AALBORG UNIVERSITY
STUDENT REPORT

The Future for Energy Neutral Renovations in the Netherlands

How alternatives to net metering affect the value of your investment

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This thesis upholds a quantitative analysis from a business-economic perspective into the effect of alternative technical and financial solutions to the current policy of net metering, on the value of an investment in energy neutral dwelling renovations. By means of energy system simulation tool EnergyPRO and net present cost calculations it is determined that the economic benefits from EN renovations on the long term are highly dependent on the development of the price for natural gas, the initial investment and the interest rates for financing the investment. The effects of feed-in tariffs, tax reductions, higher electricity tariffs for natural gas consumers and smart control heat pumps are limited, and cannot provide with similar benefits as currently provided by the policy of net metering. This thesis recommends further study into the societal costs and development of investment based governmental incentive schemes that provide reductions on the initial investment and long term loan schemes with low interest rates.

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Bart Bakker
Graduate

Preface

You are reading the master thesis 'The Future for Energy Neutral Renovations in the Netherlands', written by Bart Bakker, as the culmination and last effort in the curriculum of the Master Program MSc Sustainable Energy Planning and Management at Aalborg University in Denmark.

I would sincerely thank my supervisor and professor Poul Østergaard for his professional support during the conduction of this thesis, by providing me with clear cut advice at times I most needed it. Thank you Ulla Eurich for the conversations on Energy Neutral renovations in practice, otherwise I would probably still be guessing how dwellings are actually insulated, just being book smart is not going to cut it. Thank you Uwe and Razvan, my roommates and colleagues, for providing with mental support and valuable feedback on what I tried to achieve. And to Julia, thank you for supporting me in stressful and stressless times, by reading my writings and by reminding me to take on the tasks one at the time.

Finally I would like to thank my mother and father for inspiring me to study in the field of renewable energy and eventually to pursue a career that in itself will be sustainable for years to come.

I wish you a pleasant reading.

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List of abbreviations

DHW	Domestic hot water
EN	Energy neutral
ET	Electricity tariff
FiT	Feed-in tariff
GT	Gas tariff
PV	Photovoltaics
RE	Renewable energy
RVO	Rijksdienst voor Ondernemend Nederland
TSO	Transmission system operator

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1. Introduction

1.1. The Netherlands in a European context

In the early 60's, one of the largest natural gas reservoirs in Europe was found in the Netherlands, starting a revolution within the Dutch energy supply. In the decades that followed, a gas grid rolled out across the country and as of 2012, over 85% of Dutch dwellings were connected to this grid, mainly using the gas for cooking and for producing heat from individual boilers (Energiemodule WoON, 2012). Almost 50% of the electricity in the Netherlands was produced by natural gas in 2013, according to the IEA data as seen in Figure 1.1 (IEA, 2013).

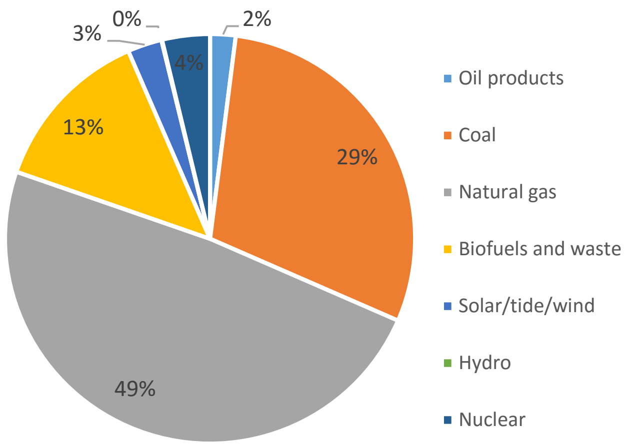

Figure 1.1 Electricity production in the Netherlands in 2013 (source: (IEA, 2013))

In 2013, over 9% of the states' revenues were generated by the exploitation of natural gas. Gas has undoubtably played a major role in the economy of the Netherlands since the discovery, yet not always a positive one. Initially, the export of gas led to an increase of the value of the Guilder, the Dutch currency at the time, reducing the competitive position of other sectors on the international market, a scenario now internationally renowned as 'Dutch Disease' (The Economist, 2014). The abundance of gas has also led to a slow adoption of renewables within gross energy consumption – with an average of 15% of renewables across Europe, the Netherlands stands extremely low with 4.5%, only surpassing Malta (3.8%) and Luxembourg (3.6%) (Eurostat, 2015). This is in significant contrast to other western European countries like Denmark (27%) and Sweden (51%) (ibid.).

1.2. The future of natural gas

Gas is a fossil fuel, and though it burns relatively clean, it contributes to climate change. It is even argued by a study of Stanford University that leakage of methane during gas extraction makes it a bigger polluter than coal or oil, as methane has a CO_2 equivalent of approximately 25 CO_2e, meaning 1 kg of methane has the equivalent greenhouse effect of 25 kg of CO_2 (Heede & Oreskes, 2015); (Brandt, et al., 2016). In densely populated Holland, the extraction of gas from the Groningen reservoir is continuously causing small earthquakes as the gas field is depleting (Boersma & Greving, 2014). In consequence, less gas is extracted from domestic ground. According to the Minister of Finance, more gas needs to be imported from other countries such as Russia and Norway, as a compensation, increasing the Dutch energy dependency on these countries (Mommers, 2013). Either way, gas needs to play a smaller part in the Dutch energy mix, even if it is only to answer to the European goals of 2030, which set out to achieve a 40% cut in GHG emissions compared to 1990, and a share of 27% in renewable energy (RE) consumption (European Commission (NL), 2014). As a response to these goals, the Dutch government presented 'Het Energieakkoord' or 'The Energy Agreement' in 2013, with the ambition to reach a fully RE mix and carbon neutrality in 2050 (SER, 2013). In this agreement between over 40 governmental and private institutions and organizations it was stated that in 2020, the share of renewables in gross energy consumption should be 14% (ibid.)

1.3. Reducing energy consumption in the built environment

A large energy consuming sector in the Netherlands, is the built environment. It consumes 28% of all energy, as seen in Figure 1.3. More than half of the built environment are dwellings (RVO, 2014 (A)). In order to reach the targets from the agreement, one aspiration of the government is to have the entire dwelling stock being energy neutral (EN) in 2050, and reducing household consumption by half in 2030 compared to 1990 (ibid.).

EN dwellings are defined by the Netherlands Enterprise Agency[1] (RVO) as dwellings that over the course of a year, have a net energy consumption of fossil fuels equal to or below zero, by delivering an equal amount or more energy back to the grid as has been consumed (AgentschapNL, 2013). This consumption includes energy consumed by the dwelling for heating, lighting, domestic hot water and supporting energy for appliances at average use and is referred to as dwelling energy demand. Not included is the energy consumed by the inhabitants through the use of electrical appliances or more than average use of heating and domestic hot water. This is called consumer demand (ibid.). Such EN dwellings are mostly all electric and cut off from natural gas (Urgenda, 2014). As a means to reach this goal, from 2020 all newly built dwellings have to be 'almost' energy neutral (SER, 2013).

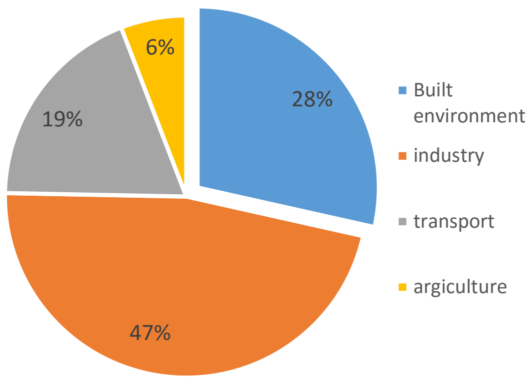

Figure 1.3 Energy consumption per sector in the Netherlands in 2013 (source (IEA, 2013))

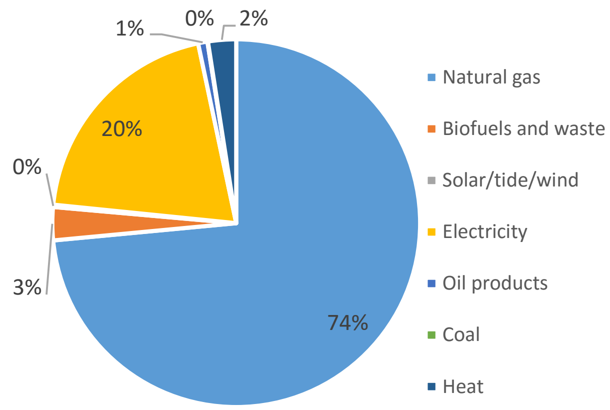

Figure 1.2 Energy consumption of the residential sector Netherlands in 2013 (source: (IEA, 2013))

However, that does not yet concern the already existing dwellings. The existing dwelling stock in the Netherlands exceeded 7.5 million in 2014, and grows with approximately 80,000 new dwellings each year (Energiemodule WoON, 2012). These households combined consume 331.5 PJ of natural gas for heating, domestic hot water and cooking, in addition to 90.5 PJ of electricity or 17.4% of the countries' total energy consumption (IEA, 2013). The rest of their energy consumption includes heat from district heating (2%), as seen in Figure 1.2.

All these dwellings have to become EN, too. This means that until 2050, almost 8 million dwellings need extensive renovation, approx. 230,000 dwellings each year starting in 2016. According to a report released in late 2015 by the Potsdam Institute for Climate Impact Research, neither the 2030 nor the 2050 goals are likely to be met. This assessment is based on a top-down approach, with current and

[1] RVO: the governmental institution concerned with the development of entrepreneurs in the Netherlands, was called AgentschapNL before 2014

increased province renovation rates, future temperature increases that have an influence on heat demand, and population growth in the Netherlands (Olonscheck, et al., 2014).

1.4. The consumer pays

Other parties in the Netherlands, like the reputable environmental foundation Urgenda, founded by a collaboration of banks, energy companies and Transmission System Operators (TSO) and probably most known for their successful lawsuit against the Dutch government on its negligence to address climate change, suggest that an EN building stock in 2030 is already possible. What it takes is consumer[2] awareness (on energy consumption and on the availability of renovation solutions), economically feasible technological solutions and widespread options on financial mechanisms for the payment of these solutions (Urgenda, 2014). 76% of dwelling owners that responded to a survey held in the Netherlands stated that they see problems when considering energy saving measures, and these problems are mainly of financial nature (52%) and due to a lack of knowledge and experience (33%) (Energiesprong, 2011).

Currently there are no subsidies on renovation of households (only on renewable technologies), so the consumer pays – keeping him from investing (Energiesprong, 2013). There are governmental initiatives on artificially lowering the interest rates on mortgages solely for the purpose of energy savings in dwellings, (S.A. Blok, 2014), but these measures are marginal. Often mortgages do not allow for additional loans once they have been agreed upon, which is before people decide to renovate their dwellings.

According to Urgenda, an EN renovation should be paid for by a consumer in monthly installments. These would substitute the monthly energy bill, which is, because of the reduced energy costs in an EN dwelling, significantly reduced. Ideally the monthly installment does not exceed the monthly energy bill that would be paid when consumers do not invest in EN, to eventually provide with higher savings on the long term. This limits the investment costs, and therefore it limits the technical possibilities in renovation measures and the effect of these measures.

Investment costs for renovations are significant. This is due to the fact that it is difficult to do EN renovations by using standardized solutions or conceptual design, which is normally the case with dwelling renovations. Dwellings are normally built according to a concept. Terrace buildings built in 1975-1991 for example, are internally basically identical at the moment of delivery. This increases the contractors' experience, lowers the cost per built dwelling and makes the process of building less susceptible for mistakes (Energiesprong, 2013). Unfortunately, in spite of the conceptual design of these dwellings, the renovation of existing dwellings into EN dwellings does not allow for this because of the changes that occurred to the dwelling (by the consumer) over the years. Added dormer windows, degenerating insulation and drilled holes are just a few examples of minor changes that have a major effect on the required heating demand. Detailed solutions are therefore highly building specific and should be individually tailored by the contractor (ibid.)

Another factor affecting the eventual design of an EN dwelling, is the difference in the amount of electricity consumed in each household. In identical dwellings, the amount of inhabitants and consumer behavior can vary the total electricity consumption with a factor of as much as four (AgentschapNL, 2012). According to Gijs van Wijk, project leader Energy Neutral dwellings at Urgenda, this difference in consumer behavior is mainly translated in the amount of solar photovoltaic panels (solar PV) that are required for dwellings to become EN. This is primarily an issue for EN renovation

[2] Consumer: a consumer in this thesis refers to the inhabitant of either an EN dwelling or a dwelling connected to the natural gas grid

concepts that include consumer demand in addition to dwelling demand, also known as 'zero on the meter' concepts.

There are reported situations of renovations which have gone wrong. In one case the consumers of a renovated apartment complex, the majority of the inhabitants being elderly people, had to give in to their comfort as the installed heat pumps could not deliver the desired indoor temperature of 22°C (De graaf, 2016). Such flaws can be attributed to poor design, and not to technological boundaries.

The message from Urgenda seems to convey that the technology is there, and it is often economically feasible (Urgenda, 2014). This is mainly due to the efficient use of solar PV, the most widely accepted technology of renewable electricity production in dwellings and therefore present within almost every EN household design (AgentschapNL, 2012). It is stated by Urgenda that an investment in solar PV is four to five times as profitable as putting money in the bank (Urgenda, 2014).

1.5. Current financial incentives

These benefits from solar PV panels are mainly due to a generous policy regulation called 'salderen' or net metering. This policy allows consumers who own solar PV panels to subtract their produced kWh from the amount of consumed kWh at the end of each year. The consumer basically receives the regular electricity tariff (ET) for their produced electricity (RVO, N/A). Depending on the connection and the supplier, this ET varied in 2015 from €0.17 to €0.25 per kWh. This tariff consists out of the supply tariff and additional energy taxes, which are currently €0.12 per kWh (MiF, 2016). With net metering, the consumer imports less electricity, which is a loss for the utilities, and the consumer is exempted from payment of the additional energy taxes, which results in a loss of income for the state.

In 2013, this loss of income for the state amounted to approximately €87.8 million, and continues to increase with the amount of solar PV capacity installed in the Netherlands. It is expected that in 2020, this will lead to a loss of income of €200 million, with governmental assumptions on solar PV capacity from 'Het Energieakkoord 2013' (Londo, 2014). This loss is currently being paid for by an additional tax on electricity and natural gas, which mainly hits the people without solar PV panels, many of them being lower income families (Z.E.P., 2014). In addition to the losses in income, there are extra costs as the TSO increasingly needs to maintain grid stability, and faces dealing with overproduction on sunny summer days and lower sales during peak times (Staats, 2015).

Therefore, in 2014 the Minister of Finance stated that the policy needs to be evaluated in 2017, and entirely reconsidered in 2020 (HollandSolar, 2016). It is unlikely that the policy will continue, but for those who invested in solar PV power, a transitional agreement will be put in place (Staats, 2015). Still, for owners that are investing in EN households in the upcoming years it creates financial insecurity. The current feed-in tariff (FiT) for delivering a kWh of non-net-metered solar PV electricity, or all electricity generated above own consumption, is chosen by the electricity supplier of the given area and is often linked to the bare electricity price, without taxes and VAT. In the Netherlands the FiT currently fluctuates anywhere between €0.03 and €0.10 per kWh, based on a comparison between the offers of current suppliers (Energieleveranciers, 2016). This differs with a factor of 1.7 up to almost 8 compared to the net metering tariffs.

The termination of the net metering policy leads to difficulties in creating feasible business cases for EN dwellings. In order to convince consumers to make an investment, the benefits have to be attractive.

One benefit is the fact that EN dwellings will be less dependent on fluctuating energy prices. Figure 1.4 shows the effect of the varying energy prices in the last 15 years on the annual energy expenses of households. Overall they have only increased, with approx. 3.5% annually. This is mainly because of fluctuating electricity prices, and with the ambitions to phase out natural gas, they might rise further.

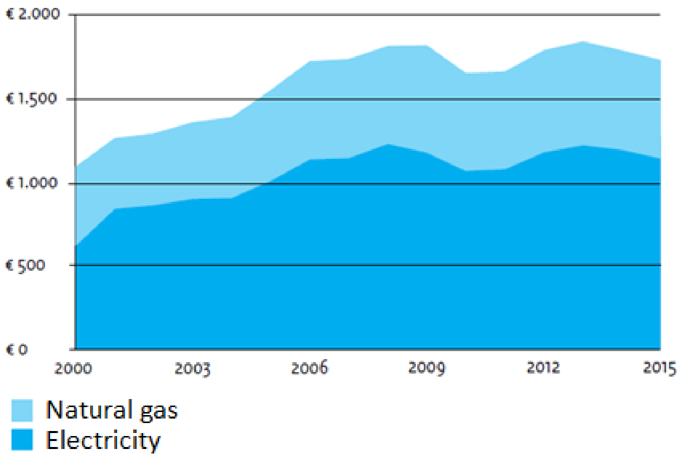

Figure 1.4 Increasing annual expenses on energy for households [€/yr.] (source: (RVO, 2014 (A)))

Another political incentive offering potential benefits to the consumer is a financial mechanism called 'Verlaagd Tarief' or 'Lowered Tariff. The idea is that consumers, united in energy cooperatives who together have invested in renewable generation (for example solar PV on an apartment complex), are as of January 2016 exempted from paying energy taxes over their share of produced electricity by the cooperation. The electricity should be produced in their surrounding area (SER, 2013). The rule is only little made use of as the limitations it brings, which is a mandatory VAT payment by the members of the cooperative either on the installation or the generated electricity, render investments under this mechanism often economically unfeasible.

Especially for the promotion of EN investments there is the 'Investeringssubsidie duurzame energie' or ISDE, which is an investment based subsidy for consumers on the purchase of small RE producing units such as heat pumps, biomass boilers or solar collectors. The size of the subsidy depends on the type of technology that is purchased, but can account up to approx. €2500 per purchase (RVO, 2016 (A)).

Also on the purchase of solar PV panels for consumers there is a financial incentive. The tax authorities grant a return of VAT on the actual panels and the costs for installing them. This is due to the fact that producers of solar power can be registered as 'entrepreneurs' and are therefore eligible for receiving the VAT. In order to receive it, consumers have to register as an entrepreneur (De Belastingdienst, 2016).

Finally, there is the 'Stimuleringsregeling Duurzame Energie' (SDE+). This subsidy is granted only to corporations and companies that can provide renewable power with a low Leveled cost of Electricity (LCOE). There is only a limited budget available which is distributed in several rounds during the year. The subsidy is intended to cover the difference between the LCOE of the project and the current price for fossil fuel generated electricity. Now, only by purchasing shares in such organizations and receiving dividend annually, the consumer is able to benefit from this incentive (RVO, 2016 (B)).

1.6. The search for alternative incentive schemes

Other political and even technical solutions have to be found in coherence with EN dwelling design that could provide with a feasible[3] business case. Technical solutions by which less electricity is provided back to the grid, and therefore less electricity is demanded on other moments in return. Production of heating and domestic hot water (DHW) by an electric heat pump during production hours (when the sun shines, either by 'smart control' or simply every day at noon for example) can reduce delivery to the grid with 10-12% (Staats, 2015). This effect seems to be significantly larger than the effect of demand side management for other electrical appliances (ibid.).

Other technical solutions would involve electrical storage, usually with batteries. Unfortunately, at a current average of €500 to €1000 per kWh (€500 for only the battery, 1000 including installation, maintenance, losses etc.) batteries are not yet economically compatible with grid power, even if the net metering policy would be entirely terminated (ibid.). With the policy of net metering in place until 2020, there is still little incentive to invest in the development of battery storage.

Alternative incentive schemes will have an effect on the economic feasibility of such technical solutions. A potential exemption from energy taxes for produced solar power as a replacement for net metering will make delivery to the grid more interesting, but lowers the effect of running the heat pump during production hours, and renders storage less feasible.

Such an incentive scheme does not have to provide with a compensation that increases with the production from individual solar PV. On the contrary, such production incentives could eventually lead to overcapacity of installed solar PV, with high societal costs that are mainly carried by renters.

1.7. Problem statement and research question

These alternative solutions to net metering and their impact on the feasibility of energy systems in EN dwellings are to the authors finding underrepresented in the existing literature on EN dwellings. There are studies on the future of consumers' investments in solar PV panels, but not in combination with other RE technologies such as heat pumps and energy savings measures. A detailed study could show whether the entire investment in an EN dwelling can provide with benefits over the long term.

Some studies are strongly general, projecting the impact of large scale integration of EN dwellings on national statistics, such as predicted CO_2 emissions or total energy savings. Examples are reports from RVO (2014 (A)) and CE Delft (2015). Other studies, by contrast, represent specific examples of households being renovated, and show feasible investments in technologies that are dwelling characteristic-specific (ThuisBaas, 2015); (ThuisBaas, 2016).

The previously mentioned survey showed that 54% of dwelling owners are considering energy saving measures, and 68% think that such measures should be done during natural events, including renovation of the dwelling (Energiesprong, 2011). Therefore a study on the impact of alternative solutions in the form of a range of alternative scenarios to the current policy, could function as useful information for policy makers aiming towards an EN dwelling stock in 2050 as well as end consumers who are considering energy saving measures and wish to become EN. This leads to this thesis' research question:

What is the influence of alternative solutions to net metering on the value of an all-electric, energy neutral renovation in typical dwellings?

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[3] Feasible: In this thesis a feasible business case for an EN dwelling refers to the overall costs that are required to suffice in energy demand. If these are lower on the long term in comparison with a dwelling on natural gas, the business case is 'feasible' or 'more feasible'

1.8. Thesis structure

This thesis will provide with a quantitative approach from the perspective of the consumer towards answering the research question, to eventually provide with qualitative conclusions that provide insight on the current feasibility of EN dwellings, which can be used for the formulation of new incentive schemes.

First the methodological framework is presented in Chapter 2. This framework is based on a case study approach in combination with scenario planning and fundamental investment theory for defining different economic scenarios. Chapter 3 provides with the development of the quantitative models, one for an EN dwelling, and a reference dwelling based on natural gas. In Chapter 4, the economic scenarios are developed that simulate alternative solutions to net metering, and the results are presented, compared and analyzed in Chapter 5. Chapter 6 provides a core review on the different sensitivities to the models, and offers insight in the results of a technical alternative to net metering: Smart control. The discussion in Chapter 7 evaluates the process of conducting the thesis. The conclusion and recommendations in Chapter 8 provide with the key insights from the analyses and options for further study.

2. Methodologies

This thesis presents a combination of a generalized study showing the impact of a variety of technical and economic changes on the investment of the consumer and an in-depth focus on a specific type of dwelling to provide with a level of detail that consumers can relate to.

Socio-economic reports provide the societal costs and benefits on integrating EN dwellings on a large scale, and with that provide with statistical utility. They do not however, provide with any graspable information for the consumer. Individual case studies, which are directly related to and comprehensible for consumers, only provide with information based on the particular needs and wishes of one consumer.

This thesis aims to bring statistical utility and the case study together, by providing with a case study from a consumer perspective, which is still applicable to a greater public. It focusses solely on the business economic aspects of EN and provides with generalizations that consumers can relate to. It is therefore considered valuable for decision makers as well as consumers. The thesis leans more towards the side of the case study, as the methodology for a case study is used as a fundamental theory from which this thesis is conducted. These theories will be explained in this chapter.

Sections 2.2 and 2.3 of this chapter provide with methodologies on general data gathering and the planning and design of scenarios that function as alternative solutions to the net metering policy. Sections 2.4 and 2.5 go into the methodologies used in this thesis to build these scenarios. Section 2.4 shows methods on generating alternative incentive schemes for external scenario conditions, and approaches to building energy systems for internal conditions. Section 2.5 shows methodologies on integration in a model and concludes the methodologies chapter.

2.1. Case study

A case study, as Flyvbjerg (2006) has put it, "is essential to understanding situations at hand". This thought contradicts another consensus of case studies, that they are too subjective and not academic. However, he insists that a case study provides the reader with knowledge and 'true expertise' to a level which a general study would not be able to provide (ibid.). Such studies tend to generalize in order to provide with reproducible results. Generalization is not necessarily the only way by which scientific understanding is gained. He states that science means 'gaining knowledge', and there are multiple ways of doing so, conducting case studies being one of them (ibid.). The implementation of the method of case study in this thesis expresses itself in the level of detail at which the dwelling and its energy system is being assessed.

2.2. Data gathering

The data that is required is oriented towards the context of the Netherlands. The terminology, statistical data and the methodology for energy system design has been obtained through governmental sources that have been used in other studies on this topic. Knowledge on the range of renovation measures is obtained through multiple interviews with Stichting Sienergie, an independent consultancy firm in the Netherlands that provides specific EN renovation solutions for consumers (Eurich, 2016). Websites of well-known retailers for gas boilers, solar PV panels, converters and heat pumps have been consulted for estimations on technology characteristics and prices. These are Nefit (2016 (A)) and CV Totaal (2016) for the gas boilers and heat pump systems, and Zonnepanelen-TeKoop (2016) for solar PV panels and converters. On electricity savings measures, applications and effects, MilieuCentraal (2016 (A)) was consulted, a platform run by the government on which the effect of many potential savings measures is presented. The platform does not guarantee the specific effects as in each dwelling, savings measures have different effects, but it provides with statistical effects useful for this study.

