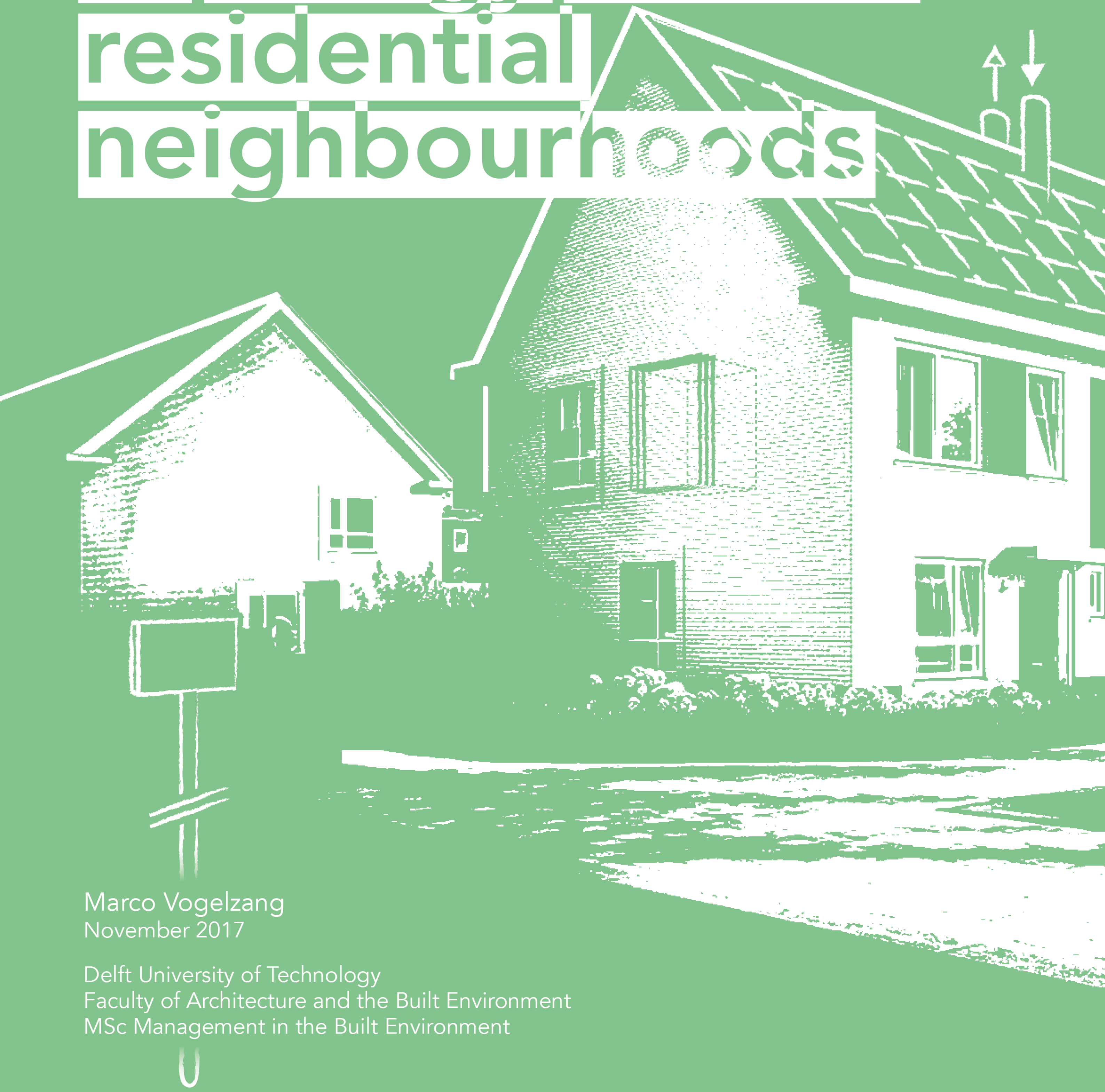
Business case optimisation for the development of energy neutral residential neighbourhoods



Marco Vogelzang

November 2017

Delft University of Technology
Faculty of Architecture and the Built Environment
MSc Management in the Built Environment

The image of the front page is designed in collaboration with Vincent Peters. When looking closely, some of the energetic possibilities of the developed decision support tool to optimize energy neutral and ZOM-neighbourhoods are visible (e.g. heat pumps, PV-panels, insulation, triple glazing, balance ventilation). The background image is based on a figure of Ooms (2017).

Business case optimisation for the development of energy neutral residential neighbourhoods

Linear programming applied in a decision support tool
for business case optimisation of multi-actor decision-making processes
in the realization of energy neutral residential neighbourhoods
consisting of all-electric, single-family and owner-occupied dwellings
from the viewpoint of the real estate developer

Marco Vogelzang
November 2017

Delft University of Technology, Faculty of Architecture and the Built Environment
MSc Management in the Built Environment

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Preface

Graduating. What a journey. Between February 2016 and November 2017 I have been conducting this graduation research about energy neutral residential neighbourhood development. Like many other students I started with sky-high ambitions. The graduation laboratory of 'Sustainable Private Sector-led Urban Development' of Erwin Heurkens and Fred Hobma offered me the opportunity to combine my interesting in urban development management, sustainability, technology and finance. Inspired by the quotes of the smart city discourse, stimulated by the courses on urban environmental management and the desire to get whole mega cities sustainable I wanted to create a decision support technology which could combine the shattered knowledge of different parties in urban area development and give support during complex decision-making processes. The dream was that it could optimises the design results to speedup decision-making in sustainable urban development. This had to be done from the local, financial viewpoint of the real estate developer. However, these thoughts were not combinable. Sustainable mega cities aren't the direct problem of the real estate developer, but of the whole society.

I slightly adapted the sky-high ambitions and presented in my research proposal to develop a decision support tool which optimises energy, water, mobility and financial related aspects in the urban area decision-making processes. The idea was that dense urban areas consume more energy and have less possibilities for renewable generation. However, relatively they are more efficient due to compactness and reduction for the need for mobility. The optimal balance of both was what inspired me. This proposed structure was criticized by the size and was founded too broad to be answered within one year. Next, I again adapted my ambitions and I decided to focus on optimal realization of energy neutral neighbourhood developments. Which was later on further demarcated to local residential neighbourhood development of all-electric, single-family units for the owner-occupied market.

During this last demarcation and after the proposal in June 2016 I got on a side track, following extra courses for the 'Technology in Sustainable Development'-annotation of the TU Delft, doing an internship at SITE urban development, organising a congress about movable dwellings with Watkostdebouwvaneenhuurwoning and working one day a week for Planmaat. These journeys were all very enriching for my experiences in urban area development. All activities led to many fruitful discussions and feedback sessions which have improved my thesis. The involvement in these activities has provided many insights and has helped me in getting a feel with the relevant topics and issues in the field of urban development. Afterward I did know what the most important focus was for the decision support tool I did want to create and the decision to start working full-time on the graduation project followed and was the right one to get the project moving forward again.

This research project would not be possible without the help of many people. First of all, I would like to thank my mentor team, Yawei Chen and Ruud Binnekamp. The different paradigms both of you have about formal and empirical research and the approach towards complex decision-making processes was really interesting and led to many useful advices. I have enjoyed the great collaboration with you both. Yawei, thank you for your critical attitude to the results and keeping focus along the process. The fast replies on my emails, even when they were send at 10 or 11pm, showed your commitment to the graduation project. Ruud, thank you for your strong paradigm about formal and empirical research. I gained very helpful insights from those discussions. It was great to develop my first and second optimisation model together and I really enjoyed your enthusiasm about both models. I also thank Rein de Graaf for helping me with all the technical support required for the correct functioning of the decision model. His knowledge about linear programming helped me in the development of a realistic design of the optimisation model. Lastly, Prof. Ellen van Bueren, for reading and judging about the TiSD-annotation.

Besides the educational component, I also got help from many people from practice. First, the team of SITE urban development and especially my internship mentor over there, Wouter Spijkerman. I learned a lot about urban development, concept development, site analysis and the structuring of decision-making process from the real life cases for provinces, municipalities, real estate developers and investors during these months. It was fun. Wouter, thank you for the feedback on the thesis, your insights in the decision-making at various scale-levels, how it functions within the whole system-in-systems and your motivation of using the approach of conceptual and design thinking. Second, the team of Planmaat and especially Patrick Nan, for the new experience I gained

in these aspects of urban development, namely financial calculations and quantitative thinking. Patrick, thank you for your time to discuss the functioning of the model, your enthusiasm about the open design approach and the possibility to have the expert focus group at Planmaat. Third, Thijs Luijkx for his time and feedback during the time we organised the congress about movable dwellings together.

In addition, I thank Thijs Luijkx and Claudia Bouwens for the possibility of being present at their congresses for professionals about energy neutral dwelling development. I also thank Sander van der Wolf (VORM), Han van Seumeren (AM), Xavier Delnoij (Blauwhoed) and Marco Dijkshoorn (Van Omme & De Groot) for their time to discuss their projects and insights. Lastly, I thank all other practitioners with whom I discussed the topic of my research during congresses, excursions or other meetings.

For my personal life, I thank my family for their support, Lambertus for his feedback on the approach, demarcation and structuring of the research, my brother Kevin for his knowledge about creative technology and applications of mathematics with which he helped in transforming some complicated energy formulas to make them suited to the model. Of course, my girlfriend Tessa. Vincent for the many discussions about the energy transition and his time for making the front image. The combination of his viewpoint from landscape and design and mine from management, finance and the city delivered interesting insights for this research. My friends and fellow studies for the fun and having the privilege of studying together at the Delft University of Technology and WageningenUR.

After almost three years at the Delft University of Technology I will become an engineer in the built environment. My educational journey started at the Wageningen University, where I studied for four-and-a-half year on Landscape Architecture and did many extracurricular activities. This brought me towards the master Real Estate and Housing, now Management in the Built Environment and back to a half year of courses urban environmental management in Wageningen. Finally, the journey has almost reached it last stop. And with success, from January 2018 I will start as concept developer at a real estate developer in which I can apply all the things I learned during my educational journey. I am looking forward to this next step, however, I enjoyed every little step the last seven+ years.

Enjoy reading!

Marco Vogelzang
November 2017

Abbreviations

ASHP	Air Source Heat Pump
BENG	Bijna Energie Neutraal Gebouw' (Dutch for Near Energy Neutral Dwelling)
CHP	Combined heat & power
COP	Coefficient of Performance
DST	Decision Support Tool
DSM	Demand Side Management
ENRND	Energy Neutral Residential Neighbourhood Development
EPBD	Energy Performance of Buildings Directive
EPC	Energy Performance Coefficient
ESCO	Energy Service Company
GHG	Greenhouse Gases
(H)GCHP	(Hybrid) Ground-coupled heat pump
GSHP	Ground Source Heat Pump. This research usage a closed-loop, ground-coupled heat pump
IR-lighting	Infrared lighting
LP	Linear Programming
MEAT	Most Economically Advantageous Tender
MFD	Multi-family dwellings
MILP	Mixed-Integer Linear-Programming
MPG	Milieuprestatie Gebouwen (Dutch for Environmental Performance of Buildings)
NZED	Near Zero Energy Dwelling (EPC-level between 0-0,2)
NOM	Nul-op-de-Meter (Dutch version of ZOM)
NSS	New Stepped Strategy
PPP	Public Private Partnership
PSD	Passive Solar Design
PV-panel	Photovoltaic panel
PV/T-panel	Photovoltaic/ thermal panel
R_c-value	Insulation value of a part of the thermal envelop of a building
RDM	Former location of the Rotterdamse Droogdok Maatschappij
RvO	Rijksdienst van Ondernemend Nederland (Dutch for National service of enterprising Netherlands)
SFD	Single-family dwellings
SOK	Samenwerkingsovereenkomst (Dutch for Collaboration Agreement)
SRQ	Sub research question
TCO	Total Cost of Ownership
UFA	Usable Floor Area
VO&DG	Real estate developer Van Omme & De Groot
VWH	Residents Association 'Vereniging Wijkbewoners Heijplaat'
Wp	Watt peak
ZED	Zero-energy dwelling (only building-related energy is 'zero')
ZEN	Zeer Energiezuinige Nieuwbouw (Dutch for: Very Efficient New Dwellings), ZEN is also the name of the platform investigating this topic
ZOM	Zero-on-the-Meter (both household and building-related energy is 'zero')

Abstract

In this management summary, the context, objective, research methods, results and conclusions of the graduation project "*Business case optimisation for the development of energy neutral residential neighbourhoods*" are described.

Context – The stricter regulations on energy-efficient developments to prevent climate change and resource depletion, the expected rising energy prices and hence the rising monthly living costs for households, the changing process in urban area development, the demand for housing in the western part of the Netherlands and the increasing possibilities of technology.

Objective – To identify effective possibilities for optimisation of the business case of a real estate developer in the realization of energy neutral residential neighbourhoods with all-electric, single-family, owner-occupied dwellings. The definition of energy neutral in this research is about net zero building-related energy demand.

Methods – Literature review, expert meetings, case study research with semi-structured interviews, linear programming, expert focus group meeting and unstructured expert interviews

Results – 1) Identification of various solutions within current practise to optimise the business case from a viewpoint of the real estate developer to realize energy neutral residential neighbourhoods. Aspects of the business case are split in: organizational aspects (e.g. parties involved, public-private collaboration, type of contracts), the financial aspects (e.g. method of financing, amount of investment and total costs of ownership) and the physical aspects (e.g. dwelling program, spatial and/or building technical interventions) 2) Creation of the decision support tool (DST) for modelling the optimal business case with output in the form of the optimal dwelling program and energy installations 3) Identify the optimal business case to get an energy neutral neighbourhood by applying the DST.

Conclusions - All outcomes of the different research methods show that it is possible to create a feasible business case for a real estate developer in the development of the highest energy ambition of present-day, zero-on-the-meter, within current available methods and means. The business case of energy neutral residential neighbourhood development can be optimised within all its aspects. First, by integrated contracts and involvement of (energy) advisors early in the project. Second, by the involvement of third financing (e.g. Energy Service Companies) and a higher selling price, which is made possible by the additional borrowing capacity for the mortgage. Third, it is recommendable to apply a conceptual approach within the dwelling design and to the installation technology on the scale level of a single-building. In the case study and most of the modelled outcomes these concepts are based on ground source heat pumps and PV-panels. Last, the modelled output showed that BENG-legislation could lead to bigger dwellings. In addition, the designed DST has added value for the multi-actor decision-making processes in residential energy neutral neighbourhood development. The DST could help as guidance to provide insight in the various possibilities by exploring the solution/ design space during multiple decision moments and the DST could also be useful in education of laymen.

Keywords - Energy neutral residential developments, BENG, zero-on-the-meter ('nul-op-de-meter'), financing energy efficiency, Energy Service Company (ESCO), green mortgage, additional borrowing capacity, decision support tool, case study research, linear programming

Summary

In this management summary, the context, objective, research methods, results and conclusions of the graduation project "*Business case optimisation for the development of energy neutral residential neighbourhoods*" are described.

Introduction

This research is about how the real estate developer can optimize his business case to realize an energy neutral residential neighbourhood development (ENRND-)projects consisting of new build, all-electric, single-family and owner-occupied dwellings.

The motivation for the research is the stricter regulation on energy-efficient developments to prevent climate change and resource depletion. The new BENG-legislation is going to replace the current EPC-legislation and requires all new residential developments to be nearly energy neutral from 2021 onwards (Bouwens & Bouwmeester, 2017; Haytink & Valk, 2017). This change in legislation is required by the '*EU Energy Performance of Buildings Directive (EPBD)*' (European Parliament & Council of the European Union, 2010).

Further motives are the expected rising energy prices and hence the rising monthly living costs for households (J. W. J. De Vries, 2010; RvO, 2017e) and the changing process in urban area development where public parties are taking less risks by withdrawing from their active land policy and the real estate developer becomes the initiating and executing party more often (Bentvelsen, 2014; Heurkens, 2012; Peek & Van Remmen, 2012). Energy neutral neighbourhood development would help to counteract the following problems on a local and global scale. On a local level the natural gas resources are depleting (Bazelon *et al.*, 2010; Van Rossum & Swertz, 2011) and also the demand for housing in certain parts of the Netherlands asks for urban growth (Fackeldey *et al.*, 2017; Huisman *et al.*, 2013; Van Duinen, Rijken, & Buitelaar, 2016).

The research motives are:

- '*EU Energy Performance of Buildings Directive (EPBD)*' requires from all member states new legislation and a plan of approach for the reduction of the environmental footprint caused by energy from new buildings (European Parliament & Council of the European Union, 2010);
- New BENG-legislation in the Netherlands requires all new residential developments to be nearly energy neutral from 2021 onwards (Bouwens & Bouwmeester, 2017; Haytink & Valk, 2017);
- Drop in CO_2-emissions required for the mitigation of climate change (IPCC, 2007b, 2014);
- Worldwide problem of resource depletion also happens in the Netherlands by depletion of natural gas (Bazelon et al., 2010; Van Rossum & Swertz, 2011);
- Depletion of natural gas in the Netherlands causes earthquakes in the northern part of the country;
- Depletion of natural gas in the Netherlands causes fluctuating energy prices (J. W. J. De Vries, 2010; RvO, 2017e);
- Geopolitics requires a higher level of energy autonomy and thus new solutions for the reduction of the dependency to natural gas (Bokeloh, Buijs, & Schotsma, 2013);
- Urban growth: demand for new houses in the urban regions of the Netherlands (Fackeldey et al., 2017; Huisman et al., 2013; Van Duinen et al., 2016);
- New style urban area development leading to private sector-led urban area development (Bentvelsen, 2014; Heurkens, 2012; Peek & Van Remmen, 2012);
- Being 'smart', being connected to the internet and measuring big data to identify possibilities for optimization during the operation phase: Smart city, smart grid, smart home, etc. (Townsend, 2013).

The three topics of energy neutral developments (as required by the EPBD), residential neighbourhood development and the real estate developer as leading party are the main concepts in this research. They are combined in the following problem statement:

> "*The real estate developer is taking a more leading position in urban area development and is facing new legislation about nearly energy neutral residential developments in ENRND-projects, which both increases the construction costs of new developments and the complexity of the project.*"

This complexity can be seen by the involvement of new parties and integrated contracts, which leads to complex multi-actor decision-making. The possibilities for financing projects also increases with different types of mortgages for home buyers and third financiers. In addition, the amount of solutions increases with the innovation in new technological possibilities.

The research investigates how the real estate developer can optimise its business case for realizing energy neutral neighbourhoods (according to the new legislation) within the multi-actor decisions making process (organisational component). This leads to the optimal yield for the real estate developer (financial component) and shows which physical solutions must be realized (physical component). This is summarized in the research framework of Figure 8.

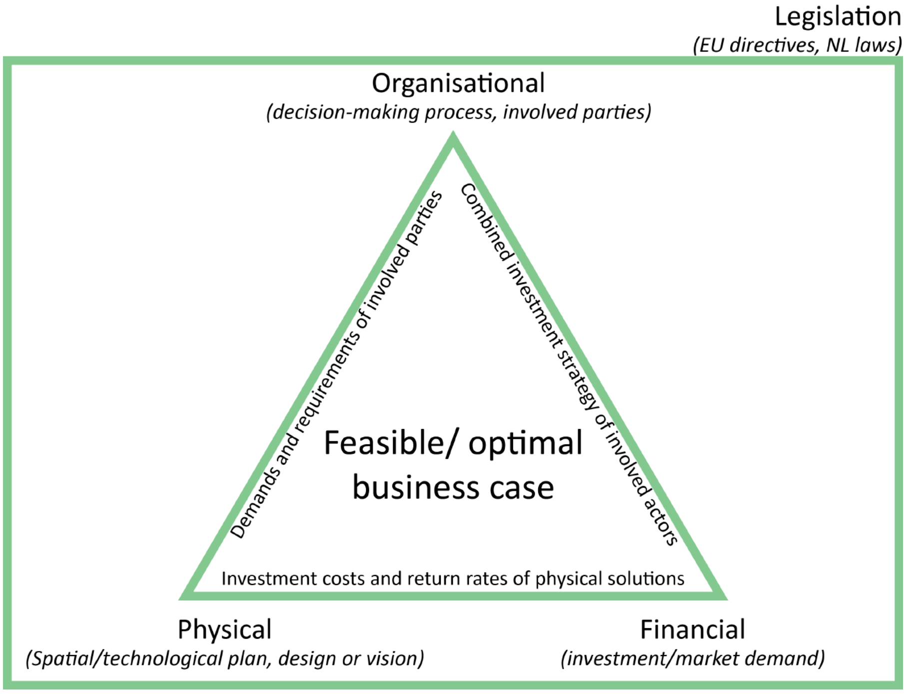


Figure 1: Research framework for realizing a feasible business case within the new legislation (own illustration based on the analysis framework of Versteijlen *et al.* (2010) and the components of a business case as described by Van der Cammen (2007) in Schouten (2013)).

The objective of this research is to construct an optimization model that optimizes financial, organizational and spatial / technical aspects to support decision-making in the initial stages of the project on the feasibility of energy ambitions. The research goes beyond qualitative exploration about what the market parties are currently doing in terms of energy efficiency. The created optimisation model gives quantitative explanation in the demonstration of the optimal business case for the realization of ENRND-projects.

Research focus

The research is demarcated on various aspects, namely new constructions, an all-electric energy concept, single-family and owner-occupied dwellings and a focus on the initial stage of urban area development.

New constructions

The new legislations on energy efficiency require new constructions to become more energy efficient (Bouwens, 2017a; Bouwens & Bouwmeester, 2017; European Parliament & Council of the European Union, 2010; Haytink & Valk, 2016, 2017; Kruithof & Haytink, 2015). In new constructions a bigger exploration of the optimal solution space is possible, as there are less technical restrictions, which are limiting possibilities within the existing stock.

All-electric energy concept

An all-electric energy concept is selected as focus of research, because this energy concept is the best alternative for the largest part of the Netherlands (Molengraaf, 2017).

Owner-occupied and single-family dwellings

The focus of this research is on the development phase from the viewpoint of the real estate developer. In order to keep this focus, the discussion on the split incentive[1], which housing associations and investors in the rental sector are facing (Ástmarsson, Jensen, & Maslesa, 2013; Bullier & Milin, 2013), needs to be avoided. Therefore, the research is demarcated to owner-occupied dwellings. Over half of the building stock in the Netherlands and in the Randstad consist of owner-occupied dwellings (CBS, 2017d).

Owner-occupied dwellings are further demarcated to only single-family dwellings (SFD). A demarcation is needed, because SFD offer different possible energetic solutions as multi-family dwellings (MFD). The edge of cities and rural locations of the all-electric concept are best suited for SFDs, due to lower density of dwellings in both of these locations (Molengraaf, 2017). In addition, SFDs are still the majority of the dwelling stock in the Netherlands and in the Randstad (CBS, 2017e).

Early stage decision moments, feasibility study (energy concept, dwelling program)

The last demarcation is to focus on the feasibility phase of development projects, because effectively influencing multi-actor decision-making processes is best possible in this initial phase of development (Wamelink *et al.*, 2010). In this initiative phase parties first explore their possibilities during an iterative start (J. C. De Jong, 2016; Versteijlen *et al.*, 2010). The end-result of the feasibility phase or initiating phase is the business case. That is why this research focus is on the exploration and optimisation of the best possible ('optimal') business case. The result of this research is an easy applicable method for optimising the energy part of the business case. This method supports the decisions made during this phase in order to make them more effectively.

Main research question

The research problem, motives and demarcation leads to the following general research question:

How can a real estate developer optimise its business case to realize energy neutral residential neighbourhood development projects consisting of all-electric, single-family and owner-occupied dwellings?

The general research question is answered by a three step approach. First, current projects with an increased energy ambition are explored to gain lessons learned. Second, these lessons learned are transformed into a decision support tool. Third, this model is applied and the added value of the model itself and its results are reviewed. The sub research questions are derived from these several steps:

1. How is an ENRND-project realized by the real estate developer in current projects?
2. How can a decision support tool optimise the results for the real estate developer in ENRND-projects?
3. What is the added value of the decision support in complex urban decision-making processes for the realization of ENRND-projects?

Research strategy, methods and design

The research is a hybrid research containing an operational and empirical part within a mixed research strategy combining qualitative and quantitative research. Methods used are a literature review, expert meetings, case study research with semi-structured interviews, linear programming, an expert focus group meeting and unstructured expert interviews. These topics are explained in the next paragraphs, which conclude with the research design.

