for this investigation. Energy plays a large role in the economy since it is needed for economic growth. Moreover, in a growing economy more energy is required to fulfil peoples growing needs for energy using products and services. Costs of consuming gas and electricity but also costs of energy consuming or energy saving equipment have an effect on the demand of energy by Dutch households. Energy conservation may be encouraged by means of financial-economic measures, aimed to make energy-intensive behaviours relatively more expensive and environmentally-friendly alternatives relatively less expensive. Increasing the costs of energy use by means of a tax on the use of gas and electricity will entice households to reduce their energy use. Furthermore, increasing the prices of products that require much energy may encourage households to choose less energy-intensive alternatives. These kinds of measures could be effective if consumers take prices into account when making such choices.

A well known measure of how consumers react to a change in price is the Price Elasticity of Demand (PED). This PED is defined as *the measure of responsiveness in the quantity demanded for a commodity as a result of change in the price of the same commodity* [Sullivan et al., 2003]. The PED shows the relative change in demand of a service or good caused by the relative change in price and is a measure for the sensitivity of the correlation between price and demanded quantity changes. A price fall usually results in an increase in the demand by consumers. The demand for a good is relatively inelastic when the change in quantity demanded is less than change in price. Since alternatives for the use of gas and electricity from the net are expensive and the use of these energy sources are surely needed for daily living, gas and electricity are considered as being relatively inelastic. Although the precise PED is uncertain, varying across regions and over time [Bohi et al., 1981], the demand for gas and electricity is not price sensitive. In the past 20 years the elasticity of demand has not changed significantly; analyses on elasticity performed in the 1980s showed approximately the same results [Bernstein et al., 2006]. The impact of a change in the energy price on the demand of gas and electricity seems very low.

Since the use of energy is so inelastic there is just a small effect of price differences on energy use or savings. Consequently there is just a little effect of energy price increases on the adoption of energy saving technologies. Furthermore the effect of the adoption of those technologies, on the demand of energy, has been measured. In these studies a 10% increase in price of energy caused technology adoption that reduced the energy demand just by 1%, so technology adoption explains just a relatively small fraction of changes in energy demand. Generally energy price increases are too small to lead people to buy energy saving measures, hence technological development has to be driven by something else than price changes [Linn et al., 2006].

Boonekamp (2005) illustrates that the decrease in energy demand in the Dutch household sector has been influenced by the large number of new policy measures in the past decades. To investigate this, issue energy trends have been simulated by Boonekamp, as a response on changing prices. The price effect has been analysed in combination with the policy measures standards, subsidies and taxes and is further discussed in the next section about policy drivers on energy saving. To consider if the purchase of an energy efficient or energy saving measure is economically feasible a person weights the costs and the benefits of the measure somehow. A cost-benefit analysis determines if the costs arising from additional investments for saving options will be paid back by the yearly saved energy costs within the lifetime of the measure. The cost-benefit ratio (CBR) is calculated as follows [Boonekamp, 2005]:

CBR = [(Inv-Subs)*Ann+O&M] / [Saving*(Price+Tax)] [Equation 1]

Inv = Investment in saving option [€]
Subs = Subsidy on saving option [€]
Ann = Fixed annuity factor to calculate yearly investment costs
O&M = Yearly operation & maintenance costs (if present) [€]
Saving = Annual savings realised with option [GJ]
Price = Price of energy excluding tax [€/GJ]
Tax = Tax on energy [€/GJ]

If costs are lower than benefits, when the cost/benefit ratio is smaller than 1, the option should always be chosen from an economic viewpoint. With a cost/benefit ratio larger than 1 the penetration of saving options should be zero (see Figure 18, `All-or-nothing'). In reality however, this reasoning is too straightforward. Circumstances, such as intensities of use, varying costs of saving options and (non) availability of investment money, differ per household. In case of a calculated CBR of 1 the real cost/benefit ratios for different households will vary around 1 and only a part of all households would choose the saving option. To account for this, the relationship between the penetration of saving options and the cost-benefit ratio can be modelled in the form of an S-shaped curve (see Figure 18, `Dispersed'). The relationship is such that in 50% of the decision cases the saving option will be chosen, given that the cost-benefit-ratio is equal to the `acceptable' ratio (see Equation 2).

$$P = 1 - 1 / \{1 + \mathrm{Exp}\,[-Stp * (CBR - CBR50)]\} \quad \text{[Equation 2]}$$

P = Penetration level saving option (fraction of replaced systems)
Stp = Steepness of S-curve
CBR50 = Acceptable cost-benefit ratio

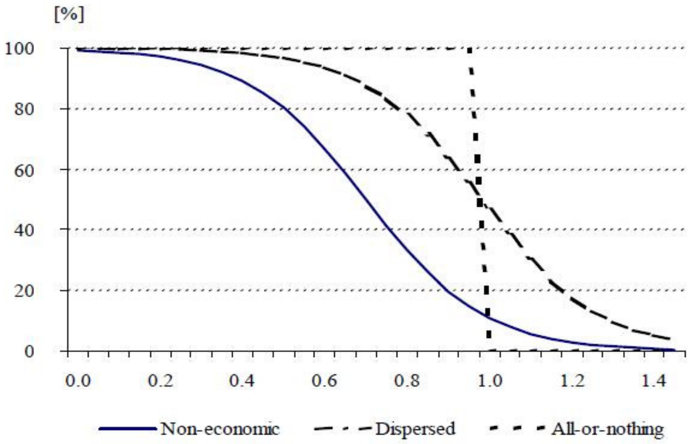


Figure 18: Relationship between cost-benefit ratio and penetration level for saving options

For households the value of the acceptable ratio often is dependent on non-economic factors. Boonekamp (2005) estimated the acceptable cost-benefit ratio of saving options apart on basis of observed penetration trends. For some options the acceptable ratio is less than 1, for example with water saving shower-heads where the reduced amount of hot water forms a non-economic burden. For double-glazing however the 50% penetration point is found at a cost-benefit ratio above 1 because of the non-economic benefit of extra comfort.

This shows a major shortcoming of cost-benefit analyse, namely that they ignore non-financial impacts. Section 4.3.2 investigates those non-financial costs to overcome this limitation. Since the Netherlands is a relatively small country, with a relatively homogeneous climate, regional differences are not influencing the average Dutch household in the ESP-Model as well as the unchanged PED in the past 20 years. For the uncertainty, heterogeneity, complexity and small effect of energy prices on changes in energy demand PED is not directly implemented in the ESP-Model. The price effects in combination with the policy measures standards, subsidies and taxes is part of the ESP-Model as further explained in Section 5.

4.3.2 Non-financial Costs

A shortcoming of cost-benefit analyses above is that they ignore non-financial impacts and fail to address resistance by effort people have make to implement energy saving equipment. Because of these perceived non-financial costs, many cost-effective energy saving measures explicitly, like floor insulation and high-efficiency heating systems, are still not implemented extensively. To overcome this limitation an investigation on these non-financial costs could enforce energy consumption reduction. This amount of resistance for different kind of consumers stays hard to measure. However if perceived costs of energy saving measures are higher than reality and perceived benefits are lower, the perceived barriers could be removed by for example effective informative feedback systems or policy measures as information campaigns.

The strength of resistance people have depend on the perceived societal importance of energy conservation. At present for example there is less sense of urgency for energy saving as after the oil crisis of the early 1970s. After that crisis many energy saving measures have been implemented. Though, when the crisis faded, however, behavioural changes did not last. Feelings of resistance are the least for investments in machines and appliances and in clean energy sources by consumers who are environmentally aware as well as price-conscious. Table 6 shows extremes in resistance in which there is greatest and least likelihood of energy saving behaviour [CE, 2006].

	Lowest resistance	Highest resistance
Type of behaviour	Machine and appliance purchase	Shifts in needs and desires
Target group	Public housing sector	Private home leasers
Consumer category	‘Green shoppers’	‘Reliability shoppers’
Energy function	Heating	Car usage

Table 6: Extremes in resistance costs

5 Policy Drivers

Energy saving measures are in the public interest. The government sometimes gives assistance to pay for such items when they cannot (yet) be supported by the economy. This will support the policy goals that the energy supply system should be reliable, affordable and clean.

The European Economic Community founding treaty, the Treaty of Rome, did not provide for environmental protection. In 1972 the European Commission started forming a Directorate of the Environment and Consumer Protection. This was the base for the current Environment Directorate-General (DGs). Nowadays the Environment DG is one of 26 DGs and specialized services which make up the European Commission. Its main role is to initiate and define new environmental legislation and to ensure that measures, which have been agreed on, are actually put into practice by the Member States. The Environment DG is based largely in Brussels and has a staff of around 550 people. The Environment DG's Mission is "Protecting, preserving and improving the environment for present and future generations, and promoting sustainable development" [DG Environment, 2007; 2008]. Next to the Environment DG there are different relevant EU monitoring and control institutions. Council Directive 90/313/EEC of 7 June 1990 brought into force by 1992, is a directive on freedom of access to information on the environment. This directive was the base for the establishment of the European Environment Agency (EEA). The EEA's aim is "to support the development and implementation of sound environmental policies in the EU and other EEA member countries by delivering timely, targeted, relevant and reliable information to policy-makers and the public" [EEA, 2008].

The household sector stand for 25% of the final energy needs in the EU. Domestic electrical appliances account for the largest increase [European Commission, 2008]. Several directives are performed to increase the awareness of energy consumption and set minimum efficiency requirements to these equipments. The European Union Directive on the Energy Performance of Buildings was set up to assist Member States in meeting the Kyoto Protocol on GHG emission reductions. The target in European Building Energy Consumption is a reduction of 10% by 2010 and 20% by 2020. Additionally, a new directive on efficiency and energy services is proposed with the purpose of increasing end-use energy efficiency through a number of measures including the development of energy services. The idea is to remove barriers to allow market forces to allocate economic and natural resources effectively.

The main barriers appear to have a harmonized and credible framework of instruments, mechanisms, definitions and information regarding energy efficiency services and measures. Finally, the European Commission released an energy efficiency Green Paper in 2005 further enforcing the need for promotion of energy efficiency at all levels of European society [EC, 2005].

5.1 Effect of Policy Measures

Generally, behaviour that deviates from energy saving legislation is met with some form of punishment. In the Netherlands some policy measures have proven to be effective strategies for behavioural change. Types of policy measures often applied in the past decade are:

- Subsidies for more energy efficient systems and appliances;
- Standards for insulation of new dwellings or appliances;
- Regulatory tax on energy carriers;
- Energy advice on saving measures (EPA) and information campaigns;
- Energy efficiency labels for appliances;
- Optimal Energy Infrastructure (OEI);
- Sustainable Building Options (DuBo).

[Oosterhuis and Nieuwlaar; 1998].

The General Energy Council in the Netherlands examines the role of soft (non-punishing) instruments such as public information, campaigns and feedback to consumers. Giving people dedicated point-of-use feedback targeted at specific categories of consumers has shown to be the most effective way of promoting energy-efficient behaviour, however this is also an expensive as well as a soft (non-committal) measure for a limited target group. Therefore manners have to be found to use this kind of policies for a longer moment of time while appealing a larger target group. Soft policy instruments on the other hand can be successful when they are accompanied by harder (punishing) measures. Hard policy instruments are cheaper and ask for a commitment. They are influencing large numbers of households to adopt energy saving measures permanently.

Boonekamp (2007) developed a simulation model reproducing past energy trends using the relationship between different policy measures and the penetration of saving options. Within this approach a 'base case' trend has been simulated, without the three most important policy measures: regulatory tax, investment subsidies and regulation of saving options. In the models’ base case the amount of gas and electricity consumption appeared to be higher than the realistic energy consumption. This means that the policy measures helped somehow on saving energy.

However, within this model evaluating realised energy savings is found that only 50% of gas savings and 15% of electricity savings is accomplished due to these three measures. Starting from this base case the efficiency gains of the three policy measures and combinations could be determined.

5.1.1 Regulation

Before 1996 the regulation for new dwellings focused on insulation measures (wall, roof, floor, windows) and energy efficient heating systems. From 1996 the Energy Performance Standard (EPN) for total gas consumption of new dwellings was introduced; first 1200 m3 for space heating in a normalized dwelling, later lowered to 1000 and 800 m3. Since that moment the choice of saving measures was left to the builder while subsidies were provided for most of the saving options. Moreover, the level of the regulatory tax on fuels and electricity was increased from 1996 on.

For new dwellings the regulated saving options were often not economically attractive. But for the existing dwellings of housing associations the simulations without regulation showed almost the same amount of saving options in most cases. After introducing regulation in the base case, the gas consumption decreased with 4.6% between 1995 and 2000; the electricity consumption was not affected (see Table 5.6). In new dwellings prices no longer affect the amount of gas saving options because there is an obligation to take these measures anyhow. For electricity the PED is practically unchanged as standards are targeted at gas consuming saving options only [Boonekamp, 2005].

5.1.2 Investment Subsidies

Subsidies decrease the consumers' investment for the saving options, and therefore the cost-benefit-ratio. This results in lower energy consumption. In the last decade subsidies often amounted to 20-25% of the extra investments into more energy efficient options. Between 1995 and 2000 gas use due to investment subsidies was 4.3% lower and electricity consumption decreased with 3.2% [Boonekamp, 2005].

5.1.3 Energy Tax

Tax on energy use increases the benefits of energy consumption reduction. Accordingly the cost-benefit ratio, for investments in saving options, is lowered (see Equation 1). The regulatory tax on gas and electricity (REB) in the Netherlands was 36% of the total gas price and 32% of the total electricity price in 2000. This tax decreased the consumption between 1995 and 2000 by 2.0% for gas and 1.9% for electricity.

In addition to the three most important measures which are used in the analyses a number of other policy measures have been in force in the last decade as stated above. The infrastructural measures caused a 50% increase for the number of dwellings connected to a town-heating system. However, this type of houses considered only 3% of the total number of households in 2000. DUBO-standards regarding energy use overlap almost completely with the insulation standards. The EPA is considered as an effective measure. But since the measure is quite new the effect on energy savings in the Dutch household sector is still too hard to measure. According to Winward (1998) labelling on the consumption of electricity has got a large effect in the Netherlands [Boonekamp, 2005].

5.2 Combined Effect of Policy Measures

To investigate energy saving potential from the different policy measures only one measure was investigated at a time. With all three measures present one might expect the sum of the effects mentioned above. However, in reality there is an overlap in the effects of the three measures. Boonekamp (2007) investigated the interaction effects between each combination of two measures. In Figure 19 the results of the combined saving effects are shown for the period 1995-2000. Changes in energy consumption are given as a percentage of total gas or electricity consumption.

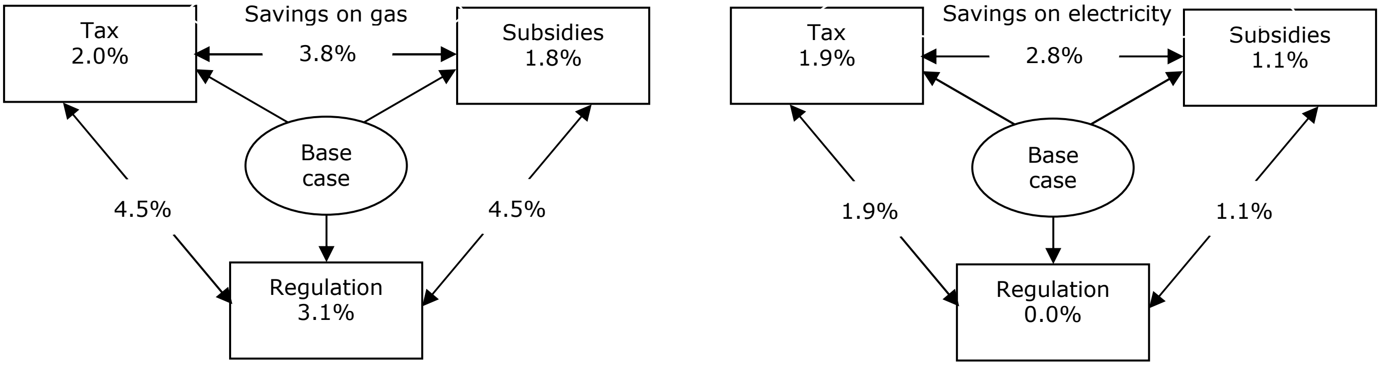


Figure 19: Savings on gas and electricity 1995-2000 for combinations of policy measures [% of base case consumption] [Boonekamp, 2005, p11]

The combined saving effects are obviously larger than that of each of the single measures since two policy measures will have more influence than one. In case of electricity the savings of `tax & regulation' are evidently equal to that of `tax' because the electricity savings due to regulation are practically zero. The same reasoning holds for `subsidies & regulation'.