On April 20th, the author was invited as a speaker for an informative evening in the municipality of Aalsmeer in the Netherlands. The goal was to inform dwelling owners of the opportunities and challenges in EN renovation and energy savings in their dwellings. Through questions to the audience it became clear that although it was expected that all the people that were present were interested in energy savings, half of the people were already actively paying attention to their energy consumption at home. Questions from the audience were mainly concerned with the topic of finance and how EN renovation could be done cost efficiently. This confirmed in a way the importance of this study for the consumers, those who need to pay for these measures. In the appendix, a copy of an article that has been written about that particular evening is included.

2.3. Scenario planning

The research question reads: *What is the influence of alternative solutions to net metering (…).* This suggests that some kind of future studies is required, to assess the influence of several alternatives to a current policy. According to Börjeson et al (2006), one of the most basic concepts in futures studies is 'scenario'. A vast amount of categorizations for scenario planning is published. Many of them based on the classical approach of Amara (1981) to divide scenarios into possible, probable and preferable futures. The different typologies distinguish themselves based on the goal of their application, whether the study aims at for example technical knowledge, a better understanding of social reality or widening the scope of options (Börjeson, et al., 2006).

Other typologies focus on the epistemologies of positivism and realism, to obtain scenarios based on objective facts (Inayatullah, 1990). Positivism shows similarities with Amara's probable scenario and realism tends to find the 'objectively good' (ibid.) These approaches, apart from expanding technical knowledge, seem for the scope of this study too focused on boundary conditions that determine the details of a possible scenario. This moves the attention away from the actual impact of such a scenario on the feasibility of the energy systems. With the energy system being central to each scenario, scenario planning should be used as a method to observe (changes to) the developed energy system, simply by asking questions of the liking '*what can happen if the net metering policy is (not) terminated',* or one step further, '*what if the policy changes towards (…)'*. The right approach therefore is found in Börjeson (2006), who divides scenarios into categories based on three principal categories, respectively Predictive, Normative and Explorative scenarios. Or, simply put in questions: What will happen? What can happen? How can a specific target be reached? The following figure provides a schematic overview of his approach.

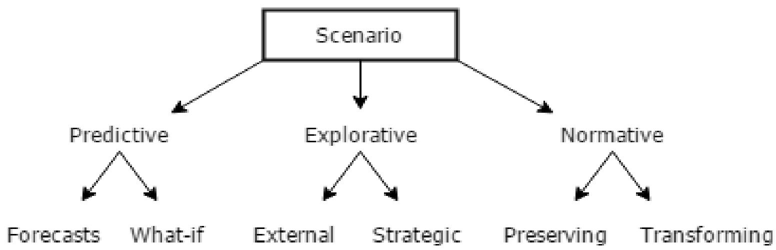


Figure 2.1 Börjesons' categorization of scenarios (source: (Börjeson, et al., 2006))

Abolishing the third question as we are initially not aiming for a specific outcome, Börjeson (2006) divides the first question in forecasts and 'what if' scenarios, and the second question in Strategic explorative scenarios and external scenarios.

Forecasts are mainly used to predict what happens should a certain trend continue, but in the case of this study, this trend is insecure. Although forecasts are useful in economic calculations, they are mainly suitable for short term timeframes, when uncertainties are not so big. 'What if' scenarios comprise out of multiple smaller forecasts that could occur when certain future events happen. It allows for a more diverse approach, as the scenarios do not focus on the most likely development but rather on a range of possibilities. What it gives up on certainty it makes up on diversity. The focus is on external factors over internal factors (ibid.) Financial alternatives to the net metering policy should be approached according to the 'what if' method for scenario planning. As there is much uncertainty to the development of external conditions such as energy prices, the aim of this thesis is to look at a wider view of options, and come to a conclusion on the effect of these alternatives on the value of an EN investment.

Strategic explorative scenarios are useful when exploring the possibilities of a future decision and when one wants to measure the consequences. They often take their starting point in the future and are useful when there is an understanding of the present system and an when there is an interest in exploring the consequences of other developments, normally on the long term. Mostly the surrounding environment of pressing influences in which such decisions are taken is not fully known. Therefore, strategic scenarios are often more qualitative than quantitative, and the focus is on internal factors under the influence of external factors (ibid.). This approach is useful for a technical alternative solution, a self-planned installation of alternative technologies in an environment of rapid changes like technology efficiencies and prices.

External scenarios have a wider focus on factors that are outside the actors' control. They are rather general and often produced with a broad target group. This type of scenario is therefore not considered for this thesis.

Proceeding on Börjesons (2006) concepts for scenario development, three steps, or elements are chronologically distinguished. These are *generation of ideas*, *integration* and *checking consistency* respectively.

Generation of ideas is necessary to gain knowledge on parts of the future and is mainly done by surveys, workshops or by having experts reflect on potential scenarios - the latter also known as Delphi Methods. This would, in the case of this thesis, be done by reading the available literature on EN renovations, on future changes for technology and energy prices and holding interviews with stakeholders. An elaboration on generation of ideas in this thesis is presented in the next section of this chapter.

Integration reflects integrating the ideas into a computer or conceptual model that could provide with quantitative and clear predictions, though normally accompanied by a quantified uncertainty factor (ibid.). This would be covered by the model that will be created for the energy system analysis, along with sensitivity analyses that account for the uncertainty factor(s). In the last section of this chapter, the methodologies used for designing the energy systems and integrating them within models are presented.

Checking consistency internally and between scenarios to increase their reliability is often done by a qualitative technique such as Morphological Field Analysis (MFA) (ibid). Fritz Zwicky is the founder of MFA, and the technique has been applied by many (Ritchey, 1998). The technique allows for the development of scenarios and external factors to the actor by categorizing the aspects in a schematic manner, for example by use of a morphological field in which for all external factors, a spectrum of values is defined (ibid.). For this thesis, a morphological overview of the cases and scenarios is shown in tables found in the chapters 'Case development', and 'Scenario development'.

2.4. Generation of ideas: Alternative incentive schemes

This section discusses alternative incentive schemes, which will eventually be used to simulate alternative policies to net metering. There are many different governmental incentive schemes available that could motivate consumers to invest in EN renovations, here the most realistic ones applicable to this study are discussed. Eventually, in the chapter 'Scenario development', the incentive schemes are worked out to provide with economic input for the analysis.

At first, the theory from Hvelplund & Lund (1998), in his book "*Feasibility Studies and Public Regulation in a Market Economy*", and from Mendonça & Stephen Lacey (2009), in "*Stability, Participation and Transparency in Renewable Energy Policy: Lessons from Denmark and the United States on the origin of public regulation and incentives*", was reviewed. However, it became apparent that focusing on the origin and examples of application of public regulation and financial incentive schemes provided with a depth mainly on socio-economic effects. Hvelplund & Lund (1998) describe the seven political struggles for radical technological change, from defining the problem to implementing and maintaining the solution (Hvelplund & Lund, 1998). Mendonça & Stephen Lacey (2009) provide with clear examples on current and past incentive schemes in Denmark and the U.S. and explains the political power play in the design of incentive schemes.

This study is concerned with business economic effects for the consumer only. Therefore, a socio-economic, political approach is beyond the scope of the incentive mechanisms that this study looks for, such approaches might be valuable for further studies. Instead, incentives here need to be translated into economic input data for the models, and thus presented in form of financial benefits. Therefore, an overview of the various types of incentives was found though a consultancy firm which comprehensibly explained the various instruments governments use to promote the use of RE. The firm provides a figure based on incentives from Europe and the United States, and is presented in Figure 2.2 (Green Rhino Energy, 2007).

The three branches distinguish the three themes in which incentives are categorized. Firstly, there are investment-based incentives, which are aimed to lower capital costs and are not affected by the differences in amounts of kWh produced by RE technologies. Secondly, there are production-based incentives which provide with benefits proportional to the electricity produced by RE technologies, the same category under which the current net metering policy is allocated. Finally, there are incentives based on a legal framework. Without a profound legal framework, other financial incentives will not be successful (Green Rhino Energy, 2007). For this study, only investment-based incentives and production-based incentives can be measured, as they provide with concrete changes on financial input data such as different energy prices or lower investment costs.

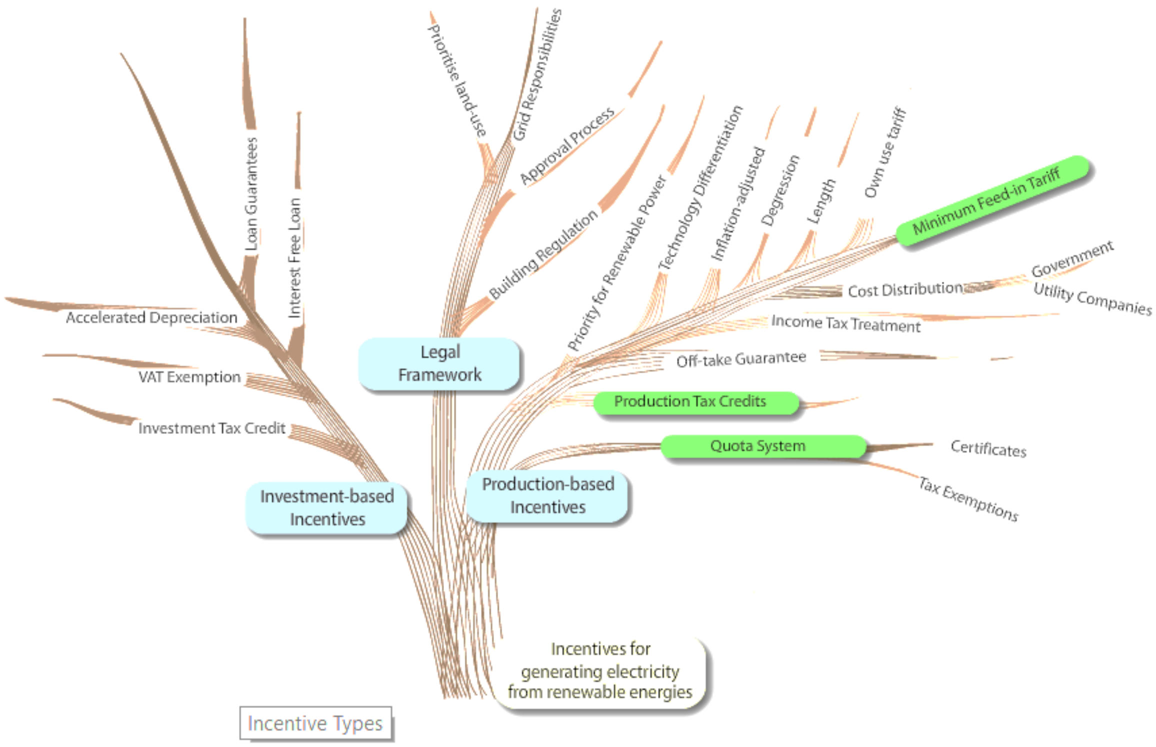


Figure 2.2 Incentive tree (source: (Green Rhino Energy, 2007))

In investment-based incentives, VAT exemption on investments and interest-free loans are relevant for this study. Investment tax credits, accelerated depreciation and loan guarantees are respectively concerned with income (not measured in this study), only applicable to companies, and concerned with the provision of guarantees (not measured either). VAT exemption can be simulated by a lower initial upfront cost (in the Netherlands there is 19% VAT on (renovation) products, with the exception of solar PV panels, of which the VAT can be returned).

Production based incentives distinguish three main systems, with the first two being relevant for this study. These are FiT and production tax credits. The third system, a quota system, provides the RE-based producer with certificates that can be traded on a market, but this concerns mainly companies. FiT generally guarantee a price per kWh for a specified period of time, so the consumer is aware of the benefits he will receive over the specified period. In this system, the net metering policy is designed. There are many varieties on feed-in mechanisms especially in Europe, which have proven to be the most efficient and effective way to encourage RE production (Green Rhino Energy, 2007). Tax credits are reductions or exemptions on, in this case, RE taxes. These are tax reductions on produced electricity. The opposite, additional taxes on consumption of fossil fuels, can also function as an incentive.

These are the potential mechanisms that are applicable to this study and which can be integrated through modelling.

2.5. Generation of ideas: An approach to building energy systems

The research question further reads: *(...) on the value an all-electric, energy neutral renovation in typical dwellings.* First, we discuss what is meant in this study by ‘energy neutral’.

The governmental concept of an EN dwelling does not incorporate the electricity consumption by inhabitants. This is because regulation in which the term ‘energy neutral’ is maintained mostly concerns new buildings – covering dwelling energy demand only. For this study, the term ‘energy neutral' refers to a dwelling that produces on an annual basis as much energy as is consumed, covering heating and electricity demand of the dwelling as well as that of the inhabitants. This is referred to as the 'zero-on-the-meter' concept. The status of 'energy neutrality' must be met at the beginning of the project, but is allowed to change over the years that follow, by factors like derating PV panels or changes in temperature.

In these dwellings, energy systems are created that could be assessed on technical and economic feasibility.

Technical feasibility is in this thesis defined as the capability of the energy system to satisfy the needs and expectations of the consumer. This means practically that at every moment of the day, the energy system should be able to provide with the most cost beneficial operation, while delivering the comfort the consumer desires. This requires simulation. Such a simulation requires input, and the nature and complexity of this input determines the validity of the results, and have to be carefully chosen. An energy system in an individual building, say, a dwelling, can be simulated with great variation in complexity.

Clarke (2001), in *"Energy Simulation in Building Design"* lays out several detailed approaches for building modelling, involving 'soft' and 'hard' building aspects, such as random occupant interactions and transient energy flows**.** Such a level of detail would be beneficial for a study in one particular dwelling, not for a study that is focused on a wider audience. To this end, a simpler theory should be used for defining the input in terms of energy demand and eventual design of the energy systems. These theories are found in the search for a heating and electricity demand, and for the technological set-up of an energy system.

2.5.1. Defining input variables for heat

Instead of simulating a dwelling with different demands at different locations in the dwelling as suggested by Clarke (2001), this thesis' approach assumes there is an overall dwelling demand for heat and for electricity. Working with an annual average heat and electricity demand is possible, but limited. For typical dwellings, like the reference case which will be explained later, this could be sufficient.

For EN dwellings, such averages are not yet available. Therefore, data of case studies could be used, but then the methods for data gathering for both the reference case and the EN dwelling are not consistent. A method is required that allows for an estimation for energy demand on a similar dwelling, before and after renovation.

Roughly, throughout the year, the outside temperature and desired indoor temperature determine when heating is required. This is simulated in time steps. This does not mean that the energy system has to provide with a load profile that covers every minute of the day for the entire simulated period. However, as desired demands can change from hour to hour (e.g. day and night for temperatures, light and dark for solar PV production), a profile addressing an hourly time-step at least is necessary to 'satisfy the needs and expectations of the consumer' and to calculate the required and produced energy from the technologies that are modelled.

The amount of heat required to meet a certain desired indoor temperature is dependent on dwelling characteristics. The method for estimation this demand should therefore incorporate a sufficient level of detail with regards to the building type and size, and insulation quality. Such a method would provide with a level of depth that owners can relate to.

An option for incorporating outside temperatures and desired indoor temperature into the heat demand would be to work with the degree-days method. An average annual demand is spread out over the heating season according to the amount of degree days on each day of the year, calculated through the following formula (Caicedo, et al., 2012):

$$DD = \frac{(T_{Max} + T_{min})}{2} - MTT$$

In which:

DD = Number of Degree Days

T_{Max} = Maximum temperature at the given interval (day) in °C

T_{min} = Minimum temperature at the given interval (day) in °C

MTT = Minimum Temperature Threshold in °C (desired indoor temperature)

This method holds limitations, such as the assumption that heat demand responds linearly to a change in outside temperature. It is expected that this influence will be diminished by a sensitivity analysis on the eventual heat demand. With the accuracy from the above stated formula, a steady outdoor temperature is assumed throughout the day, regardless of day and night. As it was decided to use an hourly time-step, degree days would have to become degree hours.

Contractors calculate heat losses, and with that the required capacity for heating system design, through a method provided by the European standard EN 12831 Heating Systems in Buildings (NEN, 2004). This method calculates the maximum transmission heat losses and ventilation heat losses of every compartment in a building, depending on material properties and thickness, and the desired indoor temperature of these compartments and sums up the losses in each compartment to calculate the total required capacity (ibid.). This result can eventually be used in combination with the degree days method to calculate annual heat demand. However, the method is not freely available and has to be purchased. It additionally requires a high level of available initial data for the calculation. An assessment for an individual building is based on more than 150 characteristics (RVO, 2015 (B)).

Therefore, EN 12831 has to be discarded, and instead, a method that similarly provides with a high level of detail, but requires only few initial assumptions is chosen. This method, called 'A method to estimate space heating demand in existing buildings' and published by Nielsen, et al. (2013) was created to give an alternative, automatic approach to calculating detailed energy performances.

The method requires broadly available data on the type of house that is considered in the study, such as floor area, number of floors, building footprint, insulation values, and wall and windows sizes and provides with the demand for space heating initially per degree hour (ibid.). The insulation values, or U-values (heat transmission values), represent the amount of heat that is lost through each segment of the house (floors, walls etc.) Simply put, the lower the U-value, the better the insulation of the house. Multiplied by the amount of degree hours in a certain year the annual heat losses are calculated, to which the internal heat gain is accumulated. The outcome could then be used to create an hourly heat demand profile. Limitations of this method uphold that it does not include demand for domestic hot water (DHW) and it is assumed all areas are heated equally, while this is often not the case. In addition, there are limitations to the accuracy of the calculation of the dwelling volume, as it is assumed that the shape of the dwelling consists out of boxes placed on top of each other, for easier calculation.

The elements and equations for this method are as follows (in order of appearance) (ibid):

Element	Description	Value	Unit
HD	Total annual space heating demand	Calculated	[kWh]
$TRANS$	Transmission heat losses	Calculated	[W/K]
WA	Wall area excluding windows	Data	[m²]
U_*	for building segments	Data	[W/m²K]
RA	Roof area	Data	[m²]
$WINA$	Window area	Data	[m²]
BA	Basement area	Data	[m²]
FA	Floor area	Data	[m²]
$VENT$	Ventilation losses	Calculated	[W/K]
$V_{building}$	Building volume	Calculated	[m³]
ACR	Air change rate	Estimated	[1/h]
Ca	Heat capacity of air	0.34	[Wh/m³K]
DH	Degree hours in the heating season	Calculated	-
IHG	Internal heat gain	Estimated	[kWh/m²]
LA	Living area	Data	[m²]

Table 2.1 Parameters required for the method for estimating heat demand (source: (Nielsen, et al., 2013))

The formula for space heating demand is as follows (Nielsen, et al., 2013):

$$HD = (TRANS + VENT) * DH/1000 - IHG * LA.$$

In which

$$TRANS = WA * U_{outerwall} + RA * U_{roof} + WINA * U_{windows} + 0{,}7 * (BA * U_{basement} + FA * U_{floor})$$

$$VENT = V_{building} * ACR * Ca$$

Transmission losses through the floor are smaller than through the roof and walls and therefore, a factor of 0.7 is awarded. The internal heat gain is used for calculating the annual heat demand, but cannot be used for the estimation of the required heat capacity at a given time, as it is not a consistent source of heat. If it is included in the required capacity estimation there is a risk that the estimated capacity is too low.

Using this method for heat demand would allow for the incorporation of a level of detail that speaks to the mind of the consumer as it reflects their dwelling type. Meanwhile it does not incorporate (too) complex details on precise energy streams and leaves room for generalization in a certain type of dwelling. The input to this method should resemble a type of dwelling that is significantly represented in the Dutch building stock, which will be discussed in the chapter ‘Case development’.

Additionally, this method allows for the estimation of the required heating capacity that a potential heat pump system (for the renovated building) should be able to provide. The method provides with a capacity that is required in W/K at any given time, and with a maximum temperature difference the total required capacity can be calculated. This is necessary in order to calculate costs that come with certain systems.

The maximum temperature difference is estimated by integrating one value from EN 12851, the basic outside temperature, or ‘basisbuitentemperatuur’ on which the heat pump is designed. This is for the Netherlands -8°C (NEN, 2004). With this, the maximum temperature difference can be calculated, and the heat pump can be sized accordingly.

As stated before this method does not yet regard the demand for heat for DHW which is mainly dependent on the number and behavior of inhabitants (AgentschapNL, 2012). Here a generalization is in order. In terrace dwellings that are not renovated and thus have typically bad insulation, domestic hot water accounts for approximately 20% of heating demand according to a report from the government of the Netherlands (ibid.) The required capacity of the heat pump is therefore considered to be 20% larger in size, as to be minimally able to supply in peak heat demand and DHW at a given moment in time. Although it is unlikely that at the peak demand for space heating, there will also be a demand for DHW, it is concerned in this thesis as to minimally provide with the extreme conditions in which the energy system could be situated.

2.5.2. Defining input variables for electricity

As with the heat demand, electricity demand requires an hourly time step as well. This means that an electricity demand profile needs to be generated. According to research in electricity demand profiles in the residential sector in Europe by Hayn et al (2014), there is a wide variety of factors, ranging from lifestyles, sociodemographic factors as the number of occupants and to technical factors as the number and characterization of electric appliances, that influence the electricity demand of a household. The researchers suggest that segmentation based on a cluster of such factors is necessary for creating reliable demand profiles in modelling (ibid.) They claim that sociodemographic factors indirectly include choices on lifestyle, and the purchase of electrical appliances (ibid.) As a result of the method used for estimating space heating, an hourly profile for electricity is preferred to reach a similar level of detail. Research in the effect of household type and number of occupants provided a single case study performed in Northern Ireland in 2006 on a variety of dwellings. The study was concerned with the influence of household characteristics and number of occupants on the average daily annual electricity demand profile (Yohanis, et al., 2008). Assumed here is that the electricity consumption demand profile from Irish consumers does not differ much from consumers from the Netherlands. The method is useful for determining the differences in electricity consumption in the course of a day. This variation could then be applied to an annual average from the Netherlands, to provide with an electricity demand profile. The profile from the method represents an average annual profile over the course of a day. The level of detail is therefore limited, but as estimating an electricity demand is highly dependent on a wide variety of factors (lifestyles etc.) that are not defined in this thesis as it would limit the outreach, it is considered valid. A sensitivity analysis on the annual electricity demand should be carried out to identify the impact of changes on the simulation results.

From the study, hourly annual averages in kWh/m² for terrace dwellings were deducted, along with averages for households with a varying number of occupants. The influence of the number of occupants, in this case 2 and 4 or more, and the terrace house averages are shown in Figure 2.3. The influence of occupants was measured in detached, semi-detached and terrace dwellings, explaining the lower profile of the terrace average. The graph shows a similar composition of the three profiles. The number of occupants influences total demand, but this manifests itself mainly by scaling up the profile. It is decided to use the profile of the terrace average, but scale it to match the annual demand of an average terrace household in the Netherlands. This would then function as the electricity demand profile of a dwelling in its initial state. This average is chosen as it represents the majority of electricity consumption amounts in terrace dwellings, and is therefore least prone to changes in lifestyle etc.

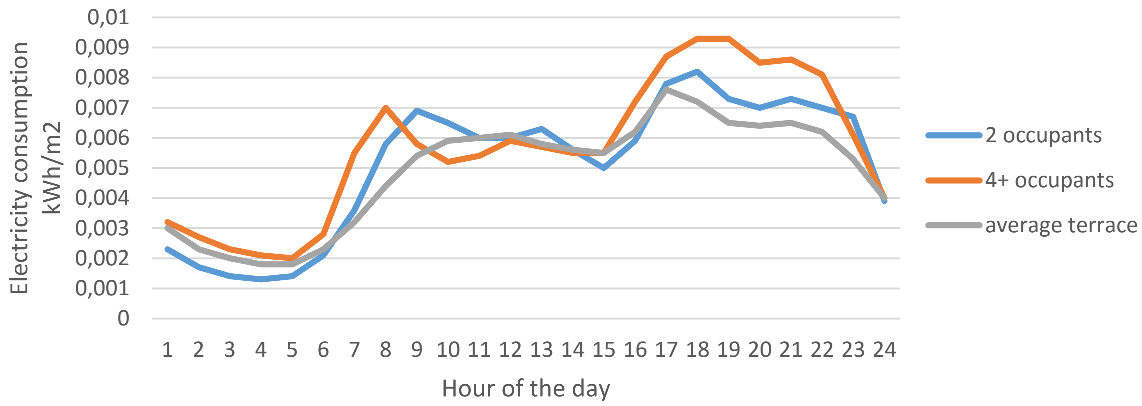


Figure 2.3 Average hourly consumption in [kWh/m2] from the Irish case study (source: (Yohanis, et al., 2008)

The electricity demand profile for an EN dwelling, is different. An additional demand of electricity is required for running an electric heat pump for example. This additional demand is not included in the electricity consumption profile, but will be integrated in the model. The demand for the EN dwelling will be discussed in the chapter 'Case development'.

2.5.3. Overall energy system design

As stated in the introduction, an EN dwelling requires alignment between the characteristics of the dwelling and the technologies that are used. Simulating on such a level of detail tends towards the complex theory of Clarke (2001). Instead, a simpler approach is favored, with the best intentions to pursue energy savings and RE production. This is found in the theory used by the Dutch government in EN dwelling design, called Trias Energetica (RVO, 2015 (A)).

The original theory presents a three-step approach to reducing negative effects of energy consumption. First, minimizing energy demand; then, producing as much energy from renewable sources; finally, making use of fossil sources as clean and efficient as possible (ibid.). See Figure 2.4.