Operational and empirical research

The goal of this research is to improve the future business cases of energy neutral neighbourhoods from the viewpoint of a real estate developer, which is an operational related research. A decision support tool (an artefact) supports the exploration of the optimal business case. However, to optimize these business cases, first knowledge is needed about the possible solutions to optimise this business cases. This is done by investigating past developments of energy neutral neighbourhoods and presented by lessons learned. This focus on the past and future makes the research a hybrid.

[1] The split incentive is related to the landlord-tenant dilemma. The only difference is that the landlord-tenant dilemma is explicit for the real estate exploration for rental dwellings during the operational phase.

Lessons learned from theory and practise are used as direction for the design of the decision support tool. In the research first a conceptual design is made of the decision support tool: Which variables are used, and how are they mathematically related to each other? Feedback from practise on the designed decision support tool is used to determine the added value of the created tool in the decision-making about the business case of ENRND-projects. In the end, the tool optimises the input variables of one in-depth described case study and compares the results to what have been done in reality.

Research strategy

Each of the three proposed research-related SRQs present a part of the research and is related to different research strategies. This research starts with a qualitative explorative investigation about the current practises in ENRND-projects. A explorative research has the objective to explore an area where little is known (Kumar, 2005). In case possible, some numbers about the amount of dwellings and financial calculations are added, but this cannot be qualified as the quantitative research. The whole approach is rather unstructured. This means that not everything that forms the research process, from objectives, design, sample and the questions asked to respondents, is predetermined. That is why the unstructured approach gives more flexibility. This is useful when an unknown topic is explored. The explorative research can also be used to develop, refine and/or to test measurement tools and procedures (Kumar, 2005). Therefore, also the second part is of an exploratory nature. However, its main focus is on operational research, because an artefact is created and its focus is on changing and improving a situation in the future (Barendse *et al.*, 2012). The second part follows the design circle for engineers as presented by Dym and Little (2004). The third part is based on explanatory research. This research types tries to clarify why and how there is a relationship between two aspects of a situation or phenomenon (Kumar, 2005). In this part the model gives quantitative data as outputs of the optimisation process based on different input variables. The objective is to find the optimal combination of input variables to identify the best possible business case. The third part is also used for verification of the first two parts. The investigation of the added value of the model according to professionals has a qualitative nature. The combination of this mixed research strategy makes it possible to identify effective solutions to the optimisation of the business case (qualitative part) and the extent of the effect of these solutions (quantitative part).

Literature review

The literature review results in the most important theoretical concepts. This body of knowledge gives a fundamental basis for the research. It also ensures that new knowledge is added. The further study is not limited to the concepts presented in the literature review. New concepts and new details can be added in an unstructured research design (Bryman, 2012).

Expert meetings

Literature is complemented with congresses and presentations to gather knowledge from experts working in the practise of urban area development.

Case study research

Case studies are used to explore specific knowledge about current practises. Case studies are an implementation of a descripted research, which describes what is prevalent (Kumar, 2005). In that way case studies can present an detailed and intensive analysis of a single case (Bryman, 2012). In this research multiple cases are involved to gather multiple lessons learned and identify multiple approaches to realize ENRND-projects. However, only one is described in-depth and used in part 3 about the optimisation of the business case.

Purposive sampling will be used as sampling method. This a non-probability form of sampling, where the researcher does not sample participants or cases on a random basis. The aim is to sample strategically, so that those sampled are relevant to the research questions. A disadvantage of this method is that the results cannot be generalized to the whole population (Bryman, 2012).

Semi-structured interviews

The objectives of the interviews in this research project are to get in-depth knowledge into a situation and to verify the desk research of the case studies by gathering first-hand information. A flexible and open approach with a certain structure fits best for these objectives. Knowledge saturation determines the amount of interviews needed. Knowledge saturation is based on the term 'theoretical saturation' of Bryman (2012) for describing the amount of cases needed.

Linear programming

Linear programming (LP) is used as method for optimisation modelling. LP is a mathematical modelling technique aimed at optimisation calculation. In these calculations both the objective function and the constraints are reduced to linear functions. This makes it possible to optimise a certain objective or to check whether there even is a solution space (Barendse *et al.*, 2012; Vlek *et al.*, 2016). An important note is that all optimisation models can only produce single-criterion solutions, because, in mathematical terms, only one objective function can be optimised (Barendse *et al.*, 2012).

In this research a LP algorithm is developed that can assist in maximizing the profit of the real estate developer within the constraints of other stakeholders to achieve the requirements for a neighbourhood consisting of all-electric, single-family and owner-occupied dwellings.

Expert focus group

An expert focus group is organized to reflect on the added value of the created LP-model. The theory also adds that a focus group needs an emphasis in the questioning on a particular fairly tight defined topic (Bryman, 2012). This is executed by handling only one question: "*What is the added value of the created model for various stakeholders?*" The emphasis in a focus group is upon interaction within the group and the joint construction of meaning (Bryman, 2012). In that way the group can discuss upon the added value of the LP-model and can create a shared opinion. The participants are selected based on their knowledge about decision support tools and the topic of energy neutral residential developments. This is the same non-probability sampling method as used for the case study selection.

Unstructured interviews

The second method of feedback by experts is executed by unstructured interviews. In these interviews individual experts give their ideas on the possibilities for application in practise. The experts were all supervisors during different stages of the development process of the model. The experts all have different background knowledge and a different profession within the field of urban development. The applied method is comparable to the 'unstructured interview'. This approach is different in comparison with the 'semi-structured interview', because beforehand only a range of topics is prepared and not an interview schedule (Bryman, 2012). This approach looks similar to a conversation. The unstructured interview method offers the possibility to adjust the emphasis of the interview as a result of interesting topics that emerge during the interview (Bryman, 2012: 470). The specific focus of the interview about the added value of the model therefore rapidly shifted to the specific knowledge of the three different supervisors.

Research design

The described strategy and methods are all summarized in the research design. This design is shown in Figure 2. The figure is designed in the structure of the whole report.

Main research outcomes

The next paragraphs describe the main research outcomes. It is structured to the different parts of the research: 1) In-depth case analysis, 2) Design of a decision support tool with linear programming, and 3) Model outcomes and expert reflections.

In-depth case analysis

The case 'Het Verborgen Geheim' of real estate developer 'Van Omme & De Groot' was researched. Desk research and an interview with the development manager Dijkshoorn (2017) of the real estate developer gave a holistic overview. The case is located at Heijplaat, Rotterdam and consists of 170 'zero-on-the-meter' (ZOM)-dwellings, which are currently under development (Gemeente Rotterdam, 2013; Ooms, 2017; Raets & Aboutaleb, 2015; RvO, 2017f). Those are dwellings which supply all the building-related and household-related energy demand by PV-panels on the roof of the dwelling.

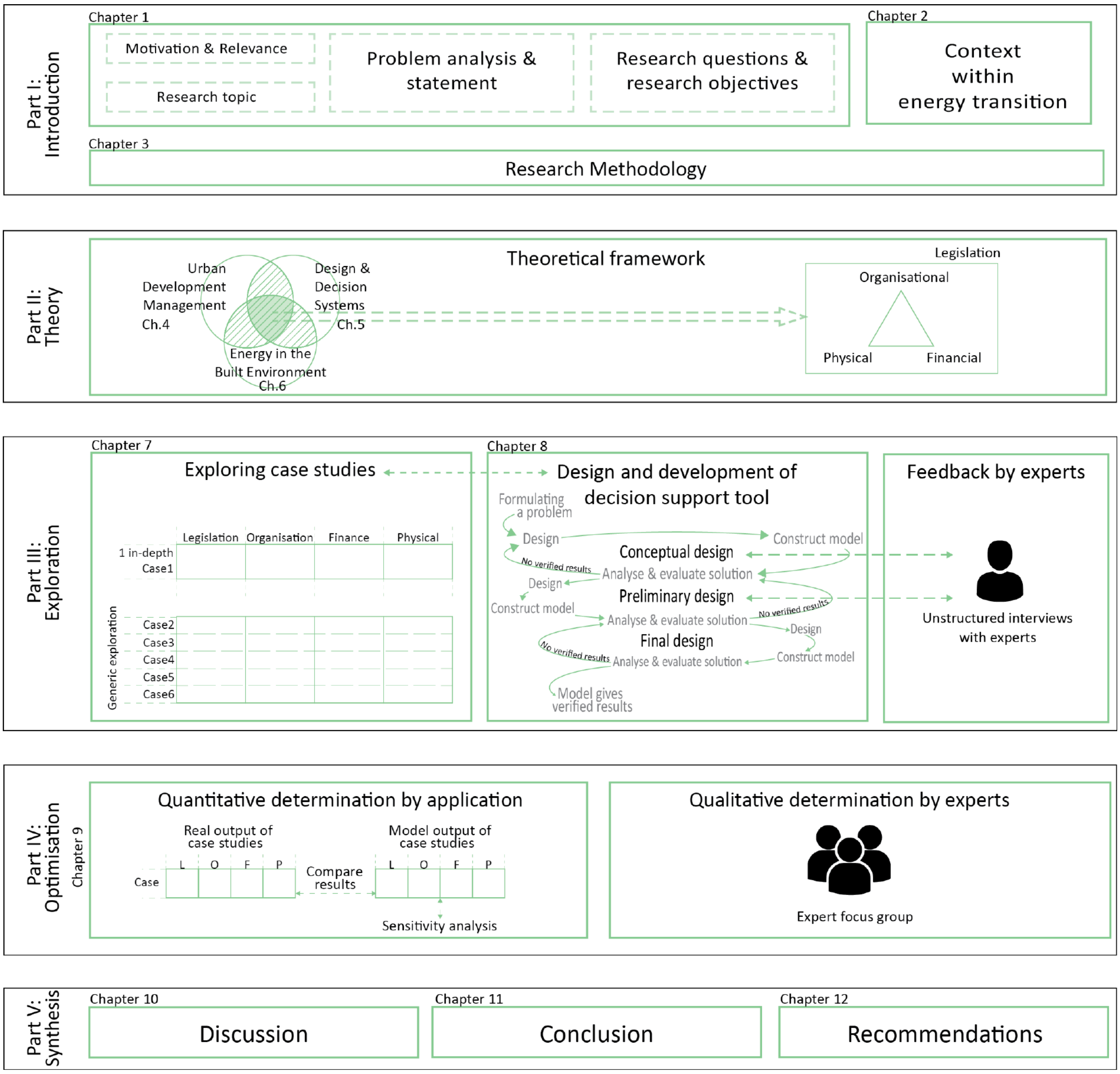


Figure 2: Research design based on the research steps and reading guide (own illustration).

The realization of the zero-on-the-meter ambition was stimulated in the MEAT-tender of the municipality. This ambition was part of the pilot project to realize an energy neutral ambition for the whole location of Heijplaat in 2020 (Gemeente Rotterdam, 2013; Stadshavens Rotterdam, 2009, 2011; Vereniging Wijkbewoners Heijplaat, 2014). Early on in the process the real estate developer involved an Energy Service Company (ESCO). The ESCO required a certain energy concept based on the GSHP and the PV-panels. The ESCO had already proof of concept and guaranteed a 25-year operation of the installations within the ZOM-ambition. This party brought knowledge and invested in the installations. The ESCO was therefore key in the decisions about the organisation, financial and physical aspects of the energy concept.

Design of a decision support tool with linear programming

The business case for energy neutral residential developments can be optimised by a decision support tool (DST). The DST is based on the linear programming method. The LP-model is a goal oriented system and can be used from the viewpoint of a single actor to optimize his objectives within the defined constraints. All relationships in the model are linear and the design-decision variables within these relationships are related to different stakeholders. In that way an unfeasible solution can be changed to feasible by renegotiating these decision variables. The objective function of this LP-model is profit for the real estate developer. Constraints are the energy ambition and the interest of the various stakeholders. A schematic overview of the LP-model is shown in Figure 3.

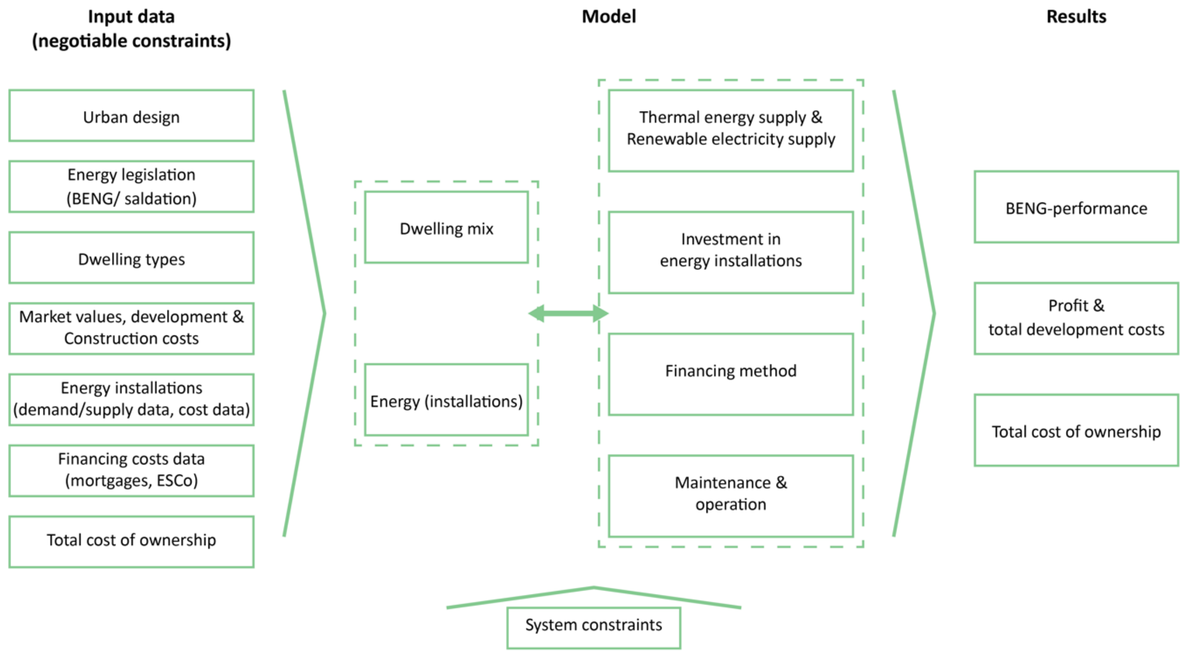


Figure 3: Schematic overview of the conceptual design of the linear programming model (own illustration).

Model outcomes

In the conclusion the results of the comparison of the LP-model and the real life situation are explained and the main outcomes of the sensitivity analysis related to the results of the case are presented. Both are oriented at the identification of the added value of the model.

In the first runs the LP-model proposed to develop smaller dwellings as in the real life situation. Larger dwellings were infeasible to the energy constraints. The proposed dwelling type, financing method and heating installations were almost the same as in the case. The model proposed larger dwellings after widening the energetic limitations of the power output of the PV-panel (max Wp) and GSHP (COP). The limits were increased till values which were proven and guaranteed in practise in other projects. The model did not show large differences to optimise the business case after this adaptation.

The model did not identify or propose a new solution for this case. The model proposes the same energetic concept with the GSHP and proposes to develop the largest dwelling size possible within the possibilities of the roof surface, PV-panels, COP of the GSHP and all the other input and decision variables.

The added value of the model was in its fast exploration of the possible solution space and by showing if there is a feasible solution within the constraints set. No trial-and-error methods are needed with architects and urban design who incrementally design new design alternatives. However, in this case the LP-model would not have speeded up the development. The slow start of the project had different reasons as explained in the in-depth description about the process. Since the municipality started the tender the project started moving. By the involvement of the ESCO Klimaatgarant by the real estate developer Van Omme & De Groot knowledge about ZOM-dwellings was brought into the design team. The ESCO had learned from previous projects what the most important decision variables are and how the energy concept of a dwelling can be optimized. The added value of the model was already added by the knowledge of the ESCO.

Value is added by quickly showing none-informed people the effects of the decision variables on the business case. This has been executed by the sensitivity analysis. The analysis clearly shows the effect on the profit rate of the involvement of the ESCO in case the selling price was not increased. This theoretical effect was in between the +8 - +13pp in all feasible runs. It also shows the effect of not increasing the selling price, which was decided by the real estate developer because of different market location (Dijkshoorn, 2017). Within that boundary condition the model shows that involvement of an ESCO is a smart decision. The model also shows that this financing method influences the selection of a heating installation. Though, this is not really an added value, because that became very clear without the model. The model does show the added value of other insights in the physical constraints, such as the effect of the COP of the GSHP, amount of roof surface and the maximum Wp per PV-panel. The model teaches practitioners how these variables as technological constraints influence the outcome of the business model.

The model therefore not only shows information to improve the insights of the skilled and experienced professional, it also teaches the other practitioners about the effect of their decisions by showing it.

Concluding for organisation: the involvement of an ESCO has in most runs a positive effect on the profit rate. Only if both financing solutions are used and the energy ambition is ZOM, the effect of using the ESCO or not will not be big. In all cases the involvement of an ESCO has a negative effect on the TCO.

Concluding for financial aspects: increasing the selling price with the amount of additional borrowing capacity for a mortgage of an energy efficient dwelling more profitable in all situations, except for the situation in which the ESCO was more profitable. The profit rate increased most (+8,9pp-14,6pp) in case of the ZOM-energy ambition and without the involvement of the ESCO. However, this last one would lead to an increase of the selling price by €29.000. In most comparisons the higher selling price led to increased TCO. The financing method with the increasing selling price also leads to an increased profit rate in most comparisons to the involvement of the ESCO (38/59) and it also leads to a lower TCO in most comparisons (56/59).

In addition, the model also showed that one of the effects of the BENG-legislation could be an increase of the dwelling size in case of a ZOM-energy ambition.

Reflections on added value by expert focus group

The expert reflections were given by an expert focus group. According to the expert focus group of Nan *et al.* (2017), the model has added value in the exploration of the decision problem from a single-actor viewpoint. Its high level of transparency makes it less interesting for multi-actor decision-making. The relevance is bigger, not only for the real estate developer, although, the model is initially designed for that actor. The model can assist during different decision moments, for instance concerning the energy ambition, ground price, dwelling program and installation technology needed. The model can also serve as a learning tool for new possibilities within new legislation.

Conclusions and recommendations

The following can be concluded and recommended about the optimal business case and the DST based on the case study, expert focus group and the linear programming-model.

Conclusions

The business case of energy neutral residential development can be optimised within all its aspects to successfully realize ENRND-projects. First, in the organisational aspects are all kinds of public-private partnerships possible, but the relationship developer-contractor is in all cases based on integrated contracts (at least design-and-build) and the (energy) advisors were involved early in the project (pre-design phase). Second, for the financing methods the involvement of third financing (e.g. Energy Service Companies) helps, as well as additional borrowing capacity for the mortgage. According to the modelled output without one of those the realization of a high energy ambition is hardly possible. Investment could also be postponed by developing future-proof dwellings. In that case the decision is postponed to the home owner. Third, physically it is recommendable to apply a conceptual approach within the dwelling design and to the installation technology. The physical implemented solutions in the case study are on the scale level of a single-building because of risks and sense of ownership and are based on ground source heat pumps and PV-panels. Heat pumps have high investment costs, but are costs-effective in the long run, due to the high effectiveness of COP and PV-panels, although the amount of rooftop surface is limiting. Last, the modelled output showed that BENG-legislation could lead to bigger dwellings, which consume less energy per m^2, but more energy in absolute sense. All outcomes of the different research methods show that it is feasible for a real estate developer to realize the highest energy ambition of present-day, zero-on-the-meter, within current available methods and means.

The designed DST has added value for the multi-actor decision-making processes within urban area development on a smaller scale level of a neighbourhood for the optimisation of dwelling program and energy systems. The DST could help as guidance and as a means to provide insight in the various possibilities by exploring the solution/ design space in multiple decision moments from first feasibility of urban design to installation technology within building design. The DST brings fast results and could also be useful in showing laymen the extent of the effects of changing the decision variables related to their constraints.

These are the conclusions of the case study, the model outputs and the expert focus group. The approach with the case study and the used purposive sampling method causes that the results are not generalizable to the whole population of ENRND-projects. The results are specific for the projects and bound to the locations. However, the outcomes of this results provide useful lessons for other cases.

Recommendations

Recommendations are split for research, practise and policy.

For research:

- Exploring the implementation of additional functions within the DST, such has higher scale levels, other functions (e.g. retail and/or offices), other energetic solutions (e.g. heat grid, IR-lighting, biomass and/or geothermal) and/or multiple layers of (sustainable) urban development.
- Exploring the involvement of comfort for the end-user within the optimisation. The current tool optimises a technical-economical problem. Adding comfort would add the social component of sustainability and is in line with the current research within the ZEN-platform. This platform implements applied research for market parties on this subject.
- Implement the MPG-legislation as improvement of the current DST. This updated version calculates the optimal cost-environmental solution by including the total environmental burden of the used energy installations. This total environmental burden includes among others the energy burden of the construction of the energy installations. This improvement would make it a life cycle optimization.
- Testing the application of the DST in a real decision-making process.
- Explaining the market value of energy efficiency in dwellings. Research is already done, but the market value is changing rapidly (J. W. J. De Vries, 2010; Hooijschuur, 2013; Van Groenestein, 2011; Wilting, 2012). This research needs an update and recommendations are needed in how the market value could be improved.
- Exploring the role of institutional investors and housing associations in ENRND-projects. The current research was focused on owner-occupied dwellings. The research question would be like; how can the business case of energy neutral developments be optimized for rental dwellings? Research for housing associations is already executed, but the institutional investors are getting an increased market share in the Netherlands (CBS, 2017d) and their role is interesting. These parties have a vision and strategy for the long run. Their role could be vital.
- Exploring and explaining the role of the ESCO in the Netherlands. They are currently hardly known, but this is different in other places in Europe (Bertoldi & Boza-Kiss, 2017). How can its role be increased in the Netherlands?
- Exploring and explaining the effect of a new calculation method for the mortgage capacity. Currently, there is the possibility for additional borrowing capacity within the total mortgage for dwellings with a high energy efficiency (Blok, 2014a, 2015a, 2016; Dijsselbloem, 2013). In 2016 the government proposed a research to change the calculation based on mortgage costs to living costs (mortgage + additional energy costs). What would this effect be for the development of energy neutral dwellings?

For practise:

- Using additional financing methods can make zero-on-the-meter dwellings financially feasible and can improve profit rate.
- Apply the DST in the decision-making processes for a fast exploration of the feasibility of the solution space and the optimization of the business case for energy neutral residential developments.
- Apply the DST on training activities for professionals for to get them to understand the effect of their decisions concerning utilization of energy saving and supply installations.
- Involve energy advisors early on in the process to show the energetic possibilities for the location, the selection of an energy concept and its optimal implementation.

- Involve residents during the development of their energy neutral dwelling. Majcen (2016) showed that many energy efficiency social rental dwellings in the Netherlands do not perform much better as theoretically expected. Education and motivation can have a huge effect on the energy demand (Staats, 2016).
- Keep a permanent eye on the rapidly increasing possibilities of technology. This is of key relevance, because the quick increase of efficiency of GSHP and PV/T-panels (Sarbu & Sebarchievici, 2014; Schiro *et al.*, 2017), which are having a huge effect on the possible design of the dwellings. In addition, IR-lighting can become competitive to a GSHP, due to the lower investment costs and direct responds in temperature increase (L. De Vos, 2017).

For policy:

- Develop a nationwide plan of action to stimulate and streamline the energy transition. This needs to be on a nationwide scale, because provinces with a lower population density and only little industries have to compensate for the provinces with the larger population densities and big industries. Another element to consider is to tighten the energy legislation after 2021 in such a way that real estate developers are stimulated to develop zero-on-the-meter dwellings.
- Reconsider the formulation of the BENG-legislation, because currently in some cases it stimulates the development of bigger dwellings. Bigger dwellings consume more energy, which is counterproductive to the objective of BENG.
- Keep the additional borrowing capacity in green mortgages for ZOM in place. This additional borrowing capacity makes it possible to get ZOM-dwellings financially feasible and without it would require the involvement of a third investor or it would drop the residual value of land. The last effect creates a negative competitive position in relation to other dwelling types with a higher residual value of land.
- In relation to the above mentioned recommendation it is also recommended that policy makers suggest to explore the optimal amount of this additional borrowing capacity and the way it is calculated (see topic in research and discussion in the Parliament in Blok (2016)).
- Consider additional investments on the scale of the individual dwelling in case the balancing agreement will be abolished. This recommendation is relevant, because of the huge positive effect the balancing agreement has on the business case of home owners.
- Consider on the long run an adjustment of the MPG-legislation to stimulate the innovation of an installation system in an energy neutral dwelling that have a less environmental burden. This is relevant, because the model outcome proposes the most installation intensive solution, namely a roof covered with PV-panels, a GSHP, balance ventilation and more. This needs environmental improvement in the future. The current DST can be improved with this additional MPG calculation to define the optimal cost-environmental solution.