For gas the combined effect of `tax & regulation' is -4.5% against -5.1% for the sum of the two effects. Accordingly the amount of overlap between these measures is about 13%. For the combination `subsidies & regulation' the amount of overlap is 8%. For electricity the overlap for `tax & subsidies' is 4%. However, in the case of gas and `tax & subsidies' the combined effect is the same as the sum of the two separate effects. This combination shows its reinforcing nature. The overlap for the three measures together is more than 13% for gas and 4% for electricity. To reach an optimal set of policy measures in individual policy measures should be directed to specific energy applications. Furthermore different measures will have to be tuned. For example, standards can assure a minimum level of efficiency while subsidies will stimulate specific most efficient equipment.

Conclusively, to generate more energy saving potential by policy measures it is recommended to implement hard policy measures, backed up by soft policies to improve their effectiveness [CE, 2006]. Moreover, incentives and policy measures influencing efficiency behaviour will be more effective and acceptable than disincentives and policies changing curtailment behaviour [Steg et al., 2006]. One has to keep in mind that several external criteria influence the choice of policy measures on energy saving, for instance the policy expenditures and public acceptance. Subsidies aimed at reducing the costs of improvement, along with research and development to make more alternatives available will be the most effective [Boonekamp, 2005].

6 Energy Saving Potential Model

To investigate the underlying research sub-questions the Energy Saving Potential Model is constructed to consider possible scenarios to 2020 to have insight in the effects of many correlated variables. The ESP-Model gives more understanding of the energy saving potential of the changes in improving energy efficiency and energy consumption reduction. This chapter elaborates on the concepts used to build the ESP-Model. The model can be applied by ESCOs to identify service opportunities as shown. Furthermore the results from such a model can be used by governments and industries while the accomplished savings are apprehended by the consumers of energy.

6.1 Conceptual Model

At the basis of the ESP-Model a conceptual model for energy saving potential is derived by linking the investigated concepts as described below. The model is a relational model built from different methods and relationships. It is used to outline possibilities to continuously reduce energy consumption and to make it simpler to find right indicators to answer the research sub-questions. The model consists of the three stated areas of investigation which are connected with socio-economic trends, energy saving activities as well as feedback mechanisms to indicate drivers of energy consumption and potentials for energy saving.

The concept of increasing energy consumption reduction by increases in feedback, awareness and behaviour as found by Wilhite and Ling (1995) is slightly modified to combine with the main categories of feedback as discussed by Darby (2006), and put in the yellow model boxes in Figure 20. Within the third yellow box the relationship with and between the multi-disciplinary directions technology, society & policy are shown. From the earlier sections some targets of energy saving potential emerged. The ESP-Model focuses on these targets; namely the purchase and use of energy efficient appliances (technology development), the effect of feedback on energy consumption (societal development) and the existence and effect of policy measures (energy policy). These focus areas are coloured green, blue and red in the conceptual model.

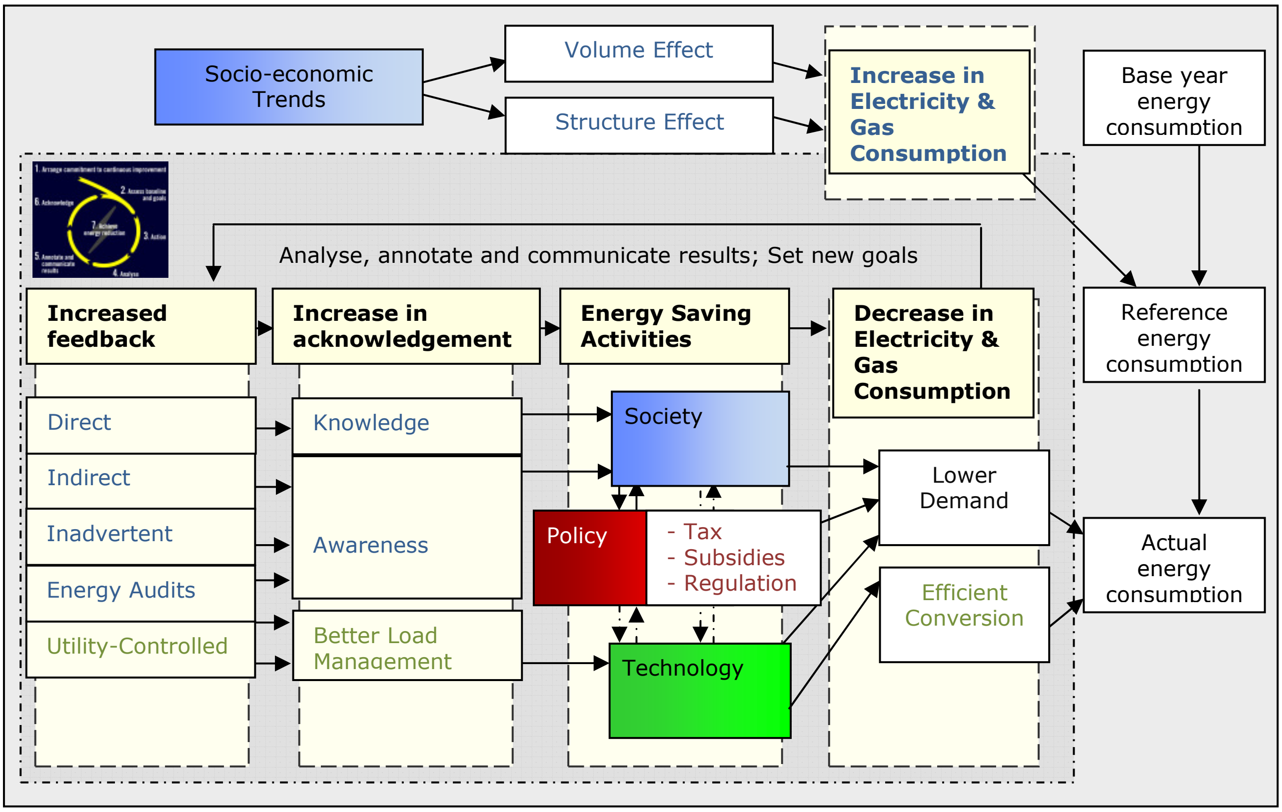
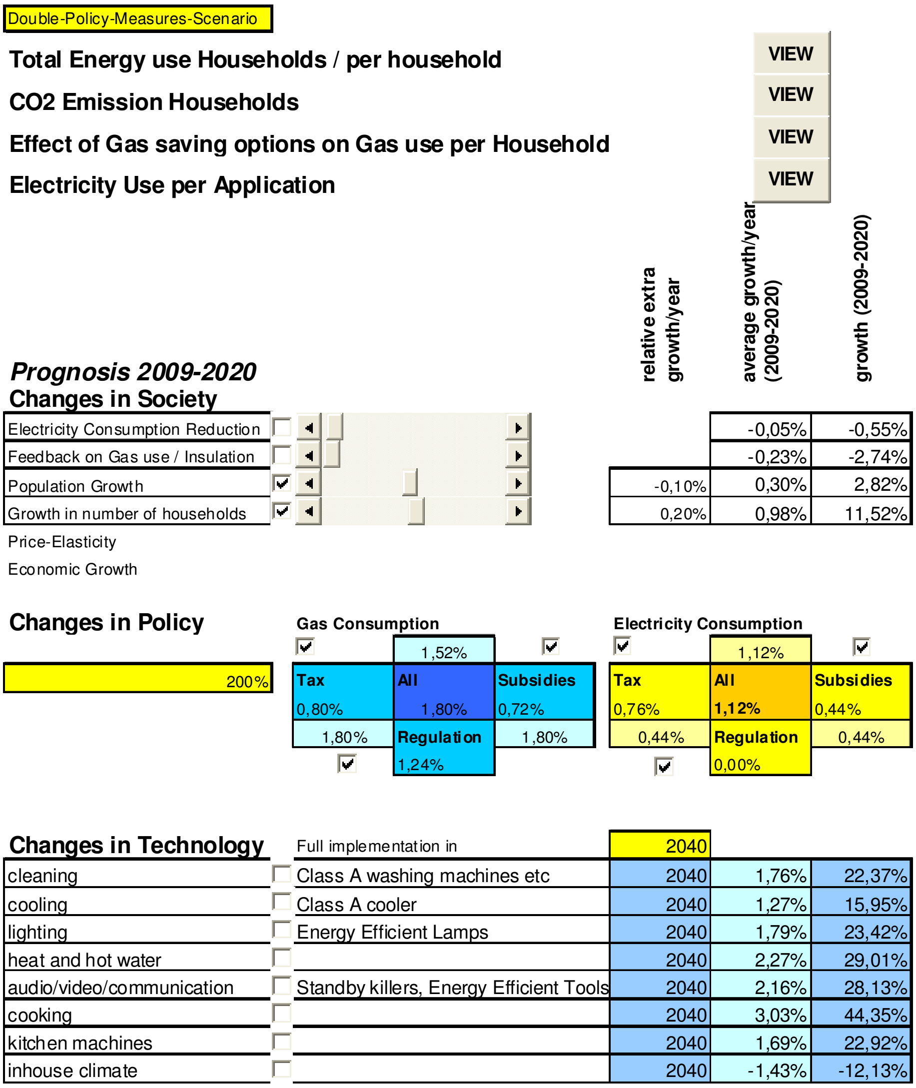


Figure 20: Conceptual Model - Energy Saving Potential

6.2 The ESP-Model

The Energy Saving Potential model in Excel (see Appendix D) is constructed from the conceptual model with help of parameters arisen from the research as treated in Sections 3, 4 & 5. In this Section the variables used from the different areas of investigation, its units, data sources and methods of estimation of numbers for the future are explained.



Double-Policy-Measures-Scenario

Total Energy use Households / per household VIEW

CO2 Emission Households VIEW

Effect of Gas saving options on Gas use per Household VIEW

Electricity Use per Application VIEW

Prognosis 2009-2020

Changes in Society

		relative extra growth/year	average growth/year (2009-2020)	growth (2009-2020)
Electricity Consumption Reduction	☐		-0,05%	-0,55%
Feedback on Gas use / Insulation	☐		-0,23%	-2,74%
Population Growth	☑	-0,10%	0,30%	2,82%
Growth in number of households	☑	0,20%	0,98%	11,52%

Price-Elasticity

Economic Growth

Changes in Policy

200%

Gas Consumption		
☑	1,52%	☑
Tax 0,80%	**All** 1,80%	**Subsidies** 0,72%
1,80%	**Regulation** 1,24%	1,80%
☑		

Electricity Consumption		
☑	1,12%	☑
Tax 0,76%	**All** **1,12%**	**Subsidies** 0,44%
0,44%	**Regulation** 0,00%	0,44%
☑		

Changes in Technology		Full implementation in	2040		
cleaning	☐	Class A washing machines etc	2040	1,76%	22,37%
cooling	☐	Class A cooler	2040	1,27%	15,95%
lighting	☐	Energy Efficient Lamps	2040	1,79%	23,42%
heat and hot water	☐		2040	2,27%	29,01%
audio/video/communication	☐	Standby killers, Energy Efficient Tools	2040	2,16%	28,13%
cooking	☐		2040	3,03%	44,35%
kitchen machines	☐		2040	1,69%	22,92%
inhouse climate	☐		2040	-1,43%	-12,13%

Figure 21: Total input screen for ESP-Model

The variables are presented in this structure:
Abbreviation = explanation [unit] (min/max range 1980-2020 if relevant) = formula

Firstly demographic factors as population size, number of households and the average size of households are derived from estimations by CBS and RIVM:

Demographic variables:
pop = Population on January 1st [number] (14 M – 16.9 M)
hh = Households on January 1st [number] (5 M – 7.9 M)
Shh = Average Size of Households [number of people] (2.77 – 2.1) = pop/hh

These variables signify the dependency of population and average size of households on total used energy within the household sector. Next general historic data until 2009 on energy consumption are derived from CBS [2010], RIVM, KWA and VROM. Until 2009 the model is based on empirical data. For most parameters the numbers from 2009, onwards for each year, are based on trends by growth estimations over the previous 10 year, or calculated by use of other parameters if declared so. In Excel, the Growth function returns the predicted exponential growth based on existing values provided. The formula below show a way of writing this exponential growth formula:

$$y = b*(1+r)^x \qquad \text{[Equation 3]}$$

b = initial value (year(t-10))
r = growth rate
x = number of time intervals = 10
t = year

For the demographic variables this formula is multiplied with a corrected growth factor to match the RIVM predictions for population and number of households.

$$y_{corr} = b*(1+r)^x*(1+corr) = y*(1+corr) \qquad \text{[Equation 4]}$$

corr = relative extra growth per year

In case of standard exponential growth as in most parameters this correction factor are 0%. Compared with the predictions of RIVM the relative extra growth factors for population and number of households to fit this model are respectively -0.20% and -0.10%. Next numbers on future total energy consumption and energy consumption per household are calculated with help of parameters on changes in technology, society and policy. The parameters that have been used for the predicted changes in energy consumption are:

Parameters on Development in Technology

WI% = Wall insulation penetration [%]
GI% = Glass insulation penetration [%]
RI% = Roof insulation penetration [%]
FI% = Floor insulation penetration [%]
TH% = High Efficiency Heating system penetration [%]

EA = Electric appliances per household [number]
EA% = Electric appliances use of total electricity demand [%]

For appliances used in cleaning, cooling, lighting, heat and hot water, audio video/communication, cooking, kitchen machines, inhouse climate and other use.

Parameters on Changes in Society

ccg = Consumers Cost of Natural Gas [€/m3]
peg = Price Elasticity Natural Gas
cce = Consumers Cost of Electricity [€/kWh]
pee = Price Elasticity Electricity
hhm2 = Average Size of Households [m2]
fbc = Feedback on Gas & Electricity consumption
C02 = Growth in Population & number of households

Parameters on Changes in Policy

PT = Taxes yes/no
PS = Subsidies
PR = Regulation

At this instance predictions on the effects of these changes on future energy consumption can be calculated by the following parameters:

Parameters on Energy Consumption:

tc = Total Consumption per Household [€]
tec = Total Energy Consumption per Household [€]
tec-m = T.E.C. ex. Motor Fuels per Household [€]
tec-m% = T.E.C. percentage ex. Motor Fuels per Household [%] = tec-m/tec * 100%
dd = Degree Days [number] (3500 – 2700; average = 2050)

Ug = Natural Gas use per Household [m3]
Future natural gas use is determined on estimated growth from 1980 based on average house size {hhm2}, diffusion of insulating measures {WI%, GI%, RI%, FI%, TH%} and is further dependent on the presence of policy measures {PT, PS, PR}. The parameter is corrected for variation in degree days {dd}.

Ue = Electricity use per Household [kWh]
Future electricity use is determined on estimated growth from 1980 on basis of amounts of kWh used in cleaning, cooling, lighting, heat and hot water, audio video/communication, cooking, kitchen machines, inhouse climate and rest of the appliances and the diffusion of energy efficient appliances {EA%}.