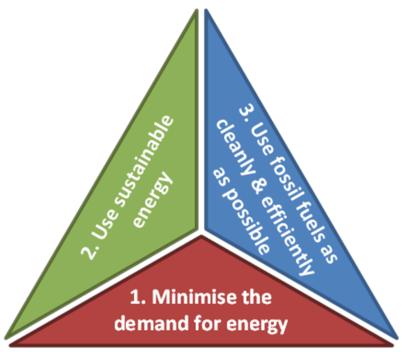


Figure 2.4 The three steps of Trias Energetica (source: (RVO, 2015 (A)))

An addition to the theory presented by the government in 2013, adds 'the utilization of waste energy' to the second step (ibid).

Minimizing energy demand resembles passive renovation measures, which do not require supporting energy. Under this category falls mainly insulation measures and zoning of hot and cold spaces.

Using waste energy and sustainable sources manifests itself in the choice for heat recovery from showers and ventilation for the use of DHW, and solar PV in combination with a heat pump and heating or cooling storage. In some cases the electricity is provided by local biomass, wind, or solar PV plants.

The last step, using fossil fuels cleanly and efficiently, requires efficient (use of) electrical equipment to minimize consumption from the grid and enable full compensation by renewable sources. This means changing to high efficiency lighting, but also high efficient refrigerators, dryers, washing machines and removing energy demanding items (e.g. waterbed, tropical aquarium). In addition, this step requires practical measures as well as consumer awareness (ibid.)

Using Trias Energetica will help provide with the technologies and measures required to develop an EN dwelling. In combination with the method for space heating based on typical dwelling characteristics and temperature data demand energy systems can be developed that will eventually be assessed within different scenarios.

This defined the generation of ideas section of scenario planning. The inputs from this step need to be integrated in a program to provide with clear, quantitative results.

2.6. Integration: Technical feasibility assessment through modelling

In order to fulfill the requirement for a technically feasible energy system, a computational tool is required that could account for the required solar PV output and the right operation sequence for each time step in the simulation. By using a computational tool, it is possible to calculate the eventual input and output of energy for each technology, given the external and internal conditions that are affecting these technologies.

The following bullet points summarize what the tool needs to be able to do in order to be considered for use in this thesis:

- Ability to model single project energy systems integrating solar PV panels, heat pumps, thermal storage, the electricity grid, and a demand for heat and electricity on an hourly time step
- Ability to calculate solar PV output based on panel specifics, temperature and radiation data on an hourly time step
- Ability to integrate demand profiles for electricity and heat based on an hourly time-step
- Ability to extend the simulation over a longer period than on year, to also simulate long-term effects (such as derating solar PV)
- Ability to define an optimal operation strategy and user-defined energy conversion units so to include technical effects such as smart control

Ideally, the program could provide with the option to perform sensitivity analysis on differences in heat and electricity demand, technology capacities, efficiencies and costs, so to directly see the impact of uncertainties on the outcome of each scenario. Doing this manually is particularly time consuming.

D. Conolly et al. (2009) published an article reviewing a fair amount of energy system modelling programs. From this article, two programs were selected that could potentially be useful. The programs, HOMER and EnergyPRO, are mainly intended for single projects and simulation (usually 1 year) and scenario (usually more years) design of energy systems. Both could calculate a solar PV output based on local whether data, and could address hourly time steps. A closer look in the two programs focusing on their qualities and weaknesses will point out the eventual program used in this thesis.

2.6.1. HOMER

The newest version of HOMER, called HOMER Pro, is a widely used tool especially designed for the simulation of single (micro) grid projects (HomerEnergy, 2016). The interface is user friendly, and allows the user to understand the basics relatively fast. The tool simulates operation of a wide range of pre-defined technologies over the course of one year with a minimum time-step of one minute. Its major focus is on simulating power systems, as there is a wide range of innovative technologies available that generate or store electrical power. The tool offers a large database on exciting technology suppliers, along with technical and economic specifics. Especially when the users' knowledge on technologies can be improved, this database supplies with up-to-date technical specifications. It allows for an automatic as well as manual integration of demand profiles for heat and electricity, which are standardly on an hourly basis. It generates seasonal, daily, and monthly graphical representations providing with a direct visualization on the validity of the profile. The results are presented in a wide variety of plots and options, on hourly and monthly basis.

Perhaps the most beneficial aspect of HOMER Pro is that it easily allows for direct sensitivity analysis by using uncertainty factors on almost all input variables. For example, the demand profiles are used to calculate annual averages, which are then multiplied by this factor. The different results are easily accessed after calculation, directly spotting the impact of changes to input variables. The same counts for changing technical and economic variables, which are often uncertain in future studies. HOMER pro allows the user to run the program with sensitivities on different inputs, say, recurring costs being €100/200/300 per year. This enables the user to easily spot configurations which are feasible and decreases the influence of uncertainty. In addition, it allows for a calculation of optimal input variables in some cases, such as calculating the optimal capacity of solar PV panels with certain grid sellback rates.

HOMER Pro is primarily made for the design of power systems, and it places less importance on thermal loads and therefore limits the possibilities with design. While it allows for the simulation of a boiler, it has no ability to directly model heat pumps or other forms of electric heating and thermal storage, which are often used technologies in EN dwellings. There are indirect possibilities on simulating the effect of a heat pump, such as assuming an additional electric load consumed by the heat pump and battery storage that represents the thermal storage. However, it would bring along limitations to the configurations of such technologies, such as assuming constant efficiencies, and disregarding the capacity of the heat pump.

One evaluation of both programs has been the assessment of the solar PV array output. EnergyPRO and HOMER use a similar formula to calculate the array power output, but HOMER works with the 'rated capacity of the PV array' whereas EnergyPRO works with the 'Maximum capacity of the PV array. In the calculations, EnergyPRO provides with a higher overall output and expected is that HOMER provides with a more detailed approach as they require the 'efficiency at standard test conditions' whereas EnergyPRO works with the peak capacity (HomerEnergy, 2015).

Regarding economic assessments, the program provides with a calculation on the Internal Rate of Return, Net Present Value, Return on Investment, and payback time over the lifetime of the simulation. These are based on extensive input options per technology and in the overall operation settings. It allows for the input of a discount rate, inflation rate, and upfront investment costs as well as replacement, operation and maintenance costs. An additional option allows for the direct comparison between cost calculations of different set-ups. In HOMER, the possibility exists to incorporate annual net metering in the cost calculations. This has no influence on the operation strategy, as the reimbursement is calculated in hindsight of the operation. In fact, no user-defined operation strategy is possible, showing that HOMER is mainly a solver tool that provides with general output. This is particularly difficult when simulating the effect of technical solutions such as smart control – which require the program to be able to incorporate formulary input for the operation of units. HOMER does not allow for this.

HOMER is also not particularly a tool for the assessment of a scenario with constant changes occurring during the scenario timeframe. It calculates an operation strategy for one year and assumes the same conditions for the rest of the project lifetime (energy consumption and production). It therefore does also not allow for changes in energy prices for example five years into the scenario. This issue can be overcome with a sensitivity analysis, assuming different energy prices resembling such a change. The program allows for additional investments over the course of the scenario, as it for example calculates the lifetime of a battery, and integrates replacement costs after this lifetime into the economic calculations. Illustrations of the program in which a simulation for an EN house is generated are shown in the figures below.

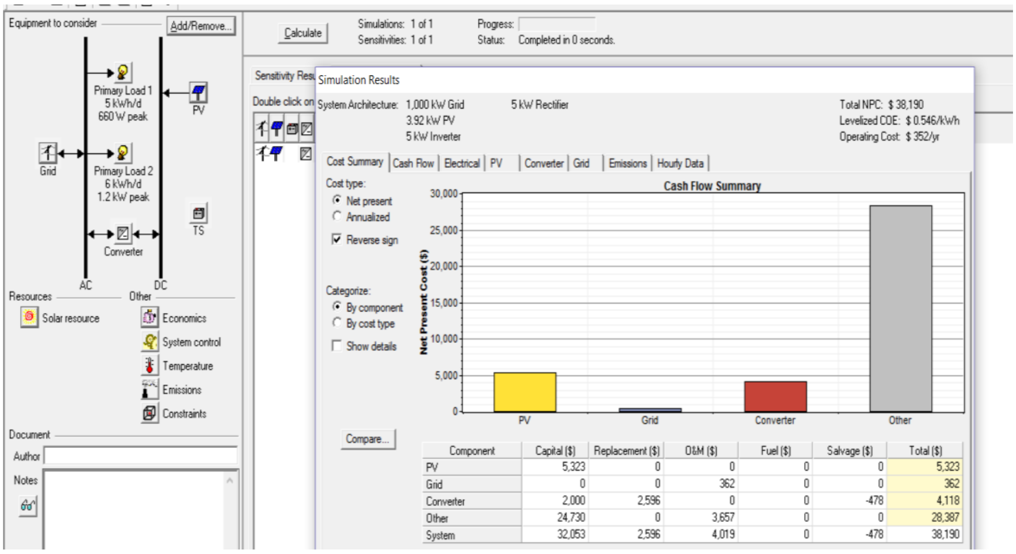


Figure 2.5 Illustration of HOMER Legacy (due to an overdue license only the older version of HOMER was eventually available) scenario overview and results (in the upper left corner, the energy system is shown, with the two primary electricity loads - one functioning as a substitute heat load for the heat pump. The black lines represent AC and DC power, with the solar PV array providing in DC and requiring a converter as shown in the system. In the middle the results for a set up with almost 30 solar PV panels is shown – eventually much more than necessary. The sheet provides with a clear overview on the NPC calculation, and other tabs can be seen that provide with energy conversion information).

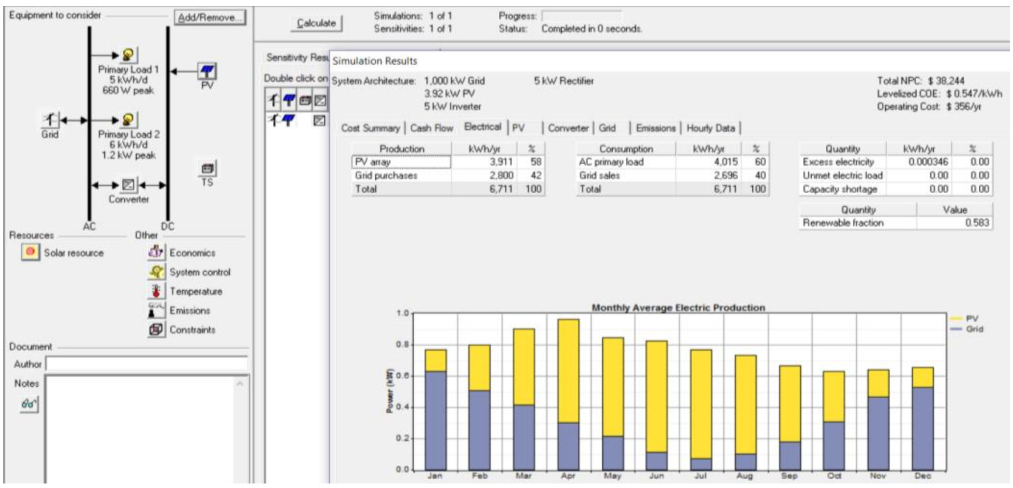


Figure 2.6 Illustration of HOMER simulation results (the energy conversion figure of the monthly solar PV output. The overview clearly shows the increase of solar PV output and the decrease in electricity import. It calculates the fraction of RE in the system, and whether on an annual basis more electricity is exported than imported (EN)).

2.6.2. EnergyPRO

EnergyPRO (version 4.4) is a techno-economic optimization tool that, although especially used for district heating projects and therefore big projects, can also be used to model building energy systems for single projects (EMD International A/S, 2016). One quickly encountered problem is that energy demand is put in MWh, with an accuracy to 0.1 kWh. On an hourly step, this is a low accuracy for a single household. This limitation could be circumvented by 'assuming' the MWh unit represents kWh, and taking a factor 1000 into account with the other input variables as well.

It allows for the simulation of user-defined technologies over the course of endless years. The minimum time-step is one minute, but mainly hourly time-steps are used within time-series. These time series serve as a valuable asset to EnergyPRO, and allow the user to basically change each input value to whatever is pleased per hour. This means that precise developments, such as fuel price changes, or temperature changes after a certain period can be modelled with relative ease. Compared to HOMER Pro, EnergyPRO requires more initial input data. Ready-to-use projects and technologies can be downloaded to serve as examples. In EnergyPRO it is also possible to simulate a heat pump with a thermal load.

A valuable advantage of EnergyPRO over HOMER is that the tool lets the user define an operation strategy, in which priority in operation can be given to certain technologies over others. This allows for 'smart optimization' in which certain technologies only operate at user-defined moments. In default, EnergyPRO calculates for each time-step the costs of producing and consuming energy for each technology, and based on the cheapest technology at that given time, it specifies an hourly production sequence. This operation strategy is called 'minimizing net production costs'.

The simulation runs for the input that is specified and nothing else, as there is no option to do a direct sensitivity analysis. This issue can be solved by using the additional tool INTERFACE, that allows the user to vary the value of a range of parameters used in EnergyPRO. It works through the Macro function in Microsoft Excel .xml files, and automatically substitutes parameters from the original EnergyPRO file with alternatives and performs a number of calculations.

The economic assessment of EnergyPRO in default consists out of calculating the Net Present Value and Internal Rate of Return, based on upfront and reoccurring costs, optionally influenced by taxation, inflation and other factors. The user can define additional economic indicators through entering its own formulas. It proved to be impossible to incorporate a formulary approach to net metering in these costs, and so this function of EnergyPRO could not be used.

HOMER Pro would provide with the most optimal calculations concerning the output of the solar PV array. As this serves to be a significant addition to the energy system of an EN household, HOMER has been considered for a significant time during the conduction of this thesis.

EnergyPRO requires more practice than HOMER to fully understand even most of the basic possibilities but allows due to the function of time series for practically endless options on the design of technologies and the development of energy prices. The option to define an operation strategy to simulate smart control as it will be explained in following chapters serves as the main argument for eventually choosing EnergyPRO. Adding to that is the integrated option in EnergyPRO to simulate a heat pump with a thermal load.

As a final addition to the thesis, in the sensitivity analysis the HOMER Net present cost result for an identical system as the proposed system is evaluated.

2.7. Integration: Economic feasibility

The thesis concerns a business economic perspective from the consumer, without focusing on societal costs. Eventually, the thesis looks into alternatives to net metering, which could provide the consumer with a feasible business case. The results therefore need to present the most cost beneficial case when compared to each other in each scenario.

Initially, the results should show the net costs made by each dwelling within a scenario after the scenario has ended. At that point in time, it is assumed that a new investment for both dwellings has to be made. The case providing the least costs made is the most beneficial. Economic feasibility is therefore defined as the total costs of a scenario and a more feasible case refers to the dwelling providing with the least costs.

Different costs are made at different moments in time. The value of a cost in the beginning of the scenario is different than the value of the same cost at the end of the scenario. Therefore, a Net Present Cost calculation should be done, that incorporates the total costs and revenues of the project over the project lifetime and shows these costs discounted back to the start of the project (Serup, 1998). By using this method, there is accounted for differences in investments made at the start of the project and in the future. Methods including internal rate of return or payback periods are not applicable. The scenarios will not reach a return on investment, as with conventional investment projects. Instead, the EN dwelling costs will be compared to a reference case, to see which case provides with the least costs within the different scenarios. Should the EN dwelling have a lower net present cost (or higher net present value), this would show that with these case configurations and external scenario conditions, it would be more beneficial to make the investment. The net present cost is calculated through the following formula (Serup, 1998):

$$\sum_{t=0}^{n} NP_t * (1 + Discount\ Rate)^{-t}$$

In which:

n	= the duration of the investment in years
NP_t	= Net Payment at a given year t
Discount rate	= the factor that represents the yield capital could give when it would be spent in a different manner
t	= the difference between the given year and the start of the scenario

The discount rate could be low, as it concerns individual consumers who do not need considerable benefits on their investments. Sensitivity analysis should point out what the influence of different discount rates would be on the feasibility of each scenario.

As mentioned in the introduction, ideally the investment for an EN dwelling is financed by a scheme that allows for installments similar to the payment of the monthly energy bill. The size of these equal installments depend on the loan, interest rate, and payback period of such a loan. The annuity payment method as mentioned by Serup (1998), suggests equal installments paid back to the loan firm. A growing share of debt and a shrinking share of interest is covered in each installment. The formula for calculating the monthly payments for a loan according to the annuity method is as follows (Serup, 1998):

$$MP = \frac{LS * i/100}{1 - (1 + \frac{i}{100})^{-m}}$$

In which:

MP	= Monthly Payment
LS	= Loan size
i	= monthly interest rate
m	= time span in months

In the Chapter ‘Scenario development’, an elaboration is given upon the assumed interest rate, inflation rate and discount rate in each scenario.

With the NPC calculated, it is interesting to look into the required input for the different economic parameters, at which both cases are reaching a break-even point. This is at ΔNPC = 0. With these specific values, further studies in the socio-economic costs of implementing alternative policies that could provide with these economic conditions can be done.

3. Case development

This chapter will explain the stepwise development of the internal conditions of the energy system in an EN dwelling. Based upon a typical dwelling that is highly represented in the Dutch dwelling stock, two eventual energy systems are created, the first representing the dwelling in its initial state with a natural gas boiler, from here referred to as the ‘reference case’. The second case represents the same dwelling in its EN state after being renovated, further referred to as the ‘proposed case’.

After the cases are developed, they will be subjected to different scenarios, which will be developed in the next chapter. The table shown below presents an overview of the cases. All the specifics in both cases are elaborated upon in this chapter.

Technological specifics	**Reference case**	**Proposed case**
Total annual heat demand*	13,099 kWh	7684 kWh
Total annual electricity demand**	3200 kWh	2200 kWh
Heating system	Natural gas boiler	Monovalent air source heat pump with integrated thermal storage
Efficiency	88%	COP: 4.7
Capacity	30kW	7kW
Lifetime	15 years (10 years at start of project)	25 years
Higher calorific value of gas	9.77 kWh/m³	
Store size	-	190 L, utilization 100%
Outlet temperature	-	55 °C
Inlet temperature	-	40 °C
Electricity system	Grid connection	Solar Photovoltaics with converter Grid connection
Wp (per panel)	-	327Wp
Derating factor	-	0.5%
TCoP	-	-0.33%/°C
NCOP	-	45°C
Installation inclination and orientation	-	35° South
Lifetime	-	Solar PV: 25 years Converter: 10 years

Table 3.1 Technological specifics of the reference and the proposed case (- see figure for details) (** - see figure for details)*

Economic specifics	Reference case	Proposed case
Periodic costs (PC)		
Gas grid	€148 / year	-
Electricity grid	€210 / year	€210 / year
Investment costs (IC)		
Solar PV		€436 / panel
Heat pump	-	€5760
Insulation		€9970
Converter	-	€2000
Removing gas connection	-	€610
Appliances		€1500
Service	-	€7500
Total Loan size:	-	€32,136
Replacement costs (RC)		
HR+ boiler (2027)	€2000	-
Converter (2027)	-	€2000
Converter (2037)		€2000

Table 3.2 Economic specifics of the reference case and the proposed case

First, the type of dwelling that is being analyzed is considered.

3.1. The dwelling

As determined in the methodologies, it is preferred to base the models on a characteristic dwelling, often represented in the building stock of the Netherlands. Data from dwellings built before 2005 is gathered, as these are in the near future susceptible for renovation. In Table 3.3 these dwellings, obtained from RVO, is shown. The data is from 2011, and changes in the dwelling stock have occurred in the meantime, but the data provides with the most detail on dwelling type, average sizes of dwelling components such as walls, windows, and living area (AgentschapNL, 2011). The colors point out the significance of the amount of dwellings on the total dwelling stock. A terrace dwelling represents the typical suburban family house attached to others on both sides. Maisonettes, Gallery dwellings and shared porch dwellings are types of dwellings found in a flat. The total amount of dwellings shown in the table (6,792,000) does not incorporate dwellings built after 2005.

Dwelling type	<1945	1946-1964	1965-1974	1975-1991	1992-2005	TOTAL
Detached	-	441000	119000	221000	178000	959000
Semi-detached	-	285000	142000	224000	173000	824000
Terrace (row)	523000	478000	606000	879000	353000	2839000
Maisonette (flat)	-	226000	22000	94000	40000	382000
Gallery (flat)	-	69000	174000	109000	113000	465000
Shared porch (flat)	256000	267000	112000	142000	70000	847000
Rest	-	90000	125000	125000	136000	476000
Total	**779000**	**1856000**	**1300000**	**1794000**	**1063000**	**6792000**

Table 3.3 dwelling types and building year (source: (Energiemodule WoON, 2012))

The most frequently occurring dwelling in the Netherlands is the terrace dwelling, built between 1975 and 1991. In 2014, this type of dwelling represented 11.7 % of the dwelling stock (Energiemodule WoON, 2012).The dwelling in its 'current situation' in 2016 has already undergone some renovation changes compared to the moment right after it was built. It has 106 m2 of floor space for inhabitants. Table 3.4 shows the average energy consumption of these dwellings along with their CO_2 emissions (AgentschapNL, 2011).

Figure 3.1 Terrace dwelling (1975-1991) (source: (AgentschapNL, 2011))

Heating	**HR boiler**
Gas consumption (m^3)	1562
CO_2 emissions (kg/yr.)*	3303

Table 3.4 Initial energy efficiency of the dwelling (CO_2 emissions will not be assessed in this thesis (source: (AgentschapNL, 2011)))*

Data regarding insulation quality of the different structural components of the dwelling is derived from the same source (AgentschapNL, 2011). The U-values of the reference case are based upon an example provided by the governmental institution 'Rijksdienst voor Ondernemend Nederland' (RVO). These values are shown below in Table 3.5 and will be used for calculating space heating demand. Assumed is that one side of the roof (as seen in Figure 3.1) is oriented towards the south, which is optimal for the efficiency of solar panels. The available roof space for these panels is for the sake of simplification assumed to be half the total roof space.

Geometric component	**Surface (m^2)**	**U-values reference case (W/m^2K)**
Wall area (excluding windows)	61	0.64
Floor area	51	1.28
Roof area (inclined)	68.6	0.64
Window area (double, HR++*)	19.9	-
Window area (double, HR+*)	16.8	2.9
Window area (single)	3.1	5.2

*Table 3.5 Geometric components of reference case (*quality of glass) (source: (AgentschapNL, 2011))*

3.2. A general system based on Trias Energetica

This method shows a stepwise transformation from a reference dwelling to an EN dwelling. By using this method, all aspects of an EN dwelling are covered.

3.2.1. Step 1: Minimizing heat demand

At first, the dwelling is insulated as to minimize the demand for heat. This step leads to the following in- and outputs:

- Upfront costs for insulation
- U-values (insulation values)
- Heat demand for the reference and proposed case

Upfront costs for insulation

Several available solutions on insulation measures are reviewed and their prices considered. This is done by consulting literature sources, and having conversations with an energy advisor from the foundation Sienergie, an independent consultancy firm for EN renovations (Eurich, 2016). The literature concerned business cases on EN renovations done by Urgenda, as seen in ThuisBaas (2015); (2016)**.** From these cases, it became apparent that insulation measures are done in a variety of ways, not necessarily aiming to maximize insulation effects as initially proposed by Trias Energetica. This is done with a concern towards cost-effectiveness, as Urgenda aims to realize EN dwellings with the lowest costs possible. Instead of insulating as much as possible, only the most obvious measures for insulation are taken, such as filling up gaps and holes from which hot air is leaking away. Often the business cases concern dwellings that are already insulated to a certain extent, and additional costs for insulation are kept low - in these cases from €0 to €4000 in total. The rest of the investment is spent on the second and third step of Trias Energetica.

One source from the government, which was initially used to determine the type of dwelling that would be concerned in this study (AgentschapNL, 2011), provided with an insulation package that costs €9970, but the insulation values this package would bring are not as high as insulation values in newly built EN dwellings. To be precise, the walls, roof and floor would have an U-value of 0.36 with this package, whereas newly built EN dwellings have U-values as low as 0.10 (AgentschapNL, 2012). As there proved to be a lack of financial data on renovation packages that could reach such low values, a conversation with Sienergie was held in which was stated that such solutions vary greatly in price, from €40,000 to €90,000, the latter including other technologies as well. However, the market is evolving and more solutions arrive on the market for lower prices (Eurich, 2016)

Given these findings, it proves to be difficult to pin a price on insulation, and the risk arises that by combining low U-values with a price between €40,000 and €90,000, the uncertainty is too large. Eventually there is chosen for the mentioned insulation package of nearly €10,000 with U-values that are slightly higher. Expected is that this would be beneficial for the business case, as the costs are not extremely high, and are more in line with the approach from Urgenda.

The insulation costs are incorporated as an upfront investment. Insulation is expected to last for the lifetime of the scenario. The result of these measures presents itself in dwelling U-values for roof, floor, walls, and windows, which are incorporated in the method for estimating the heat demand. As stated by the source, technical service, expertise, contracting etc. are included in the upfront costs. The insulation values are shown in Table 3.6.