Table of content (extensive)

PART 1

INTRODUCTION

Energy ambition	Zero-on-the-Meter
Project	‘Het Verborgen Verheim’
Location	Rotterdam
Real estate developer	Van Omme & De Groot

1 Introduction

The research about the optimisation of the business case on the realization of energy neutral residential neighbourhood development (ENRND-)projects from the viewpoint of a real estate developer.

This report is the final product of the master thesis conducted at the department '*Management in the Built Environment*' of the Delft University of Technology. The thesis investigates the problem of increasing tighter regulations for energy efficiency in the development of new dwellings and the shift of the private sector in urban area development towards a leading role. It tries to formulate an answer how the real estate developer can optimise its business case for realising ENRND-projects. This is executed by first exploring the topic by an extensive literature review and case studies of current neighbourhood development projects with a better energy performance as required by legislations. Secondly, this information is used to develop and test a decision support tool which can identify the optimal cost-effective solutions in developing residential neighbourhood within the constraints of the involved parties.

This chapter introduces the research. First, the problem is defined, followed by the major motives for this research. Thirdly, the research topic is demarcated to a focus on one of the development phases of urban area development and new construction projects of single-family, owner-occupied dwellings. After that the research framework is described (1.4), leading to the general research question (1.5), research objectives and results (1.6) and research relevance (1.7). In the end the reading guide for the whole report and research structure is described in 1.8.

1.1 Problem definition

The problem is defined by some major worldwide trends, their effects and countermeasures of the European Union, which results into the problem statement for the Netherlands.

One of the biggest, maybe even the biggest, worldwide trends is that we are limiting the possibilities of future generations by overexploiting the worlds' fossil resources for energy consumption (CBS, PBL, & Wageningen UR, 2007, 2016), which causes climate change (IPCC, 2014) and rising energy prices (RvO, 2017e; Vethman & Gerdes, 2011). Energy neutral neighbourhood development would help to counteract these trends on a global scale, because the building sector and energy supply sector have the highest mitigation potentials for countering climate change (IPCC, 2007b). A sustainable energy supply in the built environment contributes to the mitigation of climate change, solve the problem about resource depletion for energy purposes and consequently increases the energy security of the future.

Energy efficiency has become one of the key objectives of the European Union, as buildings in the European Union account for 40% of the total energy use and 36% of the total CO_2-emissions (Burman, Mumovic, & Kimpian, 2014: 153). In 2010 the union acted with the '*EU Energy Performance of Buildings Directive (EPBD)*', stating that after 2020 all new buildings in the EU are requested to consume nearly zero energy (article 9 from the directive 2010/31/EU, European Parliament and Council of the European Union (2010)). In addition, the directive obligated the Member States to develop national plans to increase the number of 'nearly zero-energy buildings'. These targets can be achieved by a combination of energy efficiency improvements and on-site or nearby renewable energy production (Burman *et al.*, 2014: 153).

The national plan in the Netherlands to comply with the EPBD is executed by the name of BENG. BENG stands for nearly zero energy building (Dutch: '*Bijna Energie Neutraal Gebouw*'), requires all new buildings to consume nearly zero energy from 2020 onwards and replaces the current legislation on energy efficiency, measured by the energy performance coefficient (EPC) (Haytink & Valk, 2017; RvO, 2016). This new legislation implements three levels of energy efficiency, namely a requirement for the reduction of the energy demand, a requirement for the maximum level of primary energy usage and a third requirement for the minimum amount of on-site or nearby renewable energy production (Haytink & Valk, 2016, 2017; Kruithof & Haytink, 2015). This approach is in line with the method of Burman *et al.* (2014: 153). However, unless this expected change in legislation is the Netherlands still lacking behind in addressing energy issues compared to other European countries (e.g. the share of renewable energy is one of the lowest in Europe and with the reduction of the GHG-emissions the Netherlands scores among the worst half[1]). One of the biggest contributions can be made by a more energy efficient residential sector, because this sector a substantive part of the total energy usage by consuming 14% of the gross inland consumption of primary energy, which is the total energy usage including energy losses due to conversion (CBS, PBL, & Wageningen UR, 2014a, 2014c) and about 22% of the total final energy consumption, which is the total energy usage minus the losses due to conversion (EEA, 2016)[2]. The residential building stock in the Netherlands offers a great potential for reducing GHG-emissions to counteract climate change, securing the future energy supply by using local, renewable sources and stopping the prospected future price rises. A main challenge lies within the implementation of the new BENG-legislation for residential buildings.

Besides the topic of energy efficiency, the development process is changing to the new style urban area development (Bentvelsen, 2014; Peek & Van Remmen, 2012). In this process the real estate developer is more often involved in the initiative and also taking a leading role in urban area development projects, while the government is more often operating in a facilitating approach, because they have become more restrained to the financial risks involved in urban area developments since the financial crisis (Heurkens, 2012; Peek & Van Remmen, 2012). The initiating and leading position of the real estate developer increases the influence of this actors on the decisions made in the early phases of the development.

The three topics of energy neutral developments (as required by the EPBD), residential neighbourhood development and the real estate developer as leading party are the main concepts in this research. They are combined in the following problem statement:

> "*The real estate developer is taking a more leading position in urban area development and is facing new legislation about nearly energy neutral residential developments, which both increases the construction costs of new developments and the complexity of the project.*"

This complexity can be seen by the involvement of new parties and integrated contracts, which leads to complex organisational decision-making. The possibilities for financing projects also increases, by different types of mortgages for home buyers and third financiers. In addition, the amount of solutions increases with the speed of innovation in new technological solutions. These topics are more explained in the theoretical framework (chapter 3).

For this problem a solution has to be found how the real estate developer can optimise its business case to realize these ENRND-projects, without derogation to its financial position. A solution is needed, because the demand for housing in the Netherlands is significant in the coming decades (Huisman *et al.*, 2013). The increased energy requirements and the new style of urban area development demand for a change in the products and development process of the real estate developer in order to apply to the new regulations. The problem becomes more difficult when taking into account the heavily fragmented value chain of real estate development (Putman, 2010; Vlek *et al.*, 2016; WBCSD, 2007), which is a huge problem in realizing energy ambitions due to the split incentive (Bullier & Milin, 2013).

The main concepts of the problem statement are explained in more detail as research motives in the next section.

1.2 Research motives

The research motives lead to the connected focus of the energy part of sustainability and private sector-led urban development projects. The research motives are current, relevant trends, which also demarcate the research. Three major trends are framing this research: (1) the need for sustainable development, because of climate change, resource depletion, fluctuating energy prices, geopolitics and urban growth, (2) the new style of urban area development and (3) technological development, wherein 'smart' is hot: smart city, smart grid, smart home, etc.

[2] Numbers and graphs are shown in Appendix 1 and based on CBS *et al*. (2014a, 2014c); EEA (2016).

1.2.1 Need for sustainable development: Near energy neutral developments required from 2021

A drop in CO_2-emissions is required for the mitigation of climate change (Imbrie & Imbrie, 1980; IPCC, 2007b, 2014). Climate change is a widely known subjects, however, there are still discussions if climate change is caused by humans. Schmidt and Wolfe (2009) computed that the odds of this being a natural occurrence are one in a billion! So, the change that these people are right, is very small. The topics of climate change and sustainable development are further discussed in chapter 2 and Appendix 13.3. In addition to climate change are the CO_2-emissions also causing other problems like health problems, the heat island effect and increasing the cooling demand of buildings. Reducing these GHG-emissions, and especially our CO_2-emissions related to the energy supply sector and building sector, helps to mitigate the effects of climate change.

One of the causes of climate change is the huge demands for energy. On a worldwide scale level are fossil fuels resources depleting, but at a rate that there are enough fossil fuels to supply energy to the world for more than a century (BP, 2014; CBS *et al.*, 2007). On the other hand, on a local scale are the natural gas supplies in the Netherlands depleting at a fast rate (Bazelon *et al.*, 2010; Van Rossum & Swertz, 2011). Households in the Netherlands are unique in sense of the extremely high connection rate of almost 100% to the natural gas. This explains why the Dutch households are so dependent on the usage of natural gas for heating (CBS, 2016a; CBS *et al.*, 2014a). A dwelling is developed to last for over 50-100 years and with a natural gas supply of only several decades (Bazelon *et al.*, 2010; Van Rossum & Swertz, 2011), our dwellings have to start using a new source of energy. The increase in prices of natural gas (see Appendix 13.1) stimulate the business case behind this new renewable energy based energy concepts within dwellings. If the dwellings in the Netherlands does not get this new source of energy, gas needs to be imported from Russia and Norway (Bazelon *et al.*, 2010; Bokeloh *et al.*, 2013), which would cause whole new discussions of geopolitics and a new international position of the Netherlands within the international energy supply.

1.2.2 Urban growth: demand for new houses in the urban regions of the Netherlands

Another trend within sustainable development is the challenge of urban growth. In 2008 more than half of the world population lived in cities (UN, 2010). The United Nations expects that this urban population is doubled in 2050 (UN, 2012). This does imply that globally a huge demand for housing, employment and others facilities is expected in the city. Also in the Netherlands urban growth is expected in the urban regions of the Netherlands. This growth will not happen with the massive urban growth rate of developing countries, but still there is a need for housing. PBL and CBS[3] calculated that the amount of households will grow from 7,5 million in 2012 to 8,2 million in 2025 and even towards a 8,6 million in 2040 (Huisman *et al.*, 2013). Two reasons are fundamental to this expectation. First, the amount of people in each household is going to decrease from 2,2 people/household in 2012 to 2,1 people/household in 2025 and second, the amount of inhabitants of the Netherlands is continuing to grow. In 2040, a population of between 17.0 million and 18.6 million is possible (Huisman *et al.*, 2013).

This means that housing needs to be available for more than half a million households by 2025 (Huisman *et al.*, 2013). After 2025 the growth rates will decrease, but still it is expected that 1 million new homes are needed in 2040 (Huisman *et al.*, 2013)[4]. The demand of one million new dwellings in the next 25 years, combined with a growing economy and rising housing prices, triggered the development of additional housing and the related question, where all these dwellings should come (Van Duinen *et al.*, 2016). In the first period till 2025, growth can mainly be expected in the Randstad-region (Huisman *et al.*, 2013; Nabielek, Kronberger-Nabielek, & Hamers, 2013; Van Duinen *et al.*, 2016), but in the long-term scenario (2025-2040) it is becoming increasingly difficult to find suitable construction sites in the Randstad. This causes a shift in the growth rate to outside of the Randstad (Huisman *et al.*, 2013). This question about where to develop all these houses triggered a big discussion in the Netherlands. Van Duinen ***et al.*** (2016) divides the discussion into two camps. The first group argues for new greenfield locations. Growth should be outside of the existing city, like a new VINEX-development. Their main arguments are that there is simply not enough space to develop these houses in urbanized areas and it too costly to develop these houses on those grounds. The second group argues for transforming the existing city and develop on urbanized areas. This can be done by transformation of vacant properties and developments on unused or underused areas (including social real estate and land). Their main arguments are that creating a

[3] The PBL and CBS are Dutch agencies for the environment (PBL) and statistics (CBS)

[4] The report uses a bandwidth: a margin of 8.0 million households or 9.1 million households in 2040 is also considered plausible (Huisman et al., 2013). This bandwidth thus indicates that the amounts of new houses will lie between 0.4 and 1.5 million new houses.

higher density in the city by inner-city transformation creates an efficient use of space, agglomeration benefits and it conserves open space and landscape quality outside the city. (Van Duinen *et al.*, 2016)

In order to help the discussion, representative organizations of public and private organizations related to housing development signed the '*Manifest urbanized area transformations*' (Dutch: '*Manifest Binnenstedelijke Gebiedstransformaties*'). The Manifest shows the importance of these transformations, as they contribute to the energy transition, mitigation of climate change and the sustainability of our built environment through the efficient use of space, infrastructure, energy zones and urban facilities, and by reducing mobility and emissions (Fackeldey *et al.*, 2017). One of the representative organizations is the NEPROM, the Association of Dutch Project Development Societies. They want the following clause in the new government agreement (Dutch: '*regeerakkoord*'):

> "*The State contributes financially to (partly) unprofitable investments in infrastructure adjustments, OV facilities and excessive costs of land acquisitions and environmental remediation for the more complex transformation of urbanized areas.*" - Fackeldey *et al.* (2017: 5), translated from Dutch

Chapter 1.3.3 introduces some insights in the likely outcomes of the government agreement.

1

If the State is going to financially contribute to these unprofitable investments, it seems a lot more realistic that the more complex area developments are also actually being addressed by private real estate parties. The director of the biggest housing developer of the Netherlands, Walter de Boer of BPD, states in an interview with De Blauw (2016c) that many private parties are unable or willing to take big risks by a large upfront investment in these complex area developments and that the new rules for housing associations will have the side-effect that housing associations are going to develop far less owner-occupied dwellings. Private real estate developers/investors can attract part of that production. In that case the task is getting bigger for private parties. Contributions from the State would take the first statement, the second statement shows the increased importance of the private sector. The next section is going more into depth about that trend.

Concluding, urban growth also has it effects in the Netherlands, and it needs to be tackled in a sustainable matter. It would be great if all these 1 million houses will become energy neutral, and that these can be an international example.

1.2.3 New style urban area development leading to private sector-led urban area development

The practise of urban area development in the Netherlands is changing and the private sector is taking a more central position in the decision-making process. Since the rise of public-private partnership structures in the 1980s, the topic of urban area development (Dutch: '*gebiedsontwikkeling*') is being discussed. Urban area development focuses on the development of a whole area, in all its facets, over a long period of time and across all stages of management initiative, involving actors risk-taking (Peek (2014) in Bentvelsen (2014)).

The traditional focus on the preparation of master plans in urban area development, followed by the execution of these plans through a series of fixed steps and agreements is in our past (Bentvelsen, 2014; Peek & Van Remmen, 2012). Bentvelsen (2014) explains the change and defines the traditional and the new-style approach. The traditional approach involves a supply-based model, whereby the sale to the end-user indicates the end of the supply chain. The time before the crisis that was possible, because everything that was developed was sold. For that reason, real estate developers had little concern about the sale of their real estate products. The large scale approach and the major investment willingness that characterize traditional area development no longer works according to the new style. These changing market conditions led to a new approach to urban area development, the new style of urban area development (also called 'new development' or 'organic development' or 'urban area development 2.0 or 3.0'). The new style of urban area development radically reverses the traditional line of thinking. In the new style it is about attracting and retaining the end-users. The approach is focussing on a demand-based model. It is not the traditional one-off value jump, created by the development of land and real estate, but it is a broader value creation from a longer term perspective. (Bentvelsen, 2014) Chapter 4.3 gives a more in-depth explanation about the changing practise of urban development.

As stated before, municipalities are withdrawing from their active role in urban area development and taking a more facilitating role with a less risk-baring nature. This came in an acceleration after the economic crash in 2008. Dutch municipalities had taken big risks with their active ground policies. The economic crash exposed those risks. In the decades before the crisis, many municipalities bought ground for their own account and risk, with the aim to develop the land and afterwards sell them with profit. Partly as a result of the economic crisis on municipal land development many millions have to write off of the land development (Rfv, 2015). After the crisis the losses are in the billions throughout the Netherlands (Rfv, 2015).

The private sector is stepping into the gap, which is created by the new role municipalities are taking. Heurkens (2012) has explored this and identified that the changing urban development processes in the Netherlands are also changing from public sector-led to private sector-led. Private parties are taking the initiative more often and this central role could give the private real estate parties more opportunities for control in the decision-making.

1.2.4 Being smart: Smart city, smart grid, smart home, etc.

The third trend is the opportunity of technological innovation or in other worlds, the emergent of digitalization of technology. The year 2008 was not just the year that more people lived in cities than at rural areas, but also the year that there were more wireless connections (i.e. mobile phones) than wired connects (i.e. desktop computers) and the year that more things got connected to the internet than humans (Townsend, 2013). Townsend (2013) identifies how these landmarks lead to the development of the 'Smart City' concept. In this concept digitalization and big data play a major role in delivering information to decision makers in how to manages their cities. Last years, many smart concepts got developed based on the concept that big data can deliver information for decision makers. For instance, the smart grid delivers information about electricity flows through the more and more decentralized energy grid (e.g. Molengraaf (2017)) and in a smart home many appliances are connected to the internet-of-things, providing the home-owner all kind of information about the performance of the appliance (e.g. if it is on or off, the amount of energy-usage).

However, seeing purely the technology as the holy grail in (sustainable) development is old fashioned. According to Matthewman (2011) a shift had occurred from a technocratic expert approach to an equal placement of technology in a larger network of social and technological actors, called the Actor-Network Theory. In this theory the importance of non-human agency, the power of technology, is seen in a social network of actors. He mentioned the positive and empowering aspect of technology, as stimuli for thought, reflection and personal development. Levels-Vermeer and Van der Weerd (2012, December 12) are giving an example of why renewable energy generation in the Netherlands is not being implemented. The technology is available, but implementation is not solely a technical problem, but even more a political and economic challenge. Often you hear that the technology is available, but that are other problems. The same can be found in the book of Townsend (2013: 77), he state that it is often not the technology that is failing, but that the real challenge lies in managing the people and organizations that would use such big, complex technical systems. In this case systems of urban dynamics were used.

The same can be stated for this thesis, because the technology for the realization of ENRND-projects is available. However, the challenge is a social and economic one. These three aspects of organisation (social), economic (financial) and technological (physical: spatial/technical) are the main pillars of this thesis.

1.3 Research focus

The research topic is further focussed on new constructions of all-electric, owner-occupied and single-family and dwellings and on the early phases of urban area development. The next paragraphs explain why.

1.3.1 New constructions offer a bigger exploration of the solution space

The new legislations on energy efficiency require new constructions to be even more energy efficient as before (Bouwens, 2017a; Bouwens & Bouwmeester, 2017; European Parliament & Council of the European Union, 2010; Haytink & Valk, 2016, 2017; Kruithof & Haytink, 2015). In new constructions a bigger exploration of the optimal solution space is possible, as there are less technical restrictions, which are limiting possibilities within the existing stock. For new constructions decision-makings can still decide to develop a neighbourhood without a natural gas connection. For existing constructions this natural gas connection is already present. For new constructions it is possible to realize dwellings which have a positive yearly energy balance (Bouwmeester, 2015; Sijpheer *et al.*, 2015; Staats, 2016). There is proof of concept, but research is needed in the optimal combination of the three pillars, organisation, financial and technological. For instance, Van de Griendt and Van Estrik (2010) and Van de Griendt and De Vries (2013) notify the difficulties in financing the additional investment in energy efficiency due to lack of market demand (because of the lack of knowledge and interest of the consumer).

For reasons of completeness, it needs to notified that the largest energy saving potential is in the existing building stock, because only 1% of new dwellings is added to the housing stock annually and those new developments already have a better energy performance (Visscher *et al.*, 2016). For instance in 2009, 82% of the existing stock of almost 7 million dwellings has an energy label of at most D (Dijk, Hocks, & Revier, 2009). The researchers base this statement on the level of insulation required in the building degree at the time that the dwellings were constructed. With an average economic lifespan of 50 years, all non-monumental buildings constructed before 2007 have to be replaced before 2060 (Dijk *et al.*, 2009). The economic lifespan is only accountable to landlords, like housing associations. The technical lifespan of those buildings are much longer. Therefore, it can be expected that owner-occupied houses will not be reached at that time. By only focussing on adding new building to the existing stock the CO_2-reduction targets would not be reached. As stated before, the technological possibilities are limited and no generic optimum can be found as the technical state of the current building is critical in the decision-making of the best suited renovation concept. And in addition, another type of stakeholder management is needed to overcome the difficulty to get 70% of the tenants approve the renovations that require an increase of the rents (Visscher *et al.*, 2016), which are required to overcome the split-incentive (Ástmarsson *et al.*, 2013).

1.3.2 All-electric concept energy concept

An all-electric energy concept is selected as focus of research, because this energy concept is the best alternative for the largest part of the Netherlands (see Figure 4). The map in the figure is the result of a road map made by CE Delft to determine the best alternatives for residential and commercial buildings to switch from natural gas to another (renewable) energy resource (Molengraaf, 2017). The road map presents three main alternatives: All-electric, district heating and renewable gas (e.g. green gas or biogas based on biomass). Of which the district heating can be applied as a classic heating grid, low temperature heating in a local network or as low temperature grid in a connected network with multiple sources (Molengraaf, 2017). The all-electric concept is excluded within the inner city developments and near the big industries. For the inner city developments, it is possible that interesting case studies have made the choice for one of the possible energy concepts. This decision-making process is included in the research. However, the list of possibilities is too broad if all renewable energy concepts are included. With the selection to the all-electric concept combined heat & power (CHP)-plants and biogas installations are, among others, excluded from the research.

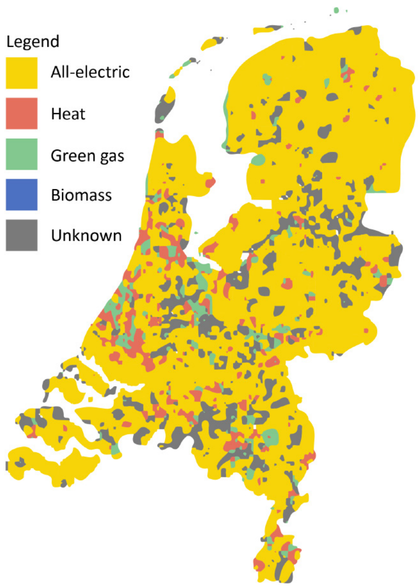


Figure 4: Best alternatives for residential and commercial buildings to switch from natural gas to another (renewable) energy source (own illustration based on Molengraaf (2017: 9), who got it from CE Delft)

1.3.3 Owner-occupied and single-family dwellings

The focus of this research is on the initiative phase from the viewpoint of the real estate developer. In order to keep this focus, the discussion on the landlord-tenant dilemma/ split incentive, which housing associations and investors in the rental sector are facing (Ástmarsson *et al.*, 2013; Bullier & Milin, 2013), needs to be avoided. Therefore, the research is demarcated to owner-occupied dwellings. Figure 5 shows the effect of this focus on the line of reasoning for the financial calculations and the central financial position of the real estate developer.

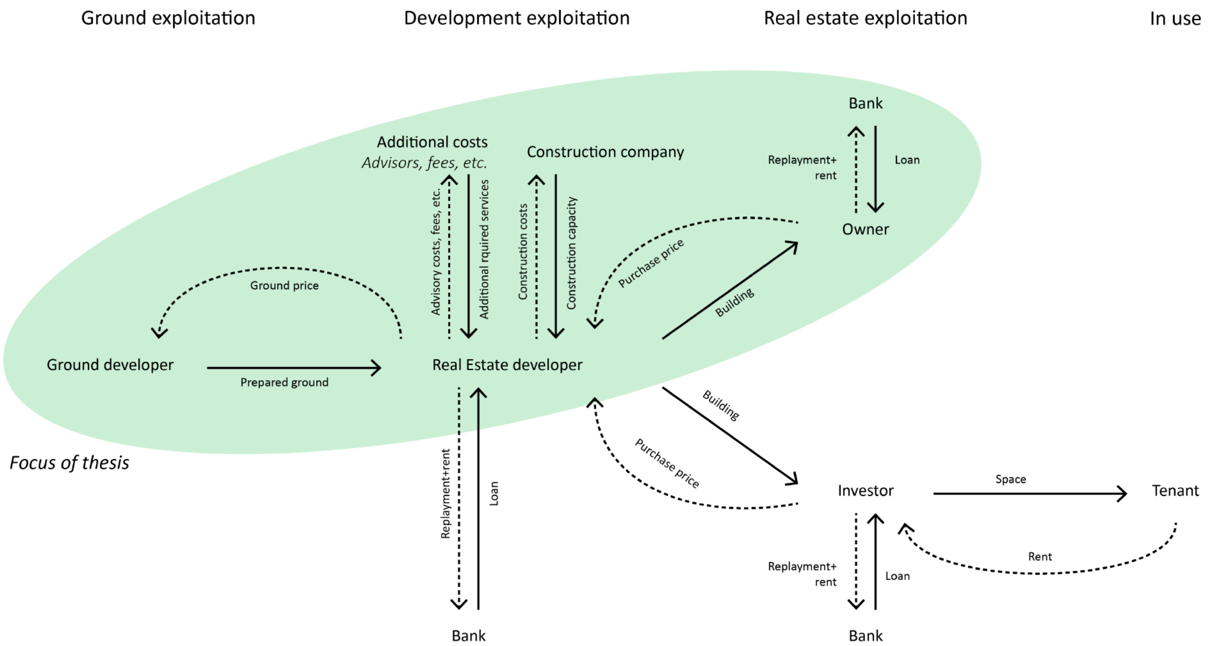
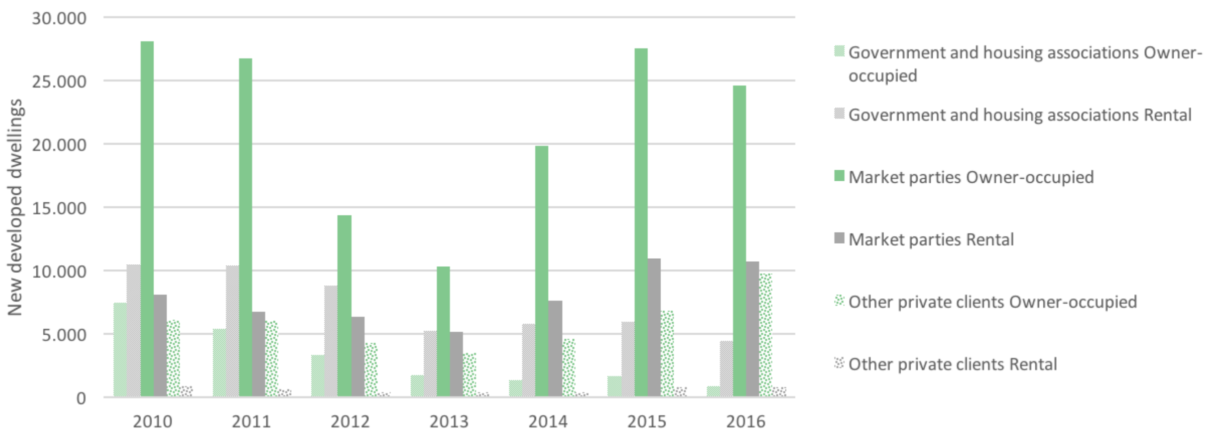


Figure 5: Focus on owner-occupied dwellings (own illustration, scheme is based on Putman (2010) and Vlek *et al.* (2016)).