ETnl = Total Energy use in NL [PJ]

ET = Total Energy Use Households ‡ [PJ] = EE+EG
EE = Electricity Use Households‡ [PJ] = $hh*Ue*Eep*10^{-9}$
EG = Natural Gas use Households [PJ] = $hh*Ug*Eng*10^{-9}$

Eep = Energy per unit Electricity Production = 9.0 [MJ/kWh]
Eec = Energy per unit Electricity Consumption = 3.6 [MJ/kWh]
Eng = Energy per unit Natural Gas = 31.7 [MJ/m3]

Et = Total Energy Use per Household‡ [MJ] = Ee+Eg
Ee = Electricity Use per Household‡ [MJ] = $EE/hh*10^{9}$

Eg = Natural Gas use per Household [MJ] = EG/hh*10^{9}

C02t = CO2 Emission households [ton CO2] = CO2e+CO2g
CO2e = CO2 Emission by Electricity use [ton CO2] = Ue*hh*kgCO2g*10^{-3}
CO2g = CO2 Emission by Use of Natural Gas [ton CO2] = Ug*hh*kgCO2g*10^{-3}

kgCO2e = 0.63 [kg CO2/kWh]
kgCO2g = 1.78 [kg CO2/m3]

‡ Based on primary energy

Based on this model, scientific literature on changes in energy consumption and on interviews with experts in the field of energy, different scenarios are constructed as shown in the next Section. Data analyses are prepared to examine the impact of the changes on energy consumption reduction and to consider the likely impact of services to be provided to increase energy saving potential. Based on this assessment the opportunities and threats are investigated further.

7 Scenarios

The next step in this research is to identify different energy consumption scenarios to illustrate the impact of the different possibilities to save on energy consumption. The scenarios demonstrate in which of the areas (technology, society and policy) development should take place mainly, to save on energy consumption optimally. After a business as usual scenario is calculated to estimate energy consumption by ordinary developments, different scenarios with changes in the separate areas are evaluated. Finally scenarios with combined energy saving effects are shown. The scenarios with different energy consumption reduction (ECR) potentials identified in this section, together with there principles and outcomes, are:

- **Business as Usual**
  Business as usual scenario - *Energy consumption by unaffected development*

- **Technological Change**
  Best Practice Scenario - *ECR by technological change*
- **Policy Changes**
  Double-Policy-Measures-Scenario - *ECR by policy changes*
- **Changes in Society**
  Feedback-System-Scenario – *ECR by changes in society*

- **Combination of Changes**
  Modest-Energy-Saving-Scenario - *Ambitious but modest changes in all areas*
  Technology & Policy Scenario – *ECR without feedback*
  Technology & Feedback Scenario – *ECR without policy changes*

7.1 Business as Usual

In this part of the analysis different scenarios are calculated. At first the 'business as usual' (BAU) scenario is estimated. This scenario holds when the society and economy grows as predicted by RIVM until 2020, while the amount of consumed electricity and gas follows the trend as in the 10 previous years. In this scenario the amount of insulation options and energy saving measures grows on average and the influence of policy measures will stay the same as in the previous 10 years. In this scenario, total electricity consumption in the Dutch household sector increases with 21% per household and total gas consumption decreases with 33% from 2009 until 2020. The total energy use in the Dutch households increases with 2%.

	2009 PJ	2020 PJ	Total growth %
Electricity Use Households*	239	321	+34%
Natural Gas use Households	300	230	-23%
Total Energy Use Households*	539	551	+2%

* Based on primary Energy

Society

	growth, (2009 -2020) per year	total growth
Electricity Consumption Reduction	0,00%	0,00%
Feedback on Gas use; more Insulation	0,00%	-3,59%
Population Growth	0,30%	2,82%
Growth in number of households	0,98%	11,52%

Policy

	Gas	Electricity
Regulation	-0,62%	0,00%
Tax	-0,40%	-0,38%
Subsidies	-0,36%	-0,22%
Total	-0,90%	-0,56%

Technology

Electricity	2009 kWh	2020 kWh	Total growth %
cleaning	745	900	21%
cooling	589	674	14%
lighting	571	690	21%
heat and hot water	530	673	27%
audio/video/communication	532	670	26%
cooking	202	280	39%
kitchen machines	124	149	20%
inhouse climate	106	90	-15%
Electricity Consumption per household [kWh]	3400	4126	+21%

Gas	2009 %	2020 %	Total growth %
Wall Insulation penetration	77%	98%	26%
Glass Insulation penetration	96%	100%	4%
Roof Insulation penetration	93%	100%	8%
Floor Insulation penetration	73%	100%	38%
High Efficiency Heating System penetration	88%	100%	13%
Gas Consumption per household [m3]	1433	959	-33%

Table 7: Predicted amount of gas & electricity consumption from 2009-2020 BAU

The average and total amount of gas consumption will decrease due to the penetration of more insulating measures in society. On the other hand total and average electricity consumption will increase by the installation of more electricity using equipment.

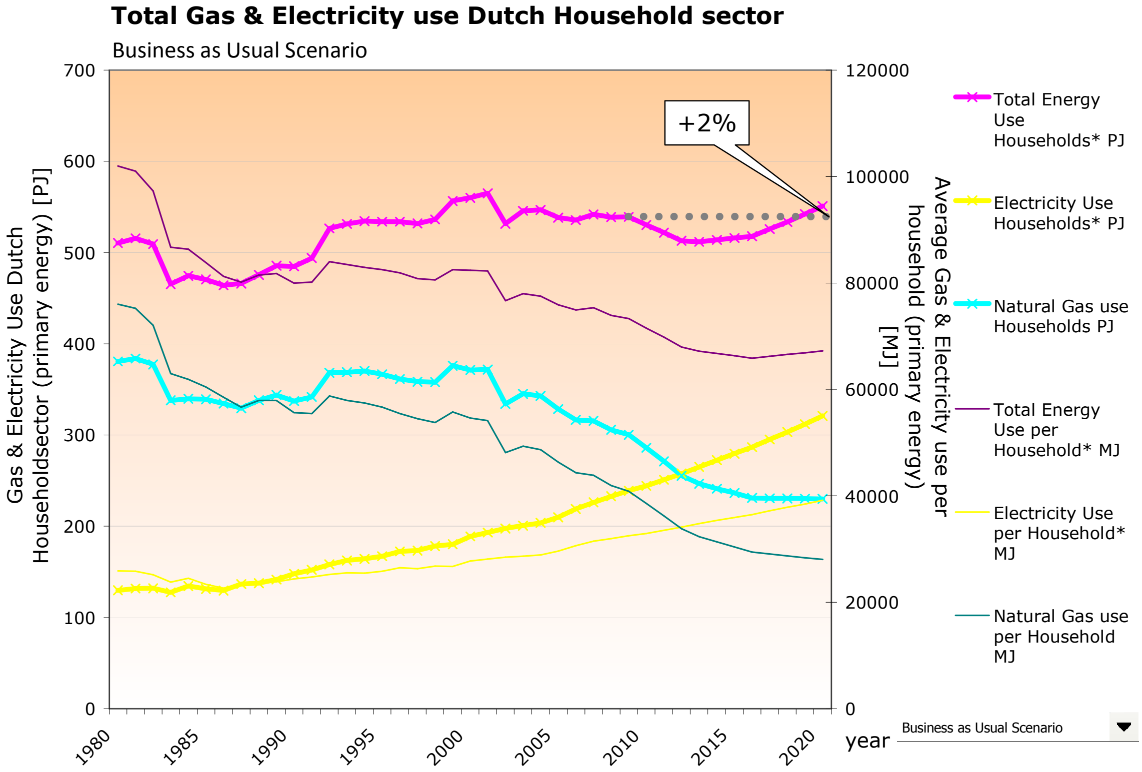


Figure 22: Total gas and electricity use in the Dutch Household sector (business as usual)

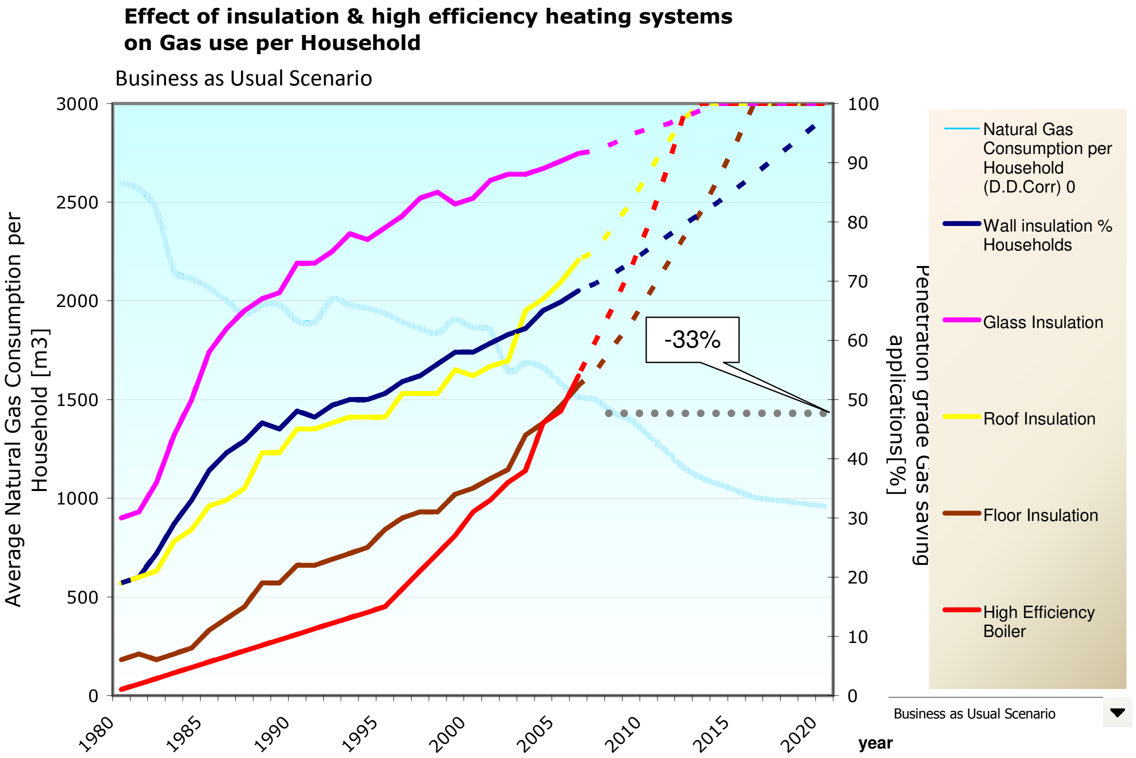


Figure 23: The Effect of gas saving technologies in the Dutch Household sector (business as usual)

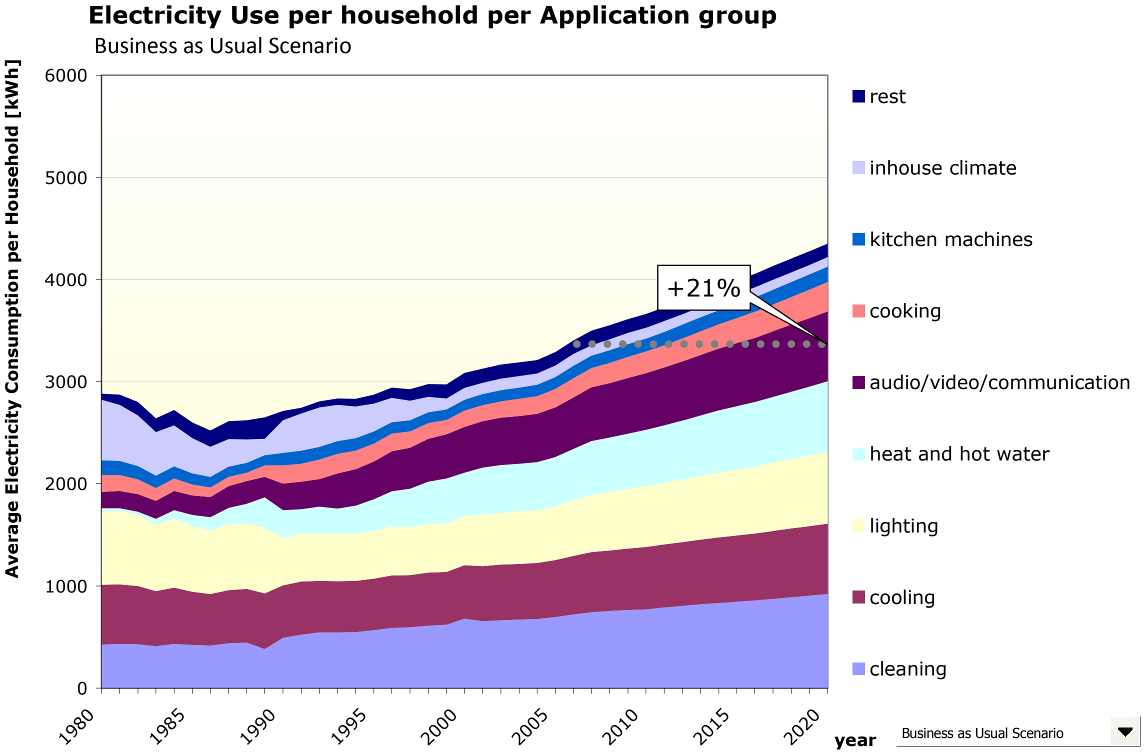
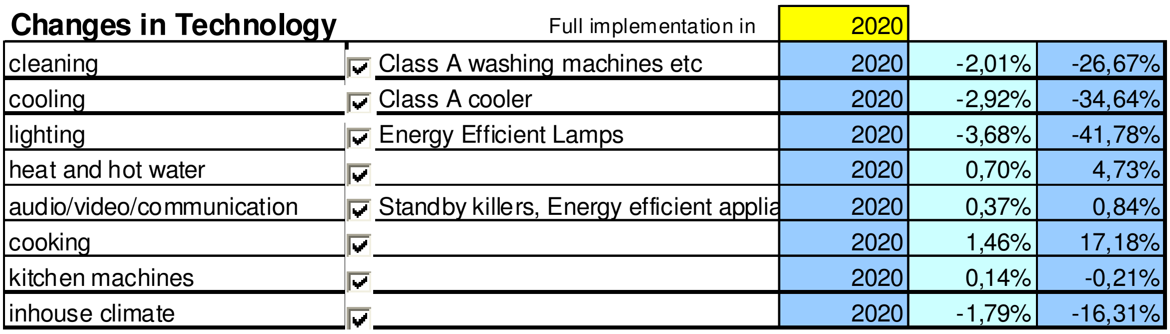


Figure 24: Growing Electricity Use in the Dutch Household sector per Application (business as usual)

7.2 Technological Change

In the Best-Practice-Scenario (BPS) it is assumed that the average Dutch household will have acquired today's best practice electric equipment in 2020 instead of owning the average owned equipment it uses nowadays. The data from the top10 website, as mentioned in Section 3.1.1, is used to examine best practice equipment to investigate what the effect would be if more energy efficient equipment would be used in the future. The comparison is based on the same penetration grade in households and intensity of use with best practice equipment. For the potential of energy saving insulation materials and energy efficient boilers, data from CBS (2003; 2004; 2006) and Senternovem (2008) is used to examine the grade of penetration of these materials within the Dutch household sector and the average amount of gas saving.

In this scenario electricity consumption in the average Dutch household, between 2009 and 2020, decreases with 17%. For insulation measures it is also assumed that in 2020 every household possesses all gas insulating measures. For gas consumption however, in the business as usual scenario estimated growth figures for insulation measures already show that the average Dutch household has implemented all prevailing insulation measures (wall, roof, floor, windows) and energy efficient heating systems in 2020. Therefore the gas consumption decrease between 2009 and 2020 in the average Dutch household will stay 33%. The total energy use in the Dutch households decreases with 19%.