Geometric component	Surface (m²)	U-values reference (W/m²K)	U-values proposed (W/m²K)
Wall area (excluding windows)	61	0.64	0.36
Floor area	51	1.28	0.36
Roof area (inclined)	68.6	0.64	0.36
Window area (double, HR++*)	19.9	-	1.8
Window area (double, HR+*)	16.8	2.9	-
Window area (single)	3.1	5.2	-
Costs		€0	€9970

*Table 3.6 Geometric components of reference case and proposed case (*quality of glass (source: (AgentschapNL, 2011))*

With these insulation values, the heat demand for both cases can be estimated according to the Danish method as described in the chapter 'Methodologies' (Nielsen, et al., 2013).

Estimating heat demand

From Table 2.1 in the previous Chapter 'Methodologies', there are two input variables that first need to be assumed: the air change rate in cycles per hour and the internal heat gain in kWh per m².

The air change rate and the internal heat gain are adopted from the same Danish study as several attempts to finding Dutch standards did not provide any results. The Danish study used air change rates from national statistics for Danish terraced dwellings built before and after 1979, which were respectively 0.6 and 0.7 cycles per hour. It shows there is not much difference regardless of the building year, and the higher value of 0.7 is chosen as to be not too optimistic. The internal heat gain is estimated at 55 kWh/m² per year. It is possible to calculate the value, but it would depend much on the orientation of windows, and people in the dwelling. This number reflects an average value for Danish dwellings. Though the value is supposed to slightly decrease with the renovation of a dwelling and the purchase of more efficient appliances, it is in this thesis kept constant in order to avoid overcomplicating the formula.

In the calculation for these cases, it is assumed that there is no basement in the dwelling, as this particular space is most likely not being heated. The total volume of the building has been calculated by assuming the following geometric characteristics:

- The roof is built with an inclination, like an isosceles triangle (roof inclination 35°)
- The length and width of the dwelling are respectively 9 and 6.5 meters (assumed, to add up to the useful floor area of 106 m²)
- The height of each building level is 2.8 m (2.4 meters until ceiling, 0.4 meters of material, which is standard in the Netherlands (BRIS, 2015)

The degree hours for several years have been calculated through the degree-days method in the period October 1st – May 1st, which is the heating season. For both the reference and the proposed case, it is assumed that the heating system is not providing with space heating during the summer months. In reality the owner can choose whether heating is switched on or off, both with a heat pump and with a natural gas boiler. As to remain consistent for both cases, the same heating season is maintained.

The desired indoor temperature is set at 18°C, which is a standard from the Royal Dutch Weather Institute (KNMI, 2016). Hourly temperature data from 2013, 2014, and 2015 is downloaded from its website, and measured at De Bilt, the location used for the calculation of national temperature averages (KNMI, 2016). From these years, the average number of degree hours were calculated. This recent, three year time frame is chosen as it represents a diverse outlook: where 2013 had a relatively cold winter, 2014 was extremely soft, significantly lowering the number of degree hours in that year. For unexplained reasons, as 2015 is stated to be the hottest year ever, there are more degree hours than in 2014. It is believed that in the upcoming decades temperatures will keep increasing due to climate change, stressing the importance of the incorporation of both hot and cold years in the model.

Energy required for DHW is, according to various sources, approximately 20% of the total heating demand for non-insulated dwellings (AgentschapNL, 2012). This demand is assumed to be spread over each hour of the year equally, because at any hour, day or night, summer or winter, there could be a demand for DHW. The height of this demand is slightly different in EN dwellings, as it is lowered by using techniques such as heat recovery. As this exact effect is not known, demand for DHW is set at the same value as for non-insulated dwellings.

The outcome of the estimation for the reference case (see 'Total heating demand' in Table 3.7), closely matches national averages for the use of natural gas for heating and DHW in terraced buildings. According to the Central Bureau of Statistics, this is estimated to be 1400m³ per year, or almost 14 MWh (CBS, 2016). According to the initial data as seen in Table 3.4, this dwelling consumes an average of 1562m³ of natural gas annually.

The limitations that these methods have posed are overcome by an additional sensitivity analysis. It is expected that DHW and the internal heat gain could present a limitation, as they are largely affected by the number of inhabitants, which is not represented in the method. We assume a sensitivity of 10% should be enough to address these uncertainties, but not too much to disregard the level of detail that was put into the estimation.

Dividing the estimated annual heat demand by the number of degree hours and multiplying this value with the amount of degree hours per hour of the year results in an annual hourly load profile for heat for both cases during the heating season. The combined heating profiles are shown in Figure 3.2 and Figure 3.3**.** Note that there is only DHW demand during the heating season.

Demand	**Reference case**	**Proposed case**
Demand for space heating [kWh]	10,479	5064
Demand for DHW [kWh]	2620	2620
Total heating demand [kWh]	13,099	7684

Table 3.7 Estimated heating demands for reference and proposed case

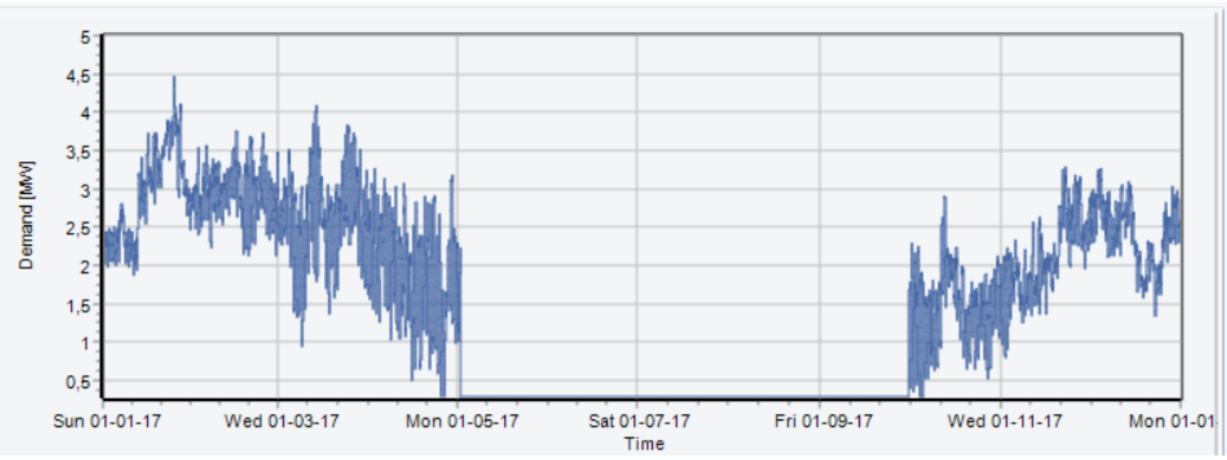


Figure 3.2 reference case heat demand profile (source: EnergyPRO)

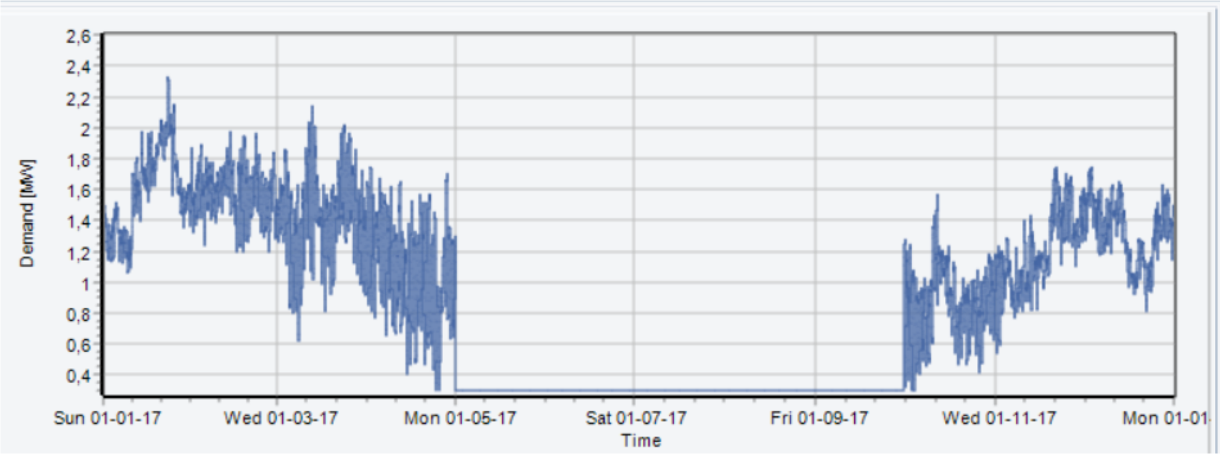


Figure 3.3 Proposed case heat demand profile (source: EnergyPRO)

It was deliberately chosen not to include cooling demand for the proposed case, in order to maintain consistency with the reference case. Cooling is assumed to be for additional comfort, not a bare necessity.

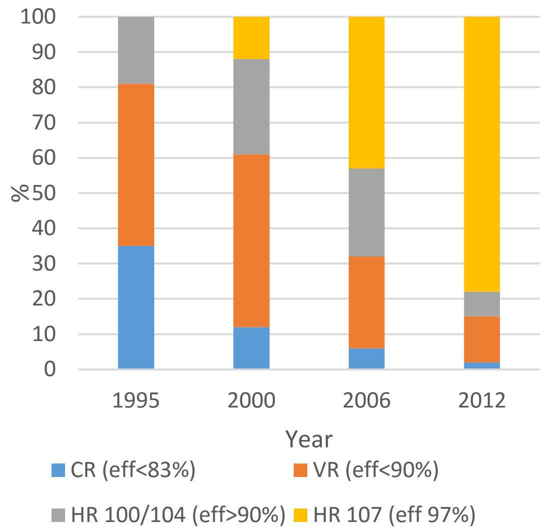
3.2.2. Step 2: Use renewable energy

Secondly, the utilization of waste heat and integration of renewables is considered. This means moving away from individual natural gas boilers to renewable forms of heating for space and DHW. Often these technologies are powered by solar PV and use heat recovery, ventilation, and low temperature radiators to efficiently utilize energy streams. This step leads to the following specifics:

- Reference case energy system
    - Natural gas boiler efficiency, replacement costs, capacity
    - Upfront and periodic costs for gas and electricity network
- Proposed case energy system
    - Peak capacity, efficiencies, and capital costs of solar PV panels and converter
    - Coefficient of Performance (COP), capacities ,and capital costs of renewable heating unit
    - lifetime of the units, to include new investments if necessary in the project lifetime
    - upfront and periodic costs for electricity network

Reference case energy system

Most dwellings now have a high efficiency (HR 107) natural gas boiler, with a maximum efficiency of approximately 97% (see Figure 3.5). This efficiency is only reached when heat is required in low temperature distributing systems. This is often not the case, for example when DHW is needed. On average, the efficiency of these boilers drops to 88% because gas is not burned under optimal circumstances and due to overall losses (Bovens, 2014). According to boiler supplier Nefit, operating in the Netherlands, their range of HR 107 boilers have a life expectancy of approximately 15 years. A new high efficiency boiler is priced anywhere from €1000 to €2000 based on offers from (CV Totaal, 2016), without service costs. For the reference case, it is assumed that on the start of the project, a HR 107 boiler is present, with a consistent efficiency of 88%. Once during the duration of the simulation, an investment of €2000 has to be made to replace the current natural gas boiler. Natural gas burns at a rate of 9.77 kWh/m³, the higher calorific value of gas from the Netherlands (Energieleveranciers, 2016).



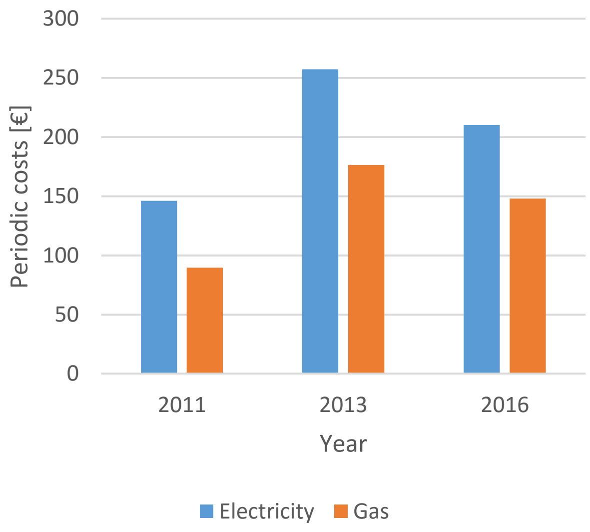


Figure 3.5 Installed individual boilers in the dwelling stock in the Netherlands [types in %] (source: (Energiemodule WoON, 2012))

Figure 3.4 Periodic costs for electricity and gas connections in [€/year] (respectively 3x25A and <4000m³ connections, source: (Liander, 2016))

The periodic costs for use of the gas grid and electricity grid depend on the supplier. For both cases, the supplier Liander, active in both gas and electricity supply for about half the country, has been consulted for their periodic costs in 2016, 2013, and 2011. These are seen in Figure 3.4, all including VAT.

This figure shows that any prognosis for future increase or decrease of periodic costs is not linear. The costs have been going up in 2013, and went down again recently because of the lower prices for fossil fuels. For the reference case, the periodic costs for 2016 are maintained, without changes occurring during the scenarios. This cost is €148 annually for the gas grid, and €210 for the electricity grid.

Proposed case energy system

There are numerous technological set-ups for renewable heating used in EN dwellings, such as electric concepts with air or ground heat pumps providing heating and cooling with thermal storage and electrical water heaters to infrared panels and solar collectors. (Urgenda, 2014). Other concepts burn biomass such as pellets in stoves or boilers that provide heating and DHW.

In this study, an often-used combination of technologies that could supply with space heating, DHW, and electricity in an all-electric concept is used. This will be a combination of Solar PV with converter, and a heat pump, a combination of technologies found in approx. 80% of all EN projects (RVO, 2014 (B)). The specifications of these technologies are based on what is frequently used in EN dwellings today.

For solar PV panels, a brand is chosen that has been frequently used in the case studies of Urgenda, and which claims to have the highest efficiencies on the market at the moment. The price does not include service or installation costs. In the Netherlands, the additional VAT on these solar PV panels is returned by the government. Therefore, the price without VAT is considered in these calculations. The solar PV panels have a derating factor, meaning that they provide with a lower power output over the years compared to the first year.

Solar PV panels require a converter to change the DC output of the panel into AC output used in electrical appliances and the main grid. The costs are dependent on the capacity that is installed, as this determines the size of the converter. Depending on the brand, prices vary (originating from the same retailer as for the solar PV panels) roughly between €1000 - €2000 for plus minus 4 kW of solar PV capacity (Zonnepanelen-tekoop, 2016). The lifetime of a converter is approximately 10 years. After this period, a new investment should be made. See Table 3.8 for the determined specifics of both technologies.

Technology:	Monocrystalline Solar PV Panel
Name:	BenQ Sunforte
Size [cm]:	105x156
Capacity:	327 Wp or 200Wp/m²
Derating factor:	0.5%/year
Lifetime:	25 years
Nominal Operating Cell Temperature	45 °C
Temperature coefficient of power	0,33 %/°C
Price:	€436 per panel
Converter capacity:	Approx. 5kW
Lifetime:	10 years
Price:	€2000

Table 3.8 Solar PV panel and converter characteristics (source: (Zonnepanelen-tekoop, 2016))

For the choice of a heat pump, only air/water heat pumps were considered. These are typically used in EN renovations since they are easy to install. Ground source heat pumps require additional costs for drilling and permits and are therefore more often used in newly built dwellings. There are many available heat pumps to choose from but the starting point is that the system could deliver with heat and DHW. Such systems are called monovalent systems. Supplier Nefit, who has supplied with the natural gas boiler, also provides monovalent heat pumps. A small thermal storage is located internally. Table 3.9 shows the system that is eventually chosen.

Technology:	Air-source heat pump
Name:	Nefit Tower Split
Heat capacity	7.0kW, 9.0kW or 12.0kW
COP	4.7, 4.8 or 4.4 respectively
Lifetime:	25 years
Thermal storage:	190 Liter, 55 °C delivery temperature , 40 °C return temperature
Price including placement:	€7760, €8895, €9465 respectively

Table 3.9 Heat pump characteristics (sources: (Nefit, 2016 (A)) (Nefit Expert, 2016) (Nefit, 2016 (B)))

The costs for these heat pumps are subsidized in the Netherlands by the ISDE subsidy (RVO, 2016 (A)). It is assumed that €2000 is granted. This reduction is incorporated in the calculations.

The minimum required heat capacity is estimated based on the maximum temperature difference multiplied by the heat losses in W/K for the proposed case. In Table 3.10, the required capacity is calculated.

Transmission heat loss (TRANS)	95.33	W/K	Annual Space heat demand	5064	kWh Formula: (TRANS+VENT)*DH/1000-IHG*LA
Ventilation loss (VENT)	97.46	W/K	Req. Cap.	5.0	kW Formula: (TRANS+VENT)*(BOT-DT)/1000
				-8	Basic outside temp. (BOT)
Internal heat gain (IHG)	5571	kWh /year		18	Desired temp. (DT)

Table 3.10 Required heat capacity calculation

The transmission losses, ventilation losses, and the internal heat gain are calculated through the Danish method as discussed before. The required capacity, 5.0 kW, is calculated without the internal heat gain. Additionally, 20% has to be added to the required capacity to account for domestic hot water. The required capacity is then 6.0 kW. Based upon the available systems as stated in Table 3.9, the system with 7.0 kW of capacity is chosen as the heat pump for the proposed case, as to account for other peaks that might occur during the year.

The thermal storage of 190 Liters is provided with the system. The delivery temperature of the water from the thermal store is 55 °C, as stated by Nefit (2016 (A)). A return temperature was not provided and instead, 40 °C is assumed, based on a low ΔT between delivery and return temperatures that are seen in low temperature radiators (Schietekat, 2010). No losses and 100% utilization are assumed because of the small size of the storage.

The supplier provides a maximum theoretical COP, the Carnot efficiency. This efficiency can be reached under the right conditions, with a low difference between ambient and desired indoor temperatures (Lucia, 2013). The actual COP is constantly fluctuating, and therefore varies for each hour of the year. For the heat pump in the model, the Carnot efficiency is maintained for reasons explained in the section 'Case analysis' in this chapter.

Heat recovery through waste water, ventilation, and heat delivery technologies –concepts that are often used in EN dwellings- are on a level of detail beyond the scope of this thesis and will be disregarded.

The periodic costs for the electricity network in the proposed case are the same as for the reference case. The additional electricity consumption required by the heat pump is not expected to result in an annual electricity consumption of >15,000 kWh, which is on average the value at which a larger capacity grid connection needs to be installed. There are no periodic costs for a gas connection, however, a one-time payment for removing the gas connection needs to be considered. In 2016, these costs are €610 including VAT, as provided by Liander (2016). Assumed is that these costs do not increase in 2017.

Overall, an additional cost of €7500 has been considered for the installation, service, expertise, guidance and additional technologies, costs that would be made in the process of realizing an EN dwelling. This cost has been deducted from comparable costs in cases conducted by Urgenda (ThuisBaas, 2016).

There are no O&M costs considered with both the reference case and the proposed case. These costs are difficult to assume, as suppliers on one hand recommend annual check-ups, and on the other hand guarantee a certain lifetime. Although the absence of these costs might artificially decrease the net present costs of both cases, the effect is the same for each case. Unless O&M costs for one case would in reality significant exceed the costs for the other case this effect can therefore be disregarded. There is to the author's knowledge no reason to believe this.

3.2.3. Step 3: Minimize remaining use of fossil fuels

Finally, in the last step, the use of fossil fuels is minimized. Existing electrical appliances are exchanged for highly efficient ones (label A+) and 'conscious consumption' by consumers is 'promoted' to reduce heat and electricity demand. The effect on the electricity demand is assumed based on papers on the effect of such appliances. The outputs of this step:

- Electricity demand for the reference case
- Costs and effects of saving measures
- Electricity demand for the proposed case

Estimating electricity demand

From the Central Bureau of Statistics (CBS), the national average electricity consumption for terraced households was 3200 kWh in 2014 (CBS, 2016). Scaling the terrace dwelling profile from the Irish case study mentioned in the chapter 'Methodologies' down to match the annual demand, the profile then looks as seen in Figure 3.7**.** That is, for the reference case. To overcome the remaining uncertainty to the reliability of this demand, such as more or less inhabitants, a sensitivity analysis is performed. Alternative demands of 2880 kWh and 3520 kWh (-10% and +10% respectively) are seen in the figure as respectively the low and high boundary. This sensitivity is assumed to account for the differences between each dwelling. The demand covers both dwelling and consumer demand, thus also electricity for lighting and supporting energy for appliances.

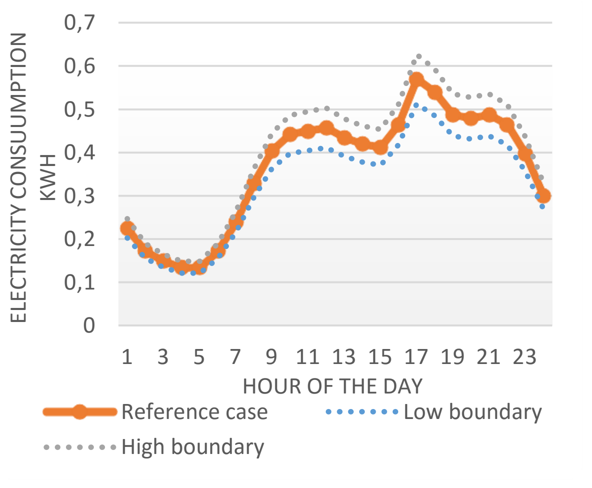


Figure 3.7 Electricity demand profile of reference case, the average hourly consumption [kWh/h]

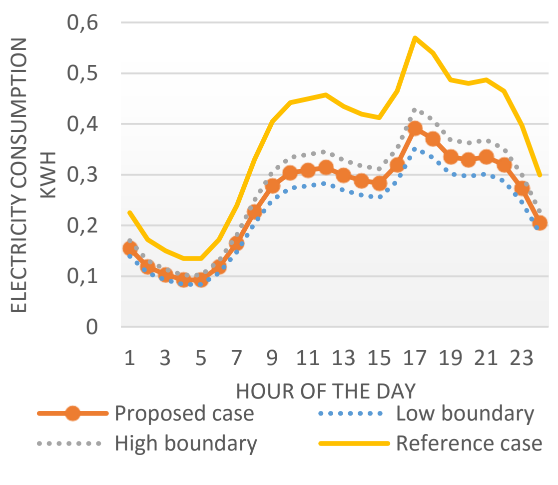


Figure 3.6 Electricity load profile of proposed case, the average hourly consumption [kWh/h]

For the proposed case, electricity consumption is different. Based on the daily profile used for the reference case, one is built for the proposed case taking into account the effects of savings both by efficient appliances and consumer behavior. According to Urgenda, mere consumption awareness can lead to 10%- 20% of savings on electricity consumption (Urgenda, 2014)**.**

The proposed case electricity demand includes electricity for consumption by residents, and support energy for appliances such as ventilation etc. In that particular situation, electricity consumption is lower compared to the reference case, as heavily consuming appliances have been changed with efficient ones. The actual savings on the purchase of appliances is largely dependent on the appliances that are present prior to the purchase, the frequency of their usage, and whether they are all replaced.

To simulate the effect of savings, the costs and consequences of general measures obtained from MilieuCentraal (2016 (A)), a platform for information on energy savings funded by the Dutch government, are used.

These measures, comprising of conscience measures such as washing on low temperatures and turning off appliances, but also replacing light bulbs for LEDs, replacing the old dryer, refrigerator and freezer, washing machine and a 'special item' such as an aquarium or a waterbed, can lead to a decrease of electricity consumption of 2000 kWh on the annual electricity bill.

In contrast, moving from gas means that cooking is also done on electricity. According to MilieuCentraal (2016 (A)), this is an additional 225 kWh of electricity annually.

Another effect that limits the actual savings by these measures, is the so called rebound effect. This effect has been described and proven by numerous specialists, such as Herring and Sorrel (2009) with "Energy Efficiency and Sustainable Consumption and Gillingham et al. (2015) in "The Rebound Effect and Energy Efficiency Policy" to name a few. The effect suggests that once a certain commodity (in this case efficient energy appliances) has an economic beneficial effect, the consumer will consume more of the commodity (either consume more electricity by using the appliances more, or purchase more appliances) (Herring & Sorrell, 2009). The eventual savings on the annual energy bill can therefore be smaller than MillieuCentraal (2016 (A)) suggests. The application of the methods by these authors to estimate the rebound effect in this case, is not considered in this thesis due to the complexity of integrating them.

Instead of 2000 kWh, it is assumed that a total decrease in electricity consumption of 1000 kWh is considered, including savings and additional consumption through electric cooking. The effect is equally spread over the electricity demand profile, as it is assumed that the additional electricity consumed for cooking mostly at evening hours is proportional to the decreasing consumption of other appliances that are often running in the hours in which residents are home, also mainly evening hours. This means that the original demand profile used for the reference case is also used for the proposed case, but scaled down based on the average annual values and according to the measures above.

Thus the annual electricity demand for the proposed case is 2200 kWh. Only for energy savings from appliances the costs can be assumed: a one-time upfront cost of €1500 is considered. This cost is based on several reviewed prices for electric furnaces, washing machines, and refrigerators, and an additional sum for small appliances from MilieuCentraal (2016 (A)). These prices and technologies are not further specified in this thesis, due to the price differences between suppliers.

This demand does not include additional electricity demand for the use of the heat pump. This amount will be calculated through modelling. Support energy required to run other appliances present after renovation, such as pumps to circulate water, presents a small share, and is assumed that it is similar to the amount of electricity used normally by the natural gas boiler. As the boiler is taken out, and new measures are put in, this share does not change. Therefore, it is included in the profile.