In the period after the financial crisis (2012-current day), the amount of owner-occupied dwellings increased with 2,7% for the Netherlands and 3,6% for the Randstad (see Appendix 13.2). Most of the owner-occupied dwellings are developed by market parties, as indicated by Graph 1. The graph also shows the decline in amount of dwellings developed by the (semi-)public sector and the increasing amount realized by the private sector. This connects the focus on the real estate developer and the focus on owner-occupied dwellings.



Graph 1: Owner-occupied dwellings are the most developed new dwelling type in the last years and they are developed mostly by market parties, such as the real estate developer (own illustration based on data of CBS (2017c)).

Owner-occupied dwellings are the most developed dwellings for decades and therefore consists the majority of the Dutch dwelling stock of owner-occupied dwellings[5]. However, the amount of SFD constructed declined fast (see Graph 28 in Appendix 13.2). Graph 1 indicate that this trend is changing by the rapid increase of new owner-occupied dwellings developed since 2014. This trend breach is also supported by the demand for about 1 million additional new dwellings in 2040 (according to Huisman *et al.* (2013) and Van Duinen *et al.* (2016)) and by the lobby with new solutions presented in the manifest of Fackeldey *et al.* (2017), see 1.2.2 on urban growth. The focus on owner-occupied dwellings is therefore also useful for future projects.

[5] See Appendix 13.2 for the numbers and associated graphs.

This research is further demarcated to a focus on single-family dwellings (SFD), because they require different types of energetic solutions as multi-family dwellings (MFD) and those SFD fit to the all-electric concept. The requirement for other energetic solutions is tangible in, for instance, the extent to which PV panels can support the energy concept. This is different, because the ratio of the available space on the roof for PV-panels to the amount of dwellings under the roof is far smaller for the MFD as for the SFD. The higher density of dwellings makes a heating grid more feasible for the MFDs. These energetic concepts also fits in the story about Figure 4. The edge of city and rural locations of the all-electric concept are best suited for SFDs. Owner-occupied SFDs are 47% of the new developed dwelling between 2009 and 2012 and most of these owner-occupied dwellings are developed by market parties (see Figure 6). Since 2015 are more than half of the new dwellings are single-family dwellings in the Netherlands (see Appendix 13.2). Therefore, this research is useful for almost half of the new dwellings developed.

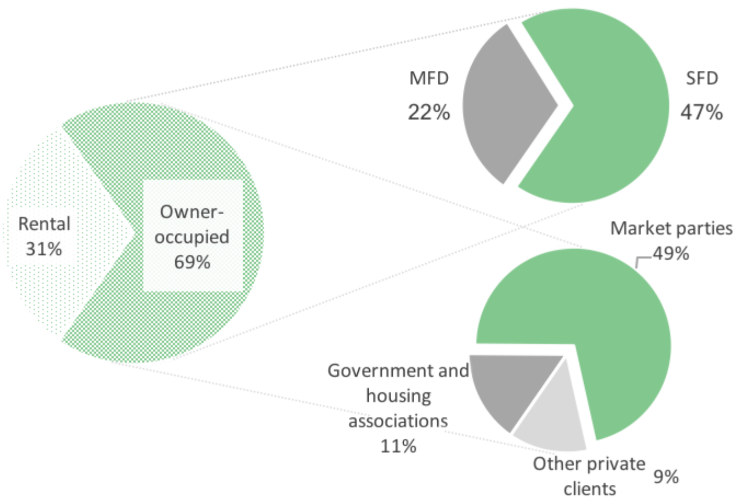


Figure 6: Impact of the demarcation on to owner-occupied, single-family dwellings is in line with the most developed products of the real estate developer between 2009-2012[6] (own illustration based on data of CBS (2014b)).

The used demarcation is thus in line with the focus on the real estate developer. The demarcation also has a big impact on the energy consumption of new dwellings, because on average different types of single-family dwellings[7] consume 150% to 400% more natural gas than an average apartment building (NIBUD, 2017). Because the research focus is on the all-electric concept and the selected dwelling type and ownership is used in about half of the new developed dwellings, the outcome of this research will help in reducing the dependency of natural gas in the Netherlands by creating all-electric, energy neutral residential neighbourhoods.

1.3.4 Feasibility phase of development projects

The last demarcation is to focus on the feasibility phase of development projects, because effectively influencing multi-actor decision-making processes is best possible in this initial phase of development. This is according to the decision paradox of Wamelink *et al.* (2010), which describes that parties still have the most influence on the outcome, while having the least information to base their decisions upon. In order to overcome the decision paradox, parties first explore their possibilities during an iterative start in the initiative phase (left triangle in Figure 7). This phase is continued by a converging design- and realization phase (right triangle in Figure 7).

The focus on the first phase of the development keeps many options open for the best solution. However, involved parties need information to support the decision-making process. This research has to help real estate developers to make the optimal decision for energy efficiency in the first exploring stage of the decision-making processes during urban area development by overcoming the decision paradox of having only little information.

[6] CBS (2014b) had no later numbers available.
[7] NIBUD (2017) uses terraced dwelling, semi-detached dwelling and detached dwellings.

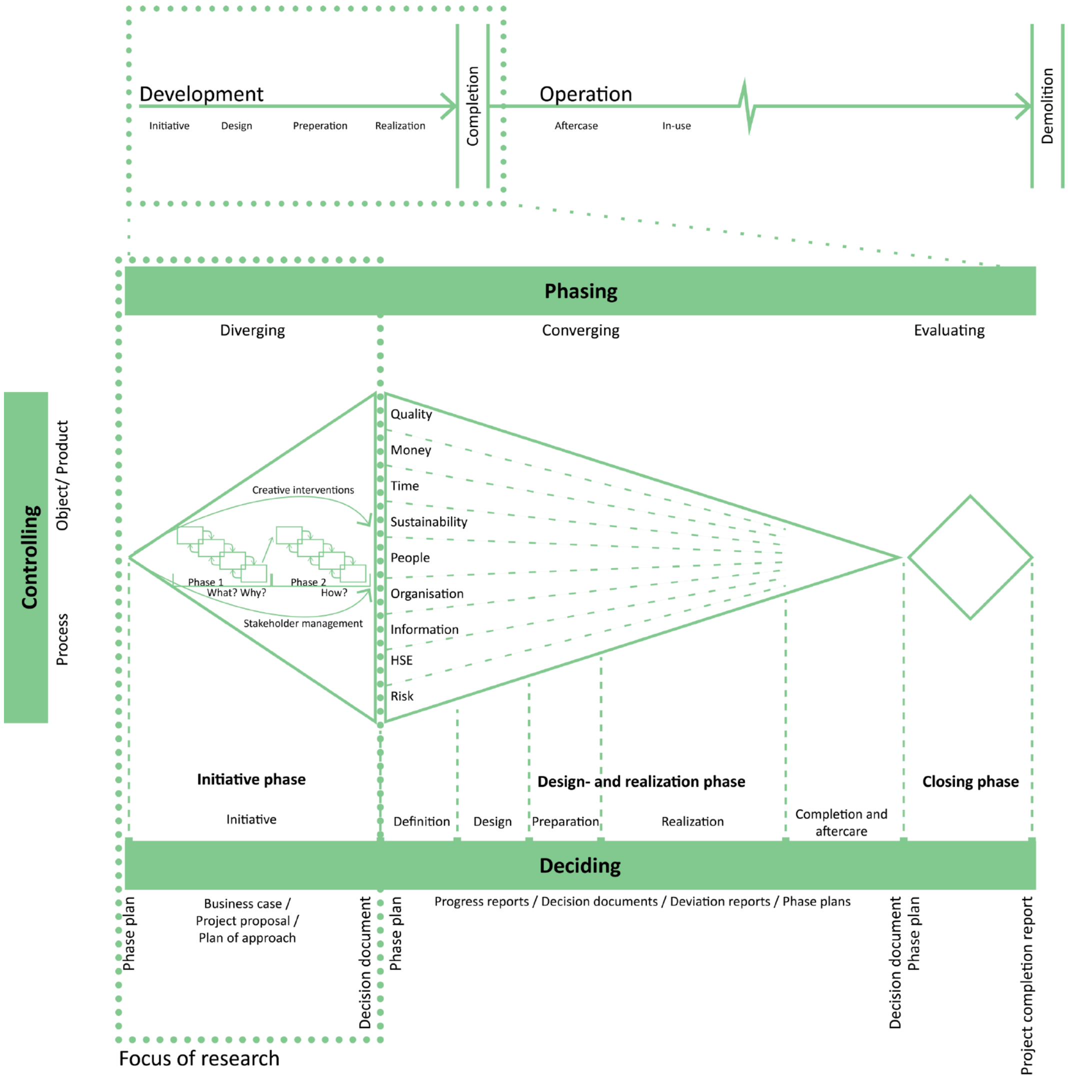


Figure 7: Focus phase of research (own illustration, based on the development phases of J. C. De Jong (2016: 19), the management process of real estate development of J. C. De Jong (2016: 24) and the strategic development framework as used by SITE urban development in Versteijlen *et al.* (2010)).

The end-result of the feasibility phase or initiating phase is the business case. That is why this research focus is on the exploration and optimisation of the best possible ('optimal') business case. The result of this research is an easy applicable method for optimising the energy part of the business case. This method supports the decisions made during this phase in order to make them more effectively.

1.4 Research framework

A real estate developer has to take into account many different variables in the realization of an ENRND-project. In this research these variables are composed of the organisational, financial and physical aspects within the legislative boundary conditions (see Figure 8).

Starting point for the framework was the analysis framework of SITE urban development, which combines (market) demand, (financial) investments and spatial (design concepts) into a development strategy (Versteijlen *et al.*, 2010). A development strategy has similarities with a business case. According to Veseli (2014) the business case shows, by means of financial calculations, whether the desired vision for the area (which can also be called the plan or the project definition) with the associated model of collaboration between different parties, is financially feasible. The business case of a real estate developer consists of three main components (Van der Cammen (2007) in Schouten (2013)): 1) A plan, design or vision of the area; 2) A budget/ financial exploitation; And 3) An agreement of collaboration.

The difference between the definitions of the business case, business model and revenue model is described in Veseli (2014: 38). Van Mierlo (2010: 12-22) clearly explains the difference between business models and strategy and how they relate to each other and the real estate developer.

The analysis framework of SITE and the components of the business case are combined. The (market) demand of the framework of SITE is split in two components. The financial aspect of the market demand is combined with their investment component and included into the financial component. The demands of the end-user are included into the organisational component, into the role of the end-user in the decision-making process.

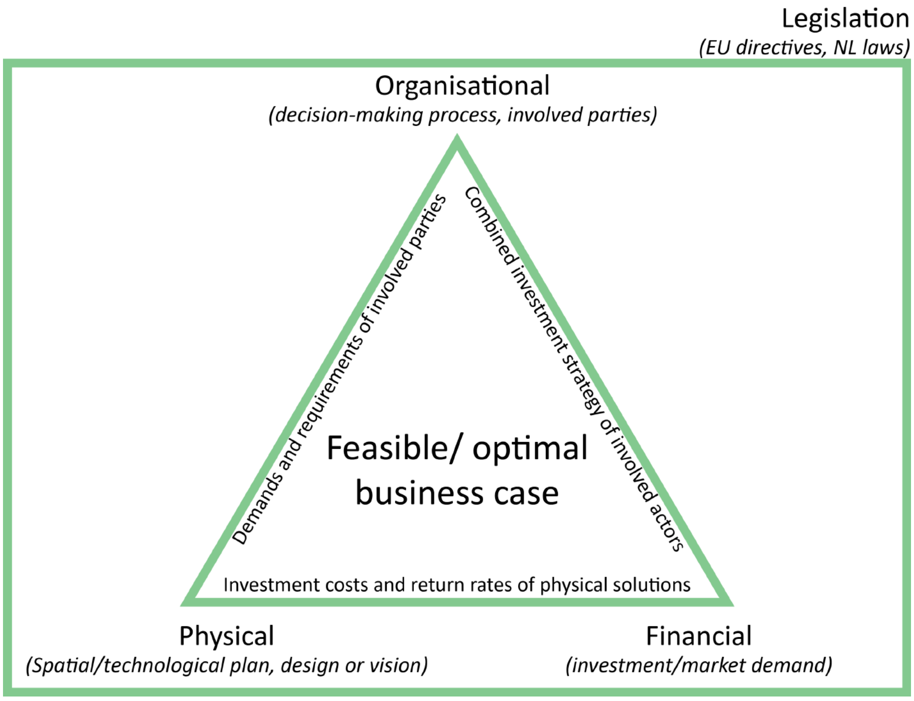


Figure 8: Research framework for realizing a feasible business case within the new legislation (own illustration based on the analysis framework of Versteijlen *et al.* (2010) and the components of a business case as described by Van der Cammen (2007) in Schouten (2013)).

The research investigates how the real estate developer can optimise it business case for realizing energy neutral neighbourhoods (according to the new legislation) within the multi-actor decisions making process (organisational component), which lead to the optimal yield for the real estate developer (financial component) and which physical solutions must be realized (physical component).

1.5 General research question

The general research question for this thesis is:
How can a real estate developer optimise its business case to realize energy neutral residential neighbourhood development projects consisting of all-electric, single-family and owner-occupied dwellings?

The sub research questions are stated in the research methodology chapter. These questions are derived from the several steps within the research.

1.6 Research objectives and results

In the end of this research three objectives are reached:

1. Identification of organisational, financial and physical aspects for an optimal business case from the viewpoint of the real estate developer to realize ENRND-projects.
2. Identify the optimal business case to realize ENRND-projects.
   - Organizational aspects (parties involved, collaboration, contracts)
   - Financial ingredients
   - Physical (spatial, technical) on a conceptual base
3. The decision support tool for modelling the optimal business case with a focus on maximal profit within high ambitions for energy efficiency.

1

1.7 Research relevance

This research is relevant for both practise and research. It investigates a large societal issue in practise, namely the need for sustainable development. However, the foundation of the research is the tighter regulations for the real estate developer (as problem owner) to develop energy neutral dwellings. The research also shows new possibilities in how research can help in practise, as elaborated in the recommendations.

First, this research helps to counteract climate change, resource depletion and rising energy prices of fossil fuel based energies by investigating the opportunities for realizing ENRND-projects on a commercial scale. This would also reduce the dependency of new households to fossil fuels. Increasing the energy ambition of new developments will speed up the annual CO_2-savings. The current CO_2-savings need to speed-up by a factor 3 if the Netherlands wants to realize the promises made in the Kyoto-agreement (Molengraaf, 2017).These arguments show that the research help to find possibilities to speed up sustainable development and the energy transition and helps realizing the Kyoto and Paris-agreement[8]. *Second*, the research identifies possibilities for the real estate developer to tackle a future legal problem when the BENG-legislation get introduced. *Third*, this research add new knowledge to the academic world, because 1) in practice there are already several projects which are totally energy neutral (Bouwmeester, 2015; De Wit *et al.*, 2016; Sijpheer *et al.*, 2015). There is proof of concept and this should be added to the body of knowledge. And 2) the research investigates how decision support tools can help in urban development processes from the viewpoint of the real estate developer to successfully realize ENRND-projects. The shift from public to private sector-led urban development[9] and energy neutrality[10] are very actual topic in the academic world, but none has the solution yet how the business case can be optimised in the early stages of development. Both topics are going to add to the body of knowledge about urban area development and real estate management.

1.8 Reading guide

The structure of the report is described below and presented in Figure 9.

Part 1 continues with chapter 2. This chapters places the research in a broader context and shows that research on the optimisation of energy neutral dwellings is also reflect from a societal point of view and is part of the energy transition. The research results can help to make a further step in this transition. How this research is executed is explained in the next chapter on the research methodology. At the end of this part a clear introduction is given on the motives, structure and methods of this graduation research.

Part 2 is the theoretical foundation of the research. At the end of the chapters the different possibilities for optimising the business case of ENRND-projects are clear. The structure of the chapters is based on the research framework (see Figure 11). Each of the three chapters within this part provide an answer to one of the three knowledge-related sub-research questions (see chapter 3.3). The theoretical framework starts with chapter 4

[8] More on the need for sustainable development and the impact of the energy transition can be found in the next chapter.
[9] E.g. Heurkens (2012) and De Zeeuw *et al.* (2011).
[10] This research uses more than 30 journal articles, which contain 'energy' in their title and were published in the last five years.

which gives a more in-depth analyses about effective decision-making in sustainable urban area development. The chapter explores the changing practise, the real estate developer, barriers and incentives for the involvement of sustainability and concludes by approaches for the involvement of sustainability within the decision-making process. Chapter 5 explains why the linear programming method as a quantitative instrument in multi-actor decision-making processes, is suitable for the development of a decision support tool to optimise the business case of ENRND-projects from the viewpoint of the real estate developer. Chapter 6 explores the barriers and solutions of the individual aspects within the business case of energy efficiency in urban area development. The changing legislation related to energy efficiency is described as part of 'legislation', possible public-private partnership, contractual agreements and the involvement of new types of parties in the urban area development process as part of the 'organisational' aspect, new financing schemes and business models as part of 'financial' aspect and the spatial and technical solutions for energy efficiency in the built environment as part of the 'physical' aspect.

Part 3 explores possible lessons learned from current practices in ENRND-projects in the realisation of high energy ambitions in chapter 7. For this chapter multiple interviews were held in multiple cases. One case is selected to be described in-depth and to be optimised later on in the research. Chapter 8 shows the final result of the exploration of the possibilities for the development of the DST. It clearly describes in a qualitative way how the different aspects of the business case have its place in the model and how they are optimized.

In part 4 'optimisation' the lessons learned and the developed DST are used to identify the added value of the decision support tool and search for new optimal business cases for ENRND-projects. This is described in chapter 9. The execution is applied in two ways. First, the application of the DST to the in-depth described case and second, by means of letting an expert focus group reflect upon the final design of the DST.

The final part 5 'syntheses' reflects upon the whole research. In chapter 10 are the conclusions of the research presented. Chapter 11 discusses these results and the whole research by reflecting upon the relation to theory, the level of sustainability, the research methods and it gives a view upon future directions of ENRND-projects. All advantages and possible future improvements identified by this research are summarized in a list of recommendations in chapter 12.

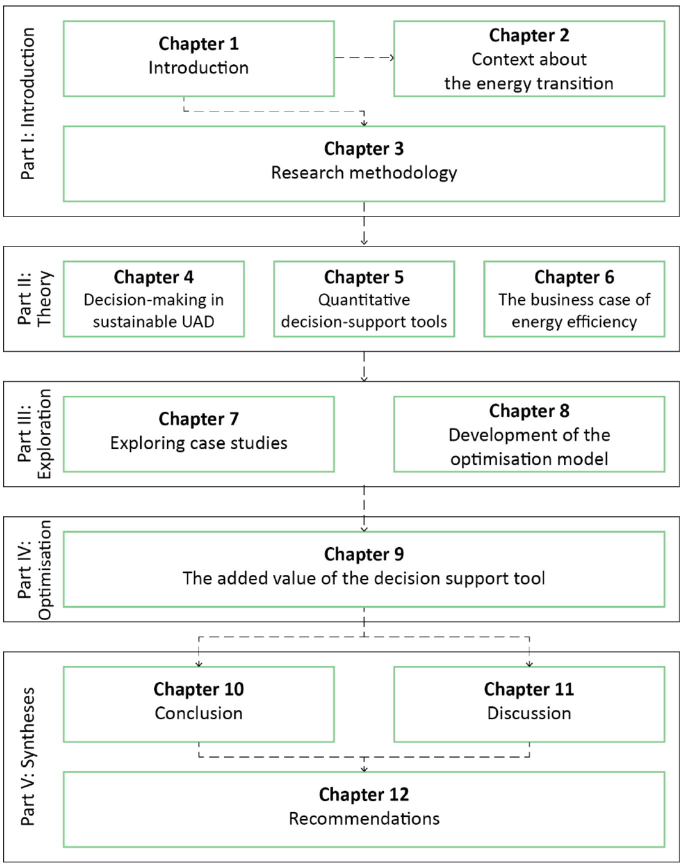


Figure 9: Reading guide and research structure (own illustration).

2 Context: Energy neutral dwellings are part of the energy transition

2.1 Introduction

The Netherlands is highly dependent on fossil fuels. The combusting of these fuels for energetic purposes are causing worldwide problems. This creates a need to adapt our whole society to a society based on renewable -none fossil- fuels. This process of change is called the energy transition and because this need for a future based on renewable energy, the energy transition has it part within the broader topic of sustainable development.

2

This chapter shows a short introduction in the broader context of the problems underlining to the need for sustainable development and the energy transition. The energy demand of the Netherlands is large and that is why there is a big (spatial) impact to get this demand supplied by renewables. The chapter let people realize why it is not enough to only increase the number of windmills in the North Sea to get towards a renewable energy future. The chapter concludes by the importance of energy neutral dwellings in this transition.

2.2 Main problems caused by fossil fuel usage for energy purposes

The biggest motives for sustainable development are climate change and resource depletion. Especially the last one causes fluctuating energy prices and dependencies on foreign countries. Those topics are introduced next, a more in-depth explanation about the history of sustainable development and its application can be read in Appendix 13.3.

First, the climate is changing and research showed that humans are causing this rapid change (Imbrie & Imbrie, 1980; IPCC, 2007a). An indication of how rapid is rapidly can be found in the report of the Intergovernmental Panel on Climate Change (IPCC, 2007b). The effects could be devastating. For instance, more than two third of the cities are situated in a delta and thereby vulnerable to the indirectly consequences of climate change, namely the risk of flooding (Aerts et al., 2009). Flooding is caused by heavy rainfall and a rising sea level, which again is caused by the rising temperature. Global warming is part of climate change (Blackmore, 2010; IPCC, 2007b). There are still discussions if climate change is caused by humans. Schmidt and Wolfe (2009) computed that the odds of this being a natural occurrence are one in a billion! So, the change that these people are right, is very small. Without a drop in CO2-emissions, the current society is effecting the possibilities of future generations, which is the core definition of sustainable development (also called the '*Brundtland definition*' of sustainable development):

> "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*" - Brundtland (1987: 43)

The second trend is the challenge of resource depletion. Even 30 years after the publication 'Limits to Growth' of Meadows *et al.* (1972)[11], the same writer still state "*the flows of energy and materials required to sustain industrial growth are depleting non-renewable stocks.*" (Meadows, Randers, & Meadows, 2004: 129). In the Netherlands resource depletion is tangible by the depletion of natural gas in Groningen, which is causing earthquakes and rising energy prices (Bazelon *et al.*, 2010; Van Rossum & Swertz, 2011). With this depletion of natural gas and without new solutions, the Netherlands will become more dependent on fossil fuel producing countries. Fossil fuels are mainly located in unstable regimes (e.g. in the Middle East for oil and Russia for natural gas) and dependency creates uncertainties (Bokeloh *et al.*, 2013: 9). More autonomy in the field of energy is therefore desirable from a geopolitical point of view. The government is already lowering the maximum amount of natural gas that can be produced in the Groningen (Bazelon *et al.*, 2010; Van Rossum & Swertz, 2011).