Changes in Technology		Full implementation in	2020		
cleaning	☑	Class A washing machines etc	2020	-2,01%	-26,67%
cooling	☑	Class A cooler	2020	-2,92%	-34,64%
lighting	☑	Energy Efficient Lamps	2020	-3,68%	-41,78%
heat and hot water	☑		2020	0,70%	4,73%
audio/video/communication	☑	Standby killers, Energy efficient applia	2020	0,37%	0,84%
cooking	☑		2020	1,46%	17,18%
kitchen machines	☑		2020	0,14%	-0,21%
inhouse climate	☑		2020	-1,79%	-16,31%

Figure 25: Input screen for changes in technology

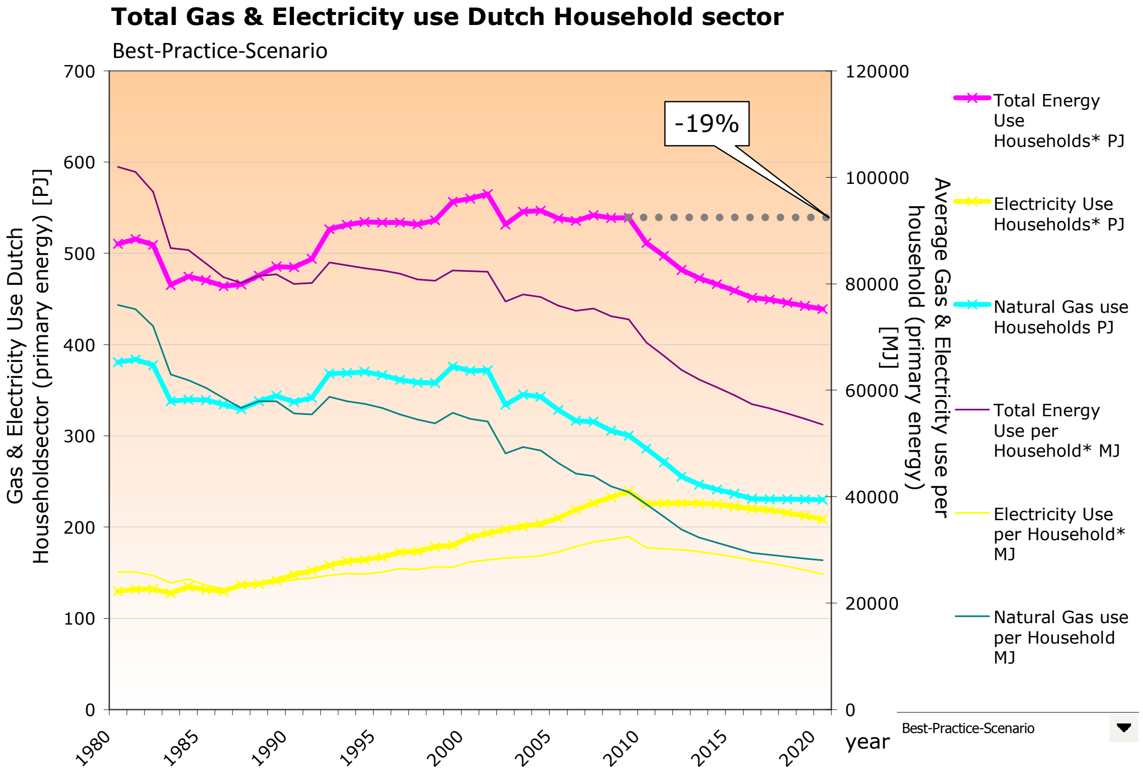


Figure 26: Total gas and electricity use in the Dutch Household sector (BPS)

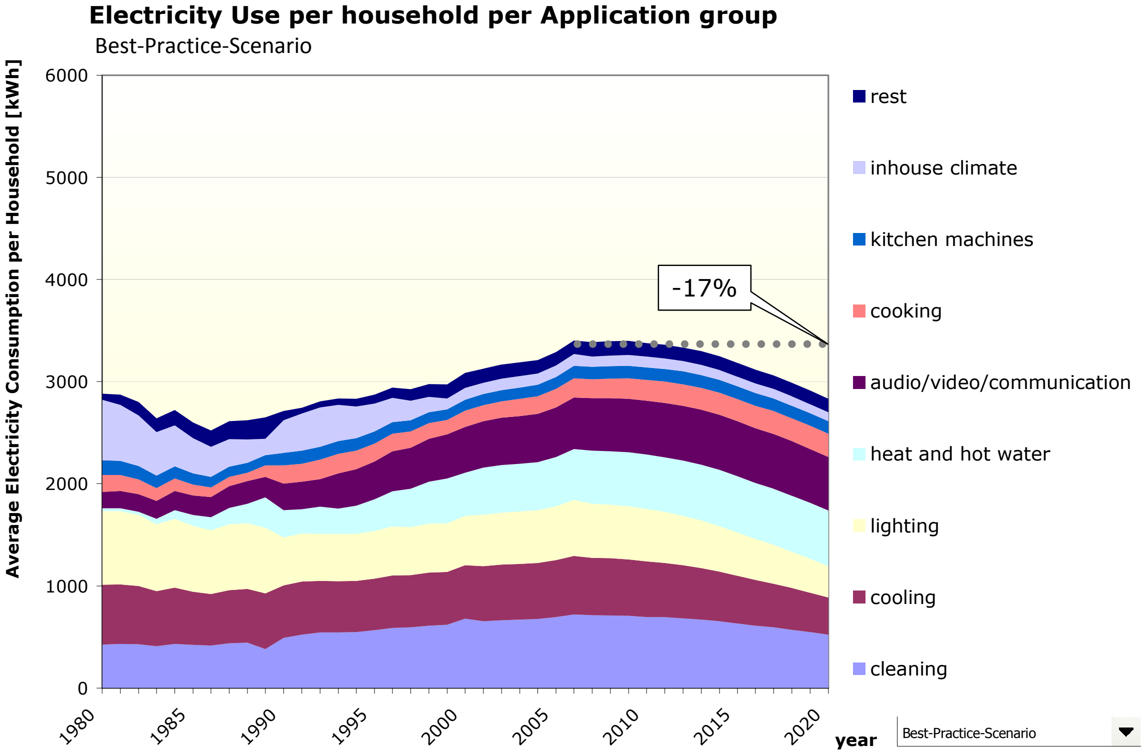
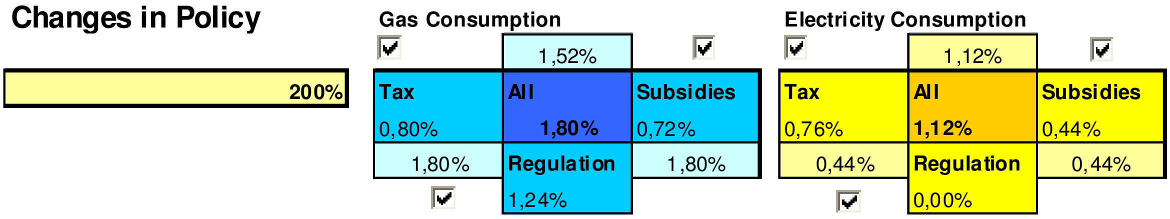


Figure 27: Declining Electricity Use in the Dutch Household sector per Application (Best-Practice)

7.3 Policy changes

Policies can stimulate or slow down energy consumption reduction. This scenario focuses on changes in applied policy measures to reduce energy consumption. The scenario shows what the impact of policy measures will be if governmental means will cause a twice as large reduction in energy consumption as they do nowadays as discussed in Section 5. This scenario is called ‘Double-Policy-Measures-Scenario’ (DPMS). The DPMS assumes policies forcing a twice as much energy saving potential between 2009 and 2020 as it was between 2000 and 2005. The effect of this doubling in effect of policy measures will just give a small effect on electricity and gas consumption in the Dutch household sector. There will still be an increase in total energy use of 2%.



Changes in Policy

200%

Gas Consumption

☑	1,52%	☑
Tax 0,80%	**All** **1,80%**	**Subsidies** 0,72%
1,80%	**Regulation** 1,24%	1,80%
☑		

Electricity Consumption

☑	1,12%	☑
Tax 0,76%	**All** **1,12%**	**Subsidies** 0,44%
0,44%	**Regulation** 0,00%	0,44%
☑		

Figure 28: Input screen for changes in Policy

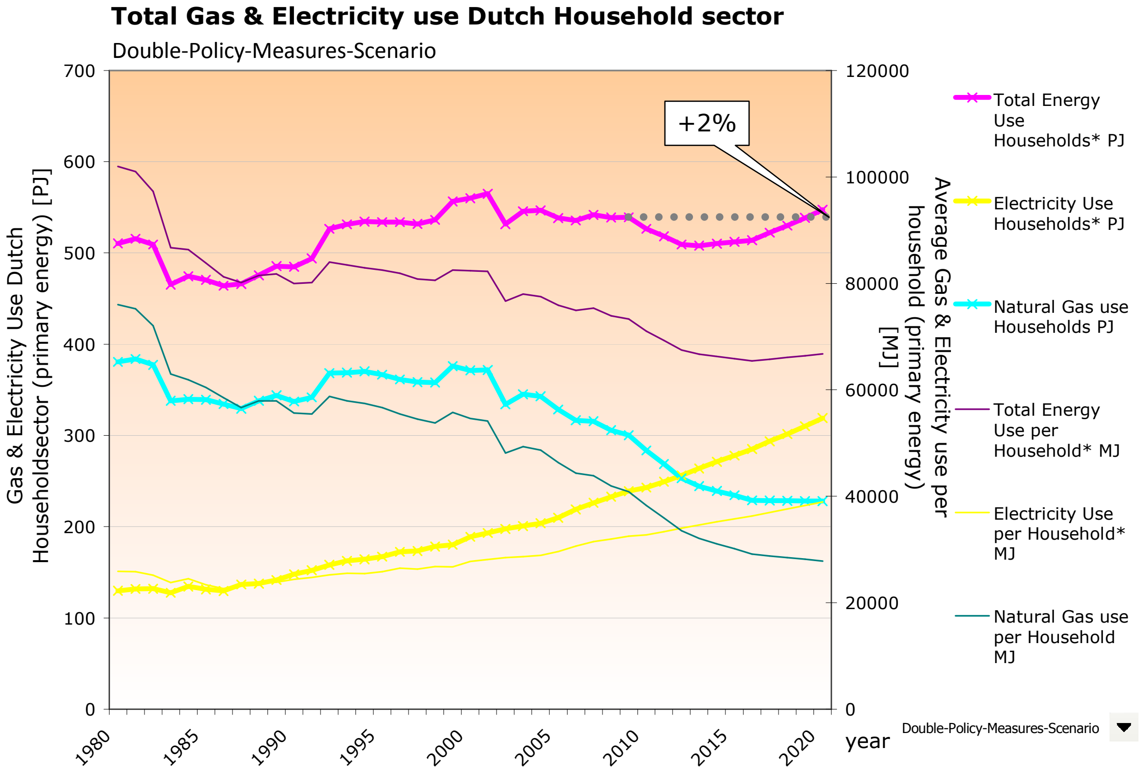
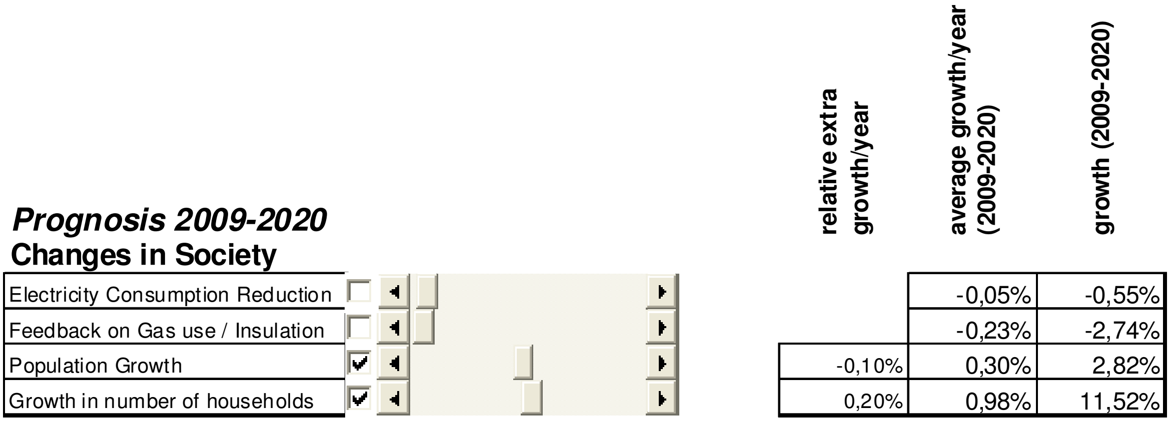


Figure 29: Total gas and electricity use in the Dutch Household sector (DPMS)

7.4 Changes in Society

This scenario shows what the impact will be when feedback systems are so effective that every person in 2020 will be motivated to save energy by an efficient tailor-made feedback system as assumed in Section 4.2.3. This scenario is called 'Feedback-System-Scenario' (FSS). It is the expectation that better insight of energy consumption by monitoring can contribute a diffusion of best practice products and other energy saving measures which will lead to longer term energy consumption reduction.

In the FSS it is supposed that from 2009 until 2020 every household will have some kind of tailor made feedback system causing energy consumption reduction working for every specific type of person. In this scenario feedback on electricity consumption causes a consumption reduction by 10% according to Section 4.2.3. Feedback on gas consumption maximally reduces gas consumption with 1.4% in comparison with the Business as Usual scenario since many insulating measures are installed anyway.



Prognosis 2009-2020
Changes in Society

		relative extra growth/year	average growth/year (2009-2020)	growth (2009-2020)
Electricity Consumption Reduction	☐		-0,05%	-0,55%
Feedback on Gas use / Insulation	☐		-0,23%	-2,74%
Population Growth	☑	-0,10%	0,30%	2,82%
Growth in number of households	☑	0,20%	0,98%	11,52%

Figure 30: Input screen for changes in Society

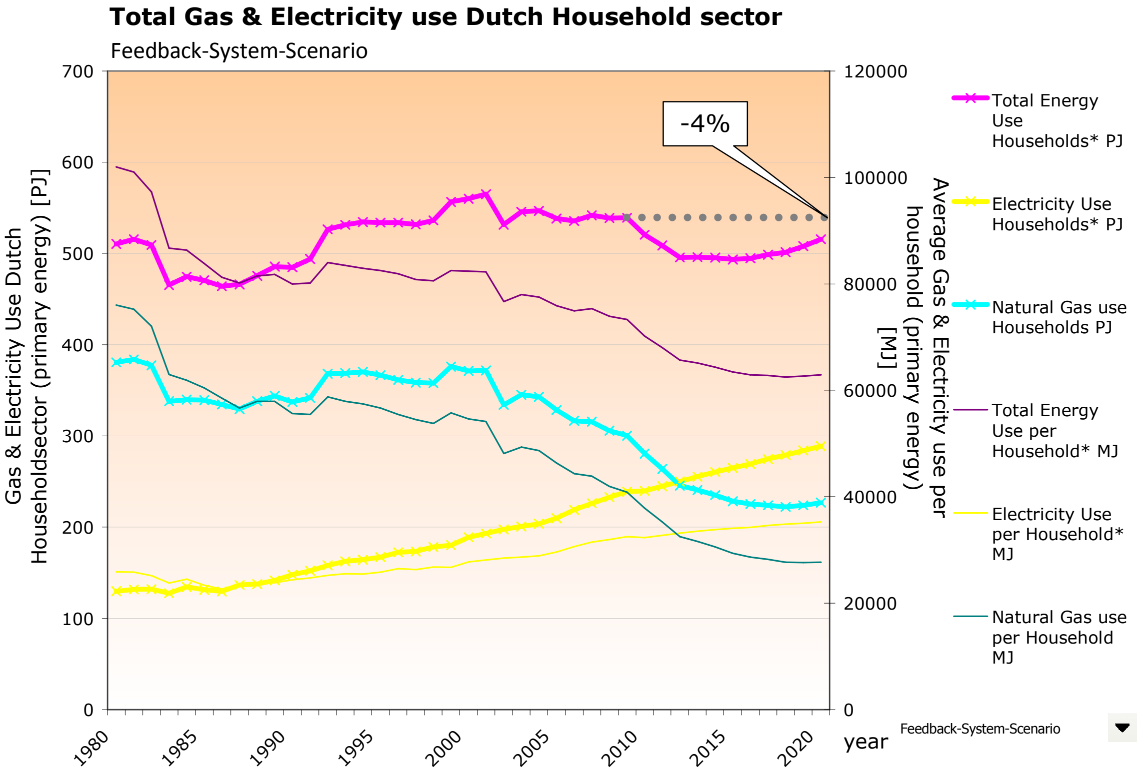


Figure 31: Total gas and electricity use in the Dutch Household sector (FSS)

7.5 Combination of Changes

The ideal way to reduce energy consumption in the Dutch household sector is if changes in the different areas are combined to strengthen each other. On basis of the earlier findings and scenarios above a reasonable scenario is constructed called 'Modest-Energy-Saving-Scenario' (MESS), which shows the energy saving potential by a combination of ambitious but modest changes.