In order to account for uncertainty within the proposed case electricity demand profile, a sensitivity analysis is carried out with a 10% margin above and below this demand. This newly acquired profile would look as depicted in Figure 3.6 on page 39.

This would conclude the input variables and step-wise development of the energy systems in the configuration of the different cases. These configurations lead to the models that are set up and analyzed in the next section.

3.3. Case analysis

In this section the models that have been used for the analysis of the scenarios are presented, based on the developed cases. The technical configuration of the models for both the reference case and the proposed case is analyzed and the first conclusions are drawn. With these configurations the models will eventually be assessed according to different economic scenarios.

3.3.1. The reference case

Initially, the reference model was built in EnergyPRO, so as to be able to calculate the annual net payments with variable energy prices. The model functions as follows: natural gas is imported and burned in a small boiler at 88% efficiency to directly serve the heating demand. Electricity is imported from the national grid to serve electricity demand.

Should a flexible tariff for gas and electricity be used, EnergyPRO provides the possibility to easily calculate the costs that are associated with such tariffs. However, as will be shown in the chapter 'scenario development', this thesis only works with fixed ET and GT rather than day and night tariffs, as realistic tariffs are highly dependent on the utilities that supply them. Annual tariff changes are further analyzed through Excel spreadsheets and do not require EnergyPRO to model them. In addition, the boiler has to provide the entire demand for heat for every hour of the simulation, as there are no alternative heat production units and no thermal storage.

It was therefore eventually determined that an EnergyPRO model for the reference case is not necessary. It is only used to provide with an illustration of the monthly consumption of natural gas, as seen further on.

Although in reality a small storage would be available to provide with sufficient DHW at any given time, this would not change the annual gas consumption unless there are losses assumed in this storage. As the storage is small these losses are disregarded. The simulation of a thermal storage in this model is thusly obsolete, and a simplified calculation suffices

With an annual heat demand of 13,099 kWh, this results in an annual gas consumption of:

(13099/0.88)/9.77 = 1523 m^3 of natural gas

This is slightly lower than the amount of natural gas consumption by the particular dwelling as defined in Table 3.4, which was 1562m^3. This minor difference is mainly due to the assumed efficiency of the natural gas boiler, and secondly, the generalizations that were done on the geometry of the dwelling. This outcome therefore validates the use of the method for estimate space heating demand for the proposed case as it shows to be quite accurate.

Applying the heat demand profile of the reference case to the above stated formula for the calculation of required natural gas consumption results in the following monthly gas consumption (Figure 3.8). Electricity consumption is not shown as this is the same throughout the year. Notice the base load that is required in the summer months for providing with domestic hot water.

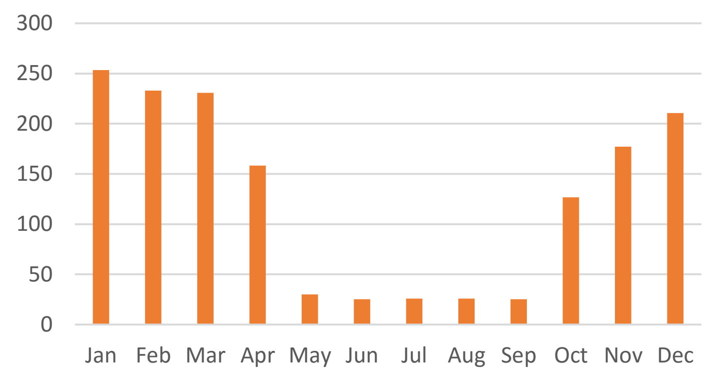


Figure 3.8 Reference case: monthly gas consumption [m³] in 2017

3.3.2. The proposed case

For the proposed case, an approach with the use of EnergyPRO is required. The configuration of the model is as follows: A heat pump covers the heat demand with additional access to a storage, where a solar PV array provides with electrical input for the heat pump and the electricity demand. The grid connection allows for additional consumption. EnergyPRO is used to calculate the solar PV output and the eventual import/export of electricity. In Figure 3.9 below this set-up is shown. Note that all units are eventually divided by a factor 1000. This overcomes the limited accuracy of EnergyPRO.

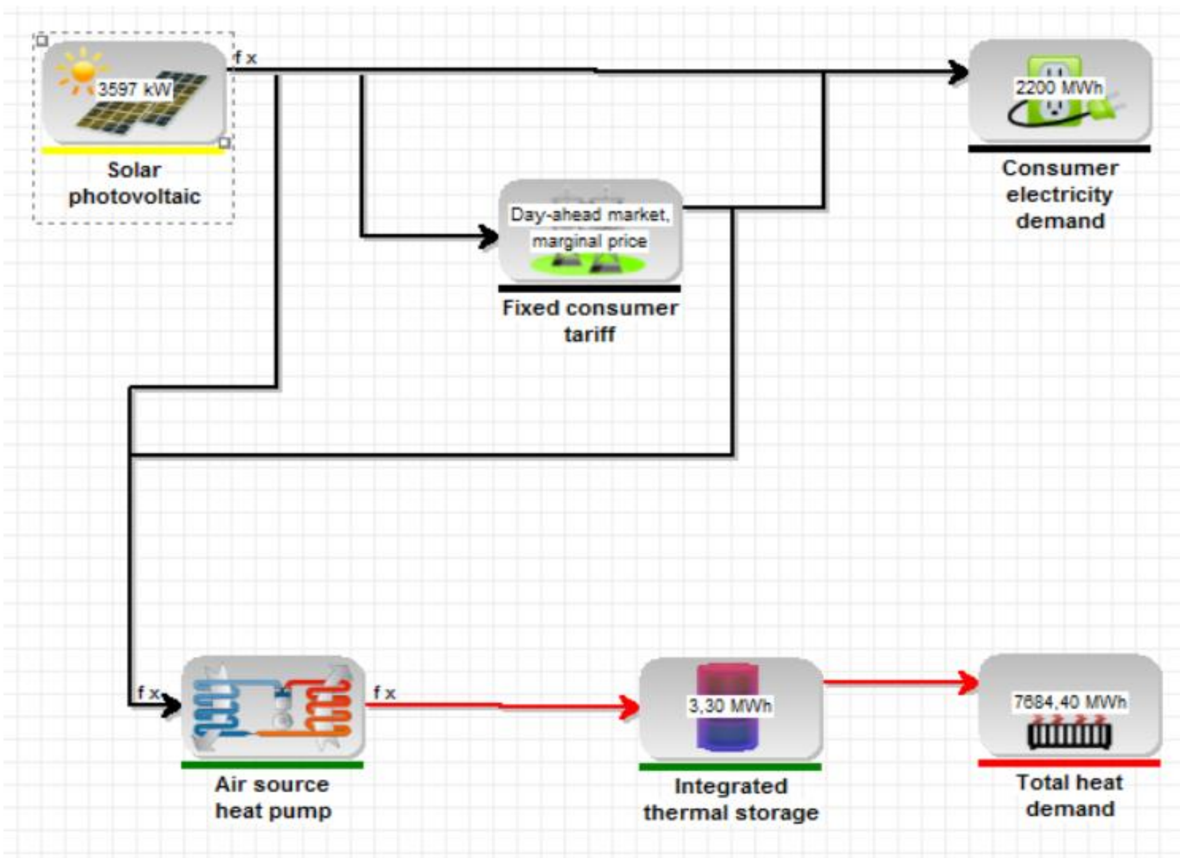


Figure 3.9 initial 'proposed case' model

EnergyPRO was initially required to calculate the solar PV array output. The program maintains the following formula for calculating this output (EMD International A/S, 2013)

$$P_{pv} = P_{Max} * \left(\frac{I_S}{I_{STC}}\right) * [1 - y_s * (T_{cell} - T_{STC})]$$

In which:

P_{pv}	= Solar PV array output [kWh/h]
P_{Max}	= Installed capacity [W]
I_S	= Solar radiation [W/m²]
I_{STC}	= Radiation at standard conditions (1000 W/m²) [W/m²]
y_s	= Temperature coefficient for module efficiency [-]
T_{cell}	= Operation cell temperature [°C]
T_{STC}	= The cell temperature at standard conditions (25 °C) [°C]

$$T_{cell} = T_a + I_s * (\frac{NOCT - 20°C}{800W/m2})$$

In which:

T_a	= Ambient temperature
NOCT	= Nominal Operating Cell Temperature

These specifics have been supplied earlier in the definition of the technologies used in the energy systems. Additionally, EnergyPRO assumes losses from the solar PV module to the grid, but they have been assumed to be zero in this model as these potential losses were not specified by the supplier and the module is small in comparison to plant-size solar PV arrays. The ambient temperatures and radiation time series EnergyPRO requires to generate the production have been obtained from the Dutch weather institute, as stated in the Methodologies (KNMI, 2016). Solar irradiation is calculated through another formula based on the inclination of the installed solar PV panels and radiation data obtained from measurements on a surface perpendicular to the ground, but that explanation goes beyond the scope of this thesis. The effect of the assumed inclination of 35° on the output of the solar PV panels is calculated in EnergyPRO to be approx. 15% higher than with horizontally placed solar PV panels. This inclination is maintained throughout the simulation.

It was determined that in order to become EN, an annual production of 3825 kWh of electricity is necessary. This covers the consumer energy demand and dwelling energy demand. To reach this, 11 Solar PV panels have to be installed with a total peak capacity of 3.6 kW. Together, these produce 4187 kWh annually, which is more than required. These panels can fit on the roof, as was determined to be 0.5*68.6 (total roof space) = 34.3 m². 11 solar PV panels require approx. 11*1.5 = 16.5 m² of roof space. There is room for expansion if necessary. The total roof space can be found in Table 3.5, whereas the size of the solar PV panels is found in Table 3.8, both earlier in this chapter.

This solar PV array size does not match similar cases on the internet providing with averages on required roof space. Suggestions range anywhere from 10 solar PV panels (about 16 m²) with additional pellet boilers to 22 solar PV panels (about 33 m²) for total coverage, based on cases from Urgenda and AgentschapNL (ThuisBaas, 2015); (AgentschapNL, 2012). Assumed is that EnergyPRO calculates the solar PV output to be too high. However, it is decided to stay with the output of EnergyPRO, as integrating a higher share of solar PV would result in the calculations in high quantities of export, and a negative result on the NPC.

For the thermal storage, a volume of 190 liters is considered, which is delivered with the selected heat pump as specified earlier. This volume accounts for the direct provision of DHW for example in the kitchen and in the bathroom, but not for space heating. EnergyPRO does to the authors' knowledge not allow for a thermal storage to only serve one specific heat demand and therefore it is modelled to serve the entire demand, including space heating. This results in the thermal storage being drained faster than in reality. The effect of this will not be relevant for a scenario in which the price for heat production is the same for all heat production units. However, as will be shown later in this section, the size and speed at which the storage is drained can have an effect even with fixed tariffs. More on this will be discussed in the next section. The storage is entirely disregarded in the reference case, but in reality, might be present. Therefore no losses and full utilization of the storage should be assumed for the proposed case.

The operation sequence of this initial set-up for the first week of January 2017 (the start of each scenario) is seen in Figure 3.12. First of all, the model allows for heat storage, meaning that instead of simply fulfilling the heat demand at each given time-step, the heat pump can operate at different moments in time, when the heat production costs would be minimal. The heat pump is allowed to run on a partial load.

As the sequence shows, from the first moment it would fill up the thermal store, and it stays full for the remainder of the simulated period. This is due to the fact that it would be just as expensive to refill the thermal store, than it would be to answer to the heat demand directly from the heat pump, if there are no differences in the ET (which is the case in this assessment). In no circumstances was the required heat demand at a given hour higher than the capacity of the heat pump could deliver, as seen in the duration curve in Figure 3.11.

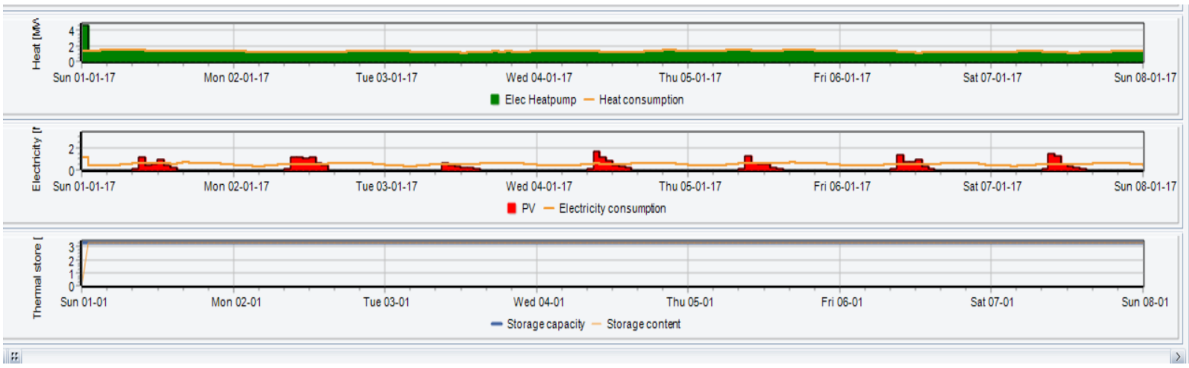


Figure 3.10 Operation sequence for 'normal control' in the proposed case

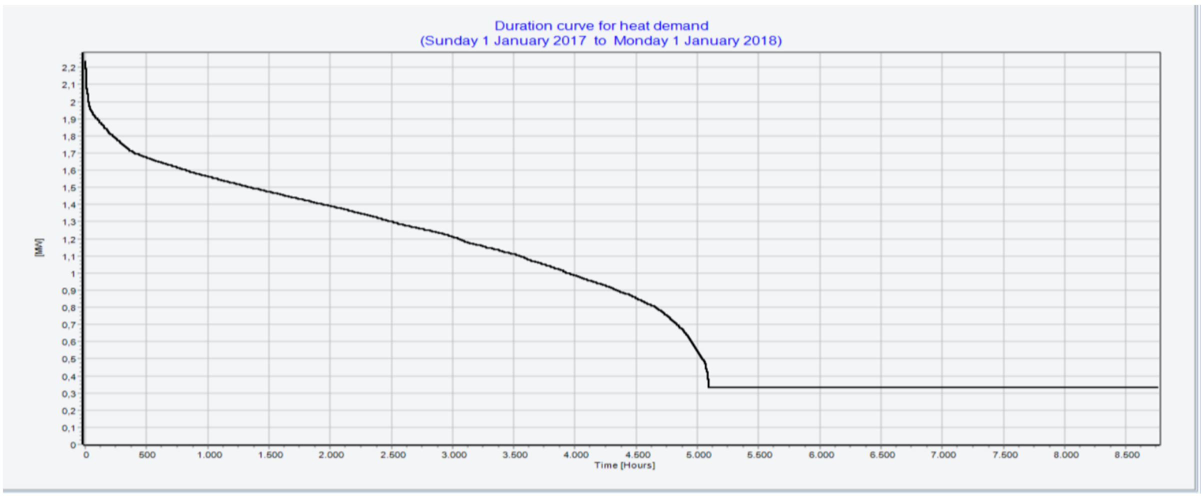


Figure 3.11 Duration curve for heat demand for 'normal control' in the proposed case

In some systems, it depends on the ET when the heat pump operates. This option, possible with smart meters, might become standard in many heat pump systems. It is not regarded in this thesis as the tariffs are stable.

An addition to this option, as mentioned in the introduction, is called smart control. Electricity is consumed from the grid at a tariff higher than the tariff that is received when electricity is delivered back to the grid. It is therefore beneficial for the heat pumps to operate in times when there is excess electricity production from the solar PV panels. First, produced electricity should be used to fulfill the consumer demand for electricity, then it should be used as much as possible for consumption in heat pumps, before it is sold back to the grid. If the heat pump is able to recognize this excess electricity production and operates accordingly, it has the option of smart control.

In EnergyPRO, it is possible to select the operation strategy of 'minimizing net production costs', in which the heat pumps consume electricity at times when the tariffs are low to fill up a thermal storage, and use the storage at times when tariffs are high. But this operation strategy would disregard the priority of using excess electricity produced from the photovoltaic panels. Over the course of a year, disregarding this optimization leads to a higher share of exported electricity to the grid, and a higher share of electricity being imported.

With net metering, this is not much of an issue, as electricity delivered to the grid that is required later in the year is exported for the same price as it is imported. But without this, which is the case in the economic scenarios that will be determined in a later chapter, this leads to higher costs on imported electricity.

For the proposed case, we assume that such a technology is in place, as it is expected to be beneficial for the business case. In reality, heat pumps might increasingly be equipped with smart options. Therefore, the operation strategy is not set at 'minimizing net production costs' but is user defined, as explained below.

The model should run as follows: the heat pump rather operates in hours of excess electricity production, but should still be delivering enough to suffice in the hourly heat demand. In EnergyPRO, this means that instead of one heat pump, an additional virtual heat pump is required in the model that is operating only during PV production hours. The original heat pump assists when the first would not be able to deliver the required heat demand. The heat pump on excess PV fills up the thermal store as much as possible. The size of this store therefore largely determines the effect of this option. More information on the thermal store size is given later in this section.

This new set-up looks as seen in Figure 3.12. Notice that the PV array 'Solar PV' is chosen to be a 'user defined' array, in which the hourly production is already defined in a time series. This is required as EnergyPRO cannot calculate the hourly production of the PV array, and immediately integrate these values in the calculation for the correct operation sequence of the heat pumps. The PV output serves as input for the heat pumps. The time series for PV production is produced from the initial model and could be scaled in the final model by a time series function.

The virtual heat pump, seen in Figure 3.12 as the 'HP restricted to excess PV', is dimensioned as an electric boiler (as the original heat pump unit does not allow for input in formulas) with a maximum heat capacity that is equal to the produced PV electricity at a given hour, multiplied by the heat pump Carnot efficiency, which is 4.7.

The original heat pump as seen in Figure 3.12 as 'Backup HP on imported electricity' is also dimensioned as an electric boiler but according to the given supplier characteristics, with a maximum heat capacity of 7kW and an initial Carnot efficiency of 4.7. It is specified to only operate when there is more electricity demand than electricity production by the PV array, meaning that it only operates should the virtual heat pump not be able to meet the demand.

In EnergyPRO 4.4 (in comparison to version 4.3) it is possible to calculate the realistic COP of a heat pump based on heat source temperatures and temperatures at which the heat is delivered and returns to the heat pump at a given hour. However, with the above-stated user-defined heat pump operation strategy it proved not possible to integrate heat pumps with a fluctuating COP. This limitation is overcome by performing a sensitivity analysis with a higher and lower assumed COP of respectively 6.0 and 3.0, which, to the authors' knowledge, resembles to a certain extent the available range of individual heat pump Carnot efficiencies at the moment. The model results in the operation sequence as seen in Figure 3.13.

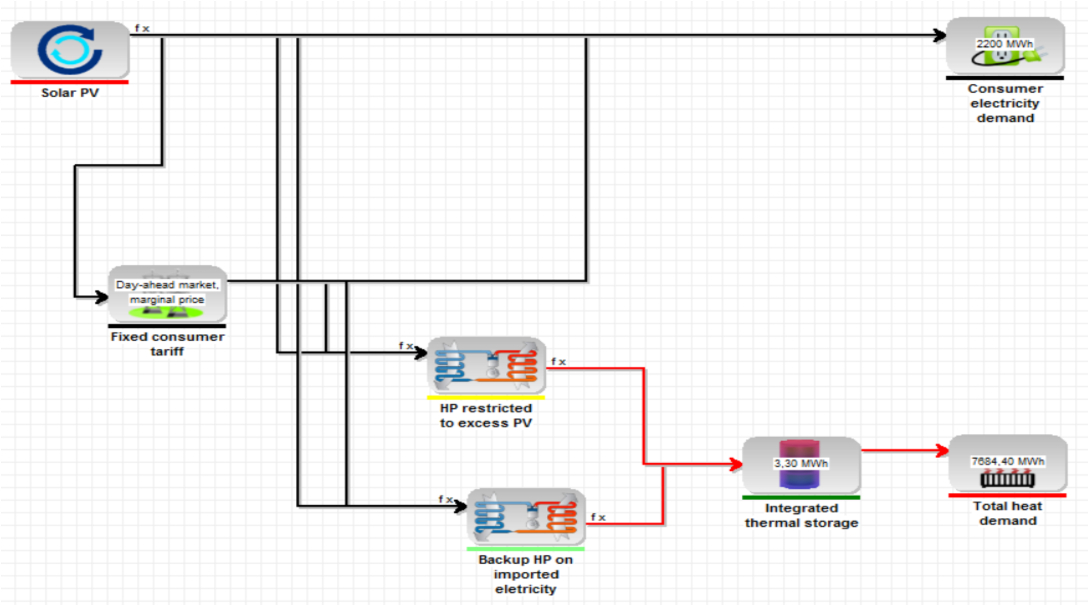


Figure 3.12 Smart control integrated in the proposed case model

Figure 3.13 Operation sequence of smart control in the proposed case

One notices from Figure 3.13 that the thermal store is actively used, to overcome moments of heat demand during hours in which electricity is not being produced by solar panels. The effect of this modification in the model is visible in the amount of exported and imported electricity. For a model without this optimization, this is respectively 2662 kWh and 2310 kWh for the first year. In the optimized model, these amounts are less, 2459 kWh and 2106 kWh respectively in the first year. This shows a decrease in export of about 8%, whereas Staats (2015) suggested a decrease of 10-12%, as written in the introduction. How this difference is accounted for is unclear, as no investigation into the details of the latter's research has been done.

Sensitivity analysis into higher heat and electricity demands point out whether additional panels are required. Additionally, the effect of smart control over 'normal control' on the NPC is analyzed.

Over the course of the scenario, the output of the solar PV panels decreases with a derating effect of 0.5% annually. This derating effect is shown in Figure 3.14, compared to the variation of import/export of electricity. The share of exported electricity is decreased.

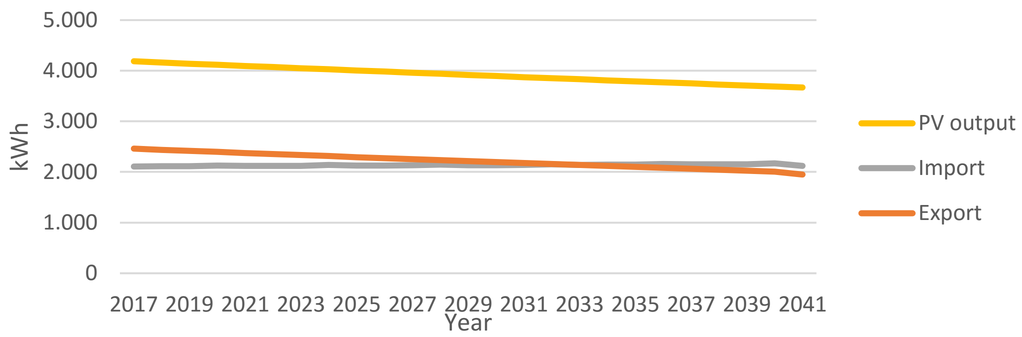


Figure 3.14 Derating annual solar PV output compared with electricity import and export [kWh]

Coming back to the previous issue of the correct estimation of the thermal store in the proposed case, this seems to be only of relevance in the previous mentioned set-up with smart control and when working with flexible tariffs for electricity – the latter not being the case in this thesis. As it was stated earlier, the thermal storage is realistically only allowed to function for the use of DHW. The realistic effect therefore of smart control without a thermal store is lower. Without a thermal storage in place for space heating, the heat pump running on excess PV production can only provide with so much heat as is required at that given moment in time. This suggests that smart control is more beneficial with thermal storage, provided that the added value of smart control would justify the additional investment costs for such a storage.

Theoretically, the maximal effect of smart control would be reached when all electricity required by the heat pump is drawn from the solar PV array. Based on the model from Figure 3.12, this would be 1635 kWh annually. A reversed calculation, in which the required thermal storage is calculated with only the virtual heat pump on excess electricity serving the heat demand, results in a required thermal storage of 116,000 Liters. In that particular situation, there would only be an export of electricity in the first year of 1436 kWh and an import of 1094 kWh. Compared to the initial thermal storage of 190 Liters, this is a significant decrease and thus the effect of smart control is significant. However, a thermal storage of 116000L for one particular household is not realistic. Sharing this storage with multiple households will not be worthwhile, the size of the store is necessary to overcome the winter months, in which it draws from the store significantly prior to have overproduction in the summer months. As all dwellings will draw and add from and to the storage at the same time, the effect cannot be mitigated.

4. Scenario development

This chapter accounts for the economic external conditions that affect the previously mentioned cases. While the cases, especially the proposed case, are modelled in EnergyPRO, these scenarios are modelled in Excel. Prior to the discussion of the different scenarios, the general timeframe and overall economic assumptions are stated.

4.1. Timeframe & initial economic assumptions

There is theoretically plenty of time until 2050, when the building stock needs to reach energy neutrality. However, according to the Minister of Finance, net metering will probably be abandoned in 2020, thus affecting investments made now and over the next years.

There is much uncertainty to the development of energy prices in the next decades. The timeframes in which these scenarios are assessed, are of importance. The timeframe for both the reference case and the proposed case is set to be 25 years. This represents the lifetime of most of the technologies, thus the end of this period reflects the moment in which a new investment needs to be made. Assuming that the value of these technologies depreciates linearly over their lifetime, the end of their lifetime marks the end of the value of the investment.