In the near future the depleting resource of natural gas in the Netherlands will have a huge effect on the way residents heat and cook in their houses. Rising energy prices are an incentive for new, more sustainable solutions with a lower energy bill. The government wants reduction of the total amount of natural gas used, in order to

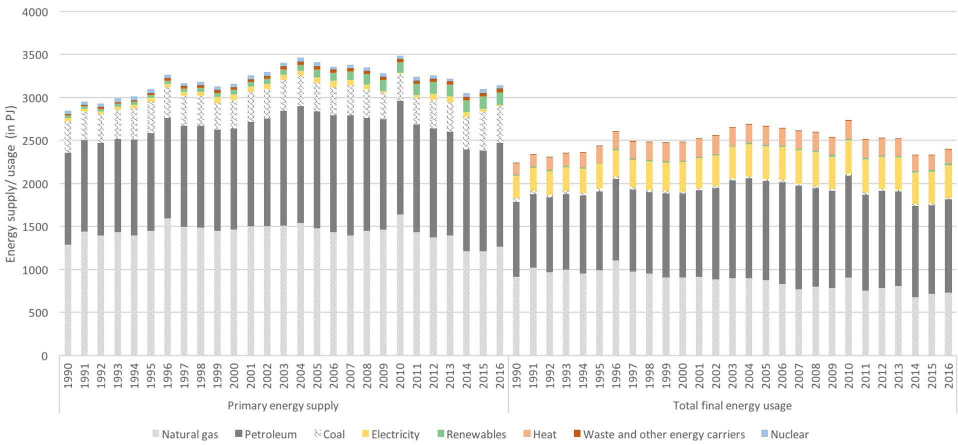
[11] More about the history of the concept 'Sustainability' can be found in Appendix 13.3.

not be dependent on countries like Russia. Energy neutral houses, or neighbourhoods without a connection to natural gas are solutions. In this way the energy transition embodies the need for sustainable development.

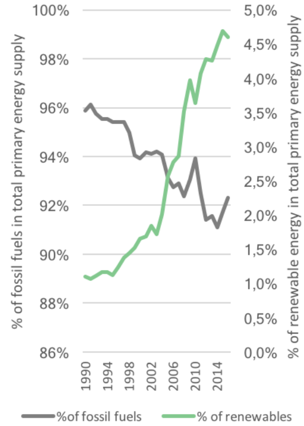
2.3 Energy transition

The switch from fossil fuels to a renewable energy future is called the energy transition. The energy transition will have a huge (spatial) effect on our (urban) landscapes (Hocks, 2017; Hocks *et al.*, 2016; Sijmons, 2017; Sijmons *et al.*, 2014). The last twenty years the Netherlands used more than 3.000 petajoule (PJ) of primary energy (see Graph 2). One PJ is about 278 million kWh (De Blois *et al.*, 2014: 30). Over the past 25 years the energy consumption in the Netherlands looked rather stable (see Graph 2). Natural gas, petroleum and coal are the main resources for the total primary energy supply in the Netherlands (see Graph 2). Therefore, the Netherlands is largely dependent on fossil fuels. This research will investigate the opportunities to reduce this dependency for new households.

A tipping point in the increasing energy consumption is visible in the year 2004 and since then both the primary energy supply and the final energy usage are decreasing. Since 1990 also the relative amount of fossil fuels is decreasing in the primary energy supply and the relative amount of renewables in increasing (see Graph 3). Still, the absolute amount of natural gas usage per person is the highest amongst other European countries (De Blois *et al.*, 2014: 31) and fossil fuels (especially natural gas) are also the main energy resource for the total Dutch energy consumption (De Blois *et al.*, 2014: 34). The Dutch energy supply is for the biggest part (96%) based on non-renewables[12].



Graph 2: Primary energy supply and total final energy usage in the Netherlands between 1990-2016



Graph 3: % of fossil fuels and renewables in total primary energy supply

Graph 2 and Graph 3 are own illustrations based on data of CBS (2017a).

Almost 100% of the household have a connection to the gas infrastructure and more than 50% of the countries' electricity demand is supplied by gas-fired stations (Bazelon *et al.*, 2010). This makes gas a major direct and indirect source of energy for most households in the Netherlands. However, the Groningen gas is of low caloric value and therefore mainly used in households for heating and cooking and high caloric gas is used for electricity generation and imported from Russia and Norway (CBS *et al.*, 2016). This type of natural gas cannot be used without modifications in households. The prospect is that our natural gas reserves are empty in a few decennia (Van Rossum & Swertz, 2011).

If the Netherlands really want to reduce usage and dependency on natural gas from Groningen, it should start with dwellings that are using other sources of energy than natural gas. Figure 10 support this statement by showing that natural gas is around 75% of the energy used by households and that households are consuming the most natural gas of all sectors. The figure does not even take into account the differentiation between high caloric and low caloric natural gas. This research provides insight in how this renewable energy future can be realized in a financial feasible way.

[12] Waste is seen as non-renewable, as the Netherlands strive for a circular economy in 2050 (Dijksma & Kamp, 2016).

A more energy efficient built environment, or even an energy neutral built environment, is only the first step (Molengraaf, 2017). As reason for this he sees that energy is more expensive for households than for big industrial companies. Therefore, households can already make a feasible financial business case with energy efficiency measures, while big industries are lacking the financial incentive to become more energy efficient. Still, about 132 companies/ industries are responsible for almost 25% of the Dutch CO2-emissons (Middel, Sengers, & De Vos, 2017)[13]. Households are maybe a first step, but these big industries have to follow.

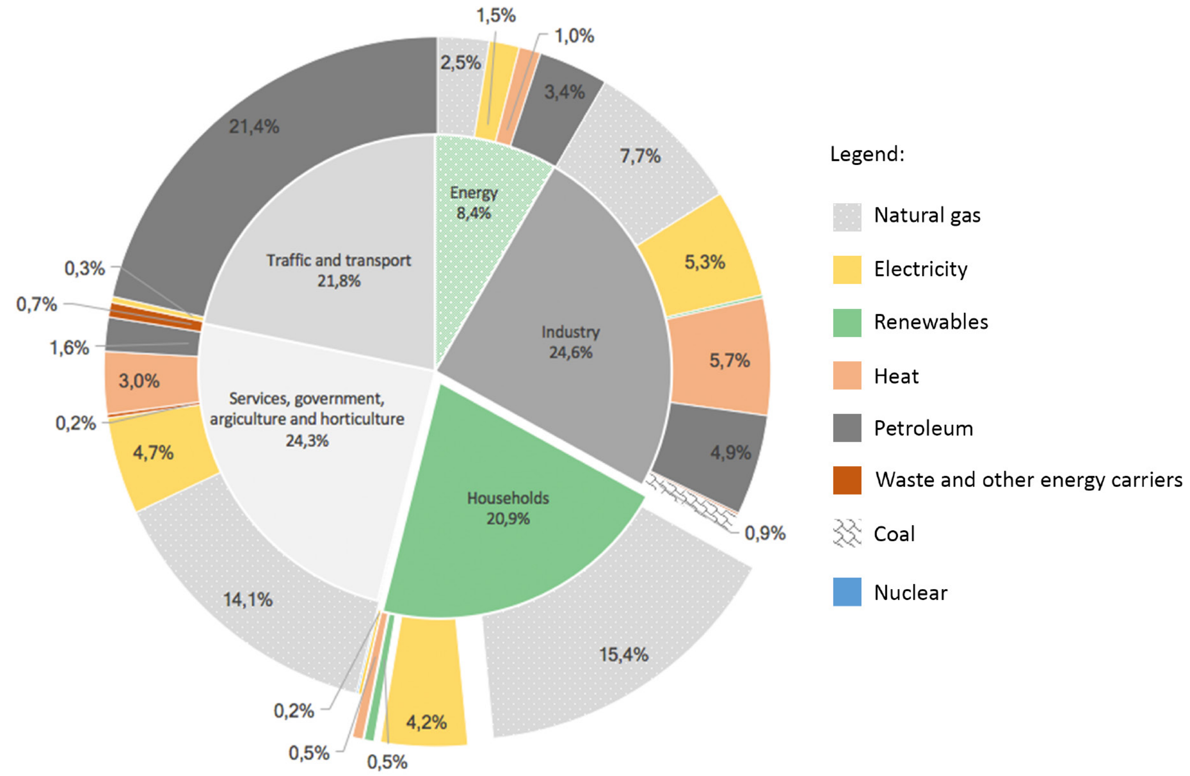


Figure 10: Final energy usage per sector in the Netherlands in 2013 (own illustration based on data of CBS (2014a))[14].

POSAD investigated the spatial impact the energy transition for Noord-Brabant faces (Hocks *et al.*, 2016) and concludes that in case the maximum geothermal potential and all biomass was used, there still would be a need to reduce the energy demand, a requirement for 2270 large 7,58MW windmills and PV-panels on all suitable roofs and in 8,1% of the rural landscape. The study was an average study for the Netherlands based on energy demand of the province per sector and size (based on Hocks *et al.* (2016) and CBS (2017b)). This shows an evident spatial impact on the future of our landscapes if the Netherlands wants to be independent of fossil fuels.

According to the conclusions of the research of Hocks *et al.* (2016) it is theoretically possible for a whole province to become energy neutral in 2050[15]. Realization is only possible when substantive savings are achieved and the chosen scenario for the energy supply is close to the maximum scenario for the renewable energy sources. Measures will therefore have substantial effects on the landscape in order to achieve the objective. For example, this result is achieved by creating a landscape full of solar fields and windmills in the mixed rural area and in the green blue mantle. In addition, all geothermal potential and biomass are used. However, these last ones only add for 17% in the maximum scenario. Minimizing the spatial impact can be achieved by saving the maximum. If the chosen scenario does not appear to be energy neutral with renewable energy sources within the province, the remaining part can be utilized through any surpluses from adjacent provinces (e.g. wind at sea or the import of biomass). Still the energy demand is not generated in the correct energy carrier. Heat and fuel make up a large

[13] Two industries (TATA Steel and YARA) consume the same amount of energy as 49% of all the household in the Netherlands. More information about this impact of a few industries on the total energy consumption can be read in Appendix 13.5.
[14] The difference with the primary energy usage per sector is shown in Appendix 13.4.
[15] Hocks *et al.* (2016) used the province of Noord-Brabant as example. Appendix 13.5 shows more information about the spatial requirements of renewable energies like wind and solar.

amount of the total expected energy demand in 2050. Wind and solar can currently only supply electricity. Therefore, biomass and geothermal energy are meaningful options, given the high demand for heat in the province.

Hocks *et al.* (2016) shows that minimizing the energy demand is needed to make it possible to become energy neutral in 2050. Households offer a great potential, as there are solutions realized in practise to develop net zero-energy houses (more on this topic in the following chapters).

2.4 Conclusion

Energy neutral dwellings are part of the energy transition. The energy transition has to counteract climate change and resource depletion. This is important in the Netherlands, because most of the Dutch cities are located below sea level and the natural gas resources are depleting rapidly. Households in the Netherlands consume a great deal of energy based on fossil fuels, for instance 15% of the total final energy usage and 25% of the natural gas usage in the Netherlands is natural gas usage in households. The last number would be higher, maybe doubled, if low caloric Groningen gas is separated from imported high caloric case. Low caloric Groningen gas is about 75% of the total final energy consumption of households. About 20% of the energy consumption of households is electricity, which is based for 93% on natural gas, petroleum and coal (see figure 92). Households thus consume for more than 95% fossil fuel based energy and energy neutral dwellings would thus support the energy transition.

Energy neutral dwellings would also decrease the dependency of households on the natural gas connection in the Netherlands. This is required, because of the depletion and because the another available type of natural gas, high caloric, cannot be used without modifications in households. Both cause rising energy prices[16] and especially the rising price of natural gas. That is why energy neutral dwellings increase the possibility to turning off the gas tap in Groningen.

Lastly, besides the need to counteract the problems, there are opportunities, because there is proof of concept that it is possible to cover the household and building related energy usage within the built environment[17], the tighter legislation offers an equal playing field for all real estate developers and there is a business case for future home owners in energy reduction. Enough possibilities and problem-solving capacities why dwellings support the energy transition in the Netherlands.

[16] Appendix 13.1 show the fluctuating prices of energy for households. Energy scenarios are designed in Appendix 13.25, based on data of the RvO (2017e). The base scenario is the average increase of energy in the last 16 years. For natural gas this increase was 3,0% and for electricity 0,5%.
[17] See ZOM-concepts of Bouwmeester (2015), De Wit *et al*. (2016) and Sijpheer *et al*. (2015).

3 Research methodology

3.1 Introduction

This chapter elaborates on the research methodologies used in this research. The research applies aspects from both formal and empirical research and can therefore be called a hybrid research. These concepts are explained in the first subchapter together with why and how they are applied (see 3.2). The research further is divided in a qualitative part and a quantitative part. This is explained after the hybrid research strategy (in 3.4).

These research concepts define the main boundaries of the research. Within these boundaries the research questions and methods are created (see 3.3 and 3.5). Together with the research steps this leads to the final research design, as presented in 3.5.5. The chapter concludes with a reflection on the research design in sense of the expected validity, reliability and generalization.

3.2 Operational and empirical research

This research generates knowledge based on lessons learned from practise. These lessons are used together with theory to design and construct an optimization model. The application of this model is reflected by experts. The first step uses decisions made in the past to create knowledge (which is empirical research) and the second step looks at the future and want to change situations (which is operational research).

Empirical research and formal research thus differ in related approaches and focus. In addition, they also differ in related problems and results. Both concepts are clearly defined by theory. In operational research are engineers dealing with operation-related problems, which can be identified by the "How can..." type of research questions (Barendse *et al.*, 2012). Scientist in empirical research are dealing with knowledge-related problems, which can be identified by the "What is..." type of research questions (Barendse *et al.*, 2012). This focus on the future or past also determines the type of research problems. Within operations research, engineers deal with design problems and within empirical research, scientists deal with research problems. In addition, operations research is about creating new artefacts (material or immaterial), whereas empirical research/ scientists is about creating new knowledge (Barendse *et al.*, 2012). These distinctions are summarized in Table 1.

Table 1: Distinctions between operations research and empirical research (Barendse *et al.*, 2012: 1).

	Operational research	Empirical research
Type	Operation-related	Knowledge-related
Aim	Creating an artefact Changing situations	Producing knowledge Formulating explanation
Relevance	Operational	Theoretical
Subject	Future	Past
Goal	Improvement	Understanding
Methodology	Prescriptive	Descriptive
Science	Formal sciences	Empirical sciences

* Empirical research can look like its subject is in the future. In that case it is highly likely that historical data is gathered and used to predict the future (Binnekamp, 2016). This can be done by a regression analysis.

Both types of research have unique characteristics. When these are generalized to the extreme it can be stated that empirical research needs a hypothesis to be tested. Hypotheses are importance, because they have the ability to bring direction, specificity and focus to the research (Kumar, 2005). Operations research need an artefact. An artefact can be a mathematical model or a design. The first statement implies that data collection alone cannot be empirical research, because of the demanded hypothesis. Addition to the second statement is that the artefact is created by existing data and needs to be tested. These statements are according to the feedback given at the lecture of Binnekamp (2016).

The goal of this research is to improve the future business cases of energy neutral neighbourhoods from the viewpoint of a real estate developer, which is an operational related research. A decision support tool (an artefact) supports the exploration of the optimal business case. However, to optimize these business cases, first knowledge is needed about the possible solutions to optimise this business cases. This is done by investigating past developments of energy neutral neighbourhoods and presented by lessons learned. This focus on the past and future makes the research a hybrid.

Lessons learned from theory and practise are used as direction for the design of the decision support tool. In the research first a conceptual design is made of the decision support tool. Which variables are used, and how are they mathematically related to each other? Feedback from practise on the designed decision support tool is used to determine the added value of the created tool in the decision-making about the business case of energy neutral residential developments. In the end, the tool optimises the input variables of two existing cases studies and compares the results to what have been done in reality.

The first empirical exploration to gather lessons learned does not require hypotheses. This is contradictory to the previous statement made about empirical research. However, this empirical part of the research is to explore the possible solution space and gathers not enough data to truly reject or accept a hypothesis. Instead, the objective of this to gather new knowledge. For this exploration purpose, Kumar (2011) describes an exception in the usage of hypotheses.

> "*In qualitative research, because of the purpose of an investigation and methods used to obtain information, hypotheses are not used and almost no importance is given to them.*" (Kumar, 2011: 93)[18]

Kumar (2011) describes that the emphasis of qualitative research is on describing, understanding and exploring phenomena. In order to test a hypothesis a degree of specificity is needed, which is deliberately not adhered in the qualitative focus of this first part of research. Kumar (2011) also states that "*the importance attached to and the practice of formulating hypotheses vary markedly from one academic discipline to another.*" (Kumar, 2011: 93) and "*in social sciences formulation of hypotheses is mostly dependent on the researcher and the academic discipline, whereas within an academic discipline it varies markedly between the quantitative and the qualitative research paradigms.*" (Kumar, 2011: 93). This makes it acceptable that within one academic department one researcher advocates for the uses of hypotheses in empirical research, while another does not.

3.3 Research questions

The research question provides an explicit statement of what it is the researcher wants to know (Bryman, 2012). In this research the researcher wants to know about the optimal business case for the real estate developer for ENRND, which were demarcated to neighbourhoods consisting of all-electric, single-family and owner-occupied dwellings. This is summarized in the following general research question (GRQ).

> *How can a real estate developer optimise its business case to realize energy neutral residential neighbourhood development projects consisting of all-electric, single-family and owner-occupied dwellings?*

The GRQ is supported by two types of sub-research questions (SRQs), namely knowledge-related and research-related questions. Knowledge-related questions are answered by the literature review and other already known knowledge. They are the foundation of the next chapter.

[18] The quote is found in a .pdf of Kumar (2011) without page numbers, the page number is based on the number of the .pdf document and might not be correct. The quote can be found in the summary of chapter 6.

Knowledge-related SRQs:

1. What is presented in the theory of urban area development for the involvement of sustainability in the multi-actor decision-making processes to realize sustainable urban development projects from the viewpoint of the real estate developer?
2. What is a suitable quantitative optimisation method in urban area development to support complex, multi-actor decision-making? Why? And how can it be applied?
3. What is already known about the barriers and solutions in the decision-making about the aspects in a business case, which are presented in the research framework?

The main theoretical concepts are presented in the answers to this questions.

Research-related SRQs:

4. How is an ENRND-project realized by the real estate developer in current projects?
5. How can a decision support tool optimise the results for the real estate developer in ENRND-projects?
6. What is the added value of the decision support in complex urban decision-making processes for the realization of ENRND-projects?

The presented research framework of Figure 8 is used in the first and third research-related SRQ. Each SRQ thus looks at the three areas of the research framework organisational, finance and physical.

3.4 Research strategy

The research strategy is presented is the coming paragraphs. First a theoretical underpinning of this concepts is presented and afterwards it is applied to the research.

Bryman (2012), Kumar (2014) and Robson (2011) identified three different research strategies: qualitative, quantitative or a combination of both. Bryman (2012) and Kumar (2014) are calling this a mixed method approach and Robson (2011) calls it a multi-strategy. The difference between qualitative and quantitative research is based upon different methods used for data collection, data analysis and data presentation (Kumar, 2014). Kumar (2005) describes the difference. A study is qualified as qualitative if the purpose of the study is primarily to describe a situation, phenomenon, problem or event without quantifying it. A study is qualified as quantitative if a variation in the phenomenon, situation, problem or issue is quantified. In this case the information gathered are mainly quantitative variables and the analysis is geared to ascertain the magnitude of the variation. The use of statistics is not an integral part of the quantitative study (Kumar, 2005). The research strategy thus has an effect on the amount of freedom and flexibility and if the questions predetermined or developed during data collection (Kumar, 2014). In this research a mixed method approach/multi-strategy is applied. The next paragraphs indicate why.

The three proposed research-related SRQs each present a part of the research and are related to different research strategies. This research starts with a qualitative explorative investigation about the current practises in ENRND-projects. A explorative research has the objective to explore an area where little is known (Kumar, 2005). In case possible, some numbers about the amount of dwellings and financial calculations are added, but this cannot be qualified for the quantitative research. The whole approach is rather unstructured. This means that not everything that forms the research process, from objectives, design, sample and the questions asked to respondents, is predetermined. That is why the unstructured approach gives more flexibility. This is useful when an unknown area is explored. The explorative research can also be used to develop, refine and/or to test measurement tools and procedures (Kumar, 2005). Therefore, also the second part is of an exploratory nature. However, its main focus is in operational research, because an artefact is created and its focus is on changing and improving a situation in the future (Barendse *et al.*, 2012). The second part follows the design circle for engineers as presented by Dym and Little (2004). The third part is based on explanatory research. This research types tries to clarify why and how there is a relationship between two aspects of a situation or phenomenon (Kumar, 2005). In this part the model gives quantitative data as outputs of the optimisation process based on different input variables. The objective is to find for the optimal combination of input variables to identify the best possible business case. The third part is also used for verification of the first two parts.

In more detail this research will be a cross-sectional design with case study elements, like explained in Bryman (2012: 69). The cross-section will be made in the current time. Current time means projects currently under construction or recently finished. This is tackled in the sampling criteria. Developments in time during the decision-making and development process are taken into account. Maybe some aspects could be like longitudinal design –used for identifying the effect of time by surveying the sample at least twice (Bryman, 2012) –, but the sample is not surveyed twice.

The research design is showed in Figure 11. This plan of approach also incorporates the research methods, which are presented in the next part.

3.5 Research methods

In this research literature review, expert meetings (e.g. congresses and presentations), case-studies, semi-structured interviews, linear programming and an expert focus group are used as methods. These methods are explained consecutively. The sampling criteria for the case study are briefly address in the part about case studies, but are discussed in detail and executed in chapter 5. In the end of this subchapter is reflected if triangulation is reached.

3.5.1 Literature review

The literature review results in the most important theoretical concepts, which are presented and explained in the next chapter. This body of knowledge gives a fundamental basis for the research. It also ensures that new knowledge is added. The further study is not limited to the concepts presented in the literature review. New concepts and new details can be added in an unstructured research design (as used in part 1). Robson (2011) sees this as a typically for a flexible research design and states that the new features can emerge and evolving during the research project and of the project.

Literature is complemented with congresses and presentations to gather knowledge from experts working in the practise of urban area development. See Appendix 13.7 for the list of visited congresses and presentations.

3.5.2 Case study research with desk research and semi structured interviews

Case studies are used to explore specific knowledge about current practises. Case studies are an implementation of a descripted research, which describes what is prevalent (Kumar, 2005). In that way case studies can present an detailed and intensive analysis of a single case (Bryman, 2012). In this research multiple cases are explored and one case is described in-depth case and will be used to gather multiple lessons learned and identify multiple approaches to successfully realize ENRND-projects. This case is also used in part 3 of the research about the optimisation of the business case.

3.5.2.1 Theory on case studies

"*In a case study design the case you select becomes the basis of a thorough, holistic and in-depth exploration of the aspect(s) that you want to find out about. […] The case study is based upon the assumption that the case being studied is typical of cases of a certain type and therefore a single case can provide insight into the events and situations prevalent in a group from where the case has been drawn. […] it is a very useful design when exploring an area where little is known or where you want to have a holistic understanding of the situation, phenomenon, episode, site, group or community. […] This design is of immense relevance when the focus of a study is on extensively exploring and understanding rather than confirming and quantifying. It provides an overview and in-depth understanding of a case(s), process and interactional dynamics within a unit of study but cannot claim to make any generalisations to a population beyond cases similar to the one studied.*" (Kumar, 2014: 155)

The case must be a bounded system, an entity in itself (Kumar, 2014). An urban area or real estate development project is qualifying for such a bounded system.

Case studies can especially be used to get in-depth insight in the experiences of the stakeholders, the bottlenecks they encountered and whether or not they found solutions to these problems. This knowledge can be used to optimise designs or policies (Swanborn, 2008: 43). A case study can thus be used for an in-depth exploration of the first SRQ.