Besides this scenario, 2 other scenarios with a combination of changes are constructed. These scenarios are constructed to calculate what the outcome of the energy saving potential is while excluding some of the energy saving changes. These scenarios already give an indication of the outcome of the sensitivity analysis as described in Section 7.7. These scenarios, containing a combination of changes as well, are: the "Technology & Policy Scenario" and "Technology & Feedback scenario". The first one lacks the energy saving effect of feedback systems and the second one doesn't regard policy changes.

7.5.1 Modest Energy Saving Scenario

The MESS shows an altered business as usual scenario with 2009s best practice equipment on average in all Dutch households just in 2030 and a total feedback energy saving effect of 5% on electricity and 1.4% on gas consumption, which is the effect when 50% of households would save 10% by feedback on energy consumption. In this scenario electricity consumption decreases with 7% and gas consumption decreases with 34% per household. There will be a decrease in total energy use of 14%.

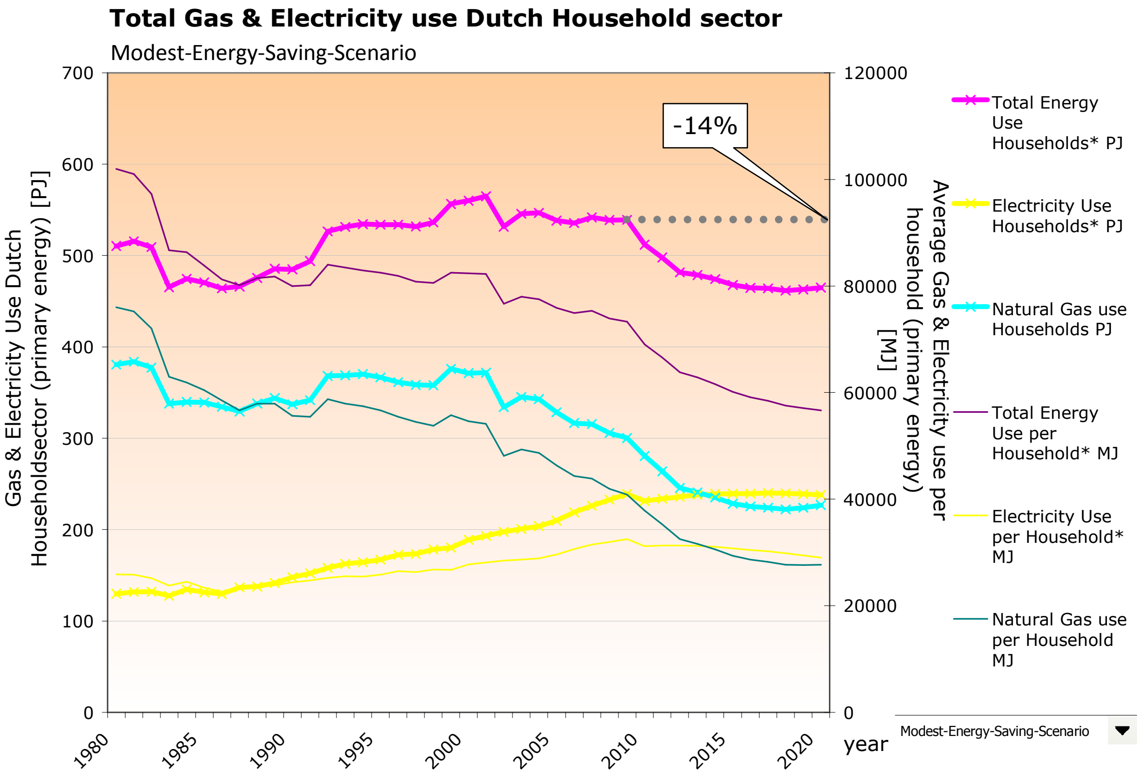


Figure 32: Total gas and electricity use in the Dutch Household sector (MESS)

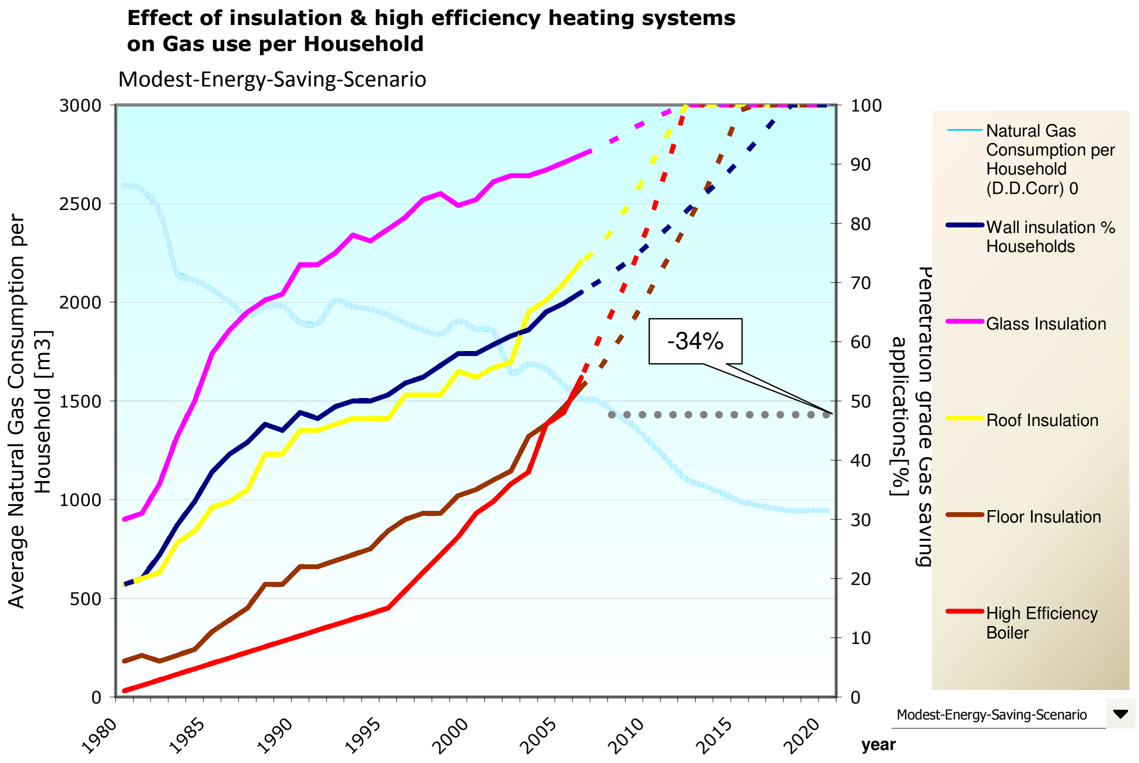


Figure 33: The Effect of gas saving technologies in the Dutch Household sector (MESS)

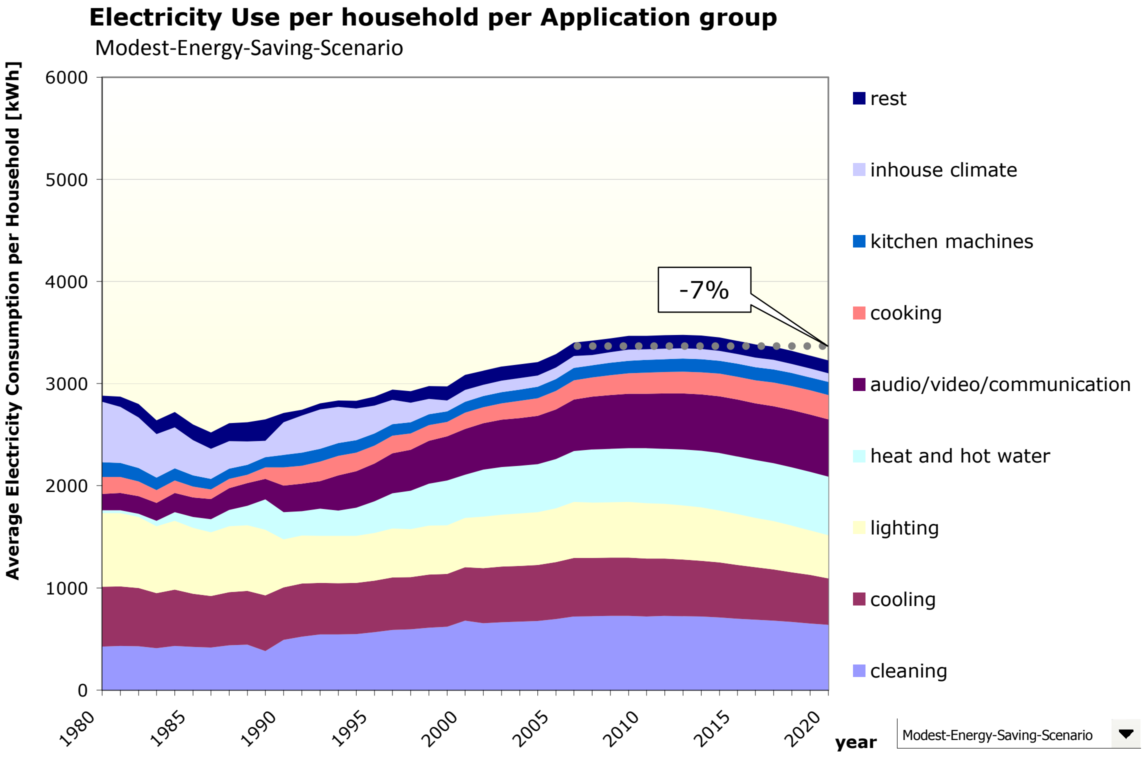


Figure 34: Growing Electricity Use in the Dutch Household sector per Application (MESS)

7.5.2 Technology & Policy Scenario

The T&PS shows an altered business as usual scenario with 2009s best practice equipment on average in all Dutch households in 2040 and no feedback on electricity and gas consumption. The effectiveness of regulations, taxes and subsidies is as high as it is in the business as usual scenario. In this scenario electricity consumption increases with 4% and gas consumption decreases with 34% per household. The total energy use in the Dutch households decreases with 8%.

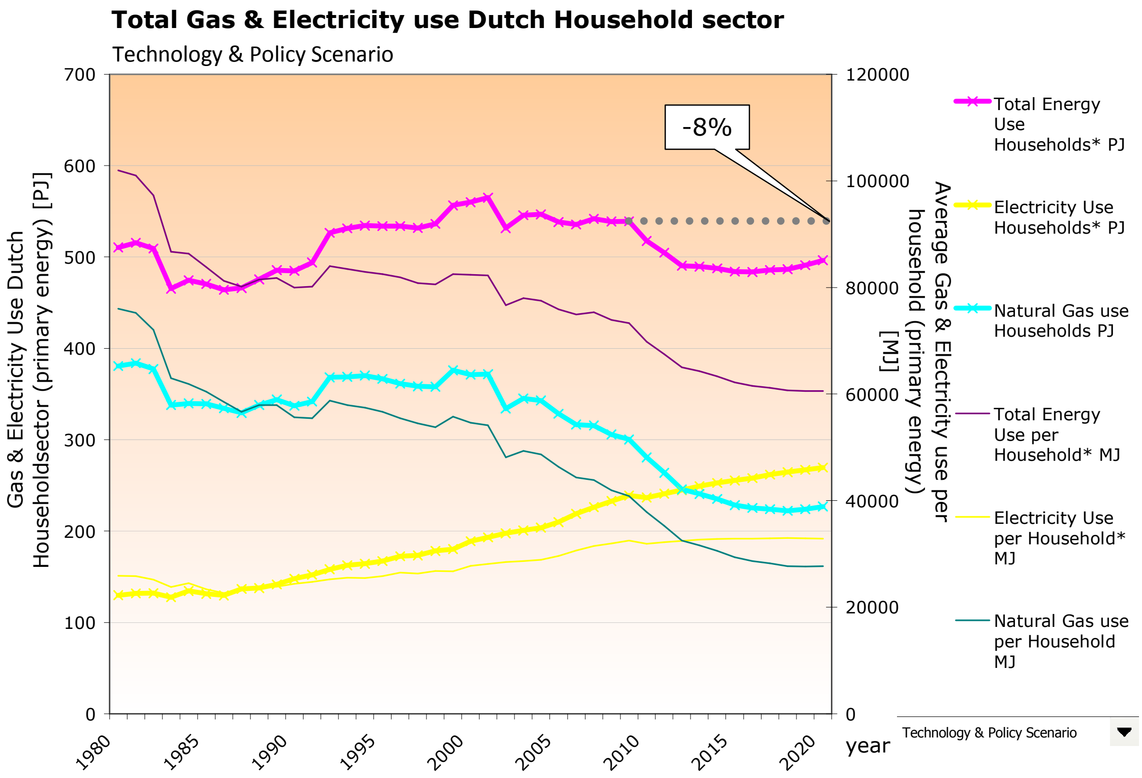


Figure 35: Total gas and electricity use in the Dutch Household sector (TPS)

7.5.3 Technology & Feedback Scenario

The T&FS shows an altered business as usual scenario with 2009s best practice equipment on average in all Dutch households just in 2040 and a total feedback energy saving effect of 5% on electricity and 1.4% on gas consumption, which is the effect when 50% of households would save 10% by feedback on energy consumption. The effectiveness of regulations, taxes and subsidies is set to zero. In this scenario electricity consumption decreases with 1% and gas consumption decreases with 33% per household. The total energy use in the Dutch household sector decreases with 10%.

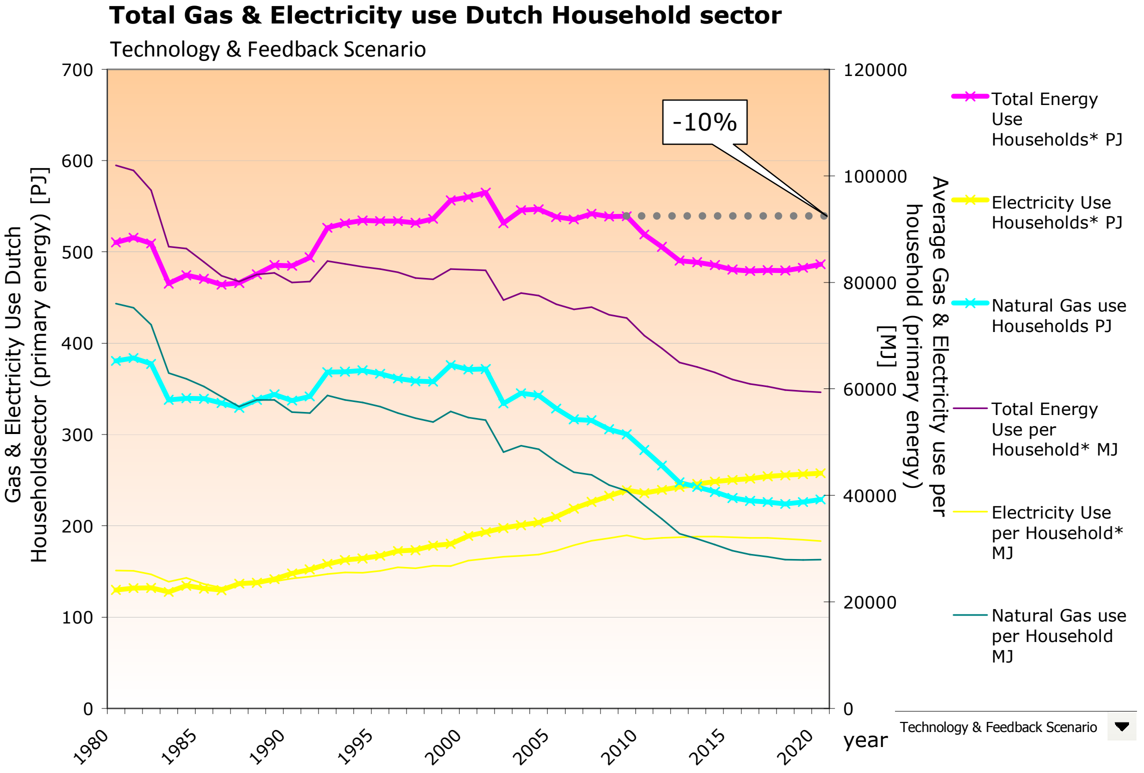
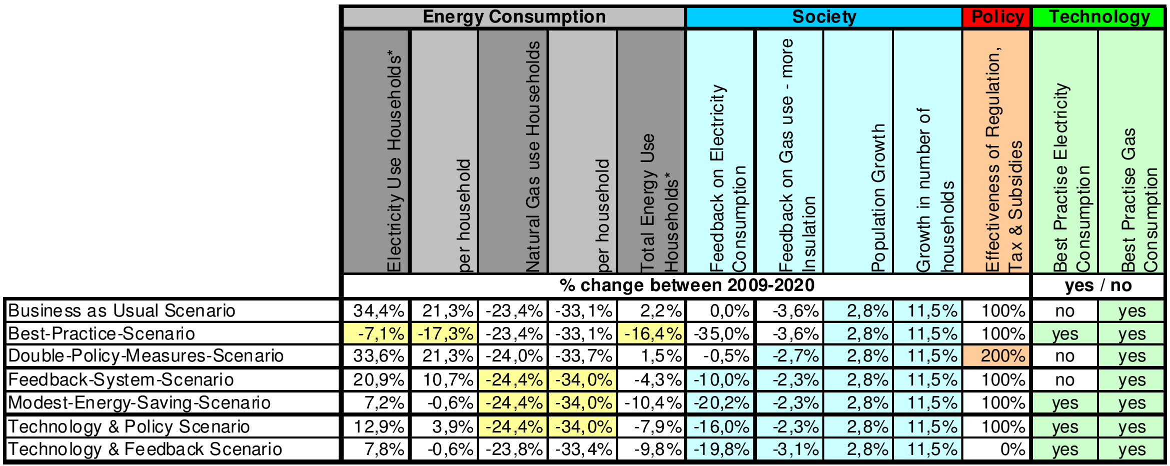


Figure 36: Total gas and electricity use in the Dutch Household sector (TFS)

7.6 Energy Saving Potential

Now that the assumptions of the different scenarios have been explained, the alternative scenarios will now be compared on energy saving potential with the original Business as Usual scenario. Table 7 below gives an overview of the compared scenarios and their energy saving potential. Table 8 shows the relative differences between the alternatives and business as usual scenario. The conclusion is that most energy saving potential is in technological change however that even with ambitious but more modest changes large energy potential in the areas of technology and society can be realised.