The projects start in 2017, reflecting a realistic investment for next year, assuming variations on the current policy of net metering coming in place from 2020 on. This means that in all scenarios, the proposed case will profit from the benefits of net metering for the first three years.

It is assumed that in each scenario, the investor does not have an initial capital to spend on investments. A loan or mortgage on the house has to be granted, of which a fixed interest rate for the length of the project is estimated. This interest rate should be based upon common interest rates for such mortgages in the Netherlands. Hypotheker (2016) provides with actual nominal interest rates from a multitude of agencies that could be fixed for the entire scenario. An annual interest rate of 3.27% and a payback period of 25 years are obtained as realistic and timely values. Not every consumer can opt for such interest rates or payback periods. 'Normal' loans usually go with higher interest rates and shorter payback periods. Other mortgages present lower rates. As to assess the impact of different interest rates to the net present costs a sensitivity analysis is done on a loan with 1% and 5% annual interest, considering a payback period of 25 years.

Next to this, it is assumed that this loan is paid back for in equal monthly steps, according to the annuity method (Serup, 1998). This is done in order to simulate equal monthly payments for the energy bill that would be paid for in the reference scenario. The monthly interest rate is calculated by dividing the annual interest rate by 12 months.

Finally, even though all scenarios start without initial capital, it is assumed that the investor does not pay additional interest over the monthly payments of electricity and natural gas, as these are expenses that can be directly made. Realistically, one can cover monthly expenses on energy directly from its payroll, and does not have to get additional loans to cover these expenses. This is also assumed for replacement costs over the course of the scenarios, which are being paid for without a payment plan.

The discount rate is initially set at 3%, a low rate. A high rate would suggest that money spent or gained in the distant future is worth less than money spent or gained closer to the present. This analysis looks into eventual costs compared between two cases, meaning that a higher assumed discount rate results in lower net present costs. The discount rate of 3% is based on the following assumptions:

- A lower discount rate is more realistic, as this would regard to a higher extent the influence of future price changes on the net present cost

- A higher discount rate is favored to reduce costs. However, the consumer is not particularly skilled in investments, and therefore future costs are a heavier burden to the consumer than they would be for a company. A maximum discount rate of 5% should therefore be considered.
- A discount rate of at least 1% should be maintained, as future costs are worth less when compared with the minimum increase capital would gain when it is saved in the bank – 1% representing the current interest rate on long term saving accounts at various banks in the Netherlands, based on data from Aktuele Rentestanden (2016).

Sensitivity analysis on 1% and 5% will point out what the influence of different discount rates would be on the net present cost.

From here, we will discuss the different 'what if' scenarios, in which alternatives for the net metering policy are evaluated.

4.2. 'What if' scenarios

The variation of economic parameters represent the external conditions that define the different scenarios to which the two cases are subjected. According to the methodology of scenario planning, 'what if' scenarios are useful when a diversity of policy alternatives can be substituting an existing policy, but the specifics of these alternatives are not fully known. For this reason, a range of 'what if' questions are developed, meant to simulate the conditions of a certain replacement policy. However, as these future policies are difficult to specify, the scenarios are qualitative, describing the replacement policy instead of putting assumed values to economic parameters.

Instead, the scenario analysis will point out what these values should eventually be, in order to reach a similar business case as would be reachable with the policy of net metering enabled. In other words, the scenarios will be compared with the initial scenario that is explained below.

Additionally, the analysis provides with the required economic input per scenario in order to obtain a higher net present value for the proposed case in comparison to the reference case. The values for the economic parameters at the 'break-even' point at which the NPC for the reference case is equal to the NPC of the proposed case are calculated, representing the minimum values for which the proposed case presents a more feasible solution.

In 2014, a panel of experts from 'Organisatie Duurzame Energie', an advocator for civilians on RE, developed a series of possible scenarios, or alternatives, to net metering. The document is called 'The future of net metering' (ODE, 2014). At the time, net metering was supposed to end in 2018, which is now postponed until 2020. Based on their scenarios, a variety of 'what if' questions are posed for the reference case and proposed case. Initially, the study assesses the economic and technical feasibility of the cases if nothing changes to the current policy, the initial scenario. This will be discussed in the first *'what if'* question. In short, the following scenarios are developed:

Initial scenario

Divestment scenario

Consumption scenario

Production scenario

Investment scenario

4.2.1. Initial scenario: What if net metering continues?

Initially, both cases are subjected a to a Net Present Cost calculation based on the initial scenario: assessing the economic feasibility of both the reference and proposed case, should the policy of net metering continue for the length of the scenario timeframe. This initial scenario is chosen as to compare the effects of other scenarios to the effect of a scenario with 'business as usual'.

We assume that electricity is consumed for €0.20/kWh, without a difference for day and night tariffs for the duration of the project. This tariff is based on average tariffs in 2016, as obtained from MilieuCentraal (2016 (B)) . The electricity sellback price after net metering is kept steady at €0.07, which is the current average price (between €0.03 and €0.10). The gas tariff (GT) is currently €0.66/m³.

The net present costs of both cases will be evaluated in Chapter 5 and from there, the alternative scenarios are assessed. This scenario is characterized by the following economic assumptions, in addition to the preset discount rate and loan interest rate.

ET	€0.20/kWh for entire scenario
Fixed FiT	€0.07/kWh for entire scenario
Net metering policy	On for the entire scenario
GT	€0.66/m³ for entire scenario

Table 4.1 Economic assumptions of Initial scenario

4.2.2. Divestment Scenario: What if the price for fossil fuels increases?

This scenario is based on the assumption that either by artificial increase (higher energy taxes) or by a global increase of the bare costs for natural gas, the consumer GT will increase over time. The scenario would only influence the NPC of the reference case, leading to higher overall costs compared to the proposed case. This is a production-based 'disincentive'.

Currently, energy taxes on natural gas, per kWh, are significantly lower than those on electricity. This is visualized in Figure 4.2. Depending on the installed boiler, taxes per kWh of efficient heat from gas will be slightly higher, still significantly below electricity. While energy taxes on electricity have decreased for the first time since 2009 in 2016, taxes on gas have been increased with almost 32%, or €0.06/m³. One could argue that in order to generate 1 kWh of electricity, around 2.5 kWh of gas is required, therefore the electricity taxes per kWh should be at least twice as high as the taxes on natural gas per kWh, but currently these are about four times as high.

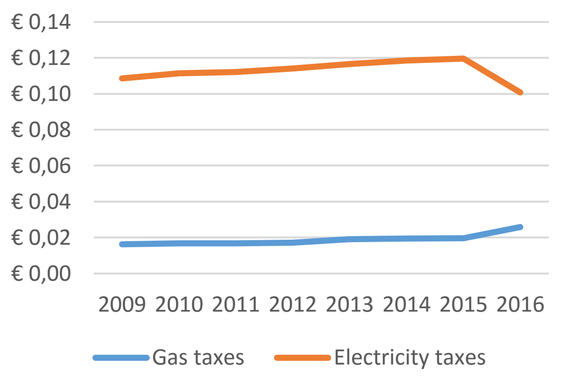


Figure 4.2 Energy taxes for the consumer on natural gas and electricity in [€/kWh]. The higher calorific value for gas is used here (9.77 kWh/m³) (source: CBS STATLINE)

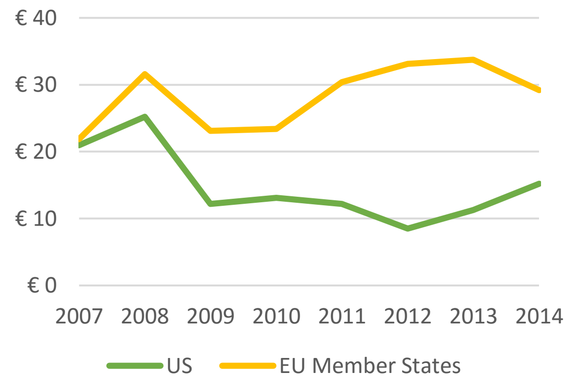


Figure 4.1 Development of the Import prices for natural gas [€/MWh] (source: (IEA, 2015))

Import prices of natural gas have been fluctuating around €20/MWh for the last decade according to the IEA, see Figure 4.1**.** Though there are many speculations on the future of global import prices for natural gas, the Dutch government wants to demotivate consumers to keep using natural gas, and could therefore artificially keep the prices for natural gas for consumers high by means of taxes. Either way, the effect of higher taxes or an increase in import prices will be the same for the consumer.

For this scenario, the policy of net metering is abandoned. Assumed is that the price for electricity and FiT are kept stable.

The output of this scenario will be shown by a required increase of the GT in order for the reference case to break even with the proposed case.

The economic parameters are set as follows:

ET	€0.20/kWh for entire scenario
Fixed FiT	€0.07/kWh for entire scenario
Net metering policy	Off from 2020
GT	Calculated

Table 4.2 Economic assumptions of Divestment scenario

4.2.3. Consumption Scenario: What if the energy taxes for small consumers are lowered, paid for by the big consumers?

This is a production based incentive. The idea arises from leveling the energy taxing system on electricity. Big consumers now pay significantly less taxes per kWh of electricity, where small consumers pay more. Up to 10,000 kWh annually, the consumer pays about €0.12/kWh including VAT. Above a consumption of 50,000 kWh, the big consumer only pays €0.016/kWh (MiF, 2016). If these tariffs are leveled, small consumers are encouraged to consume more electricity from the grid, an incentive to move away from natural gas. In contrast, a lower ET means that investments in energy savings and solar PV panels are becoming less attractive.

In this scenario, the required decrease in ET (made up of energy taxes and the bare electricity price) is calculated that is required in order for the proposed case to reach a breakeven point with the reference case. In addition, the required decrease is calculated in order to reach a similar financial effect as provided by the net metering policy. This price becomes active from 2020, when net metering is abandoned.

An additional application of this scenario would be to decrease taxes only for consumers of the proposed case, as to motivate people to invest in EN renovations. This would cost the state.

A third option would be to instead of lowering taxes, raising the taxes only for reference case consumers to create an incentive for such investments.

ET	€0.23/kWh for 2017 – 2020, then calculated
Fixed FiT	€0.07/kWh for entire scenario
Net metering policy	Off from 2020
GT	€0.66/m^3 for entire scenario

Table 4.3 Economic assumptions of consumption scenario

4.2.4. Production scenario: What if a feed-in tariff for locally generated electricity would be introduced?

Instead of receiving only a bare electricity price per kWh, which is the case now for the electricity produced above your own consumption, this scenario aims to simulate the effect of a simple FiT on the produced electricity, a production based incentive.

A FiT on all produced electricity that would replace the net metering policy, is attractive for investments into solar PV, given the total cost per kWh would not exceed this FiT.

In this scenario, the necessary fixed FiT is calculated for which the proposed case breaks even with the reference case, given that other economic parameters remain stable. The FiT becomes active from 2020. In addition, the required fixed FiT are presented which lead to a NPC of the proposed case equal to the NPC with net metering enabled.

ET	€0.23/kWh for entire scenario
Fixed FiT	€0,07/kWh for 2017-2020 , then calculated
Net metering policy	Off from 2020
GT	€0.66/m³ for entire scenario

Table 4.4 Economic assumptions of production scenario

4.2.5. Investment scenario: What if a reduction in investment costs would serve as a compensation for consumers?

The government could decide that not the consumers themselves are directly compensated, but instead the suppliers of products and services related to EN renovation. This compensation can then be transferred into a reduction of costs for services and products for the eventual consumer. This translates to lower investment costs, and instead of receiving a compensation per kWh, the consumer receives a ‘fixed compensation’ at the start of the investment. This is an investment based incentive.

Alternatively, it can be given directly by the government in the form of subsidies on the products that are purchased. Already in the Netherlands there are governmental subsidies for the purchase of a heat pump and solar collectors, and VAT on solar PV panels is returned (RVO, 2016 (A)).

For this scenario, the required upfront compensation in 2017 is calculated in order for the proposed case to break even with the reference case. Assumed is that this compensation decreases the size of the loan, reducing the annuity payments that have to be made. In addition, the required upfront compensation is calculated that would lead to a NPC for the proposed case equal to that when subjected to net metering.

ET	€0.23/kWh for entire scenario
Fixed FiT	€0.07/kWh for entire scenario
Net metering policy	Off for entire scenario
GT	€0.66/m³ for entire scenario
Subsidy on upfront investment	Calculated

Table 4.5 Economic assumptions of Investment scenario

5. Results and analysis

This chapter shows the economic analysis of the reference case and the proposed case based on the scenarios that are defined in the previous chapter. The approach to the analysis and the results are discussed here and are compared and subjected to a sensitivity analysis in the next chapter. This leads to conclusions and further discussion on the realistic development of these scenarios, and the influence on the economic feasibility of each case.

5.1. NPC analysis of initial scenario

Payment of the energy bill is done monthly. For the reference case, these monthly payments accumulate into annual net payments. The calculation of this payment is as follows:

Reference case

$$NP_{ref_t} = \frac{\left(\frac{HD}{\eta boiler}\right)}{HHVg} * GT_t + ED * ET_t + PC + RC_t$$

In which:

NP_{ref_t}	= Annual net payment in year t [€]
HD	= Annual Heat demand [kWh]
$\eta boiler$	= Boiler efficiency [%]
$HHVg$	= higher calorific value of gas [9.77 kWh/m³]
GT_t	= Gas tariff in year t [€/m³]
ED	= Annual electricity demand [kWh]
ET_t	= Electricity tariff in year t [€/kWh]
PC	= Periodic costs [€]
RC_t	= Replacement costs in year t [€]

The periodic costs and replacement costs for each case are stated in Chapter 4, Table 3.2.

Proposed case

For the proposed case the annual net payments are calculated differently. Also here, the bill is paid for each month, and so is the mortgage. An annual mortgage payment with an annual interest rate accumulates up to a higher payment, in comparison to twelve monthly payments. Eventually, these twelve monthly payments are integrated in the annual net payment, which is calculated as follows, for the years in which the policy of net metering is not in place:

$$NP_{prop_t} = 12 * MP + PC + RC_t + IE_t * ET_t - (EE_t * FiT_t)$$

In which:

NP_{prop_t}	= Annual net payment in year t [€]
12	= The amount of monthly mortgage payments per year
MP	= Monthly mortgage payment (calculated by the annuity method) [€]
IE_t	= Imported electricity in year t [kWh]

EE_t = Exported electricity in year t [kWh]

FiT_t = Feed-in Tariff in year t [€/kWh]

For the years in which net metering is still active, from 2017 to 2020, the annual net payments are calculated as follows:

$$NP_{prop_t} =$$

$$12 * MP + PC + RC_t + IE_t * ET_t - (EE_t * FiT_t + \mathrm{IF}(IE_t < EE_t; IE_t * \Delta T; EE_t * \Delta T)$$

In which:

ΔT = the difference between the electricity tariff and the feed-in tariff [€/kWh]

In this formula, the 'IF' function is a function in excel, used to simulate the effect of the net metering policy. In reality, each month the exported kWh of electricity are sold for the existing FiT at that time. The net metering policy annually reimburses the difference between the ET and the feed in tariff for each exported kWh up to the amount of imported kWh on a yearly basis.

Based on the formulae for the net payment, the NPC calculations are conducted based on the conditions of the initial scenario. The NPC is shown in Table 5.1. Based on the spreadsheet for this calculation, all other scenario NPC are calculated. This initial spreadsheet is found in the Appendix.

Initial scenario	**Proposed case**	**Reference case**
NPC	€ 40.054	€ 37.419

Table 5.1 NPC calculations for proposed and reference case in initial scenario

It is found that the NPC of the reference case is lower, meaning that with the external conditions as defined in the initial scenario, the reference case provides with a more feasible business case compared to the proposed case. This means that even with the net metering policy still functioning, an investment in EN renovation with relatively low investment costs, solar PV and a heat pump, proves to be less feasible compared to keeping the gas boiler. This is assuming that all current energy prices remain stable. The difference of approx. €2,500 is over a lifetime of 25 years not significant (€100/year) and accounts for approx. 5% of the total NPC of the proposed case. Additionally, the proposed case remains with a converter with technically 5 years remaining of its lifetime. The cause of this negative outcome can be for a large part accounted to the decreasing costs over time for the reference case whereas the proposed case accumulates interest in the same time period. The discounted costs for the mortgage sum up to be almost equal to the initial investment costs (with a discount rate of 3.0% and interest rate of 3.27%).

On the other hand, one can argue that the difference between the NPC of both cases is so small, that an investment in EN is justified, assuming the other benefits an EN dwelling would bring, such as potentially higher comfort and less of an environmental burden.

5.2. NPC and break-even analysis of economic scenarios compared to the initial scenario

In Table 5.2 below, the four alternative economic scenarios are presented along with the values that have been calculated in order for the NPC of the particular scenario to break-even with the NPC of the initial scenario. The table shows the required value that would provide with a similar effect than the effect of the net metering policy, for which a replacement should be found.

Scenario	Case*	NPC Net metering [€]	Unit	Initial value	Break-even value	[€] Variation	[%] Variation	*[%] Annual variation*
Divestment	Ref	40,054	GT [€/m³]	0.66	0.76	0.10	15.2%	1.7%
Consumption (1)	Prop	40,054	Electricity taxes [€/kWh]	0.13	0.002	-0.128	-98,5%	-
Consumption (2)	Ref	40,054	Electricity taxes [€/kWh]	0.13	€0.185	0.055	42%	4.5%
Production	Prop	40,054	FiT [€/kWh]	0.07	0.19	0.12	171.4%	9.8%
Investment	Prop	40,054	Cost reduction [€]	0	3,915	3,915	-	-

*Table 5.2 Required change of economic parameters to break-even with the NPC proposed case with net metering (*Ref=reference case, Prop=proposed case, numbers in purple show unlikely scenario outcomes)*

Divestment scenario

In the Divestment scenario, the GT has to be increased from 2020 on to 0.76 €/m³ in order for the NPC of the reference case to increase to €40,052. An increase of 15.2%, or similar, an annual increase of 1.7% or a little over €0.01/m³ from 2020 on, allows for a more feasible proposed case over the reference case. Considering the actual increased taxes on natural gas, €0.06/m³ in 2016, this increase is possible.

Consumption scenario (1) and (2)

The consumption scenario shows the required reduction in governmental taxes in the ET. In order to meet a similar effect to net metering, the government has to abolish the posed taxes entirely from 2020 on. Electricity is required to be sold back to the grid for the same tariff as it is consumed: €0.07 / kWh. The effect of a higher feed-in tariff in combination with a higher bare electricity price is not assessed. The societal costs for such a required decrease in taxes have not been calculated, but it is expected that they will exceed the costs for net metering, as also the consumer with a conventional gas boiler profits from the scenario. This scenario is unlikely to unfold, as it would not create incentive for consumers to invest in EN renovation.

The alternatively considered option in this scenario - an increase in the ET for reference case consumers - results in more acceptable values. The table shows that an increase of €0.055/kWh of energy taxes for reference case consumers from 2020 on would provide with additional costs that render the reference case just as feasible as the proposed case with the option of net metering available. Or, an annual increase from 2020 of 4.5% on the electricity taxes would cause the same effect. The additional income for the state from levying these additional taxes could be used to (to a certain extend) pay for the net metering policy and to maintain it for the years to come.

Production scenario

The production scenario shows that a FiT of €0.19 / kWh is required in order to meet the effect of net metering. The effect is logically derived, as for produced electricity a similar price per kWh is paid as wit net metering. The additionally sold kWh are not sufficient to have a high impact on the NPC. From the initial value of €0.07 / kWh, this is an increase of almost threefold. It resembles a tax exemption on the produced electricity sold back to the grid of €0.12 / kWh, similar to the required decrease in taxes on consumed electricity as shown in the previous scenario. The difference is within the societal costs. FiT are paid for by the government (or the utility) as a subsidy on produced kWh. Tax decreases result in a loss of income for the state, but is not an actual subsidy. This difference could be regarded within further studies. However, overall the incentive of FiT proves to be quite weak, as they have to be high in order to provide with similar benefits as the current policy off net metering. This is unrealistic. As the net metering policy is too expensive to maintain, it will not be replaced with a similar policy.

Investment scenario

The investment scenario shows that a one-time reduction on the initial investment of almost €4000 is required to compensate for the loss in revenue from the absence of net metering. Basically, this value represents the quantification of net metering over a timeframe of 25 years, assuming the various technical and economic parameters. Currently, there are subsidies on the purchase of certain renewable technologies. These are also included within the model. These subsidies, accumulating up to of approx. €3000 within the proposed case, are together almost as strong as the policy of net metering. This suggests that investment based incentive schemes are good stimulants for EN investments.

From this analysis it can be concluded that:

- Energy tax reductions and higher FiT for EN consumers are weak incentives and cannot replace the financial benefits from net metering as they have a low effect on the economic feasibility of an EN investment
- Raised GT is a strong disincentive that could, with marginal and realistic increases lead to a more feasible EN case over a continuation with natural gas boilers
- The benefits from net metering can be quantified to a €4000 reduction on the initial investment of an EN dwelling.

The prior results state values required to break even with the NPC of the initial scenario. However, this scenario does not yet provide with a feasible business case compared to the reference case. The following section provides with break-even points between the reference case and the proposed case, and shows the required values in order to reach these points.

5.3. NPC and break-even analysis of economic scenarios, reference case and proposed case

The overview in Table 5.3 on the next page provides with the values that are required for each economic parameter assessed in the scenarios in order to reach a NPC break-even point between the reference case and the proposed case.

Scenario	NPC [€] (break-even)	Unit	Initial value [€]	Break-even value [€]	[€] Variation	[%] Variation	*[%] Annual* variation
Divestment	€44,168	GT [€/m³]	0.66	€ 0.96	€ 0.30	44.7%	3.7%
Consumption (1)	€57,848	Electricity taxes [€/kWh]	0.13	€ 0.55	€ -0.42	-324.6%	-35%
Consumption (2)	N/A	Electricity taxes [€/kWh]	0.13	-€0.01	-	-	-
Consumption (3)	€44,168	Electricity taxes [€/kWh]	0.13	0.27	€0.14	108%	11.6%
Production	€37,418	FiT [€/kWh]	0.07	€ 0.27	€ 0.20	290.6%	13%
Investment	€37,418	Cost reduction [€]	0	-€ 6.422	€ 6.422	N/A	N/A

Table 5.3 Break-even of NPC of reference case and proposed case per scenario (numbers in red show impossible scenario outcomes, numbers in purple show unlikely scenario outcomes)

Divestment

In the divestment scenario, an increase of the GT from 2020 to the end of the scenario (December 2042) of €0.30/m³ to €0.96/m³ is required in order for the proposed case to break even with the reference case. Similarly, an *annual* increase of 3.74% from 2020 of the GT is required to account for the same effect. This accounts up to an increase of approx. €0.025/m³ annually.

In 2016, the GT increased already with €0.05/m³. It is not known whether such an increase will be maintained in the next decades, but the outcome shows that an increasing GT could render a continuation with natural gas boilers less feasible than an investment in EN renovation, even if for the latter no additional financial incentive is available for consumers. The dependency on natural gas for the reference case is significant, therefore the fluctuating prices have a critical effect on the NPC and further study into the development of future gas prices might provide with additional clarification. Mind that for the first three years of the simulation a stable GT is maintained. A direct increase in the GT from 2017, even below €0.025/m³ annually, could render the reference case even less economically attractive.

Consumption (1), (2) and (3)

(1) In the consumption scenario, instead of a reduction in taxes, an overall increase in the ET is required in order for both cases to break-even. The ET would have to be €0.62/kWh, or the bare price of €0.07 + €0.55 additional energy taxes. The resulting increased NPC is no reason to invest in either one of the solutions and rather stimulates consumers to invest in an abundance of solar PV panels. The implementation of this scenario alternative and the results are therefore disregarded.

(2) A second alternative would be to lower only the tariff for consumers from the proposed case, as to create an incentive to invest in EN renovations. The results point out that in order to break-even with the reference case an ET reduction of €0.21 is required, leading to a negative ET. In other words, electricity has to be given away for negative prices to owners of Solar PV. This is paradoxical and therefore not further considered. Hence, the outcome of this alternative is disregarded.

(3) A third option for this scenario would be to increase the tariff for reference case consumers only. The results of this in Table 5.3 show that an energy tax of €0.27/kWh should be maintained from 2020,

or a total ET of €0.34/kWh, in order for the proposed case to be more feasible. That is equivalent to an annual increase in taxes of 11.6%, starting in 2020. Electricity taxes dropped for the first time in 2016 (with a little over 15%, see **Error! Reference source not found.**), but before that, taxes have only increased annually with less than 2% for several years. An annual increase of 11.6% is therefore possibly not well-received. A combination scenario with a drop in energy taxes for proposed case consumers could additionally reduce the burden.

Production

In the production scenario, the FiT has to raise from €0.07 to €0.27/kWh for the proposed case to break even with the reference case, which is an unlikely increase. The resulting FiT would be higher than the regular ET, a highly unlikely development. This would create an enormous incentive to invest solely in solar PV panels, and deliver in large amounts to the grid, as the payback period for these panels would be much shorter. The costs for such FiT and for the increased instability due to additional solar PV have to be carried for a large part by society, which would negatively affect solar PV owners and regular consumers alike. The scenario would be to a certain extend effective for adoption of more solar power in the energy mix, as is seen in Germany in 2010 and 2011 with the sudden massive adoption of individual solar PV (Wirth, 2015), but would not necessarily lead to an increase in other investments paired with EN renovations. Perhaps that effect is eventually best simulated with the last scenario, the Investment scenario.