3.5.2.2 Sampling

The cases have to provide new information on how energy efficiency is reached in urban development projects. Therefore, purposive sampling will be used as sampling method. This a non-probability form of sampling, where the researcher does not sample participants or cases on a random basis. The aim is to sample strategically, so that those sampled are relevant to the research questions. A disadvantage of this method is that the results cannot be generalized to the whole population (Bryman, 2012). The researcher needs to be explicit in what the criteria are that will be relevant to the selection of participants/cases.

The amount of cases is limited by time and money (Swanborn, 2008), and when theoretical saturation is reached. This is a key idea that the researcher carries on "*sampling theoretically until a category has been saturated with data. [… Meaning] that new data no longer suggests new insights into an emergent theory or no longer suggest new dimensions of theoretical categories.*" (Bryman, 2012: 421)

3

Swanborn (2008: 49) mentions that before the selection of cases is executed, it is required to demarcate the type of phenomenon and the units of measurements, where the phenomenon manifests itself. In this case the phenomenon are residential neighbourhood developments with a high energy ambition and the units of measurement are the components of the business case of the phenomenon with its related decision-making process.

The sampling criteria and execution can be found in chapter 5.

3.5.2.3 Data gathering

Data gathering is executed by desk research and semi-structured interviews. First a desk research with second-hand information will be applied. Second-hand information is information gathered from "*articles, journals, magazines, books and periodicals to obtain historical and other types of information.*" (Kumar, 2014: 172). Second, semi-structured interviews are used for more in-depth information, full gabs of knowledge and verification of the data gathered. The research method of semi-structured interviewing is explained in chapter 3.5.3.

3.5.3 Semi-structured interviews with experts and practitioners

"*Interviewing is a commonly used method of collecting information from people.*" (Kumar, 2014: 176) Interviews are classified differently according to the amount of flexibility. Kumar (2014) describes two types of interviews: the structured and the unstructured interview. The first one is characterized by an evolutionary, flexible and open approach, while the second one is pre-determined, rigid and closed. Intermediate are interviews at different levels of flexibility and specificity. "*Unstructured interviews are extremely useful in exploring intensively and extensively and digger deeper into a situation, phenomenon, issue or problem."* (Kumar, 2014: 177) "*In a structured interview the researcher asks a predetermined set of questions, using the same working and order of questions as specified in the interview schedule. […] One of the main advantages of an structured interview is that it provides uniform information, which assures the comparability of data*" (Kumar, 2014: 178) The interview schedule is the list of questions. Those questions could be open-ended or closed and pre-tested. The interview schedule is a tool, while the interview is a method (Kumar, 2014). Unstructured interviews requires more interviewing skills than does structured interviewing (Kumar, 2014). Robson (2011) and Bryman (2012) identified a third interview option, the semi-structured interview. In this category "*the interviewer has an interview guide that serves as a checklist of topics to be covered and a default wording and order for the questions, but the wording and order are often substantially modified based on the flow of the interview, and additional unplanned questions are asked to follow up on what the interviewee says.*" (Robson, 2011: 280)

The objectives of the interviews in this research project are to get in-depth knowledge into a situation and to verify the desk research of the case studies by gathering first-hand information. A flexible and open approach with a certain structure fits best for these objectives. Besides that, the researcher has little experience in unstructured interviewing and a tool like an interview schedule is useful. For that reasons semi-structured interviews are fitting the best within this research. The interview schedule in this case would include introductory comments, a list of topic headings and possible key questions to ask under these headings, a set of associated prompts and closing comments (Robson, 2011).

See Appendix 13.8 for the interview schedule used during the explorative case study interviews.

3.5.4 Optimisation using the linear programming technique

Linear programming (LP) is used as method for optimisation modelling. In this research a LP algorithm is developed that can assist in maximizing the profit of the real estate developer within the constraints of other stakeholders to achieve the requirements for a neighbourhood consisting of all-electric, single-family and owner-occupied dwellings. The theoretical framework provides more information about the LP-modelling technique.

An LP-model in itself is a product-oriented tool. It usage co-determines its added value for the process side and if it can overcome the constraints in the decision-making within the network of actors. The last SRQ addresses to this topic.

3.5.5 Expert focus group

An expert focus group in organized the reflect on the added value of the created LP-model. The expert focus group can be seen as a normal focus group, which is a group of usually at least four people interviewed together at one moment in time (Bryman, 2012), but in this case the focus group consists of experts in the field. Other names also came along, like expert panel or expert session. The focus group suited best, because this is part of a cross-sectional design and it that way it differentiates from the panel study, which is a fixed, random sample used in the longitudinal design for collecting multiple data points at multiple occasions (Bryman, 2012). Expert session is not defined in the used literature and therefore not applicable. That is why the notion of 'expert' was added to the definition of 'focus group'. Experts interviewed at one moment in time in a group consisting of at least four people. The theory also adds that a focus group needs an emphasis in the questioning on a particular fairly tight defined topic (Bryman, 2012). This is executed by handling only one question. The accent in a focus group is upon interaction within the group and the joint construction of meaning (Bryman, 2012). In that way the group can discuss upon the added value of the LP-model and create a shared opinion. The participants are selected based on their knowledge about decision support tools and the topic of energy neutral residential developments. This is the same non-probability sampling method as used for the case study selection.

The focus group session needs a moderator or facilitator (Bryman, 2012). If possible, the researcher tries to let somebody else be the moderator and be the observer within the group interview.

3.5.6 Triangulation of research

The usage of these different research methods and the notion that these are related to different research strategies of data collection cause triangulation of the research. Triangulation is "*a valuable and widely used strategy involving the use of multiple sources to enhance the rigour of the research.*" (Robson, 2011: 158) Triangulation can be reached by using more than one method for data collection (data triangulation), using more than one observer (observer triangulation), combining qualitative and quantitative approaches (methodological triangulation) and using multiple theories or perspectives (theory triangulation) (Robson, 2011).

In the first part of this research multiple cases and semi-structured interviews ensures data and observer triangulation for the case studies. The use of data from the LP-model, expert interviews and the expert focus group has to ensure the data triangulation. Theory triangulation is ensured by the use of multiple references to make a bold statement. Theory triangulation is also applied for the development of the LP-model by checking the method used with multiple references. Methodological triangulation is ensured by the qualitative first two parts and its quantitative optimisation in the last part.

3.6 Research design

The research design is a road map, plan, structure and strategy that the researcher decides to follow to obtain valid, objective and accurate answers to the research questions as economically as possible (Kerlinger, 1986; Kumar, 2005, 2014). It obtains procedures and logistical arrangements to undertake the study and thereby the research design is the conceptualisation of the operational plan to undertake the various tasks to complete the research (Kumar, 2005).

The operational research design of this research is based on a combination of the research steps from empirical research, formal research and the five stages of an operation research project, as explained in Kumar (2014) in Barendse *et al.* (2012: 4), Dym and Little (2004) in Barendse *et al.* (2012: 3) and Ackoff and Sasieni (1968: 11) in Barendse *et al.* (2012: 7):

1. Problem definition
2. Conceptualizing the research design
3. Instrument: Research methodology
4. Sampling: Case selection and desk research
5. Collecting data, methods used:
    a. Literature review
    b. Semi-structured expert-interviews (preparation and execution)
    c. Case studies by desk research and semi-structured interviews
6. Constructing and validating the model
    a. Clarify objectives, user requirements, constraints and functions
    b. Conceptual design (specifications and alternatives)
    c. Preliminary design (analyse, test and evaluate)
        i. Evaluate results by comparing modelled results to real life (verified) results
        ii. Evaluate results by unstructured interviews with experts
    d. Detailed design model: Redefine and optimize model (continuously)
    e. Final design model
7. Collecting data (2), methods used:
    a. Applying model to derive the solution and evaluating the solution
    b. Expert focus group to evaluate the constructed model
8. Conclusions
9. Discussion
10. Recommendations

In the sixth step about constructing and validating the model, the model is continuously tested by evaluating its derived solutions. This is in line with the third and fourth step of Ackoff and Sasieni (1968: 11). More information about the design approach is described in chapter 6. The last step of Ackoff and Sasieni (1968: 11) is stated as 'implementing and maintaining the solution'. This step is skipped as this project is a research project. Instead recommendations are given how the derived solution can be implemented or further researched.

These steps and the related methods are summarized in the research design of Figure 11.

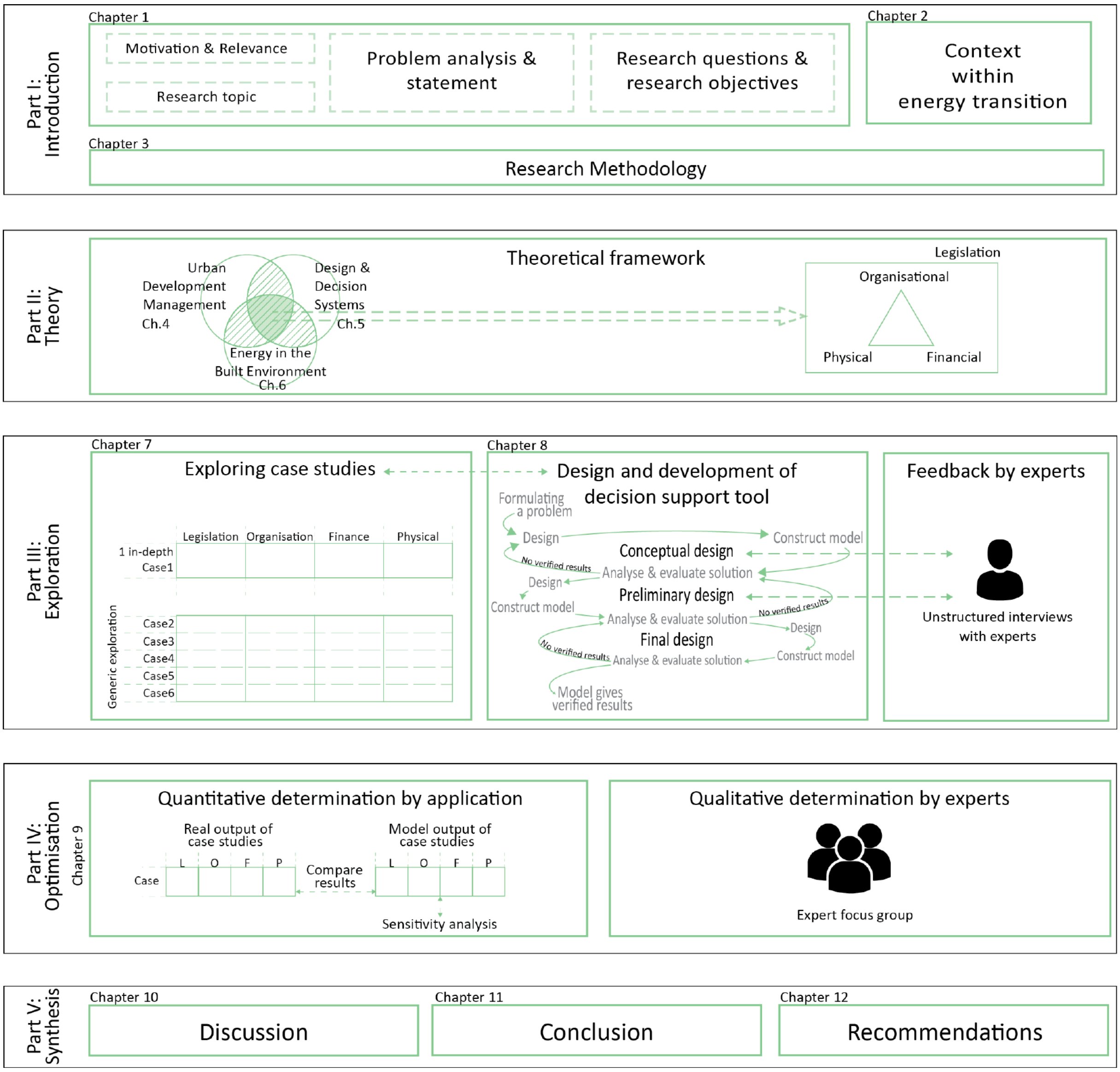


Figure 11: Research design based on the research steps and reading guide (own illustration).

3.7 Validity, reliability and generalization

This section reflects on the proposed research design by stating expected limitations in sense of validity, reliability and generalization. This will help to identify possible risks during the research and this can also be the guideline for the discussions and recommendations for further research.

First, the topic of validity and reliability. “*Validity is the ability of an instrument to measure what it is designed to measure.*” (Kumar, 2014: 213) and a research instrument can be called reliable if it is “*consistent and stable, hence predictable and accurate.*” (Kumar, 2014: 215). For qualitative research “*none of the methods of data collection provides 100 per cent accurate and reliable information.*” (Kumar, 2014: 172). Some factors are affecting the reliability in social sciences: the wording of questions, the physical setting, the mood of the respondent or interviewer, the nature of interaction and the regression effect of an instrument (Kumar, 2014). According to Robson (2011: 156) threats to validity in flexible designs can be categorized in three main types: description, interpretation and theory. In ‘description’ is the main treat making a valid description, because of inaccuracy of incompleteness of data. In ‘interpretation’ the main treat is imposing a framework or meaning on gathered data rather than letting this emerge or occur from what you learn. The main threat in ‘theory’ is not considering alternative explanations. These three can be tackles by fully transcribing interviews, check interpretations on appropriateness (for instance by others) and actively search to data which are not consonant with your theory (Robson, 2011). The threat of interpretation is also mentioned by Kumar (2014: 197) as "*Personal bias – Information from personal diaries, newspapers and magazines may have the problem of personal bias as these are likely to exhibit less rigour and objectively than one would expect in research reports.*"

"*There seem to be no set procedures for determining the various indicators of validity and reliability in qualitative research.*" (Kumar, 2014: 220). But he advices to improve the validity and reliability in this type of research by (Kumar, 2014):

1. Justifying your choice of research method, it is important to highlight the strength and its weaknesses, as well the relevance to the main objectives of the study.
2. Operationalize major concepts, and how they will be measured.

The main concerns mentioned in the first paragraph are the threats of inaccuracy, incompleteness and a personal bias within the first qualitative part. These are tried to be tackled by the triangulation. The qualitative part consists of the case studies. By using theory, semi-structured interviewing and desk research a coherent, accurate description should be given. Incompleteness is tackled by first doing a desk research and later verifying the results and filling the gabs with the semi-structured interviews. The last aspect of personal bias is likely to occur within the case study selection. This feeling can be further motivated by a sensitivity to subjectivity of the selected sampling method of purposive sampling. This needs to be executed carefully with a clear description of the method performed. For the reason of validity and reliability, in the structure of the previous parts is first theoretical underpinning given and afterwards the application to this research. The operationalization will be more clear after the literature review.

Lastly, the topic of generalizability. For two reasons, it is unlikely that the results out of the case study can be generalized for the whole population of the same type of projects. First, it is an assumption that the selected case study is typical for a certain type of cases (Kumar, 2005). Kumar (2014) adds to this that the objective of a case study is not to confirm or quantify, but to an overview and in-depth understanding and that is why any generalization to a population beyond cases like the one studied cannot be claimed. And second, Bryman (2012) explicitly state that the disadvantage of the used sampling methodology of purposive sampling is that cannot be generalized to the whole population.

For that reason, the conclusions about the case study cannot be generalized to the whole sample, irrespectively the level of validity or reliability of the research findings. That is why the first part results into lessons learned. These could be opportunities for new projects and those have to be investigated by them.

PART 2
THEORY

Energy ambition	Mix: ZOM, energy neutral & building degree
Project	‘Helsdingen’
Location	Vianen
Real estate developer	Blauwhoed

4 Effective decision-making in sustainable urban area development

4.1 Introduction

The focus of this chapter is on the urban development process and provide an answer to the first knowledge-related sub-research question:

> *What is presented in the theory of urban area development for the involvement of sustainability in the multi-actor decision-making processes to realize sustainable urban development projects from the viewpoint of the real estate developer?*

First, a general description of the urban area development process is given, including the main categories of involved actors and the phases. This is followed by explaining the chances within the field. Thereafter the main actor of this research, the real estate developer, is further investigated by identifying its goal and different appearances in the field. Fourth, the topic of sustainability and the relationship to the real estate developer is explored. What are incentives and barriers for the real estate developer to involve sustainability? Finally, two main approaches for involvement of sustainability during the multi-actor decision-making processes in urban area development are presented. One of them is selected as most suitable for the topic of energy efficiency and proving a positive business case.

4

The aspects of this business case and the realization of energy efficiency are elaborated in chapter 6. This chapter takes a more general focus on the involvement of sustainability in urban development projects.

4.2 Basics of urban area development

These paragraph explain the definition of urban area development, the involved parties and the phasing of the process.

4.2.1 Defining 'urban area development'

Franzen *et al.* (2011: 9) positions urban area development as a "*part of a broad range of activities involving government intervention at various levels, from local (municipal), regional or provincial to national or even international level, and in interaction with the activities of private organisations such as property developers*". The goal of urban area development is "*the development of a specific area within a town or city or the expansion of a town or city, which generally has an identity of its own.*" (Franzen *et al.*, 2011: 10)

There is a difference between 'urban development' and 'urban area development'. According to Franzen *et al.* (2011: 17) the difference is in the aim of developing urban areas: "*Urban development manifest itself through spatial changes in various areas, which act in mutual correlation to form the urban region and shape its functioning. Urban area development is aimed at developing these particular areas.*"

Lastly, urban area development is more than a spatial development and it must take into account economic, social and various other developments (Franzen *et al.*, 2011: 18).

4.2.2 Involved actors in urban area development

The definition of an actor is "*an individual or an aggregated social entity (collective actor) that has the ability to make autonomous decisions and act as a unit.*" (Pahl-Wostl (2005) in Glumac (2012: 13)). Thus, in order to be seen as separate actor one should have the ability to make own decisions. The urban area development process is shaped by the actors involved. "*A distinction can be made between actors in the public and private sectors. Additionally, local citizens and other parties involved in an area, need to be taken into account in urban area development.*" (Franzen *et al.*, 2011: 26) Those three different categories of actors are discussed below. Wamelink *et al.* (2010: 401) sorts the actors according to the same three categories and adds the amount of influence: directly involved into the project, indirectly and the external surrounding.

4.2.2.1 Public sector

The public sector consists of governmental parties, such as the municipality. The municipal players make decisions about a specific urban area development. They do it either by public law (e.g. creating the land-use plan, granting building permits, etc.), or by private law (Franzen *et al.*, 2011: 26). In case the municipality solely focusses on public law and are willing to support the development, they take a facilitating approach. In the last approach, also called active land development or active land policy, the municipality pursuits its own land development. Franzen *et al.* (2011: 26) explains that it is fairly common for municipalities in Dutch practise to develop land or to establish development companies. In addition, the municipality can also participate as a partner in a development or in a development company. More about these partnerships can be read in chapter 6.4.2.

4.2.2.2 Private sector

The private sector consists of market parties. There are many different types of actors who participate in urban area development. Franzen *et al.* (2011: 27) named the real estate developers, investors, builders, urban designers and architects, owners of land and buildings, real estate agents, housing associations and the end-users. More about the real estate developer and its appearances can be read in chapter 4.4.

4.2.2.3 Civil society: Citizens and interest groups

The last group is the civil society. Franzen *et al.* (2011: 29) sees them as an important category. It consists of citizens and other (current) users or representatives of the area where urban development takes place. *"The interests of these users often differ significantly. For instance, shop owners might desire car accessibility in an entirely different way to residents."* (Franzen *et al.*, 2011: 28) "*We can also count organised civic societies (or voluntary interest groups) among the parties involved. The type of organizations can also operate at national level (e.g. pressure groups).*" (Franzen *et al.*, 2011: 29)

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These categories of actors all have it place in the development process (see Figure 12). The figure is an example, the amount of involvement per phase can differ (see chapter 6.4.2 about partnerships).

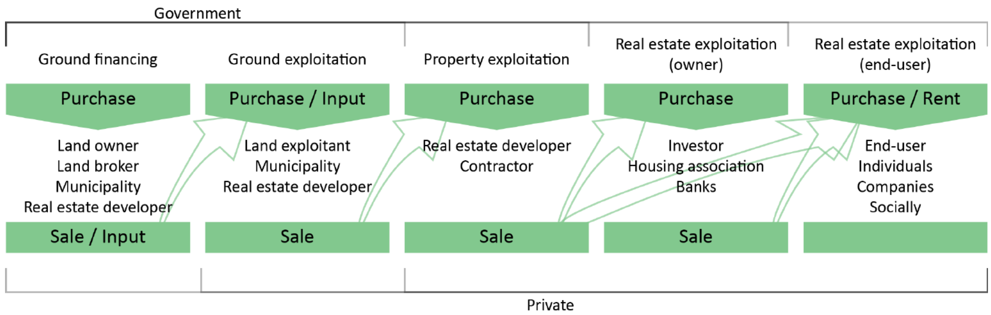

Figure 12: Actors involved during the different stages of the development process (own illustration, translated and adapted from J. C. De Jong (2016: 26)).

4.2.3 Phases in urban area development

The development of an urban area takes places in several successive phases. Franzen *et al.* (2011: 90) divides the process into four recognizable phases: Initiation phase, planning phase, realisation phase and the maintenance phase. In the first phase the ambition must be established and goals are set. The ambition has to be common ground for all actors and the goals must be seen in the social and political context (Franzen *et al.*, 2011: 91). In the second phase, all sectoral and facet-related aspects must be developed into an integrated plan in such a way that the plan offers the best possible spatial and functional quality, and that it is feasible in terms of available means (Franzen *et al.*, 2011: 91). Third, the plan is realized in the realization phase by all the relevant parties that came to an agreement in the previous phases (Franzen *et al.*, 2011: 91). In the last phase, called maintenance phase by Franzen *et al.* (2011),the operation take place.

Glumac (2012) describes a more detailed picture of the phasing. Based on Hieminga (2006) the researcher identified the following (re)development phases: **Initiative**, land acquisition, **plan development**, financing, **realization**, renting / Sale, **management / Exploitation** and demolition. The four bold phases match the phases of Franzen *et al.* (2011). "*At each phase exist a final product, defined process and actors that have different interests.*" (Glumac, 2012: 10). In these phases different actors are involved in different processes with different products as results. This research is demarcated to the first initiation phase, the exploration of the possibilities for the development of a feasible plan. Table 2 gives an overview of the characteristics of those phases by presenting the involved market types, actors, processes and products. The process aspect shows how a window of opportunity in a market get to an idea, which is applied on a location and has finally a design as result.

Table 2: Phases and characteristics of the early stages in (re)developments (Hieminga (2006) in Glumac (2012: 11)).

Phase	Market	Actors	Process	Products
Initiative	Land market	Developer Owner/user Investor Broker Market research company	*Market -> idea* Initiative Feasibility Definition	Market analysis Feasibility study Program in brief Project plan
Land acquisition	(Brownfield) market	Landlord Developer Municipality Notary	*Idea -> location* Location assessment	Location analysis Soil research Program in brief
Plan development	Market for design services	Urban designer Civil engineer Other advisors	*Location -> design* Design Test Re-adjust design	Sketch design Preliminary design Final design Changes in zoning Specification Construction design Building permission

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4.3 Changing practise

The profession of urban area development is changing during the last decennia. The most important changes are discussed in the next paragraphs. The influence of sustainability is not discussed. This involvement is explained later.

First, a short introduction in the practise of urban area development as it was, the major indications of change and the new role of the private sector. Peek and Van Remmen (2012) have outlined the features of this new style by following 24 innovative practices for their publication Urban Area Development – New style (Dutch publication: "*Gebiedsontwikkeling Nieuwe Stijl*"). These practices highlight working from the end-user demand, taking sustainability as a starting point and transformation of existing properties rather than new construction and expansion (Peek & Van Remmen, 2012), the usage of other development strategies, new activities and new roles of initiators, private parties and governments (Bentvelsen, 2014). In other words, use what you already have, do it in a sustainable way and ensure that it meets the demands of the end-users (Peek & Van Remmen, 2012). An important objective is to realize an attractive living and working environment. An attractive environment secures future value, which preserves the real estate value on the long run and leads to attracting financial capital and new employees. In financial terms, the end-users do not only look at the purchase price of a property, but at the total costs of ownership. Combining purchases (e.g. energy, waste streams and facility services) can save costs and capture the long-term value. This is called value creation and demands for a broad business case (Bentvelsen, 2014). Value creation means that besides the ground exploitation, also the costs and revenues for energy, park management and services are involved.