	Energy Consumption					Society				Policy	Technology	
	Electricity Use Households*	per household	Natural Gas use Households	per household	Total Energy Use Households*	Feedback on Electricity Consumption	Feedback on Gas use - more Insulation	Population Growth	Growth in number of households	Effectiveness of Regulation, Tax & Subsidies	Best Practise Electricity Consumption	Best Practise Gas Consumption
	% change between 2009-2020										yes / no	
Business as Usual Scenario	34,4%	21,3%	-23,4%	-33,1%	2,2%	0,0%	-3,6%	2,8%	11,5%	100%	no	yes
Best-Practice-Scenario	-7,1%	-17,3%	-23,4%	-33,1%	-16,4%	-35,0%	-3,6%	2,8%	11,5%	100%	yes	yes
Double-Policy-Measures-Scenario	33,6%	21,3%	-24,0%	-33,7%	1,5%	-0,5%	-2,7%	2,8%	11,5%	200%	no	yes
Feedback-System-Scenario	20,9%	10,7%	-24,4%	-34,0%	-4,3%	-10,0%	-2,3%	2,8%	11,5%	100%	no	yes
Modest-Energy-Saving-Scenario	7,2%	-0,6%	-24,4%	-34,0%	-10,4%	-20,2%	-2,3%	2,8%	11,5%	100%	yes	yes
Technology & Policy Scenario	12,9%	3,9%	-24,4%	-34,0%	-7,9%	-16,0%	-2,3%	2,8%	11,5%	100%	yes	yes
Technology & Feedback Scenario	7,8%	-0,6%	-23,8%	-33,4%	-9,8%	-19,8%	-3,1%	2,8%	11,5%	0%	yes	yes

* Based on primary Energy

Table 8: Energy Saving Potential from different scenarios compared

	Energy Consumption					Energy Consumption				
	Electricity Use Households*	per household	Natural Gas use Households	per household	Total Energy Use Households*	Electricity Use Households*	per household	Natural Gas use Households	per household	Total Energy Use Households*
	% difference 2009-2020 with BAU					% difference per year				
Best-Practice-Scenario	-41,5%	-38,6%	0,0%	0,0%	-18,6%	-3,5%	-3,2%	0,0%	0,0%	-1,6%
Double-Policy-Measures-Scenario	-0,8%	0,0%	-0,6%	-0,6%	-0,7%	-0,1%	0,0%	0,0%	-0,1%	-0,1%
Feedback-System-Scenario	-13,5%	-10,6%	-1,0%	-0,9%	-6,5%	-1,1%	-0,9%	-0,1%	-0,1%	-0,5%
Modest-Energy-Saving-Scenario	-27,2%	-21,9%	-1,0%	-0,9%	-12,6%	-2,3%	-1,8%	-0,1%	-0,1%	-1,1%
Technology & Policy Scenario	-21,5%	-17,4%	-1,0%	-0,9%	-10,1%	-1,8%	-1,5%	-0,1%	-0,1%	-0,8%
Technology & Feedback Scenario	-26,6%	-21,9%	-0,4%	-0,3%	-12,0%	-2,2%	-1,8%	0,0%	0,0%	-1,0%

Table 9: Energy saving potential differences compared with BAU scenario

7.7 Reliability & Sensitivity

The reliability of the Energy Saving Potential Model depends on the reliability of the input data. A number of sources have been used to gather the data. In most cases the data from different sources (RIVM, CBS, Milieucentraal, Nuon) is consistent, and therefore considered reliable. In the cases where different sources seemed to provide inconsistent data estimates on basis of the different sources are made. The data can be regarded as reasonably reliable because of the consistency of the different sources and the well educated estimates [Kirkels, 2004].

At least as important as the reliability is the sensitivity. A sensitivity analysis is done to determine how sensitive the outcome of the different energy saving scenarios is on variations in specific variables. The sensitivity analysis consists of the exclusion of energy saving changes within the three different areas. For the separate criteria the energy saving potential is excluded from the calculation, by removing the separate effects from the Business as usual scenario and from the MESS. In Table 9 the results of this analysis are shown. The left side of the table shows the sensitivity within the Business as Usual scenario. The middle part shows the scenario with exclusion compared with MESS. The result of this analysis is that exclusion of potential of best practice electricity equipment and of feedback on electricity results in large differences with energy saving potential of the MESS. Conclusively, the outcome of the scenarios is most sensitive for these two measures. The most energy savings in the MESS is caused by best practice electricity appliances (79%) and on feedback on electricity consumption (15%).

	Outcome Sensitivity Analysis										
	Electricity Use Households*	per household	Natural Gas use Households	per household	Total Energy Use Households*	Electricity Use Households*	per household	Natural Gas use Households	per household	Total Energy Use Households*	% of Savings
	% difference with BAU scenario					% difference with MESS					
Modest-Energy-Saving-Scenario	-34,8%	-28,3%	-1,0%	-0,9%	-16,0%	0,0%	0,0%	0,0%	0,0%	0,0%	
Mess excluding Society Potential											
Feedback on Electricity Consumption	-29,6%	-24,0%	-1,0%	-0,9%	-13,7%	5,2%	4,3%	0,0%	0,0%	2,3%	14,5%
Feedback on Gas Consumption	-34,8%	-28,3%	0,0%	0,0%	-15,4%	0,0%	0,0%	1,0%	0,9%	0,6%	3,8%
MESS excluding Policy Potential											
Regulation	-34,8%	-28,3%	-0,9%	-0,8%	-15,9%	0,0%	0,0%	0,1%	0,1%	0,1%	0,6%
Tax	-34,5%	-28,3%	-1,0%	-0,9%	-15,8%	0,3%	0,0%	0,0%	0,0%	0,2%	1,3%
Subsidies	-34,5%	-28,3%	-1,0%	-0,9%	-15,8%	0,3%	0,0%	0,0%	0,0%	0,2%	1,3%
MESS excluding Technology Potential											
Best Practise Electricity Consumption	-6,8%	-5,2%	-1,0%	-0,9%	-3,5%	28,0%	23,1%	0,0%	0,0%	12,5%	78,6%
Best Practise Gas Consumption	-34,8%	-28,3%	-1,0%	-0,9%	-16,0%	0,0%	0,0%	0,0%	0,0%	0,0%	0,0%

Table 10: The outcome of the sensitivity analysis

8 Conclusions & Recommendations

This research was set up to study energy saving opportunities within the Dutch household sector. Therefore drivers of energy consumption reduction have been investigated within the area of technology, society and policy. In this research the perspective on promising energy saving mechanisms was investigated with a focus on the effects of feedback on energy consumption. To find answers on the research question and sub-questions, an Energy Saving Potential Model was constructed with the outcomes of the investigation of energy saving opportunities. This section consists of a summary of the drawn conclusions, answers on the sub-questions and recommendations for further investigation.

8.1 Drivers of Energy use and Energy saving

Because the opportunities of energy saving in the Dutch household sector were unclear; the aim of this investigation was to answer the main research question: "What are the technological, behavioural and political opportunities of energy saving in the Dutch household sector?". For this reason, in Section 3, 4 & 5, drivers for people to save on energy consumption have been identified. At this point the conclusions on this subject are drawn and three of the sub-questions are answered.

"*What are the main drivers for households to save energy?"*

The main drivers for households to consume energy are predisposing factors as economic growth, demographic factors and cultural developments. The total gas and electricity consumption due to these social factors will grow with 0.7% per year. The gas and electricity consumption per household due to the same factors will decline with 0.5% per year.

Most consumers don't see reasons to reduce the amount of energy they use. Since alternatives for the use of gas and electricity from the net are expensive and the use of these energy sources are certainly needed for daily living, gas and electricity are called relatively price-inelastic. Accordingly, energy price increases are too small to lead people to buy energy saving measures and these price changes will just have an insignificant effect on energy consumption. So money is not a main driver for households to save on energy consumption, hence energy saving has to be driven by something else than price changes.

Reinforcing drivers such as institutional factors as policy measures and feedback systems are drivers to reduce energy consumption. Policy measures in act today cause about 1% per year gas savings and 0.5% electricity savings per year. However, from this investigation enabling technological factors turned out to be the main drivers to reduce energy consumption in the last decades. By installing energy efficient and energy saving equipment with best practice appliances an average household could save 41% on electricity and 33% on natural gas consumption.

Still, to make consumers aware of the energy consumption reduction potential of these technological changes effective policy measures and feedback systems are needed. Data gathered from interviews and surveys concerning intentional behaviour on energy saving has been used to answer the next two sub-questions:

"*Will households save more energy when they get feedback on their consumption?"*

Feedback on energy consumption can be an effective tool to create awareness and as mover for energy saving. Qualitative analyses carried out, by e.g. the Bristol Centre for Sustainable Energy, gives support for the thought that people are more likely to save on energy when historic instead of comparative feedback is given. Both historic and comparative feedback can encourage consumers to change energy consuming behaviour. However, in general consumers especially appreciate feedback on their own historical energy consumption patterns since consumers often do not trust the validity of the comparison group [Roberts et al., 2004]. This feedback on energy consumption is considered to be particularly effective in situations in which the energy saver is the one paying per unit gas and electricity. Accordingly, feedback services will particularly be effective if households pay per unit of energy. Hardware changes with high fixed costs will merely be done by the owner of the accommodation. Thus, efficient tailor-made feedback on changing behaviour by energy monitoring, as shown, is a driver for energy consumption reduction. The effectiveness of feedback on energy consumption will be 5% if half of the households saved 10% on energy consumption. If tailor-made feedback enabling systems diffuse trough society to a maximum in 2020 this means an effectiveness of 0.4% per year.

"Will households save on energy consumption on just feedback?"

Feedback on behaviour by energy monitoring can support household to reduce energy consumption. However, energy consumption reduction within households will just be small by feedback systems only. Feedback systems are only effective if they focus on efficiency rather than on curtailment behaviour and when this feedback system is tailor-made depending on the type of energy consumer. Accordingly, measures with a focus on behavioural change should be placed within the systems context containing the areas of policy and technology [Winkler et al., 1982].

Furthermore when feedback services on energy use will be developed, several considerations on the ways to visualise energy consumption will have to be taken into account. The visualisations will have to be understandable, functional and easy controllable to provide a high energy saving potential. For a successful diffusion of effective energy feedback systems the monitoring tool should be an object of desire.

8.2 Changes in Technology, Society & Policy

After the identification of potential drivers to save on energy consumption, Sections 6 & 7 identified the ESP-Model and scenarios to save on energy consumption optimally. The conclusions mainly based on these scenarios, together with the answers on the fourth sub-questions follow here.

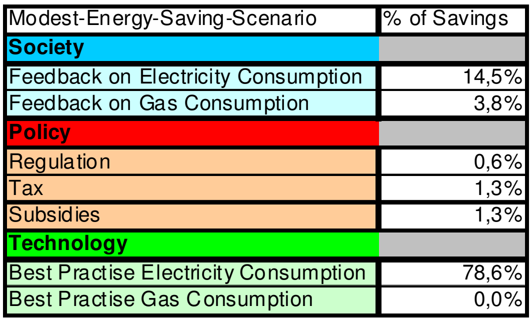
"Which changes in technology, behaviour or policy will be most effective and how will they interact?"

Changes by the implementation of complementary technologies facilitate new energy saving functionalities. To gain the amount of energy consumption reduction as proposed in EU directives, efficient load management in combination with domotics partly controlled by energy suppliers is useful to enforce further energy consumption reduction. However, there are not many possibilities in which consumers can use a large extra amount of electricity consumed by appliances that can be used overnight, compared with the current situation. Surely the dishwasher, washing machine and dryer could be, and often already are, used overnight. This behaviour is encourage by lower off-peak electricity prices. Yet the amount of electricity of these appliances is only 15-20% of the total electricity consumption within households between 2009 and 2020. Consequently the effect of this overnight use, on balanced load management, is rather low. With the average total network losses of 7% in the Netherlands the total effect from 2009 to 2020 would thus be in the order of 1%.

Focussing on changes in curtailment behaviour will just give a small effect on the total energy saving since it often asks for increased effort and/or reduced comfort and is therefore not effective on the larger scale in energy saving potential. Hence, the effects of technological developments on the reduction of energy consumption will be higher. Still, to encourage people to buy energy saving appliances changes in efficiency behaviour will be constructive. As concluded in the Best-Practice-Scenario a reduction of total energy consumption of 20% in 2020 within the Dutch household sector is possible by these technological developments, although it will be hard to realise.

Subsidies aimed at reducing the costs of improvement, along with research and development to make more alternatives available are most effective. Campaigns, policy measures and feedback systems focussing on changes in energy saving behaviour should focus on efficiency instead of curtailment behaviour including actions as switching to energy efficient equipment, implementing insulation materials or acquiring an energy-efficient domestic central heating system.

The table below shows that 79 % of total energy savings in the MESS scenario is caused by best practice electricity appliances and 15% by feedback on electricity consumption. Effective drivers of energy consumption reduction will strengthen each other. A feedback system pointing at cost-effective energy saving measures and energy efficient appliances is a good manner to reduce energy consumption, using the strengths from the different areas. To reach an optimal set of policy measures in individual policy measures should be directed to specific energy applications. Furthermore different measures will have to be tuned. For example, standards can assure a minimum level of efficiency while subsidies will stimulate specific most efficient equipment.



Modest-Energy-Saving-Scenario	% of Savings
Society	
Feedback on Electricity Consumption	14,5%
Feedback on Gas Consumption	3,8%
Policy	
Regulation	0,6%
Tax	1,3%
Subsidies	1,3%
Technology	
Best Practise Electricity Consumption	78,6%
Best Practise Gas Consumption	0,0%

Table 11: The outcome of Energy Saving Potential in the MESS

8.3 Energy Service Companies

Energy Service Companies, like Ecofys, could offer services to households to show opportunities of energy consumption saving measures by feedback or information on energy saving equipment. Feasible services can support the goals as mentioned in Section 2.1: affordability in both economical and environmental sense, reliability to secure the supply and cleanness of energy supply. The last sub-question will be answered here.