Investment

The results from Table 5.2 show that a one-time cost reduction on the initial investment of more or less €6500 is required to have the proposed case NPC break even with that of the reference case. Currently, there are already governmental incentives such as the return on VAT for purchased solar PV and a subsidy on purchases of heat pumps and solar collectors. These subsidies amount to approx. €100 per solar PV panel (19% VAT) and €2000 for the heat pump (RVO, 2016 (A)). Another subsidy that could be given on provision of the dwelling reaching the state of 'energy neutrality' would encourage consumers to invest in the whole package, including energy saving measures and efficient appliances. This would not overstimulate the purchase of Solar PV, but rather stimulate pursuing a balance between consumption and production at the dwelling level. The effect of a one-time reduction of the investment is increased as less interest is paid on the long term.

In contrast, such an incentive scheme will provide with uncertain costs for the government, as they are direct and not spread over time. This effect can be abolished by allocating a certain budget to a new policy that could only stimulate a limited amount of consumers on a first come, first served basis, before it is depleted. This type of policy is currently seen with the SDE+ policy in the Netherlands, stimulating corporate and non-profit investments in renewable energy technologies (RVO, 2016 (B)).

From this analysis it can be concluded that:

- An increase of the GT of €0.025 per year from 2020 already renders an investment in EN renovation feasible, even if the policy of net metering will not be replaced by another incentive scheme
- Electricity tariffs have to increase significantly for natural gas consumers in order for EN consumers to have a feasible case, with more than 11% annually.
- Investment based incentives seem to work best with EN renovations
- The costs of the initial investment determine for a significant part whether the EN consumer will have a more feasible case.

The results from this chapter have to be placed within the context of the initial investment of the EN renovation. If this investment is in reality much higher, the previous conclusions cannot be drawn.

6. Sensitivity analysis

This chapter aims to reevaluate the core parameters chosen in the chapters ‘Case development’ and ‘Scenario development’, which were uncertain initially. The chapter assesses the impact of their changes to the NPC of both the reference and the proposed case, and discusses these changes. The impact of net metering and smart control have also been included in the analysis. The tornado chart in Figure 6.1 below shows the impact of core changes on both the reference case and the proposed case. The vertical lines represent the NPC of both cases without any financial incentive from 2020, thus without net metering. See the next page for further explanations on the sensitivity of the core parameters.

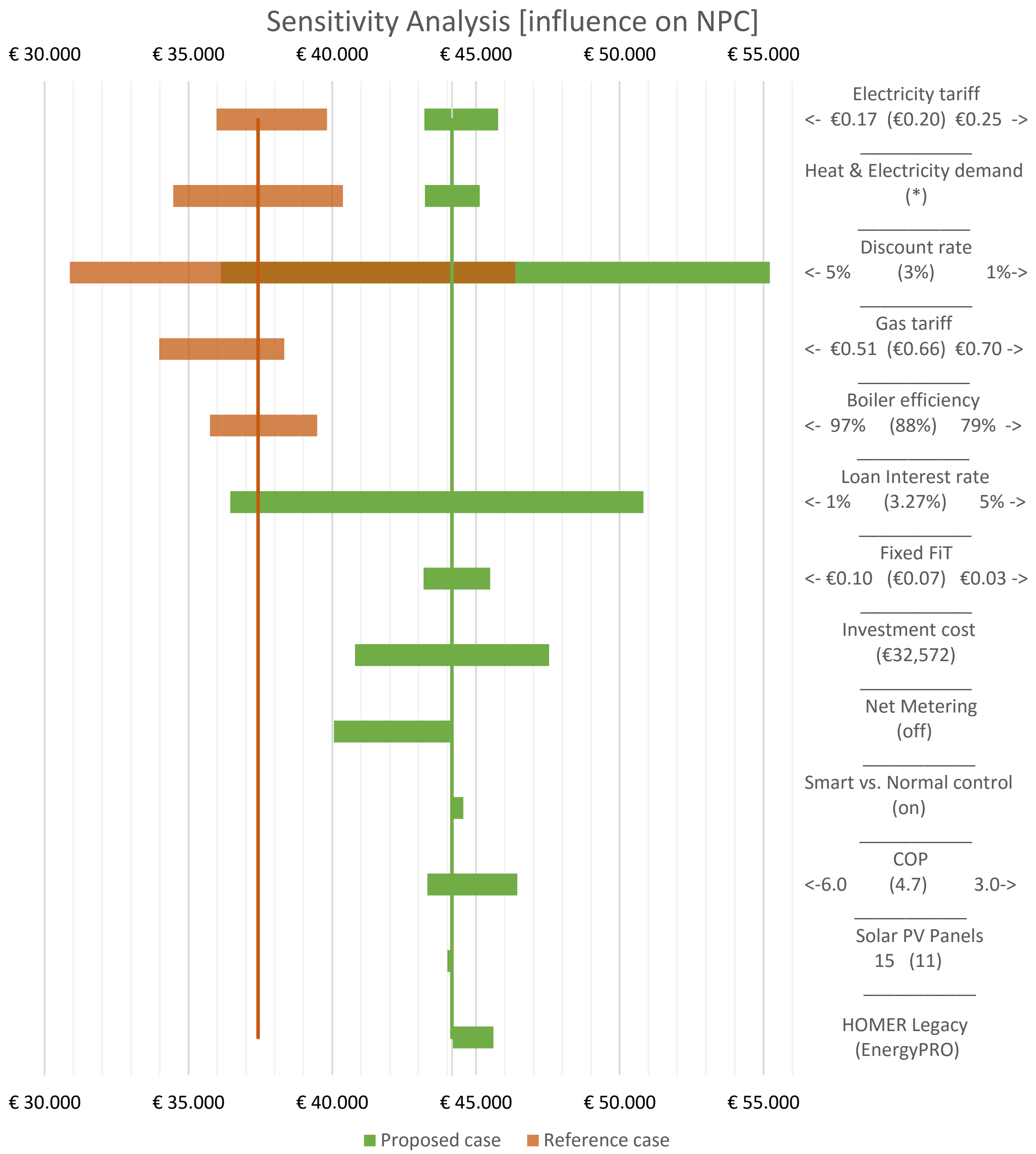


*Figure 6.1 Sensitivity analysis of core parameters (*initial heat and electricity demand are respectively 13,099 kWh and 3200 kWh for the reference case, and 7684 kWh and 2200 kWh for the proposed case)*

The legend on the right side shows the parameters that have been altered, with the initial value between brackets. Most parameters are differed with the outer boundary values that were found for the specific parameters such as electricity tariffs fluctuating between €0.17 and €0.25 per kWh. The discount rate, loan interest rate, the COP, and the amount of solar panels have been differed with a value that is assumed to cover generally possible changes. For these parameters, the changed values are shown in the legend. The heat & electricity demand parameter, and the investment costs parameters have been differered with 10%. In the initial calculations smart control is enabled, thus the sensitivity analysis points out the difference if this function is disabled.

Electricity tariff

Starting with the parameters that influence both cases, it seems that small changes in the ET, representing the fluctuation of the current ET by the different suppliers in the Netherlands, do not result in significant changes for the different cases. The reference case is slightly larger affected by such changes; this is accounted for by a larger consumption during the scenario. The limited sensitivity mainly due to the fact that the costs of electricity consumption for respectively the proposed case and the reference case only make up 1/4th and 2/5th of the total annual costs. Changing these values radically might cause a significant effect, but realistic changes do not. The overall sensitivity of this parameter is ruled out to be significant enough to be of value to the thesis.

Heat demand and electricity demand

A decrease and increase of both the heat and electricity demand of 10% leads with the proposed case to a small change in the NPV, less than €1000 over a period of 25 years. This influence is much stronger in the reference case, in which the same percentual increase leads to an increase in the NPV of almost €3000 over a period of 25 years. When extrapolated, it is assumed that this increase responds mainly linearly to an increase in demands, as net payments are increasing linearly. An increase in demand of 30% for example, would therefore already result in a less beneficial reference case compared to the proposed case, and that is without any financial incentives enabled for the latter. In non-attached dwellings or large family dwellings, this increase is quite realistic. An investment in EN renovation in such a dwelling might provide with lower costs on the long term.

However, this does not take into account additional investment costs for larger dwellings in order to reach EN status. A larger initial heat demand could very well require a stronger heat pump and additional investments into insulation, eventually having a higher negative impact on the NPC than an increase in demands with the reference case. This is why detailed design of the energy system is of such importance.

Discount rate

It appears that the largest influence on the NPC calculations of both cases would be the assumed discount rate. However, it is only interesting to look at the influence on the difference in NPC for both cases, as for this sensitivity analysis, extreme values of 1% and 5% have been chosen. The effect on each case is therefore high. The effect is clear: assuming a higher discount rate decreases the difference between the NPC of the proposed case compared to the NPC of the reference case. This effect occurs because future costs mean less to the investor than costs made in the present. The proposed case requires two replacement investments during the scenario, and the value of these investments is lower with a higher discount rate.

Gas tariff

After the discount rate, only values that appear in either the proposed case or in the reference case are evaluated. A GT based on the lowest offer in the Netherlands (supplier 'Nederlandse Energie Maatschappij' with €0.51/m³ of gas) decreases the NPC with approximately 10% - a significant decrease. This is mainly due to the fact that under initial conditions, the costs for the mere consumption of gas already makes up half of the annual bill for the reference case. From the figure, it could be obtained that the effect of low GT would result in a highly cost-efficient reference case. The chances of maintaining such a low GT over the period of 25 years is highly unlikely, considering the increase in taxes as of 2016 (an additional €0,05/m³), but it is an effect that should be considered. A higher value of €0.70/m³ (assumed, as no other values could be found) has also been assessed, but does not influence the NPC significantly.

Boiler efficiency

Although the assumption of 88% as the efficiency for the reference case natural gas boiler is representable for average individual boiler efficiencies, is it possible to reach efficiencies up to 97% if the external conditions allow for it. On the contrary, should the eventual efficiency be lower because of an older boiler and more losses in piping for example a sensitivity of 79% is also maintained. The effect of this change on the reference case NPC is approximately -7,5% and +10% respectively for a higher and lower efficiency, or -€2000 and +€2500 on the initial NPC. This is not an insignificant difference, but it can be assumed that such extreme efficiencies will not easily be reached. The real effect of fluctuating efficiencies is somewhere between these values. Assuming that these fluctuating efficiencies fluctuate above and below the initial value of 88%, the effect is even smaller. Therefore, this sensitivity can be disregarded.

Loan interest rate

A difference on the annual interest rate provided by the loan agency seems to have a significant effect on the NPC of the proposed case. A mortgage with an annual interest rate of a little above 1% instead of the initial 3.27%, would provide with a business case that is less costly than the reference case. In contrast, a green loan as they are provided by certain banks for interest rates of around 5%, ruins the chances of the investment being economically attractive. The eventual choice of the loan interest rate provides with a crucial sensitivity to the proposed case, and should be carefully regarded. On a positive note, governmental efforts in artificially reducing these rates, or governmental institutions providing loans with low interest rates would have a significant impact on the feasibility of these cases. The possibilities and associated societal costs in such incentive schemes should be further investigated.

Feed-in Tariff

It seems that a deviation of the initial FiT to respectively €0.03 an €0.10 per kWh has no significant impact on the NPC of the proposed case. The NPC decreases and increases with approximately 2.5 – 3%, depending on the supplier of electricity. This effect is due to the small annual income from exported electricity, which is almost 15 times smaller than the total annual costs. This share becomes even smaller over the years, as (due to derating solar PV panels) the share of exported electricity decreases. Hence, the influence of FiT changes is small. The sensitivity of these input values to the eventual NPC calculation can be disregarded.

Investment costs

One major assumption in the thesis are the initial investment costs for the proposed case. Although carefully selected from the different offers concerning each technology, these prices vary greatly depending on the supplier. Installment, service costs, operation and maintenance (now not considered) can only be estimated as no real representation is accurate. The sensitivity of this parameter is evaluated by deviating with 10% from the initial investment costs (€32,572). It seems that an increase of the investment costs of 10% also leads to an increase in the NPC of approx. €3200.

The investment costs are spread over 25 years in the form of a loan, and the initial discount rate of 3% would allow for a lower value of future costs. The reason why the NPC increases with a similar amount is because the additional investment costs also lead to a higher interest to be paid to the loan agency. Thus the effect is more significant. This is a sensitivity to the model that should be regarded to as important, as prices for EN renovations can differ radically as stated in the chapter 'Case development'. Prices up to €80.000 for the renovation are possible. It goes without saying that this also leads to different input variables for heat demand and perhaps other variables, but still renders the entire business case unfeasible compared to the reference case.

Net metering

Although already discussed in the previous chapter 'Results and analysis', the above stated graph also shows the effect of the benefits of the net metering policy in comparison to other sensitivities. A difference in NPC of approx. €4000 serves as the quantification of this effect over a period of 25 years. The general effect of the net metering policy is that on an annual basis, there are basically no net costs for electricity consumption, only minor revenues for excess production. However, these costs in the first place made up only about ¼ of the annual net payment. The graph shows that the effect of net metering is eradicated by other effects such as a lower interest rate. This leads to the assumption that the net metering policy is not such a crucial requirement for an EN renovation to be feasible in comparison to the reference case. It plays an important role, but can be replaced.

Smart control

The effect of smart control on the NPC turns out to be almost diminishable. A €500 decrease of the NPC over a period of 25 years is unlikely to be a reason for consumers to invest particularly in this type of technology. Especially because in this calculation, the price for such a technology on top of the investment cost for 'normal' heat pumps has not yet been considered. It is possible that adding the investment costs and additional costs for 'smart meters' or smart control technology would even result in a negative effect on the NPC on the long term.

It must be said that this effect is only calculated in the initial model including a thermal storage of 190 liters. In reality, this storage is only usable for DHW, and not for space heating. As explained in the chapter 'Case development' the effect of smart control would therefore be even smaller. In contrast, a larger additional thermal storage would result in a better effect from smart control.

From additional NPC calculations, based on the reduction of imported and exported electricity as calculated in Chapter 3.3.2. (not shown in the sensitivity analysis), it was concluded that this effect only leads to a reduction in the NPC of approx. €2500-€3000. This is with a storage of 116,000 L. Such an effect is, with regards to the additional investment costs of such a storage, diminishable. It can be concluded that smart control does not provide significant benefits, with or without thermal storage. The effect of different ET and FiT on the effect of smart control is not measured.

COP

As has been discussed in the chapter 'Case development', a constant COP of 4.7 has been maintained in the proposed case, which represents the theoretical efficiency the heat pump could reach under minimal ambient- and desired temperature differences. Consequently, a sensitivity analysis on higher and especially lower values is therefore valuable. The effect of a changing COP on the NPC of the proposed case has been assessed by changing the electricity/heat ratio of the energy unit in EnergyPRO. The actual changes this would have on the size and capacity of the heat pump, and corresponding price changes have been disregarded.

Raising the theoretical COP to 6.0 does not lead to a significant decrease in the NPC of the proposed case, especially if one considers that usually a higher COP requires higher upfront costs. This effect can be attributed to a decrease in both exported and imported electricity of about 200 kWh annually. With the initial tariffs, this only leads to a reduction of the net operation costs of about €40 annually. This effect is insignificant.

A theoretical COP of 6.0 is to the authors' knowledge only possible with a ground-source heat pump under optimal conditions. A side-effect of the higher COP is that, in total, only 10 installed solar PV panels are required in order for exported electricity to surpass imported electricity. This reduces the investment costs and thereby the mortgage or loan, but also reduces the revenues from sales of electricity. Further on in this section, a sensitivity analysis on additional solar PV panels in the proposed case is done, in order to evaluate the effect on the NPC.

A lower COP, of 3.0, has a significantly higher impact on the NPC. A COP of 3.0 for an air source heat pump is to the authors' knowledge not rare, and should therefore be regarded as a possibility. Hence, the negative effect of approx. 5% on the NPC is therefore important to consider. Both import and export of electricity increases with approx. 400 kWh annually, increasing the annual production costs with €90, in addition to the extra investment costs for the additionally required solar PV panels. The lower COP requires a higher input of electricity in order to produce heat, which requires a larger share of production from solar PV to account for that. With a COP of 3.0, 13 solar PV panels are required in order to cover total electricity demand. However, bearing in mind that lower COP heat pumps are often provided against lower investment costs, this effect reduces.

Solar PV Panels

It is interesting to assess in the calculations whether increasing the amount of solar PV panels would have a large effect on the NPC. This shows whether (under conditions without net metering) it proves to be interesting to invest in solar PV, assuming the other external conditions remain the same such as FiT and ETs. The graph shows that an additional 4 panels would decrease the NPC with a limited amount, a further look in the details shows that this amount is approx. €150. On a 25 year basis, this is insignificant. This is due to the additional investment costs that are considered with the extra purchase, and due to the limited revenue from the considered FiT of €0.07/kWh. The investment costs only cover the bare cost per panel, and do not include additional costs for installation and service. In reality, the NPC might even increase.

In contrast, instead of net metering, higher FiT might render additional PV more feasible. The effect of this is not considered in this thesis. It can be argued that additional production of solar PV electricity has a positive contribution to the share of renewable electricity in the electricity grid, justifying the purchase of additional solar PV even if the effect on the NPC is diminishable.

HOMER Legacy

Eventually an additional case analysis has been carried out with HOMER Legacy, the prior version of HOMER Pro. Due to a termination of the initial license, HOMER Pro was not available for use, but in the final moments of writing this thesis, a license for an earlier edition of HOMER, HOMER Legacy was given to the author.

As it was impossible to closely analyze the effects and in-and output parameters of HOMER in this thesis on such a short notice, a brief description of the simulation must suffice here. The reason for assessing the sensitivity of HOMER over EnergyPRO is that it was found that HOMER calculates a different solar PV panel output. An identical simulation was run in HOMER as was performed in EnergyPRO, for the proposed case without net metering as of 2020. Expected was that due to the lower solar PV output, the eventual NPC would prove to be higher. As the table suggests, this is the case. The mere use of HOMER over EnergyPRO results in a decrease of the NPC of approx. €1500. Although it is not entirely clear whether the solar PV output calculations from HOMER are more accurate, the program considers additional parameters which eventually have a negative influence on the NPC. In the chapter 'Discussion' this difference is further elaborated. Below in Figure 6.2, the results of this model are shown in terms of annualized payments. Here only the 'O&M' should be regarded, which represents the overall annual expenses on electricity, after the exported solar power is deducted. This value is imported in Excel and the eventual NPC has been calculated through a separate sheet. The NPC in the figure is not accurate as the additional annuity payment for the mortgage and a discount rate are not considered.

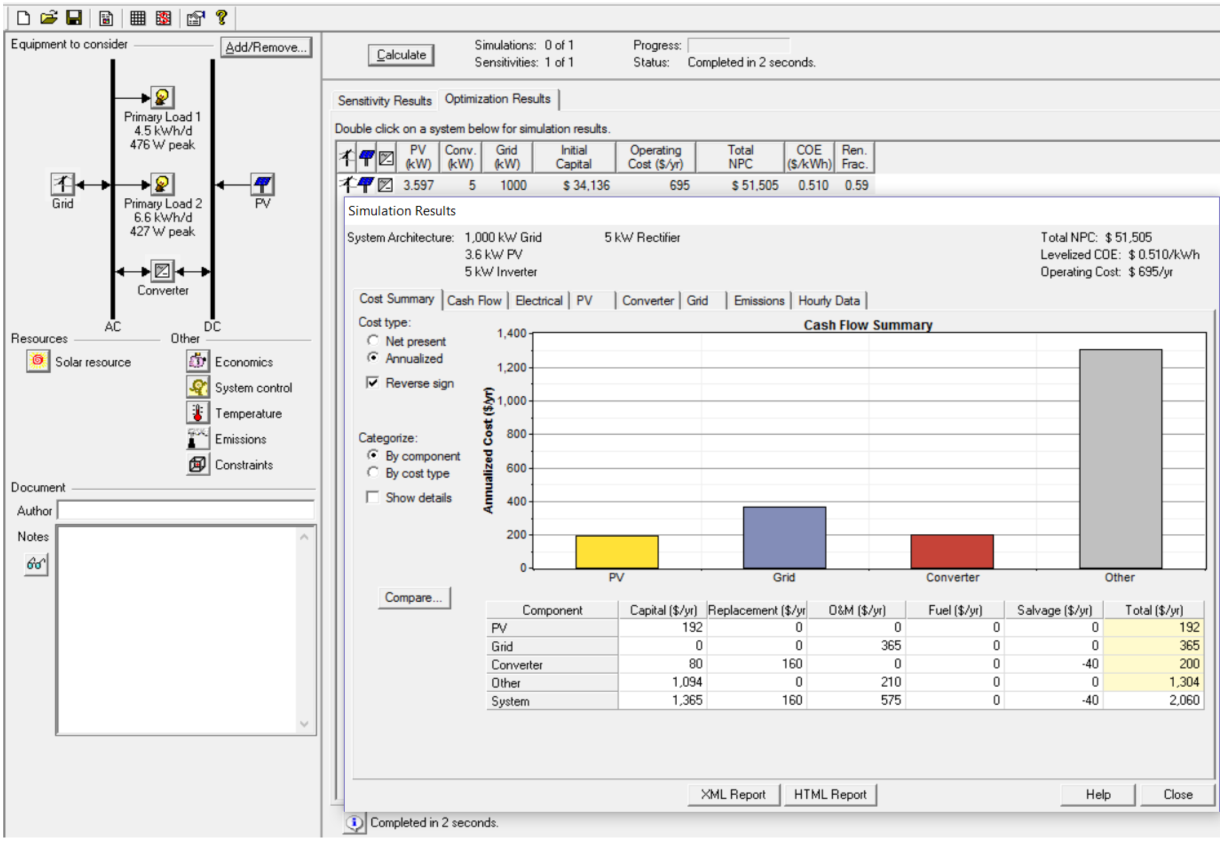


Figure 6.2 Results from HOMER Legacy, modelling the proposed case (the energy system in the top left, the installed solar PV capacity (3.597 kW) is seen in the top middle)

Conclusions

The main conclusions that can be drawn from the sensitivity analysis are:

- The GT and energy demands have a strong influence on the NPC of the reference case
- The investment costs and the annual interest rate of the mortgage are having a strong effect on the NPC of the proposed case
- Fluctuations in FiT and ET have a weak influence on the NPC of the proposed case
- Smart control provides with an insignificant financial benefit to the NPC of the proposed case

These conclusions will be further elaborated upon in the discussion and conclusion.

7. Discussion

This chapter elaborates on the obstacles that have arisen during the process of conducting this thesis. Notable results or delimitations that have not been critically reviewed in the thesis, are additionally considered here.

7.1. Reflecting on methodologies

Case study

In Chapter 3.1 it is described why a dwelling that is largely represented in the dwelling stock provides with a graspable case for the consumer. Later on, this dwelling, along with its typology, geometry, insulation values, etc. is only used to generate a demand for space heating. This might lead to thinking that much of these methods used to obtain this heating demand are abundant, and perhaps a more simple approach, such as using statistical averages, should have sufficed. However, this is not the case.

What is perhaps underrepresented and should be emphasized here, is that by proving that the method for estimating the heat demand in the terrace dwelling for the reference case is accurate, it can be used for estimating an accurate heat demand in the proposed case as well. Average demands for EN dwellings are not available yet as there are perhaps a few hundred of them at the moment. A guess into the eventual demand would be quite uncertain. A carefully estimated heating demand for the proposed case provides with the most accurate results.

Scenario design

For the design of the economic scenarios in Chapter 5, initially the approach of Börjesons' (2006) predictive 'what if' scenarios was chosen as the method of use. As these scenarios are rather uncertain, the focus is on a variation of possible parameters, to make up for accuracy. It was initially thought of that by simulating a variety of external conditions in each scenario a thorough understanding of the effect of a policy alternative would be developed. However, the approach of using variations on the development of these prices eventually only proved valuable for the sensitivity analysis.

For the actual scenario analysis, a different approach was eventually used. An approach in which the required variation of these external conditions, in this case the electricity taxes, was calculated in order for the proposed case to break even with the reference case. This approach corresponds more to another type of scenario specified by Börjeson (2006), called the normative preserving scenario, as seen in Figure 2.1. In such scenarios, one sets out to find the correct path towards reaching a specific target. This can be done by the use of a model, such as EnergyPRO and Excel, which has been the case in this thesis.

Instead of applying values to external conditions (e.g. energy prices) as a simulation of what could eventually happen, this thesis shows the required values, should a certain internal condition be met (a required NPC). This approach was determined to be more suitable as with the initial 'what if' scenarios, the resulting NPC for both cases corresponds only to the actual simulated scenario. Should this scenario in reality be different, only limited conclusions can be drawn from the results. The eventual approach instead presented the required progress of the scenario, if one wants to reach a break-even point between the two cases.

With these break-even results one can, even if in reality the scenario would develop differently, directly conclude whether this would lead to a more or less feasible proposed case in comparison with the reference case. Such outcomes are valuable for further qualitative discussion on the feasibility of EN investments.

The sensitivity analysis in Chapter 6 has a closer resemblance to the 'what if' scenario approach from Börjeson (2006), as here alternative external conditions are predefined and the eventual outcome of the internal conditions is calculated. This sensitivity analysis therefore serves as a valuable addition to this thesis.