The new style of urban area development changes existing collaboration. Peek and Van Remmen (2012) explain it by on the one hand, by introducing the parties of the flows (e.g. energy, waste and ICT related parties), and on the other hand, by involving end-users and real estate owners in the development process. This calls for a change in attitude and behaviour of traditional parties, such as the municipalities and their current partners. First of all, they have to create space for new parties and be open to another method. In addition, the role of investor rather than developer is better suited to the new process, because an investor directs a long-term return on investment from the ground exploitation and is aware of the value development of his existing property. (Peek & Van

Remmen, 2012: 5) The traditional risk-baring developer is thus disappearing in urban area development 3.0 and a directing government withdraws. New forms of cooperation and financing between government, market parties, entrepreneurs and individuals emerge. Sustainability and transformation have become important topics. In all this, the end-users are much more central. (Bentvelsen, 2014)

Some definitions of the styles of urban area development are shown in Table 3. Peek and Van Remmen (2012) see a combination of the project size, the development approach and the ecosystem as main focus, whereas the Kadaster (n.d.) sees different styles and levels of participation in urban area development as the main focus of the definition. For them the spectrum goes from UAD 1.0, with the government in the lead, till UAD 3.0, where the owners/partners of the location take the initiative themselves and develop the plan.

Table 3: Different definitions of the changes in Urban Area Development (Kadaster, n.d.; Peek & Van Remmen, 2012: 17)

	Peek and Van Remmen (2012: 13; 17)	Kadaster (n.d.)
UAD 1.0	Before financial crisis; Project development on a large scale	The government is in the lead and is looking for support in the area
UAD 2.0	The current approach; Organic development	The government is developing a plan together with the area partners
UAD 3.0	New style urban area development; Linking real estate, use and flows	The partners in the area take the initiative and develop the plan.

The next paragraphs describe each one topic of change within the practise of urban area development.

4.3.1 From a (traditional) hierarchical society to network society

The introduction of ICT has introduced a new basis for organising society, which "*had led to a drastic restructuring of production processes, now characterised by greater flexibility in forms of management, decentralisation and networks between and within companies.*" (Franzen *et al.*, 2011: 37) This introduced has also increased the speed of change. "*This has happened in conjunction with an equally speedy process of globalisation. These factors have significant consequences for the functioning of societies and the cities they inhabit. In metaphorical terms, one often speaks of the 'Network society'. [...] Essentially, [a network society] is a society organised mainly around streams of goods, people, money and information. The scope of these networks has become so vast because of the potential offered by information technology: distance has become almost irrelevant. Network of various forms overlap, are subject to constant change, and sometimes converge to form a high concentration of networks (for example at regional level).*" (Franzen *et al.*, 2011: 21) "*In a network society, physical proximity loses its significance: the term refers to a new situation where social, economic, as well as cultural relations are bound yet without physical ties. A network society is a society where social, economic and cultural structures are no longer determined by the shared use of a certain space.*" (Franzen *et al.*, 2011: 37) This also created non-location-bound activities, also referred as footloose industries (Franzen *et al.*, 2011). "*These new conditions have also led to new forms of control and management, evolving to a total departure from the traditional forms of control, where in control is held by one central actor, namely the government.*" (Franzen *et al.*, 2011: 46) The difficulty of a network society (and the shift from government to governance) is that "*all the different visions, interest and opinions that come into play during the trajectory are streamlined into a collaborative whole – this is governance. In this trajectory, the municipality increasingly depends on private parties, other government bodies and decision-making that takes places outside the realm of the municipal territory*" (Franzen *et al.*, 2011: 46) Concluding, the shift to a network society leads to the involvement of more parties on the same hierarchical level, a reduce connection to physical phase and new forms of management, called governance.

4.3.2 New role of the government in urban development

The role of the government is changing (Heurkens, 2012). Last 100 years the government was actively involved in urban planning. From the start of the 20th century they wanted to secure greater quality neighbourhoods and integral developments. After the World War II the governments was the leading party in making spatial visions and urban designs. In that time, extensive steering of the government in the planning and design phase was self-evidence (De Zeeuw *et al.*, 2010). The government secures the development program, which was built by real estate developers and housing associations. These developments got built with minimal design influence of inhabitants. The upper left part of Figure 13 shows the government in control of urban development, mostly done by an active land policy.

Around 2000 this changed, public and private parties starting collaborating in public-private partnerships (upper right part of Figure 13) and the land development was done together. Active ground policy has a major financial risk and requires municipal parties to work on conflicting interests, such as the public and financial goals (Kam, 2007). This became clear with the major financial losses for municipalities after the financial crisis (Rfv, 2015). Most municipalities shifted to a passive ground policy, shown as third step in Figure 13. In this case land development is done under the control of private parties. In case of private realization with a facilitating government, the government waits for initiatives, facilitates initiators and land owners in design and development without own investments and they determine the rules of the game. The increasing role of private parties in public policy processes is visible in that private parties are setting the agenda and in implementing policies (Franzen *et al.*, 2011). Although this shift is not new for Anglo-Saxon countries, like the United Kingdom and the United States of America, it is a great shift for the Netherlands with its strong government-driven development tradition in the 20th century (De Zeeuw *et al.*, 2010). "*In addition to these commercial organizations, there are many other organizations, companies and citizens willing to increasingly invest in spatial development projects.*" (De Zeeuw *et al.*, 2010: 905). This is also a result of the emergence of the network society.

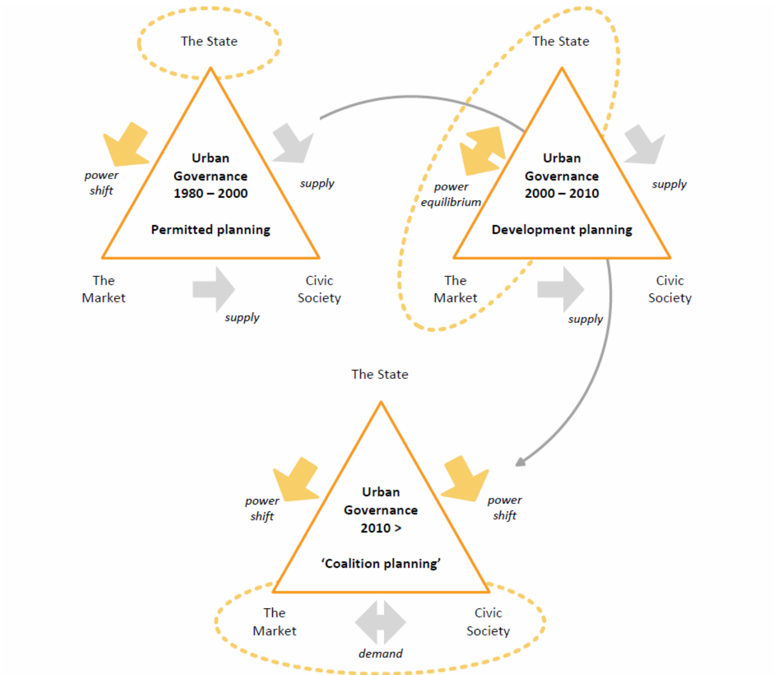

Figure 13: Dutch urban governance shifts over time (Heurkens, 2012: 140).

The result of this new playing field is that the urban area development process is getting more difficult. Instead of one party (the government) making the vision, multiple parties have to agree towards the same vision. This shift enlarges the importance of the process aspect in urban area development over the product aspect. Besides, a different party is taking over the leading role and the responsibility and risks of land development shifts from the public sector to the private sector (Franzen *et al.*, 2011).

Glumac (2012) not totally agrees with Heurkens (2012). He states that the traditional linear planning focus of the government have been replaced by public-private collaborations, which would be Figure 76 and upper right part of Figure 13. Glumac (2012) agreed upon the major influence private parties now have in the urban development processes. This shift leads to a lack in consensus among key actors due to shared, overlapping concerns or individual conflicting interests.

Regardless of which researcher it right, currently the private sector is involved in the early phases of urban area development, creating complex multi-actor environments for decision-making.

4.3.3 From blueprint thinking to dynamic and sustainable forms of planning

Last two decades the traditional centralised master planning or blueprint approach shifted to a new concept of planning as a process (Chatterji & Soni, 2016). According to Hall (1996) the former approach assumed that the objectives were fixed from the start and in the new approach the planning process was independent of the thing that was planned. Based on Hall (1996), Chatterji and Soni (2016: 64) explain that master plans are encountering difficulties of implementation after a change in government, because the new government often changes the economic plan to fit their policies, which often result into a mismatch with the fixed objects of the masterplan and inadequate political support. This is one of the reasons that the former top-down approach of planning and design was inappropriate to the long process of urban area development. Secondly, the top-down approach misses the ability to adapt the plan in latter stages of the process to changing market conditions (De Zeeuw *et al.*, 2011: 3).

The new method based on flexibility and a strategic development framework reduces the risks and creates more resilience. This is achieved by several measures: 1) the design of a much global final image in which only the framework of the plan is fixed, 2) early linking of calculations and drawing, 3) strategic and flexible phasing options, and 4) early involvement of end-users (De Zeeuw *et al.*, 2011: 3). This demand for flexible urban designs and development planning required a huge change in methods of all involved parties and makes it difficult to make final calculations for the final design, as flexibility and ranges needs to be incorporated in the calculations.

In practice this change in development strategies was also noticed by Mantel and Van Remmen (2014). They observed a change from the traditional approach whereby one land operator (either the municipality, a real estate developer or a public-private partnership) takes into account the integral development and realization of an area towards a development strategy based on step-by-step transformations of the area into the desired direction. In this case the pre-investments and risks of this process, which were considered too big by municipalities, real estate developers and banks, are replaced to a strategy in which several investors take part into the total business case. In the chapter about finance (in section 6.5.3.2) this change from one big ‘bathtub’ to several ‘sinks’ is elaborated more in detail.

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4.3.4 Focus from ground exploitation to real estate exploitation

Before understanding the change, it must be said that the fragmented building sector has as result that the value chain of real estate development is scattered among a lot of parties, as shown in Figure 14. The development has to be paid back by the users. As can be seen in Figure 15 the developers play a central role in connecting all the different actors in urban area development.

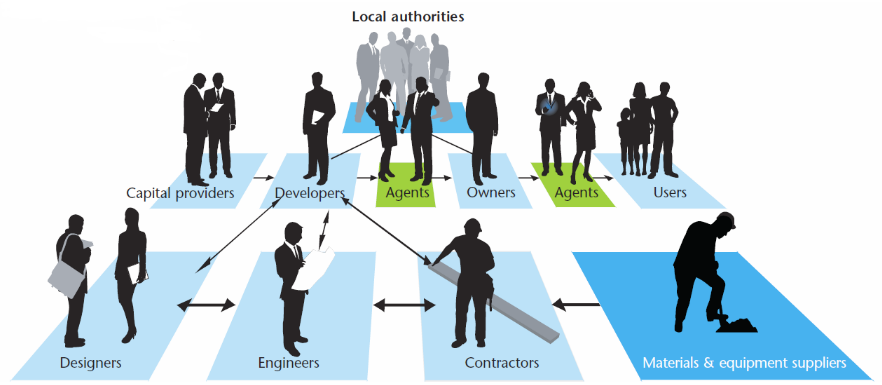

Figure 14: The complex value chain (WBCSD, 2007: 14).

There are three different financial phases in urban area development: the development of land, the development of real estate and the use of real estate (Franzen *et al.*, 2011: 183), as shown in Figure 15. The figure also shows that the investment is needed upfront and the return is in the end.

According to Putman (2010), there is a shift from the focus on government as the key partner to the end user of real estate (see Figure 15). In the period before the financial crisis of 2008, the real estate developer was focussed on the acquisition of land and involved in speculative development. A ground position gives them the possibility to become a partner of the municipality. In a collaboration process with the municipality the real estate developer created value with the change of the land-use plan. The urban planning process with the municipality as a partner was thus an important element in the pre-crisis period. The crisis made both parties aware of the risks they were facing with these kind of speculative behaviour. The result was that end-users got involved in the process more earlier and a shift occurred in the creation of a business plan from the focus on land acquisition to a focus on the exploitation of real estate. This shift of focusses to the end-use of real estate and demand-driven operation moved the role of the real estate developer backwards into the value chain (Putman, 2010). The financial aspects of this and the effects are explained more in-depth in the sections about new involved actors (chapter 6.4.4.1) and about real estate finance (chapter 6.5).

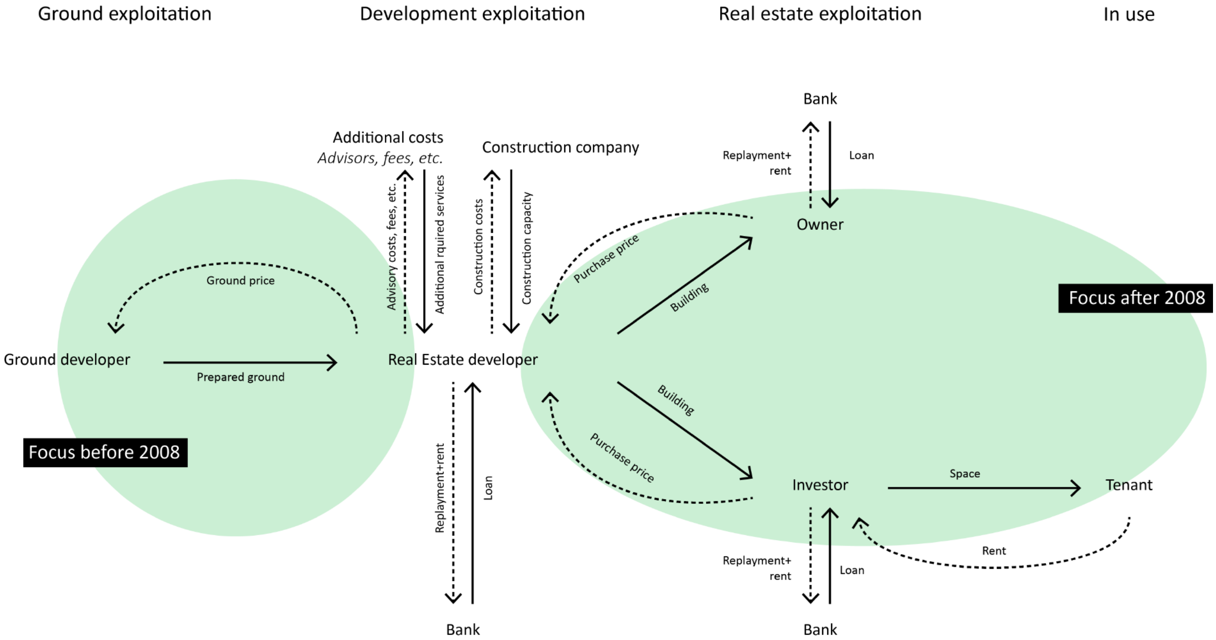

Figure 15: Shifting focus real estate developer (own illustration based on Putman (2010)).

4.3.5 Change in procurement

Since the building fraud new selection criteria for procurement are applied and to tackle the fragmentation of the sector (see Figure 14) new forms of organization are introduced. The building fraud created enormous distrust towards the construction industry. Whereas previously the lowest price was used as selection criteria, clients shifted selection based on quality aspects. This was an incentive to set the demands of clients as a starting point in the development process (Dicke & Smulders, 2005). This new procurement type is called a the Most Economically Advantageous Tender (Dutch: '*Economisch Meest Voordeligste Inschrijving*', EMVI). Chao-Duivis, Koning, and Ubink (2010: 144) are giving an enumeration of the criteria that could be involved, namely price, quality, technical merit, aesthetic and functional characteristics, environmental characteristics (including characteristics relating to production methods), etc. The last criteria demonstrate that involvement of the sustainability aspect could be more in this approach. Rijkwaterstaat (2014) confirms this by mentioning that a MEAT-tender does not only take into account the price, but also the quality. Quality includes public focus, sustainability and project management.

The second change is the formation of new organizational forms. In this case the client, building company, architects/designers and consultants have different roles and the distinction between design and construction phase is disappeared (Dicke & Smulders, 2005). Chao-Duivis *et al.* (2010) describes them as integrated contract models[19]. These integral contract forms, leading to a non-traditional form of organization, could make the fragmented building sector handling more collaborative.

4.3.6 Greenfield to brownfield development

The last change is the emergence of brownfield development. A brownfield is a location which has already been developed before. Existing buildings have to been taken into account, which enlarges the complexity of urban area development. Glumac (2012) states it as that the scope and scale of urban redevelopment projects is increased since 1999. "*The complexity of a brownfield redevelopment results from various physical, legal and financial issues underlining the involvement of numerous parties on various levels.*" (Glumac, 2012: 5)

[19] Chapter X and Appendix 13.11.2 provides more information about these integrated organisational forms and related contracts.

4.3.7 Conclusion of the changing practice of urban area development

The urban area development process is getting more and more complex. In current urban area development actors are situation in a horizontal, network society. More actors are involved in the decision-making. Huge masterplans are not flexible enough for the prolonged processes, which changed the project results to more flexible urban strategies. End-users are also more involved in the process for the financial feasibility. The focus is more on the final result instead of the land development. And more location factors have to be taken into account, because of the development shift from greenfield development to brownfields. In order to make the process less fragmented, which also tackles this complexity, new organizational forms are more and more used. More actors, a new process and different expected results are making the decision process more complex. The last part of this chapter continues on this topic of multi-actor decision-making.

4.4 The real estate developer

This part is about identifying 'the private sector' in this thesis.

4.4.1 Defining 'the real estate developer'

The focus in this thesis is on the real estate developer as part of 'the private sector'. The goal of the developer is according to Putman (2010: 31) mainly on increasing its own margin. Its therefore important for the developer to control costs and increase and optimise their own value.

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Franzen *et al.* (2011: 27)[20] explains them in the following way: "*Private project developers play a significant role in some processes or urban area development. At their own expense and risk, they undertake projects within the context of the current market. Their investment is mostly in buildings, thus taking relatively short-term financial risks. Within the world of developers we can identify many types, including a range of combinations with investors, builders, banks, and sometimes also architects. The developers also tend to specialise in a certain sector, such as housing or retail. [...] Furthermore, with greater frequency, companies that were originally builders now play an active part in more integrated area development.*"

4.4.2 Developing investor vs. real estate developer

Real estate developers and investors are broadly divided into groups, namely the institutional investors, the real estate investment funds (REIT's), private investors, housing associations and real estate developers. These groups differ considerably in the required rate of return, risk profile and payback time. Within these groups there are also difference between the companies. (Peek & Van Remmen, 2012: 26) Two main types of real estate developers can be distinguished: the developing investor and the real estate developer.

First, real estate investors are interested in improvement of the long-term financial yield of operating real estate in the exploitation phase by realizing a direct return through recurring rental income and an indirect return through increasing property value that is capitalized when the object is sold (J. C. De Jong, 2016; Peek & Van Remmen, 2012; Putman, 2010). This can be either as an investment of capital in the equity certificates of real estate in order to increase the capital value or by investing in real estate as means of production (Sturm, 2014; Van Gool *et al.*, 2013). Real estate is considered a profitable long term investment (J. C. De Jong, 2016; Sturm, 2014). The focus of the investor is mainly on the operating or exploitation phase of the urban development process (Van Gool *et al.*, 2013). The investor can invest direct and indirect in real estate. In the first case the investor owns the building and in the second case a collective fund owns the real estate, for instance a Real Estate Investment Trust (REIT) (Van Gool *et al.*, 2013). The emphasis of a developing investor is on value creation by developing real estate and keeping it in their own portfolio.

Second, the real estate developer wants to realize a new real estate project by bringing together ideas, management, labour, capital and land (Van Gool *et al.*, 2013). The real estate developer is risk-bearing by investing in land acquisition, plan development and preparations to property development (Putman, 2010). The real estate developer is focused in the first phases of urban area development and wants to sell the realized project after completion. That is the main difference with the developing investor, who wants to keep the project in its own investment portfolio.

[20] Franzen *et al.* (2011) uses property developers and (private) project developers as the terminology for real estate developers.

Buskens (2015: 112) describes that research of Sturm (2014) and Stumpel (2014) showed that investor-led development in the Netherlands is not taken for granted and is not an accepted appearance. This is caused by the limited possibilities within the regulations in the Netherlands in comparison to Anglo-Saxon counties (Heurkens, 2012). Heurkens (2012) argues that because of this, it is not likely that a shift towards investor-led urban development will occur in a short time frame. For this reason, the real estate developer will take a central role in this thesis instead of the developing investors.

4.4.3 Different types of real estate developers

Several subcategories can be distinguished within the main category of real estate developers. These subcategories are based on underlying reason to take part in real estate development. Table 4 shows several subcategories identified by Buskens (2015: 110) and Hieminga (2006) in Glumac (2012: 15).

Table 4: Characteristics of real estate developers based on goals and objectives in a more structured typology

Buskens (2015: 110)	Hieminga (2006) in Glumac (2012: 15)	Examples
Project developers emerged from or related to building companies	Contractor: Goal of this group of developers is to reach a high building production through project development. This group is also called developing constructors. This group is relatively large because almost all middle-sized and big construction companies have a project development unit. This group is largely represented in the development of owner-occupied houses.	AM (BAM) Dura Vermeer Heijmans Van Wijnen VolkerWessels VORM
Independent project developers	Independent project developer: This group of developers is not associated with other branch-related activities, like the developers that are a part of a construction company. Project development is a goal in itself. Through the project development activities, the continuity of an operational management and high returns on investments are pursued for shareholders.	Blauwhoed
Project developers related to institutional investors or private equity[21]	Asset investors: This type of project developer keeps the real estate in their own portfolio after investors development. This group considers real estate development as a mean to come to good real estate investments. Some of the big institutional real estate investors also develop real estate themselves – using the fiscally attractive status of an investment company – but this category mainly exists from wealthy particular investors.	Amvest Syntrus Achmea Pinnacle
Project developers emerged from or related to financial institutions	Financial institutions: They are also active in project development.	Bouwinvest BPD
Others	Social housing associations: They are increasingly active and influential on the commercial real estate development market after the liberation in 1995. Project development is a mean for social housing associations to finance uneconomic social investments.	Woonbron Alliantie
	Architects: For them, development activities are the means to perform design services. Considering the complexity of the total building process and the required (big) size of architectural companies to be able to do this, this group of project developers is relatively small.	

4.4.4 Involvement of the real estate developer in Urban Area Development 3.0

The involvement of the real estate developer is different as the developing investors, because the process of investment differs from the real estate development cycle. Traditionally, the investment cycle of this category of

[21] The addition of 'private equity' is not in the original source.

investors starts by a turn-key acquisition of a real estate object (Sturm, 2014; Van Gool *et al.*, 2013). After that the core business of this actors starts by the exploitation of the object (Peek & Van Remmen, 2012). Therefore, real estate investors had relatively little influence in the development process. When the economical or technical lifespan of a real estate object has ended, the investor has to decide whether they stay involved by redeveloping the object or stop the involvement by selling the object. If they decide to redevelop, a new exploitation phase starts after realization.[22]

It is more of the opposite for the real estate developer. They are involved in the development of the object, but sell it after realization. The growing influence of investors and their related demand of real estate is an argument to take their interests into account during the real estate developer. One of those aspects is the involvement of sustainability.

4.5 Incentives of real estate developer for sustainability

This part describes incentives for the private sector / real estate developer to incorporate environmental sustainability in urban development processes.

The real estate developer focus is on increasing its own margin (Putman, 2010). The (natural) environmental provides development space (land) for the developer. Environmental sustainability is only one part of the three sustainability components of people, planet, profit (or equality, environment and economy) (Rogers, Jalal, & Boyd, 2008). In Figure 16 and Figure 17 is shown that this is just a small component within the project for the real estate developer.

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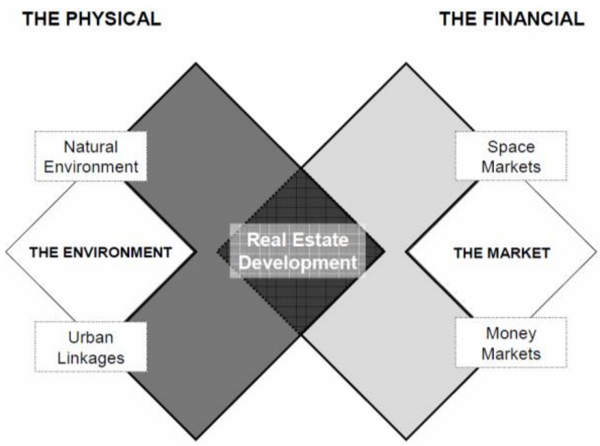

Figure 16: Real Estate Development: Synergy of physical and financial dimensions (Leelarasamee, 2005: 15).