"Which services will have to be provided to increase the energy consumption reduction in the Dutch household sector?"

Services to support developments in Technology

There are not many examples of energy monitoring devices in the domestic sector. Within Ecofys last year there have been proposals to a new product called "Home EnergyMirror". As been written this tool, to monitor the various energy flows of energy within households, should contain all different types of feedback to be the most successful. ESCOs could supply tailor-made information and feedback systems and give a valuable contribution on benchmarking between consumers. By benchmarking households with the same characteristics (building year, type of house, amount of people) valuable information and feedback on energy efficient, energy saving equipment and on largely consuming appliances can be given to support energy consumption reduction. The implementation of smart metering, domotics and micro generation systems will certainly support the success of these services.

ESCOs could also advice energy suppliers on load management. On the demand side better insight in energy consumption patterns within the household sector will help energy suppliers in estimating energy demand. On the supply side the realization of large wind farms and solar systems ask for better estimation on expected local wind speed and light intensities. When energy production and consumptions could be accurately estimated, electricity networks could be more efficient in the future. So an opportunity for ESCOs is to play a large role in improvement on estimations of energy demand and supply.

Services to support changes in Society

Households will have to get conscious of the most effective technological changes to get larger amounts of energy saving. An ESCO could supply tailor-made information and feedback systems to support energy consumption reduction and to give a contribution on benchmarking between consumers. The visualisations pointing at energy saving behaviour will have to be understandable, functional and easy controllable to provide a high energy saving potential. For a successful diffusion of these feedback systems the monitoring tool will have to be designed to be an object of desire. By this feedback system services, barriers in society will have to be removed to make perceived non-financial costs transparent. The implementation of energy efficient and energy saving technologies will certainly support the success of these services.

Services to support changes in Policy

Counseling governmental organisations could help policy makers to investigate which kind of energy saving campaigns will work best, which energy saving equipment needs subsidies and which changes in electricity networks are effective to maximize energy consumption reduction within the household sector. When energy production and consumptions are accurately estimated electricity networks could be more efficient in the future. So another opportunity for an ESCO is to play a role in improvement in estimating energy demand and supply. Furthermore, counseling governmental organisations will help policy makers to investigate which kind of energy saving campaigns and measures will work best.

8.4 Opportunities

As mentioned earlier the objective of this investigation is to find opportunities for energy consumption reduction within the Dutch household sector and service opportunities by the introduction of energy monitoring. By answering the sub-questions above the main research question is answered.

"What are the technological, behavioural and political opportunities of energy saving in the Dutch household sector?"

Enabling technological factors turned out to give opportunities to reduce energy consumption. The reinforcing factors from policy measures and feedback systems turn out to provide less energy saving potential but give useful opportunities to point at energy efficient and saving equipment. Subsidies aimed at reducing the costs of improvement, along with research and development to make more energy efficient and saving equipment available are the most effective measure. Additionally tailor-made feedback systems in turn could point at the subsidised, or in another way cost-effective, energy saving measures to reduce energy consumption using the strengths of the different areas. Drivers of energy consumption reduction enforced by changes in technology, together with changes in behaviour and policy can be successful in energy saving in the Dutch household sector.

8.5 Recommendations for further research

In this study an Energy Saving Potential Model is constructed to investigate energy saving potential in the different areas. Within this investigation variables from the different areas have been applied to investigate historical and future energy consumption. Valuable is the opportunity to show the possible impact of different technological, societal and political changes in the future. However, this ESP-Model is just a straightforward model that could be extended to be more valuable for governments, industries and ESCOs in the exploration for energy consumption saving potential. At this point recommendations for further additions in both the ESP-Model and investigations are done.

Boonekamp (2005) stated that interaction between saving effects could lead to a total saving effect unequal to the sum of the separate effects. Specifically there is an interaction between savings on end-use and savings in supply [Boonekamp, 2005]. Therefore, complementary modelling of energy consumption reduction, it would be a good addition to model energy production efficiency as well. With this addition the diffusion of renewables, micro generation systems, less network losses by better load management and an altering energy mix would show differences in use of fossil or infinite energy sources and their effect on net CO2 emission. Furthermore the model would be better when all energy producing and energy consuming sectors would be taken into account. So it would be even better to include the energy production sector, the industry sector, the whole building and mobility sector for instance.

The scenarios in Section 7 are supported by reasonable possibilities. However, the amount of energy consumed in the built environment is not solely dependent on energy consumption in the household sector. Furthermore, when all different energy producing and consuming sectors would be added to the ESP-Model it would be possible to add rebound effects, the effects of price-elasticity of demand or policy measures on penetration of every single energy consuming or energy consumption-reducing application. Moreover it possibly will be a good initiative to add the scenarios above with numbers on population growth, based on credit crunch scenarios and to compare them with famous energy scenarios as IEA’s World Energy Outlook and the Shell and WWF energy scenarios.

9 Bibliography

Abrahamse, W., Steg, L., Vlek, C., Rothengatter, T. (2005). *A review of intervention studies aimed at household energy conservation*. Rijksuniversiteit Groningen, Wageningen.

Abrahamse, W. (2007). *Energy conservation through behavioral change: Examining the effectiveness of a tailor-made approach*. Rijksuniversiteit Groningen, Wageningen.

Ajzen, I. (1985). *From intentions to actions: A theory of planned behavior*. Springer, Berlin.

Bernstein, M.A, and J Griffin (2006). *Regional Differences in the Price-Elasticity of Demand for Energy*. NREL/SR-620-39512. Rand Corporation. Retrieved May 2008, from NREL: http://www.nrel.gov/docs/fy06osti/39512.pdf.

BERR (2007-I). BERR, *Smart metering*. Retrieved December 2007, from: http://www.berr.gov.uk/energy/environment/smart-metering/index.html.

BERR (2007-II). BERR, *Energy Billing and Metering: Changing Consumer Behaviour, A Consultation on Policies Presented in the Energy White Paper*. Retrieved December 2007, from http://www.berr.gov.uk/files/file40456.pdf.

BERR (2007-III). Berr, Retrieved January 2008, from: http://www.berr.gov.uk/energy/.

Boersema, J.J., Lucas Reijnders, L. (2009). *Principles of Environmental Sciences.* Springer, Dordrecht/Boston

Bohi, Douglas R. (1981) *Analyzing Demand Behavior: A Study of Energy Elasticities. Baltimore*, Maryland: John Hopkins University.

Boonekamp, P.G.M. (2005). *Improved methods to evaluate realised energy savings.* Utrecht University, Utrecht.

Boonekamp, Piet G.M. (2007). *Price Elasticities, Policy Measures and Actual Developments in Household Energy Consumption – A Bottom up Analysis for the Netherlands.* Energy Economics 29, no. 2 (Mar 2007): 133-57.

CBC (2005). *Smart Meters.* Retrieved December 2007, from Corporation Canadian Broadcasting: http://www.cbc.ca/news/background/energy/smartmeters.html

CBS; Statistics Netherlands (2003). *Magnetron verovert Nederlandse keuken [Microwave conquers the Dutch kitchen].* Retrieved June 2008, from: http://www.cbs.nl/nl-NL/menu/themas/inkomen-bestedingen/publicaties/artikelen/archief/2003/2003-1163-wm.htm

CBS; Statistics Netherlands (2004). *Energiegebruik toegenomen [Energy use has increased].* Retrieved June 2008, from: http://www.cbs.nl/nl-NL/menu/themas/industrie-energie/publicaties/artikelen/archief/2004/2004-1420-wm.htm

CBS; Statistics Netherlands (2006). *Energierekening stijgt fors. [Energy bill strongly increases].* Retrieved June 2008, from: http://www.cbs.nl/nl-NL/menu/themas/prijzen/publicaties/artikelen/archief/2006/2006-1870-wm.htm

CBS; Statistics Netherlands (2009). Data on "Bestedingen, *Duurzame energie, electriciteit productie, energiebalans, energie bestedingen, historie bevolking, milieugedrag, tarieven [Spending, Renewable energy, electricity production, energy balance, energy consumption, population history, environmental behavior, rates].*

CE (2006). *Energiebesparingsgedrag Verkenning t.b.v. Algemene Energie Raad*. CE Delft.

CentERdata (2008). Retrieved February 2008, from CentERdata: http://www.centerdata.nl/en/TopMenu/Projecten/MESS/index.html

Curtis, T. (1992-93). Greenhouse Programme: report on the heating advice project carried out on the Packington and Market Estates 1991/92 and 1992/93. Energy Information Centre, Islington Council.

Darby, S. (2006). The effectiveness of feedback on energy consumption: a review for DEFRA of the literature on metering, billing and direct displays. Oxford: Environmental Change Institute, University of Oxford.

DG Environment (2007). 2007 Annual Management Plan DG Environment. Retrieved January 2008, from The European Commission's Environment Directorate-General: http://ec.europa.eu/dgs/environment/pdf/management_plan_2007.pdf

DG Environment (2008). Retrieved January 2008, from the European Commission's Environment Directorate-General:
http://europa.eu.int/comm/dgs/environment/index_en.htm

Dobbyn J and Thomas G (2005) Seeing the light: the impact of microgeneration on the way we use energy. Qualitative research findings. Hub Research Consultants, London.

Domotica Platform.nl (2008). Retrieved January 2008, from Domotica Platform: http://www.domotica.nl/domotica.php

EEA (2008). Retrieved January 2008, from European Environment Agency: http://org.eea.eu.int

EC (2005). GREEN PAPER on Energy Efficiency or Doing More With Less. European Commission, Brussels

Egmond, C.C. (2006) Focus on Change, Influencing Segments of Housing Associations to Adopt Energy Conservation Measures and Innovations. Uitgeverij De Gouwzee, Enschede.

Egmond – de Wilde de Ligny, Dr. Ir. E.L.C. (1999), Technology Mapping for Technology Management, TU Delft.

EnergiePortal.nl (2007). Retrieved December 2007, from EnergiePortal: http://www.energieportal.nl/tag/slimme-meter/slimme-meter.html

Energywatch (2006) 'Getting Smarter: Improved energy information for customers

Energy Saving Trust (2007). Smart Metering Roundtable. Retrieved January 2008 from
http://www.energysavingtrust.org.uk/uploads/documents/aboutest/smart%20metering%20round%20table.pdf

European Commission (2008)
http://europa.eu.int/comm/energy/demand/legislation/domestic_en.htm.

Ellis P., Gaskell G. (1978). A Review of Social Research on the Individual Energy Consumer, Department of Social Psychology, London School of Economics

European Parliament (2006). Directive 2006/32/EC of the European Parliament and of the Council. Retrieved December 2007, from http://eur-lex.europa.eu/LexUriServ/site/en/oj/2006/l_114/l_11420060427en00640085.pdf

Gatersleben, B., & Vlek, C. (1998). Household consumption, quality-of-life and environmental impacts: a psychological perspective and empirical study. In: K.J. Noorman & A.J.M. Schoot Uiterkamp (Eds.). Green households? Domestic consumers environment and sustainability (pp. 141-179). London: Earthscan.

Geller, E. S., Berry, T. D., Ludwig, T. D., Evans, R. E., Gilmore, M. R., & Clark, S. W. (1990). A conceptual framework for developing and evaluating behavior change interventions for injury control. Health Education Research: Theory and Practice, 5, 125-137.

Green LW, Kreuter MW. Health promotion planning: an educational and environmental approach. 2nd ed. Mountain View, Calif: Mayfield, 1991.

Hinterberger, F., Kranendonk, S., Welfens, M., & Schmidt-Bleek, F. (1994). Increasing resource productivity through eco-efficient services. Wuppertal Papers Nr. 13, Wuppertal Institute, Germany.

Houwelingen, J.T. van, Raaij, W.F. van (1989). The effect of goal setting and daily electronic feedback on in-home energy use. Journal of Consumer Research 16.

McCalley, L. T., Midden, C. J., & Haagdorens, K. (2005). Computing Systems for Household Energy Conservation: Consumer Response and Social Ecological Considerations. Eindhoven: Technical University Eindhoven.

Keesee, M. (2005). Setting a new standard – the zero energy home experience in California. Sacramento Municipal Utility District

Kempton, W., Layne, L.L. (1994) The consumer's energy analysis environment. Energy Policy 22 (10), 857-866

Kirkels, A.F. (2004), reader "Technologie en Duurzaamheid", TU/e

Linn, Joshua. Energy Prices and the Adoption of Energy-Saving Technology. 06-012 WP. April 2006. Center for Energy and Environmental Policy Research. http://tisiphone.mit.edu/RePEc/mee/wpaper/2006-012.pdf.

Lockwood, M., Murray, R. (2005). RED Future Currents: Designing for a changing climate. Design Council

http://www.designcouncil.info/futurecurrents/downloads/FutureCurrents-RedesigningEnergyPolicy-18-10.pdf

Lohr, L. L., (2009), Computers in Human Behavior, v16 n2, 161-182.

Ölander, F., Thøgersen, J. (1995). Understanding of consumer behaviour as a prerequisite for environmental protection. gersen, Journal of Consumer Policy, 18, 345-385.

Onsustain (2007). Retrieved January 2010, from Onsustain http://www.onsustain.com

Oosterhuis, F., Nieuwlaar, E. (1998) National survey of policy instruments – Netherlands, EPISODE-working document, NW&S, UU, Utrecht.

Priva (2010). Retrieved January 2010, from Priva EnergyMirror http://www.energymirror.com/.

Roberts, S., Baker, W. (2003), Towards effective energy information: improving consumer feedback on energy consumption, report, Centre for Sustainable Energy, Bristol.

Roberts, S, Humphries H. and Hyldon, V. (2004). Consumer preferences for improving energy consumption feedback. Report for Ofgem. Centre for Sustainable Energy, Bristol, UK.

Rogers, E.M. (2003), Diffusion of innovations, Free Press, 5th edition

Samsom, Diederik (2008) Slimme meters. PvdA. Retrieved December 2008 from http://www.diederiksamsom.nl/

Sargent (1985). Energy, Foresight & Strategy. Baltimore; Washington, D.C. : Resources for the Future : Distributed by Johns Hopkins University Press.

Schwartz, S. H. (1977). Normative influences on altruism. In: L. Berkowitz (Ed.). Advances in Experimental Social Psychology, 10, 221-279. New York: Academic Press.

SenterNovem (1996). Trias Energetica. Retrieved January 2008, from SenterNovem: http://duurzaambouwen.senternovem.nl/begrippen/trias_energetica/

SenterNovem (2008). Cijfers & Tabellen 2007. The Hague: SenterNovem.

Siderius, H., & Dijkstra, A. (2006). Smart metering for households: cost and benefits for the Netherlands. The Hague: SenterNovem.

Smith, M. H., & Hargroves, K. (2007). Smart approaches to electricity use. The Natural Edge Project, Ecos, vol. 135 , 12-13.

Sonderegger, R.C. (1978) Movers and stayers: the resident's contribution to variation across houses in energy consumption for space heating. Energy and Buildings 1 (3), 313-324

Steg, L. (2003). Factors influencing the acceptability and effectiveness of transport pricing. In: J. Schade & B. Schlag (Eds.). Acceptability of transport pricing strategies (pp.187-202). Oxford: Elsevier.

Steg, L., Dreijerink, L., Wokje Abrahamse. (2006), Why are Energy Policies Acceptable and Effective?. University of Groningen, the Netherlands.

Stern, P. C. (2000). Toward a coherent theory of environmentally significant behavior. Journal of Social Issues, 56 , 407-424.

Storper, M., Walker, R. (1989). The capitalist imperative: territory, technology and industrial growth, Oxford, Basil Blackwell.

Sullivan, Arthur O'; Steven M. Sheffrin (2003). Economics: Principles in action. Upper Saddle River, New Jersey 07458: Pearson Prentice Hall.

Targosz, R. (2008). Reducing electricity network losses. Leonardo Energy.

Tracy, Brian (2002). Eat That Frog! Berrett-Koehler Publishers, San Francicso.