Trias Energetica

Initially it was determined that the method of Trias Energetica would be used to systematically design the energy system in the EN dwelling. This method focusses on a reduction of energy consumption as the primary concern, as explained in the chapter 'Methodologies'. Though this approach is probably the best from an environmental standpoint, considering that the best renewable energy is energy not required at all, it might not be from a business-economic standpoint. As a business-economic perspective is used in this thesis, there was eventually decided to deviate slightly from the initial approach, and focus on reducing energy up to the extent that the upfront investment costs would not be radically high. This deviation is explained in the chapter 'Case development'. It is to a large extend by the case studies from Urgenda, in which the focus is to keep investment costs low as possible in order to obtain feasible business cases. In hindsight, Trias Energetica still proved useful for the structured approach towards developing the EN energy system.

7.2. Impact of delimitations

As this study carries out a case study, certain limitations and delimitations have been defined mainly in the chapters 'Methodologies' and 'Case development'. First of all, the main delimitation of this study is the approach of the consumer perspective. It is deliberately chosen not to do a socio-economic study as to provide with more insight how certain policy alternatives and technology alternatives affect an investment in an EN dwelling. Consumers and decision-makers alike can work with the outcome of this thesis by questioning themselves whether an investment is feasible or what the orientation of a replacement policy would be. Therefore this thesis provides with output that is valuable for further socio-economic studies, which aim to assess the societal costs of policy changes, and the large scale integration of EN dwellings in the energy system of the Netherlands.

Other, less significant delimitations have an impact on the eventual outcome of the study. The deliberate choice to focus on a specific combination of technologies (a heat pump with solar PV) to be able to technically simulate a system instead of working with statistical data on the use of a variety of technologies, leads on one side to results that are to a less extend applicable to consumers with a different technological set-up. Consequently, the study is less diverse, but on the other side it provides more detail for the consumer who happens to invest in such a particular set-up. This is the majority of EN dwellings. No conclusions can be drawn upon the use alternative energy systems.

7.3. The future case

Initially it was planned to analyze and model three different dwelling cases. In addition to the reference and proposed case, the idea had risen to establish a future case, in which battery storage would be assessed as an alternative to net metering. Based on future battery price developments, a scenario was developed. An alternative timeframe was chosen starting from 2020, assuming net metering is abandoned. The added value of HOMER Legacy within the analysis would be fundamental, as the focus within HOMER is on power systems, and a large database of battery technologies is provided. A simulation based on changing energy prices would eventually provide with a NPC that could be compared to the NPC of the reference and proposed case. This could eventually lead to conclusions on the use of battery storage as an alternative to net metering. Unfortunately, due to a lack of time this option had to be disregarded. It would be interesting for future studies to assess this case according to a similar methodology as the initial cases from this study, so as to provide with consistent results.

7.4. Reduction of carbon footprint

By investing in renewable energy technologies for heating and electricity in comparison to heating with a conventional natural gas boiler, one can calculate the reduction in CO_2 emissions as a result of the investment. Eventually, the reason why these dwellings are required to be EN by 2050 is to reduce the fossil fuel energy consumption of the dwelling stock. Although this thesis only concerns a business economic standpoint for the consumer, this reduction in carbon footprint might, from an ethical and environmental standpoint, be a reason for consumers to invest in an EN dwelling.

Considering 57 kg of CO_2 per GJ of natural gas and the higher calorific value of 9.77 kWh/m^3, one emits 2 kg CO_2 per m^3 of natural gas. With a total consumption of 1523 m^3, this adds up to 3053 kg of CO_2. Add to this CO_2 emissions from consumed electricity. These amount to, with a simply assumed production efficiency of 40% based on natural gas and a consumption of 2200 kWh annually, approx. 1128 kg of CO_2 annually. This adds up to a total of 4181 kg of CO_2 annually in the reference scenario. Realistically, the amount is lower because of the share of RE in the production of electricity.

For the proposed case, the term 'energy neutral' additionally suggests that there are no net CO_2 emissions on an annual basis, since at least the same amount of carbon-free electricity is delivered back to the grid as is consumed. However, the energy put in the production of the technologies that are used (solar panels, converter, heat pump, insulation material) also results in emitted kg of CO_2. According to a study done by the PV Environmental Research Center in New York, on the topic of these life cycle emissions, it is concluded that these combined do not surpass the emissions from fossil fuels, so eventually it is safe to assume that these investments have a healthy effect on the environment (Fthenakis, et al., 2008). Simply put, should 7.5 million dwellings in the Netherlands reduce 4000 kg of CO_2, this would result in an annual reduction of 30 million tons CO_2 emissions. On total annual emissions of 170 million tons (World Bank, 2011), this would be a reduction of ±20% - a good start.

7.5. Connecting assumptions

Assumed in both the reference and the proposed case is a discount rate of 3.0% and for the proposed case a loan interest rate of 3.27%. Initially it was decided that these two rates should not interfere with each other, as the discount rate would cover all future net payments, not only the monthly payments from the mortgage. A discount rate set equal to the interest rate of the mortgage would be wise when all future net payments are financed by this mortgage. However, there are additional annual operation and periodic costs. These costs can be discounted at another rate entirely, preferred by the consumer.

Changing the discount rate had a major influence on the NPC, as shown in the sensitivity analysis. Reflecting upon this in hindsight, it is because by assuming a discount rate higher than the interest rate, the future mortgage payments are evaluated to be worth less. Therefore, a higher discount rate artificially simulates a decrease in the interest rate. A better representation of the sensitivity of the discount rate would be to initially increase the interest rate and then vary the discount rate so that it always remains below or at the level of the interest rate of the mortgage.

7.6. Reflecting on simulations

As stated in the chapter 'Case analysis', it was required in EnergyPRO to generate a solar PV output time series in order for the smart control optimization to work. This time series was generated in an early stadium of the eventual calculations, one at which the full understanding of EnergyPRO was not yet attained. The output (approx. 4500 kWh/year) of the solar PV panel array with 11 solar PV panels seemed high, but several conversations with colleagues at Aalborg University lead to the understanding that EnergyPRO often assumes a too high realistic output of the solar PV panels. The output was further disregarded and used in the eventual analysis, until an additional assessment with HOMER Legacy was done based on an identical energy system.

The solar PV output of HOMER was calculated in a slightly different way but it was not understood how this small change in formulary calculations could have such a significant impact on the solar PV output. In the first year, the array in HOMER would provide with approx. 4000 kWh, whereas EnergyPRO calculates an output of approx. 4500 kWh. Eventually, a new set-up was created in EnergyPRO, providing with a solar PV output of 4200 kWh in the first year. It is possible that initially a mistake was made.

Two findings can be concluded from this mistake. Firstly, the use of EnergyPRO and HOMER Legacy does not provide with such significant differences in output. Secondly, that all results in the analyses are eventually slightly different. The actual NPC of the proposed case is therefore actually located somewhere between the NPC calculated by HOMER Legacy and EnergyPRO, thus slightly higher. An additional, uncalculated burden to the proposed case is that this would probably require another solar PV panel in order to export more electricity than is being imported. This additionally leads to extra sales, etc. The effect of this is shown in the sensitivity analysis, and is limited, though increases the NPC of the proposed case. Eventually, the consequences of the miscalculated solar PV array have a small negative effect on all requirements for the scenarios to reach a break-even point between the cases.

In addition to the calculations from EnergyPRO regarding the solar PV output, it can be discussed whether the calculated amount of solar PV panels, 11, is realistic. In the chapter 'Case analysis' it was already discussed that this amount does not match actually installed solar PV from several business cases. Disregarding the solar PV output calculated by EnergyPRO, if the investment costs for solar PV panels should double (instead of approx. €5000, €10,000), this would have a significant negative effect on the NPC of the proposed case. As was shown in the sensitivity analysis of the investment costs, a reduction or increase in costs have an almost 1:1 relation to an increase or reduction in the NPC. Thus, these additional PV costs would increase the NPC with approx. 12%. This would have a significant effect on the required external conditions as calculated in the scenario analysis.

The added value of EnergyPRO in this thesis can be questioned, as it was restricted to the calculations for the solar PV array output, the effect of the smart control optimization for the heat pump and the eventual impact of these two technologies on the import and export of electricity. The solar PV calculations turned out to be incorrect, and the effect of smart control is insignificant. Using EnergyPRO is justified however, as the import and export of electricity could not have been calculated without it. This required an hourly calculation because of the dependency on electricity demand and supply at different moments in time. However, for this also HOMER could have been used.

7.7. EN dwellings are problem solvers

According to Green Rhino Energy (2007), production based incentives such as FiT provide with the most efficient and effective incentive schemes in order to promote RE production. According to the results in Chapter 5, this is by far not the case for the promotion of EN investments. Production based incentives only have a limited impact of the feasibility of an EN investment and from this, the question arises from which perspective one has to look at large scale integration of EN dwellings.

The goal of production based incentives is not to reduce the amount of energy that is being consumed. It only aims to increase the share of RE production in the energy mix. EN investments are instead more fundamental, initially reducing the overall consumption of dwellings, eventually reducing the carbon footprint to nearly zero by adding RE technologies. It is only logical that such integrated approaches require strong, investment based incentive schemes. Increasing the share of RE production can be regarded to as treating symptoms of the consequences of fossil fuel dependency, promoting EN investments eventually really contributes to solving this problem.

8. Conclusions and recommendations

The Netherlands covers less than 5% of its gross energy consumption by renewable sources. Almost 30% of this consumption origins from the dwelling stock. To reduce the consumption of dwellings, the government implemented several subsidy policies to create incentive for individual consumers to invest in energy neutral (EN) dwellings and renewable energy technologies. Net metering, a highly beneficial incentive scheme for consumers, is too costly for the government to maintain and will be terminated in 2020. Following a quantitative approach in the framework of a case study and scenario planning, this thesis answers the following research question:

What is the influence of alternative solutions to net metering on the value of an all-electric, energy neutral renovation in typical dwellings?

By simulating heat and electricity consumption in a typical terrace dwelling in the Netherlands, this question is answered. The dwelling, built in 1975-1991, initially with a gas consumption of approx. 1500 m^3 annually, is made energy neutral with an initial investment of approx. €32,000, with a monovalent heat pump and solar panels accounting for the RE technologies. By the use of energy system modelling tool EnergyPRO both dwellings subjected to a variety of normative preserving scenarios that develop over the next 25 years, presenting changes in energy prices, initial investments, and financing schemes and the effect of 'smart control 'heat pumps that could replace the benefits of net metering for the consumer. By means of net present value calculations conclusions can be drawn on the value of an EN investment, based on these different scenarios.

It is concluded from the study that even with the current policy of net metering (assuming that the current energy prices remain stable) the investment in the EN dwelling does not provide with a financial advantage over a continuation of the use of a natural gas boiler. Increases in the GT of €0.01/m^3 annually, or a one-time additional €0.06/kWh on the ET of consumers who do not invest in EN renovation could render an investment feasible over 25 years, assuming that net metering remains available and the investment is as low as €32,000.

Should the policy be terminated in 2020, the GT should from then annually increase with almost 4% in order for the EN investment to be more beneficial. This outcome only changes marginally depending on technical and financial differences in the system that function on the long term, regarding a higher COP of the heat pump or a higher FiT. Instead, mainly the investment costs have a significant impact on the overall long term costs. A reduction in the initial investment of approximately €4000 could substitute the financial benefits that would alternatively be gained from the net metering policy over the long term. Concluded from this is that it is difficult for the heat pump and solar PV panels to make up for their investment almost regardless of FiT or ETs, and the actual benefits from these technologies are mainly depending on the development of the GT.

It is concluded that feed-in tariffs and electricity tax reductions for EN consumers as alternative financial incentive schemes will not be able to offer the same financial benefits as currently provided by the net metering policy. This is mainly due to the low excess electricity production on the solar PV panels and due to a low consumption of imported electricity. Such production and consumptions based policies could under no reasonable circumstances lead to a financially beneficial EN investment. This is partly because production based incentive schemes aim only to increase the amount of RE production in the energy mix.

One of the obstacles for consumers in EN renovations are financing the investment costs. It is concluded from the analysis that a proper financing agreement is of significant importance to the business case. This goes hand in hand with the statement of Urgenda (2014) stating that widespread options on financing investments in EN renovations have to be developed.

An annual interest rate on a mortgage for 25 years differing with 1% has an effect on the overall net present costs of 10%. The business case of an EN investment falls or stands with the size of the initial investment and the interest rate that is agreed upon. It is therefore recommended that governmental institutions focus on the creation of (additional) investment-based incentive schemes that are concerned with financing and lowering the investment costs of EN renovations. This would probably lead to more EN investments instead of mere investments in solar PV. Such an incentive can also function as a ‘transitional agreement’ promised by the government for consumers who have in the past invested in solar PV and will do so before net metering is terminated. Further study into the societal costs of investment based incentive schemes is recommended prior to this termination.

Local governments should set out to develop more possibilities in their jurisdiction on the provision of low-interest loans, as the loan conditions are crucial for the success of an EN investment. Additionally the market for EN technologies such as heat pumps, but also technologies not extensively described in this thesis such as low temperature radiators and insulation materials should be stimulated in order to reduce the investment costs for the consumer. EN investments aim to provide an overall solution to dependency on fossil fuels, by reducing consumption and increasing RE production.

Additionally, it is concluded that the financial benefit from smart control heat pumps, which work mainly during hours of solar PV production is insignificant and, depending on the additional investment costs of such a system, could even contribute negatively to the overall net present costs. This is practically regardless of the size of a thermal storage.

Finally, as was discussed in Chapter 7, the thesis maintains a consumer business economic perspective. In the introduction it was already made clear that EN investments also provide with other, non-financial benefits, such as additional comfort, modern technologies and a lower environmental burden. As it is difficult to quantify such benefits this study paid no attention to them. Further study into the value of such benefits could eventually provide with more awareness in consumers, justifying an EN investment even if it does not yet provide with a financial advantage over a natural gas boiler.

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Appendix

Newspaper article

Het panel, van links naar rechts: Bart Bakker, Jaques Ninaber, Ulla Eurich en Jop Kluis. (Foto: Jan Daalman)

JAN DAALMAN

AALSMEER - Elektrisch koken, elektrisch douchen en elektrisch verwarmen zonder maandelijkse energierekening, oftewel een energieneutraal huis. Dat is nu al mogelijk door goed te isoleren en door voldoende zonnepanelen aan te schaffen. Een gasaansluiting is dan niet langer noodzakelijk. Dit bleek woensdag 20 april tijdens een door de Doopsgezinde gemeente en de stichting Sienergie georganiseerde informatieavond over anders omgaan met energie.

Zo'n vijftig belangstellenden hoorden energieadviseur van de toekomst en student Bart Bakker vertellen dat Nederland en daarmee Aalsmeer nog ver achterlopen in vergelijking met landen als IJsland en Noorwegen. Bij handopsteken bleek de helft van het publiek al wel maatregelen te hebben getroffen om de eigen woning duurzaam te maken. In Nederland is echter nog geen 5 procent van de huizen duurzaam, dat wil zeggen het hoogste energielabel A. Bakker schetste een aantal varianten waarmee een woning energie kan opwekken, kan besparen maar vooral slim, stapsgewijs en betaalbaar energieneutraal kan worden.

Energieneutraal

Per slot van rekening moeten alle huizen in Nederland straks in 2050 energieneutraal zijn. Daar is volgens hem per woning een investering van 35.000 euro nodig die in 15 jaar is terugverdiend.

Hiermee was de teneur voor de avond wel een beetje gezet want ook uit de presentatie van Sienergie-manager Ulla Eurich bleek dat er aan de voorkant flink geïnvesteerd moet worden om voor een woning een neutraal energielabel te krijgen.

Collectieve aanpak

Zij pleitte voor een collectieve aanpak in wijken, buurten en nieuwbouwprojecten. Een goed voorbeeld waar Sienergie over adviseerde, is een project waarin voor 88 woningen per woning 3000 euro werd geïnvesteerd om zo jaarlijks 500 euro gas te kunnen besparen.

Daarna was het de beurt aan Jaques Ninaber, de man achter het project Hofstede in Zwaanshoek. In overleg met de dorpsraad werd op het terrein van een voormalige autosloperij een wijkje met twintig huizen gebouwd die elk op zich volledig energieneutraal zijn. Ninaber is er zelf bewoner geworden. Het collectieve zit daar in het ontwerp, de nieuwbouw en de gedachte er achter, maar elk huis staat op zichzelf. Bij pech aan de installatie ligt niet gelijk de hele wijk plat. En zo zijn er veel varianten mogelijk, want ook een zogenaamd natuurhuis met muren waarvan de spouw gevuld is met schapenwol of houtsnippers en er verwarmd wordt via een pelletkachel, ook wel het nieuwe verwarmen gedoopt, is er een.

Belemmeringen

In de korte paneldiscussie die op de presentaties volgde liet wethouder duurzaamheid Jop Kluis aan de hand van een voorbeeld uit de praktijk weten dat op dit moment ambities en regelgeving nauwelijks op elkaar aansluiten. Hij vertelde dat een Aalsmeerder die zijn of haar woning opwaardeert met een of twee duurzaamheidmaatregelen de rekening dubbel gepresenteerd krijgt. De woning wordt namelijk meer waard en daarmee gaat de OZB omhoog. De Vereniging van Nederlandse Gemeenten, het Rijk en de kiezer kunnen daar verandering in brengen, betoogde hij. De wethouder riep tot slot nog op om Aalsmeer zo veel en zo snel mogelijk vrij te maken van het gebruik van fossiele brandstoffen door groene stroom en groen gas in te kopen.

Initial scenario Excel spreadsheet

Initial Scenario													
Sell back price ELEC	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Consumption price ELEC	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Gas price	0.66	66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Periodic costs electricity	210	210	210	210	210	210	210	210	210	210	210	210	210
			NPV	€ -49,954.49	€ -44,598.41	€ -40,053.52	€ -36,178.10	€ -32,857.57	€ -29,998.90				
Derating PV	-0.50%		Discount rate	1%	2%	3%	4%	5%	6%				
Monthly interest rate	0.2725												
Annual interest rate	3.27												
Yearly mortgage payments	12												
	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029
Produced Electricity	4,568	4,539	4,514	4,489	4,464	4,440	4,415	4,391	4,367	4,343	4,319	4,295	4,271
Exported Elec	2,459	2,437	2,416	2,396	2,375	2,354	2,333	2,313	2,293	2,273	2,253	2,233	2,213
Imported Elec	2,106	2,112	2,114	2,128	2,117	2,119	2,121	2,136	2,125	2,127	2,129	2,143	2,133
Total Revenues (including NM)	445.91	445.15	443.94	444.36	441.46	440.25	439.04	439.59	436.76	435.62	434.48	434.9	432.2
	445.91	445.15	443.94	444.36	441.46	440.25	439.04	439.59	436.76	435.62	434.48	434.9	432.2
Periodic costs	210	210	210	210	210	210	210	210	210	210	210	210	210
Electricity consumption costs	421.2	422.4	422.8	425.6	423.4	423.8	424.2	427.2	425	425.4	425.8	428.6	426.6
Total Operating Expenditures	631.2	632.4	632.8	635.6	633.4	633.8	634.2	637.2	635	635.4	635.8	638.6	636.6
Net Cash from Operation	-185.29	-187.25	-188.86	-191.24	-191.94	-193.55	-195.16	-197.61	-198.24	-199.78	-201.32	-203.70	-204.40
Investments:													
PV	4,796	0	0	0	0	0	0	0	0	0	0	0	0
Heat pump	7,760	0	0	0	0	0	0	0	0	0	0	0	0
Insulation	9,970	0	0	0	0	0	0	0	0	0	0	0	0
Service and Appliances	7,000	0	0	0	0	0	0	0	0	0	0	0	0
Converter	2,000	0	0	0	0	0	0	0	0	0	2,000	0	0
Removing gas connection	610	0	0	0	0	0	0	0	0	0	0	0	0
Additional costs	0	0	0	0	0	0	0	0	0	0	0	0	0
Total Investments	32,136	0	0	0	0	0	0	0	0	0	2,000	0	0
Mortgage	32,136												
Total Cash From Long Term ...	32,136												
27,340													
Mortgage	1883.324075	1883.324	1883.324075	1883.324075	1883.324075	1883.324075	1883.324075	1883.324075	1883.324075	1883.324	1883.324	1883.324	1883.324
Cash Surplus	-2,069	-2,071	-2,072	-2,075	-2,075	-2,077	-2,078	-2,081	-2,082	-2,083	-4,085	-2,087	-2,088
Cash Account	-2,069	-4,139	-6,211	-8,286	-10,361	-12,438	-14,517	-16,597	-18,679	-20,762	-24,847	-26,934	-29,022
Net present payment	-2068.614075	-2050.07	-2031.353863	-2013.551453	-1994.287986	-1976.07442	-1958.02602	-1940.924783	-1922.2895	-1904.67	-3697.77	-1870.65	-1852.75
	-2068.614075	-2029.97	-1991.718642	-1954.908063	-1917.223224	-1881.088838	-1845.634377	-1811.57834	-1776.5949	-1743.05	-3350.83	-1678.52	-1646.16
	-2068.614075	-2010.27	-1953.232232	-1898.52001	-1843.845252	-1791.529821	-1740.697691	-1691.989832	-1643.2059	-1596.53	-3039.36	-1507.71	-1464.29
	-2068.614075	-1990.94	-1915.850661	-1844.279909	-1773.944429	-1707.0391	-1642.656156	-1581.338872	-1520.97848	-1463.56	-2759.44	-1355.69	-1303.99
	-2068.614075	-1971.98	-1879.532041	-1792.086449	-1707.324891	-1627.285182	-1550.996819	-1478.880997	-1408.8845	-1342.79	-2507.62	-1220.24	-1162.52
	-2068.614075	-1953.37	-1844.23645	-1741.844002	-1643.803524	-1551.961127	-1465.249257	-1383.94001	-1305.99905	-1232.99	-2280.84	-1099.42	-1037.53

Initial Scenario												
Sell back price ELEC	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07	0.07
Consumption price ELEC	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
Gas price	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66	0.66
Periodic costs electricity	210	210	210	210	210	210	210	210	210	210	210	210
	2030	2031	2032	2033	2034	2035	2036	2037	2038	2039	2040	2041
Produced Electricity	4,248	4,225	4,201	4,178	4,155	4,132	4,110	4,087	4,065	4,042	4,020	3,998
Exported Elec	2,194	2,174	2,155	2,136	2,117	2,098	2,079	2,060	2,042	2,023	2,005	1,949
Imported Elec	2,135	2,137	2,151	2,141	2,142	2,144	2,159	2,149	2,151	2,153	2,167	2,119
Total Revenues (including NM)	431.13	429.99	430.48	427.2	423.4	419.6	415.8	412	408.4	404.6	401	389.8
	431.13	429.99	430.48	427.2	423.4	419.6	415.8	412	408.4	404.6	401	389.8
Periodic costs	210	210	210	210	210	210	210	210	210	210	210	210
Electricity consumption costs	427	427.4	430.2	428.2	428.4	428.8	431.8	429.8	430.2	430.6	433.4	423.8
Total Operating Expenditures	637	637.4	640.2	638.2	638.4	638.8	641.8	639.8	640.2	640.6	643.4	633.8
Net Cash from Operation	-205.87	-207.41	-209.72	-211.00	-215.00	-219.20	-226.00	-227.80	-231.80	-236.00	-242.40	-244.00
Investments:												
PV	0	0	0	0	0	0	0	0	0	0	0	0
Heat pump	0	0	0	0	0	0	0	0	0	0	0	0
Insulation	0	0	0	0	0	0	0	0	0	0	0	0
Service and Appliances	0	0	0	0	0	0	0	0	0	0	0	0
Converter	0	0	0	0	0	0	0	2,000	0	0	0	0
Removing gas connection	0	0	0	0	0	0	0	0	0	0	0	0
Additional costs	0	0	0	0	0	0	0	0	0	0	0	0
Total Investments	0	0	0	0	0	0	0	2,000	0	0	0	0
Mortgage	1883.324	1883.324	1883.324	1883.324	1883.324	1883.324	1883.324	1883.324	1883.324	1883.324	1883.324	1883.324
Cash Surplus	-2,089	-2,091	-2,093	-2,094	-2,098	-2,103	-2,109	-4,111	-2,115	-2,119	-2,126	-2,127
Cash Account	-31,111	-33,201	-35,295	-37,389	-39,487	-41,590	-43,699	-47,810	-49,925	-52,045	-54,170	-56,298
Net present payment	-1835.7	-1818.86	-1802.84	-1786.08	-1771.78	-1757.75	-1745.97	-3369.25	-1716.28	-1702.66	-1690.89	-1675.41
	-1615.01	-1584.52	-1555.16	-1525.6	-1498.54	-1472.1	-1447.9	-2766.67	-1395.51	-1370.86	-1348.04	-1322.6
	-1422.64	-1382.22	-1343.45	-1305.11	-1269.52	-1235.01	-1202.92	-2276.23	-1136.98	-1106.06	-1077.09	-1046.5
	-1254.72	-1207.35	-1162.19	-1118.18	-1077.22	-1037.87	-1001.17	-1876.26	-928.188	-894.26	-862.462	-829.915
	-1107.94	-1055.96	-1006.79	-959.434	-915.492	-873.642	-834.731	-1549.44	-759.208	-724.491	-692.075	-659.615
	-979.496	-924.734	-873.354	-824.423	-779.243	-736.606	-697.159	-1281.87	-622.175	-588.123	-556.509	-525.403