United Nations Division for Sustainable Development (Brundtland definition). Retrieved January 2008, from http://www.un.org/search/DESA/sustdev.html

Vlek, C. (2000). Essential psychology for environmental policy making. International Journal of Psychology, 35, 153-167.

Wilhite, H. and Ling, R. (1995). Measured energy saving from a more informative energy bill. Energy and buildings 22 pp 145-155.

Wilhite H, Hoivik A and Olsen J-G (1999). Advances in the use of consumption feedback information in energy billing: the experiences of a Norwegian energy utility. Proceedings, European Council for an Energy-Efficient Economy.

Winkler, R.A., Winett, R. (1982) Behavioural interventions in resource management: a systems approach based on behavioural economics. American Psychologist 37, 421-435.

10 List of Figures & Tables

Figures:

Tables:

Appendix A: Ecofys: an Energy Saving Company

An ESCO, like Ecofys, can deliver innovative products and services to help people save on energy consumption. Within Ecofys' realisation cluster there is a subdivision called Energy and Carbon management (ECM). The target for ECM is to offer structural and systematically reduction of energy consumption for the client. With this approach both costs and environmental burden could be reduced. In their projects payback time of investments is often less than a couple of years. The products and services offered by the ECM group have as main objective to create insight in the energy usage within the company and governmental build environment. Examples of products developed by Ecofys are:

- **Energiespiegel**

Predecessor of the EnergyMirror with as main goals to communicate energy related data to visitors and employees within the utility building environment.

- **Enerlyser**

Product with as main goal to communicate energy related data to the housekeeping environment.

- **CarBon Software**

Software tool developed to determine status regarding energy related topics, to support energy management related decisions and to monitor and report energy related information, especially used by governmental instances.

As written before Ecofys is looking for possibilities to expand their activities to households. The services offered by the ECM group are often custom and economical feasible services. Examples of their energy consumption saving services are:

- Determining building efficiencies;
- Energy Monitoring and maintenance of buildings;
- Risk management & security of supply;
- Renewable energy scans;
- Energy saving campaign support

Ecofys' mission: a sustainable energy supply for everyone

Appendix B: Electricity consumption in average Dutch household

	Power Average Appliance [W]	Average use per year [hours/year]	Consumption per Appliance [kWh/year]	Penetration Grade (%)	Average Installed use per household [kWh/year]	Percentage of Consumption[%]	Costs per year [€]	Best Practise Consumption [kWh/year]	Energy Saving Potential[%]	Standby Power [Watt]	Standby consumption per year [kWh/year]	Standby Saving Potential [€]
Total					**3632**	**100%**	**€ 799**	**2146**	**40,9%**	**98**	**333**	**€ 73**
lighting			583,9	100%	584	16%	€ 128	146	75,0%			
inhouse climate			127,0	100%	127	3%	€ 28	121	5,0%		9%	
individual appliances					**2921**	80%	€ 643	**1879**	**35,7%**	**98**	**333**	**€ 73**
Koffiezetapparaat	900	89	80	67%	54	1%	€ 11,79	42	21%	3	17	€ 4
Frituurpan	850	12	10	80%	8	0%	€ 1,76	6	21%	0	0	€ -
Waterkoker	1725	20	34	74%	25	1%	€ 5,54	20	21%	0	0	€ -
Kookplaatje	750	133	100	9%	9	0%	€ 1,87	7	21%	0	0	€ -
Espressomachine	1200	6	7	33%	2	0%	€ 0,51	2	21%	3	9	€ 2
Mixer	150	6	1	95%	1	0%	€ 0,19	1	21%	0	0	€ -
Staafmixer	100	6	1	95%	1	0%	€ 0,13	0	21%	0	0	€ -
Blender	150	7	1	95%	1	0%	€ 0,21	1	21%	0	0	€ -
Keukenmachine	450	6	3	95%	3	0%	€ 0,56	2	21%	0	0	€ -
Citruspers	300	6	2	95%	2	0%	€ 0,38	1	21%	0	0	€ -
Sapcentrifuge	300	6	2	95%	2	0%	€ 0,38	1	21%	0	0	€ -
Tosti-ijzer	500	6	3	95%	3	0%	€ 0,63	2	21%	0	0	€ -
Wafelijzer	500	6	3	95%	3	0%	€ 0,63	2	21%	0	0	€ -
Mes	50	6	0	95%	0	0%	€ 0,06	0	21%	0	0	€ -
Messenslijper	50	6	0	95%	0	0%	€ 0,06	0	21%	0	0	€ -
Snijmachine	300	6	2	95%	2	0%	€ 0,38	1	21%	0	0	€ -
Blikopener	30	7	0	95%	0	0%	€ 0,04	0	21%	0	0	€ -
Broodbakmachine	1500	6	9	20%	2	0%	€ 0,40	1	21%	0	0	€ -
Broodrooster	750	6	5	95%	4	0%	€ 0,94	3	21%	0	0	€ -
IJsmachine	20	5	0	95%	0	0%	€ 0,02	0	21%	0	0	€ -
Eierkoker	350	6	2	95%	2	0%	€ 0,44	2	21%	0	0	€ -
Dompelaar	350	6	2	95%	2	0%	€ 0,44	2	21%	0	0	€ -
Flessenwarmer	350	6	2	95%	2	0%	€ 0,44	2	21%	0	0	€ -
Koffiemolen	100	10	1	95%	1	0%	€ 0,21	1	21%	0	0	€ -
Fonduepan	500	6	3	95%	3	0%	€ 0,63	2	21%	0	0	€ -
Gourmetstel	500	6	3	95%	3	0%	€ 0,63	2	21%	0	0	€ -
Steengrill	500	6	3	95%	3	0%	€ 0,63	2	21%	0	0	€ -
Rechaud	100	6	1	95%	1	0%	€ 0,13	0	21%	0	0	€ -
Koelkast 2-deurs	**48,9**	8766	429	54%	232	6%	€ 50,97	88	62%	0	0	€ -
Koelkast met vriesvak	26	8766	225	36%	81	2%	€ 17,82	46	44%	0	0	€ -
Koelkast zonder vriesvak	23	8766	198	10%	20	1%	€ 4,36	9	55%	0	0	€ -
Diepvrieskist/kast	40	8766	350	18%	63	2%	€ 13,86	25	61%	0	0	€ -
Gietijzeren kookplaten	1310	391	512	9%	44	1%	€ 9,57	34	21%	0	0	€ -
Keramische kookplaten	1360	391	532	9%	45	1%	€ 9,95	36	21%	0	0	€ -
Spiraal/halogeen inductie kookplaten	1400	391	547	9%	46	1%	€ 10,23	37	21%	0	0	€ -
Solo magnetron	460	76	35	50%	18	0%	€ 3,85	14	21%	2	9	€ 2
Combi-magnetron	1100	87	96	45%	43	1%	€ 9,50	34	21%	2	8	€ 2
Elektrische oven in fornuis	1580	35	55	27%	15	0%	€ 3,27	12	21%	0	0	€ -
Grill (los)	700	30	21	50%	11	0%	€ 2,31	8	21%	0	0	€ -
Bakoven (los)	700	30	21	50%	11	0%	€ 2,31	8	21%	0	0	€ -
Grill/bakoven (los)	700	30	21	50%	11	0%	€ 2,31	8	21%	0	0	€ -
Gasfornuis (los)	1	8766	8	83%	7	0%	€ 1,46	5	21%	0	0	€ -

Legend:

50	Input variables
13	calculated values
185	high consumption of electricity calculated
8766	consuming during the whole year

Electricity consumption in average Dutch household (continued)

	Power Average Appliance [W]	Average use per year [hours/year]	Consumption per Appliance [kWh/year]	Penetration Grade (%)	Average Installed use per household [kWh/year]	Percentage of Consumption[%]	Costs per year [€]	Best Practise Consumption [kWh/year]	Energy Saving Potential[%]	Standby Power [Watt]	Standby consumption per year [kWh/year]	Standby Saving Potential [€]
Total					**3632**	**100%**	**€ 799**	**2146**	**40,9%**	**98**	**333**	**€ 73**
lighting			583,9	100%	584	16%	€ 128	146	75,0%			
inhouse climate			127,0	100%	127	3%	€ 28	121	5,0%		9%	
individual appliances					**2921**	80%	€ 643	**1879**	**35,7%**	**98**	**333**	**€ 73**
Elektrische boiler <20 liter	1000	719	719	5%	36	1%	€ 7,91	28	21%	0	0	€ -
Elektrische boiler >20 liter	1350	1410	1903	5%	95	3%	€ 20,93	75	21%	0	0	€ -
Elektrische geiser	9000	61	549	1%	3	0%	€ 0,72	3	21%	0	0	€ -
Centrale verwarming (individueel)	133	2038	271	80%	217	6%	€ 47,70	171	21%	0	0	€ -
Elektrische badkachel	600	158	95	11%	10	0%	€ 2,30	8	21%	0	0	€ -
Elektrische straalkachel	250	104	26	3%	1	0%	€ 0,17	1	21%	0	0	€ -
Elektrische ventilatorkachel	600	210	126	5%	6	0%	€ 1,39	5	21%	0	0	€ -
Convector (elektrische radiator)	600	210	126	5%	6	0%	€ 1,25	4	21%	0	0	€ -
Elektrische vloerverwarming	300	157	47	0%	0	0%	€ 0,01	0	21%	0	0	€ -
Elektrische warmte-pompboiler	2050	341	700	10%	70	2%	€ 15,40	55	21%	0	0	€ -
Vaatwasmachine	1500	203	305	55%	168	5%	€ 36,91	98	42%	0	0	€ -
Losse centrifuge	300	50	15	20%	3	0%	€ 0,66	2	21%	0	0	€ -
Wasdroger	3000	200	599	60%	359	10%	€ 79,07	119	67%	0	0	€ -
Wasmachine	1500	154	231	95%	219	6%	€ 48,28	116	47%	0	0	€ -
Strijkijzer	600	40	24	95%	23	1%	€ 5,02	18	21%	0	0	€ -
Strijkmachine	500	40	20	10%	2	0%	€ 0,44	2	21%	0	0	€ -
Stofzuiger	900	60	54	95%	51	1%	€ 11,29	40	21%	0	0	€ -
Kruimeldief	2	8766	15	95%	14	0%	€ 3,14	11	21%	2	0	€ -
Zonnebank	1600	20	32	10%	3	0%	€ 0,70	3	21%	0	0	€ -
Gezichtsolarium	900	20	18	10%	2	0%	€ 0,40	1	21%	0	0	€ -
Föhn	900	12	11	95%	10	0%	€ 2,30	8	21%	0	0	€ -
Scheerapparaat	3	67	0	95%	0	0%	€ 0,04	0	21%	3	25	€ 5
Scheerstopcontact	2	8766	18	95%	17	0%	€ 3,76	13	21%	0	0	€ -
Elektrische tandenborstel	1	8766	5	95%	5	0%	€ 1,05	4	21%	3	0	€ -
Krulset/-tang	100	40	4	95%	4	0%	€ 0,84	3	21%	0	0	€ -
Whirlpool/jacuzzi	100	210	21	20%	4	0%	€ 0,92	3	21%	0	0	€ -
Sauna	2000	208	416	10%	42	1%	€ 9,15	33	21%	0	0	€ -
Ladyshave	3	67	0	70%	0	0%	€ 0,03	0	21%	3	18	€ 4
Gitaar	100	160	16	33%	5	0%	€ 1,16	4	21%	0	0	€ -
Basgitaar	100	160	16	33%	5	0%	€ 1,16	4	21%	0	0	€ -
Ritmebox	100	160	16	33%	5	0%	€ 1,16	4	21%	0	0	€ -
Zanginstallatie	100	160	16	33%	5	0%	€ 1,16	4	21%	0	0	€ -
Aquarium met aquariumpomp	20	8766	175	10%	18	0%	€ 3,85	14	21%	0	0	€ -
Fonteinpomp	3	2667	8	33%	3	0%	€ 0,58	2	21%	0	0	€ -
Breimache	100	30	3	33%	1	0%	€ 0,22	1	21%	0	0	€ -
Schrijfmachine	40	25	1	33%	0	0%	€ 0,07	0	21%	0	0	€ -
VCR/DVD	20	5400	108	90%	97	3%	€ 21,38	77	21%	3	9	€ 2
TV (eerste toestel)	120	1725	207	97%	201	6%	€ 44,17	133	34%	4	27	€ 6
TV (tweede + derde toestel)	80	638	51	25%	13	0%	€ 2,82	13	2%	4	8	€ 2
Losse radio	20	1150	23	95%	22	1%	€ 4,81	17	21%	0	0	€ -
Tuner	10	1200	12	95%	11	0%	€ 2,51	9	21%	3	22	€ 5
Versterker	53	1208	64	70%	45	1%	€ 9,86	35	21%	3	16	€ 3
Cassettedeck	11	1000	11	95%	10	0%	€ 2,30	8	21%	0	0	€ -
Platenspeler	50	60	3	50%	2	0%	€ 0,33	1	21%	0	0	€ -
CD-speler/DVD-speler	11	909	10	95%	10	0%	€ 2,09	7	21%	3	22	€ 5
Micro-, midi-, full-size installatie	35	1486	52	95%	49	1%	€ 10,87	39	21%	0	0	€ -
Computer (+ monitor)	130	1038	135	88%	119	3%	€ 26,14	94	21%	8	54	€ 12
Printer	35	143	5	67%	3	0%	€ 0,74	3	21%	6	35	€ 8
Telefooninstallatie	6	5667	34	95%	32	1%	€ 7,11	25	21%	0	0	€ -
Draadloze telefoon	3	8766	26	95%	25	1%	€ 5,43	19	21%	0	0	€ -
Satelietontvanger	21	5143	108	13%	14	0%	€ 2,97	11	21%	0	0	€ -
Antenneversterker	80	825	66	50%	33	1%	€ 7,26	26	21%	5	20	€ 4
Set top box	15	1725	131	13%	16	0%	€ 3,60	13	21%	30	26	€ 6
Antwoordapparaat	3	8766	26	95%	25	1%	€ 5,43	19	21%	0	0	€ -
Fax en/of modem, telefoon + fax	28	16	0	10%	0	0%	€ 0,01	0	21%	9	8	€ 2

Appendix C: Reference List

Interviewed experts Energy Saving and Climate Strategies:

Bart Wesselink (Ph. D.) studied soil science at Wageningen Agricultural University, receiving his PhD on ‘Long-term changes in the soil chemistry of European forests due to soil acidification’. At the Netherlands Environmental Assessment Agency (MNP) his attention shifted from retention of chemical substances in soils to diffusion of policy measures in society. Bart has acquired broad knowledge on environmental issues and policies in the Netherlands and Europe in the course of his career. He has also developed invaluable leadership skills through his experience in leading large complex projects. For example, he led the Dutch state-of-the-environment reporting and a mid-term review of the European Environment Agenda. In 2004 this study was presented to the EU parliament by the then Dutch president of the European Union. A key characteristic of his work is integrating partial knowledge for the development and propagation of a broader vision on environmental policy. In his work as manager of the ‘European Sustainability’ programme at MNP he focused on European policy developments in relation to sustainable development. In spring 2007 he participated as an international panellist in a series of activities organized around the 20th anniversary of New Zealand’s PCE (Parliamentary Commissioner of the Environment) (‘The forum featured a world-class line-up of international experts and panellists on environmental sustainability’).

Emelia Holdaway BE (Env) is a senior consultant with Ecofys UK, working in the areas of renewable energy, product labelling, emissions trading, carbon markets and energy and climate strategy. Ms Holdaway has an environmental engineering background. She has over ten years experience in energy and environmental management, including across the petrochemical, chemical processing, pharmaceutical, manufacturing, transport, chemical processing and tertiary sectors. At Ecofys, her work has included advising on opportunities in the international renewable energy investment market and undertaking 'bottom-up' market and financial assessments of emissions abatement opportunities, including developing marginal abatement curves to analyse individual abatement measures and technologies across sectors at both a country and international level.

Appendix D: ESP-Model in Excel

This Appendix contains the ESP-Model constructed with help of Microsoft Excel and Microsoft Visual Basic and most of the references.

If the CD-Rom is missing please send an email to E.vanderBeek@Ecofys.com for a digital copy of the ESP-model.