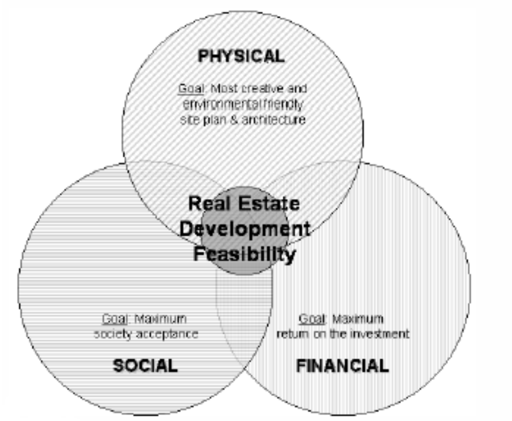

Figure 17: Real estate development feasibility (Leelarasamee, 2005: 22).

4.5.1 Incentives for the private sector

Although, environmental sustainability is only one of the many points of focus for the real estate developer, there are some incentives for this market party to engage with the subject. Franzen *et al.* (2011: 46) named a recent shift towards a more sustainable approach, which is induced by the market since sustainability has become an economic factor. Interviews by Buskens (2015: 51) identified several motives for commitment with sustainability by real estate developers (Figure 18).

[22] More about real estate investment theories in urban area development can be read in Sturm (2014: 43).

Figure 18: Mentioned motives for the commitment to sustainability (translated image from Buskens (2015: 51))

Other incentives could be the increasing legislation on sustainability issues on European level and in Dutch building policies, like the EPC and BENG (Bouwens & Bouwmeester, 2017; Haytink & Valk, 2017; Rovers, 2008), a faster process, because faster agreements into sustainable investments can be reached. A faster process saves money. And lastly, there is a market for eco-districts. Form personal communication is understood that there is a waiting list for one of the most known Dutch eco-districts; Eva-Lanxmeer. Thus, there are multiple incentives for the private sector to engage with sustainability.

4.5.2 Current role of sustainability in private sector-led urban area development

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Sustainability is one of the factors which is making the urban area development process more complex. There are several constraints to be dealt with. First of all, the risks and uncertainties (e.g. the knowledge gab) have to be managed and reduced, because the future value has to be known for making the business case. And second, the different interests in sustainability of public and private parties are making it complex to create a common urban development vision from the start of the project.

The LCTPI (2015: 2) state four shortcomings for sustainability in local multi-stakeholder engagements:

- Lack of awareness and leadership, particularly related to challenges in making the business case;
- Workforce capacity and the need for proper skills and collaboration along the value chain to implement the right solutions;
- Lack of adequate financing models;
- Lack of consistent and long-term policy frameworks (national and sub-national), including regulations and incentive schemes.

According to the LCTPI (2015: 4) the first important step towards Energy Efficient Buildings is: "*Continue driving the demonstration project led by the private sector, in order to continue showing that locally led efforts can catalyse market-wide energy efficiency investment in new build and in the renovation of existing building stocks.*"

Currently, there is already a shift is occurring, mainly caused by the shift in focus from ground exploitation to real estate exploitation, as described in chapter 4.3.4. This shift changed the way of doing things for real estate developers. Buskens (2015: 36) described this change. The next two paragraphs are based on his literature search. During the financial crisis real estate developers made major losses on ground and came to the insight that developing based on power brings major financial risks. For this reason, a transition is happening, which is referred to by Beuzenberg (2012) and Van der Ven (2011) as the transition from development on the basis of power to development on the basis of strength. Within this transition quality and sustainability of developments are getting a more central role.

Formerly the funding of developments was often done for 90% by banks. Currently, the loan-to-value ratio is high when 65-70% of the funding comes from banks (Beuzenberg, 2012). Real estate developers are searching for new methods to operate more independent. The change from supply-driven development to demand-driven development asks for a greater market knowhow of real estate developers (Beuzenberg, 2012; Bouwfonds Ontwikkeling, 2010; De Zeeuw *et al.*, 2011; Putman, 2010). This requires different abilities, knowledge and competences of their employees. Especially networking skills and option contracts are important, giving the possibility to real estate developers to reduce the necessity to own the land (De Graaf, 2011). Thus, based on this demand-driven development on the basis of strength, sustainability gets a more central role.

4.5.3 Future role of sustainability in the urban design process

Loftness (2013) describes sustainable design in the built environment as a collective process to reach unprecedented levels of ecological balance, focussing on the environmental context. Sustainable design merges the natural, minimum resource solutions of the past with the innovative technologies of the present. It creates an integrated and intelligent system that supports individual control with expert negotiation for resource consciousness. In the end, sustainable design offers architecture of long term value through the whole life cycle instead of least-costs investments (Loftness, 2013).

4.6 Barriers for involving sustainability in urban area development

The next paragraphs explain the barriers for involving sustainability in urban area development. They indicate the complexity of the problem at stake and hint why a decision support tool would help. That last aspect is elaborated in the next chapter.

4.6.1 Fragmentation and complexity of the construction sector

The different phases and different actors, which are not all involved from the beginning up till the end, caused a huge fragmentation of the building sector. Cheng *et al.* (2008: 18) even state that they are poorly integrated throughout the process and that this complexity of interaction is one of the greatest barriers to the development of energy efficient buildings. Figure 19 shows how the different focus of engineers within the different phases causes lots of operational islands. The figure does not include all parties involved, so in reality the sector is even more fragmented.

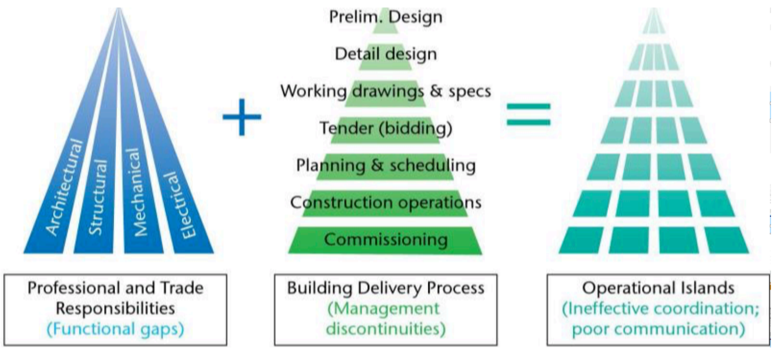

Figure 19: Complexity and fragmentation of the construction sector in an design-bid-build commissioned project (WBCSD, 2007: 15).

The fragmented involvement of parties increases the complexity of the decision-making process in urban area development. Decision-making with multiple actors is about dealing with a conflict of interest, because different actors have different, interests, objectives and values. Golobic and Marusic (2007: 994) even state that "*most of the tasks in planning involve dealing with conflicts.*" According to them they result from inadequate information about the facts, and uncertainty about the outcomes. The table in Glumac (2012: 25) gives a clear overview of the difference between public and private parties' interests and based on those it can be distracted that the biggest difference in interest between public and private parties is the public value vs. financial value (profit). Franzen *et al.* (2011: 47) gives a great statement of how the urban area development process also can be seen: "*The complex interaction between parties makes urban development an exercise in relations management.*"

Financial value is also fragmented over the value chain of real estate development. This fragmentation is causing problems. For instance, if a real estate developer would invest in energy-saving measures, he has to pay more, but the end-user is saving money. This problem is called the split-incentive and is explained more in chapter 6.5.3.3 on the financial optimisation of the business case.

Switzer (2006) gives (already ageing) financial numbers. It would cost a developer 2-4% upfront to construct a green building and the payback time is often 3-5 years. So, in the long term a green building is going to save the owner more money through energy savings. A 2% investment in green building design upfront would result in 20% savings on total construction costs. This proofs that the energetic business case is profitable, but difficult to implement due to the fragmentation of the value chain. It is therefore important to take this fragmentation into account when calculating the financial cost-benefits of sustainability or energy efficiency measures.

4.6.2 Information gab

Besides that, conflicts arise from inadequate information and be prevented by providing information and knowledge. There is a huge information gab about sustainability. For instance, Figure 20 and Figure 21 show the underestimations people in the building industry have of the contribution of buildings to the total amount of CO_2-emissions and underestimations of the extra costs of a certified building (WBCSD, 2007: 18). Although the research is already aging, it can be expected that there is still an information gab present about sustainability issues.

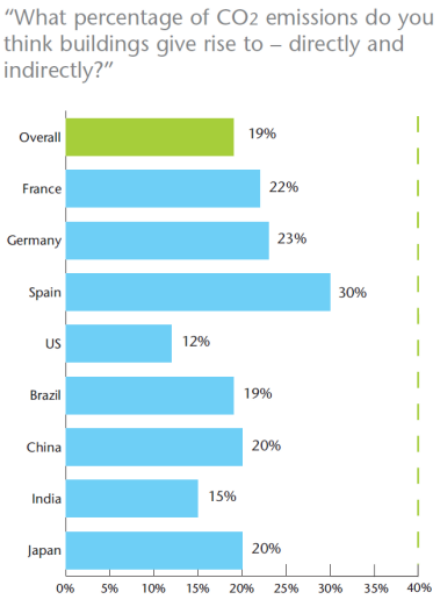

Figure 20: Estimates of buildings' contribution to total emissions (WBCSD, 2007: 18).

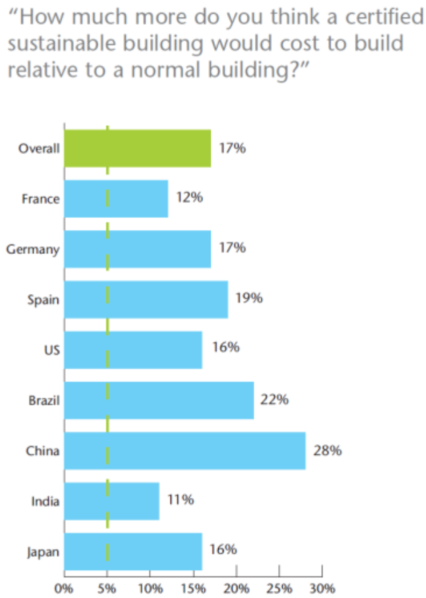

Figure 21: Estimates of cost premium for "a certified sustainable building" (WBCSD, 2007: 18).

Glumac (2012) describes that because of the information gab, different parties use wrong arguments during decision-making processes. When provided with the correct information, another decision would probably have been made.

4.6.3 The business case

"*A precondition for the realisation of an area development project is that there has to be a feasible business case. What this basically means is that at least all the costs that are incurred should be recovered from the yield, and that there are adequate safeguards against risks. [...] Most importantly, many different public and private parties are involved, all of whom have to be persuaded of the soundness of the business case.*" (Franzen *et al.*, 2011: 181) This sounds clear, but there are difference between public and private parties. Firstly, public parties have to justify their assumptions based on the past, often by using the book value method, while private parties have to proof the business case solely by expected revenues in the future (Franzen *et al.*, 2011: 181). Secondly, the accepted risk profiles are different between both sectors. Market parties have a strong focus towards managing and reducing risks, while government parties would accept higher risks on the basis of arguments about adding social value (Franzen *et al.*, 2011: 181). This would imply that with the involvement of the private parties in the urban area development process less financial risks are accepted.

4.6.4 Conclusion: Constrains for sustainability

In the urban area development process, the multiple involved parties have already a lot of different interests. For the public municipal parties, it is the public value and for the private parties it is the commercial/financial value. Implementation of environmental sustainability measures into a closed business case is constraining for private parties due to the information gab on the real costs of sustainability measures, the uncertainties of future financial benefits and the fragmented value-chain (profits are for another party). Environmental sustainability is also not directly a problem of private parties, but one of the whole society. However, they are obligated by law to realize a certain level of energy efficiency, but why would they invest in better measures which are costly and bring more uncertainly in the business case?

Rovers (2008: 81) describes a continuing complexity to involve sustainability into the urban plan. He argued that it must be incorporated from the first step: "*Having considered all these variants and their impact on the design, costs and in terms of required skills, etc., the level of ambition of the project can be selected. Once this level has been chosen (after discussing possible conflicts between areas like energy, water, materials, etc.), the urban design phase can start. Here again, the situation is complex. How can the different levels of ambition and wishes be integrated to create a sound and sustainable area?*" This aspect of integration is the topic of next paragraphs.

4.7 Influencing (sustainability in) multi-actor decision-making processes

There are methods to overcome the complexity of decision-making processes and to influence the level of sustainability in urban area development projects. The coming paragraphs explain how.

4.7.1 Interdisciplinary approach required for succeeding environmental measures.

Rovers (2008) state that an interdisciplinary approach is needed to deal with inadequately covering certain subjects. "*Accomplishing an environmentally-sound design depends on all the partners involved in the design process. They will use their influence not merely on the basis of reason, but also and more especially, on the basis of available finance and practical possibilities. To prevent the majority of environmental measures from failing during the building process, due to practical and financial objections, it is advisable to offer alternatives in an early stage in consultation with all the parties involved.*" (Rovers, 2008: 79) This can be supported with practical tools in the decision-making process (Rovers, 2008).

4

4.7.2 Multi-actor decision-making process

The design of the decision-making process gained importance within a network approach with a facilitating government. The next part describes this process.

4.7.2.1 First and second order design

Decisions can be taken on several levels. Adams and Tiesdell (2012: 14) describes the difference for place making as a '*first-order*' and '*second-order*' design activity. In the first-order design consists of the physical (urban) design. The designer is responsible for this design project, which could be about building, public space or element of street furniture. "*Second-order design is about modifying the decision environments within which other development actors operate, including developers, investors, architects and surveyors. This can be achieved by means of design frameworks, plans and policies, supported where necessary by incentives and disincentives, including financial subsidies, discounted land or infrastructure provision.*" (Adams & Tiesdell, 2012: 14). According to Adams and Tiesdell (2012: 15) requires effective place-making second-order design to set a workable context for first-order design.

4.7.2.2 Multi-actor decision-making

Harmonization and control processes are needed in multi-actor decision-making to govern the complex decision-making procedures in inter-organizational networks (Franzen *et al.*, 2011). Franzen ***et al.*** (2011) gives two types of decision-making processes. The first is a hierarchical process, in which the leader has the final call. In the second the decision power lies with several parties. Agreement between them is needed to continue, this is multi-actor decision-making and in this thesis the case.

The interactions between actors in multi-actor decision environments can be seen as complex decision systems in the built environment. "*Characteristic for this branch is not a mere people's reaction on the given conditions in the built environment but also the interdependent decisions that people perform in relation to the other people.*" (Glumac, 2012: 17) The expected decisions of other actors thus influence individual actors' decisions. In Figure 22 the categorization of the most applied approaches can be seen (Raiffa, 2002).

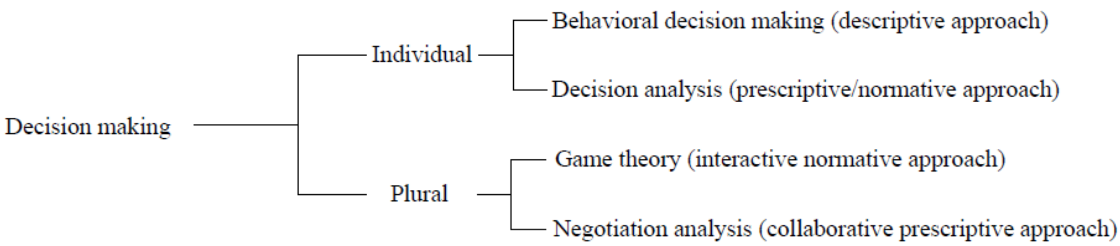

Figure 22: Four approaches in decision-making (Raiffa (2002) in Glumac (2012))

The activated parts of networks are called policy arenas (Teisman, 1998). According to Heurkens (2006) within these arenas different actors, individuals, or representatives of different (types of) organisations can be found. "*Each actor individually and constantly strives to improve his part of the design, and thus to achieve his individual optimum. The project team as a whole will also continually strive to achieve the best group result possible. This is referred to as the optimum interorganisational design (Van Loon, 1998), the final product of the decision-making process.*" (Heurkens, 2006: 253).

4.7.2.3 An integrated development vision

According to Franzen *et al.* (2011: 57) the new governance approach that builds on individual preference makes an integrated development vision indispensable. This is a coordinated and cohesive vision of the future development, independent on the scale level. An integrated development vision is constructed through an interactive and bottom-up process.

In the network approach of the urban area development process multiple actors are involved in the decision-making process. Every actors tries to improve his part of the plan to reach his individual optimum, they put their individual interest above the interest of the group. This makes the decision-making process more complicated. An integrated development vision is needed from the started, created by an interactive and bottom-up process. By second-order design smart policy arenas can be formed to keep the development process going.

4.7.3 Integration of stakeholder management, creative interventions and optimisation.

Many stakeholders are involved in complex urban area development projects. A mixed method approach consisting of a qualitative and quantitative part is useful for the exploration of the possible solutions and the quantification of an explained variety (Bryman, 2012; Kumar, 2014). In this case of urban area development, the qualitative part is about designing a shared vision and concept and the quantitative part is about the feasibility of the business case. Those two topics are explained after another.

First, the qualitative approach for influencing multi-actor decision-making is a descriptive approach for aligning the interests of the involved actors. This the core of the merger of interest approach of Van Hal (2014), who uses the needs, desires and interests of direct involved actors as a starting point of the decision-making process. The merger of interest approach is a strategy that increases the change of sustainable innovations with integral quality, in other words, a strategy that focusses on more qualities than only sustainability qualities (Van Hal, 2014: 50). Van Hal (2014: 50) gives a fixed three-stepped strategy to apply the merger of interest approach:

- Make an inventory of the interests of the people here and now (for all those involved in the project).
- Define measures that deal with these interests, while also taking into account the interests of people there and later.
- Search for (innovative) funding models that enable investment in such measures.

In such a way the interests of various parties can be aligned. This is only hard to apply when there are conflicting interest.

A mediating strategy to deal with conflicting interests of the involved stakeholders is the development of an integrated vision and concept (Spijkerman, 2017b; Versteijlen *et al.*, 2010). The vision is a desired future change (Wiek & Iwaniec, 2013). The usage of a vision is strategically and makes it possible to identify the long term goals and solve problems in the long run (Kemp, Loorbach, & Rotmans, 2007). The concept is the operationalized image of the vision. The integrated concept is "*an abstract idea generalised from various perspectives. Given shape in a proposition that mediates between all stakeholders.*" (Spijkerman, 2017a: 20) In the early development phases various possibilities are explored. This diverging approach allows for investigating many different solutions in an iterative process, as shown with the iterative process within Figure 23. An analysis is executed to know the possibilities of the location and to gather the interests of the stakeholder before the vision and concept are developed. In this method of Versteijlen *et al.* (2010), the development of a concept is followed by the development of the strategic development framework. This framework captures the phasing of the development and the actions of the different parties over time. Thus first the product is set during a collaborative process of the involved actors (the 'what'), and the next step determines the development process (the 'how'). The sequential steps to get towards a development strategy are therefore: Analysis > Vision > Concept > Development strategy.

Schiltmans (2013) also determines that the concept of an area, usually made in the initial stage of the process, largely contributes to the success of the project. Success factors for the concept, according to Schiltmans (2013), are that 1) the products complements to things which are already available in the municipality or the product provides for a new, yet unknown consumer demand, 2) a clear choice is made about the urban planning and architecture, 3) the concept is established with collaboration of the involved parties (e.g. the real estate developer and the municipality), 4) partly guaranteed sales contributes to the feasibility and success and 5) flexibility in the land-use plan allows for future changes in the program if market circumstances change.

The usage of a 'concept' looks self-evident during the development phase, however, this is not the case. The real estate developer Bouwfonds Wonen (2002)[23] introduced this new approach of concept development in urban area development at that time. The (former) directors Henk van Zandvoort and Diederik Stradmeijer[24] of BPD introduced the importance of a concept by stating that urban area development needs specific and unique concepts, because of a shift from separated development within different sectors such as shopping, living and working to integrated area development. According to them, the physical product of real estate should always be a derivative of a location-bound and unique concept. Because a concept is location-bound, all concepts have to be custom made, which causes that a central management of innovation processes is impossible (Bouwfonds Wonen, 2002).

4

The difference between concept development and the development of the business case in the initial phase of urban area development is that the concept is about a narrative about the genius loci of the place[25]. The concept is related to the physical product. In the initiative phase both the process and the product are important (the 'controlling' aspects on the left of Figure 23). After the initiative phase a plan of approach should be developed that tells a coherent story about the quality, finance, time, sustainability, people, organisation, information, health & safety and risks (see Figure 7 and J. C. De Jong (2016: 16)).

Problems will arise during the development of the concept and the business case. Problem solving by urban area development projects does require another approach than a linear one (Spijkerman, 2014: 7). Spijkerman (2014) explains an iterative process of going back and forth between the problem and a possible solution. Each iterative step goes through some of all of the linear steps, namely to gather and analyse data, the formulate a solution and to test and implement it. This approach is shown by a green line that goes back and forth between the problem and solution in the upper-left part of Figure 23.

The steps of the design process of Dym and Little (2004)[26] can be used for the design of the concept. This is additional to the steps of Versteijlen *et al.* (2010). First, the client statements with the associated interests, objectives and constraints are gathered from the involved stakeholders. This is part of the stakeholder management and during the development process those stakeholders must be considered and their values be monitored. The client statements and the location are further analysed (second step) and turned into a vision (third step as preliminary design). This vision is a creative intervention, and the values of the result can be optimised within the constraints of the stakeholders. If no feasible solution can be created, new possibilities must be sought, or the clients have to adjust their objectives or constraints. This approach is repeated several times till a feasible design is reached as final design of a concept. The concept is the first step of the second phase to create a strategic development framework. This approach incorporates the interests of the stakeholders by involving them into the design process. Figure 23 shows a summary.

[23] Currently named Bouwfonds Property Development (BPD).
[24] Henk van Zandvoort was the director of the department of residential development and Diederik Stradmeijer was director of the department of real estate development (Bouwfonds Wonen, 2002).
[25] For Genius Loci, see Vroom (2010).
[26] In Barendse et al. (2012: 3).

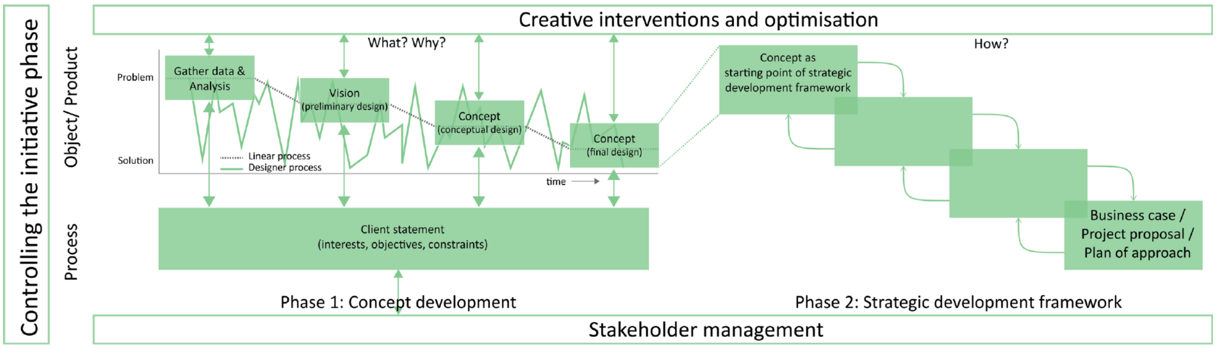

Figure 23: Stakeholder management, creative interventions and optimisation to control the multi-actor decision-making processes during the initiative phase of urban area development projects (own illustration based on J. C. De Jong (2016: 19), Spijkerman (2014: 7), Versteijlen et al. (2010) and Dym and Little (2004) in Barendse et al. (2012: 3))

Second, this vision, concept and strategy development framework needs a quantitative underpinning about its feasibility. The feasibility can be checked during each step by looking for a solution space via quantitative urban management instruments (Franzen *et al.*, 2011). These instrument can also provide possibilities for optimising the objective of various stakeholders (Barendse *et al.*, 2012; Binnekamp, Van Gunsteren, & Van Loon, 2006). In addition, the financial feasibility has to be checked by a financial real estate calculation (J. C. De Jong, 2016; S. H. C. Van den Berg, Deleroi, & Wytema, 2016; Vlek *et al.*, 2016). More elaboration about these topics is given in the next chapters.

4.7.4 Key moments

Key is to incorporate sustainability from the start of the project. Glumac (2012: 10) briefly describes how the start of the process works: "*In the initiative and land acquisition phase the key actors such as market parties, users, and governmental representatives are identified, as well as their properties: internal organization, constraints, demands and power to influence and affect a development process. In the first two phases of the redevelopment, the process forwards certain market knowledge to an idea. [...]. Together, these products can support the assessment of the risks and opportunities in the redevelopment process mainly related to the program in brief and location analysis.*" According to Rovers (2008) a conceptual approach needs to be taken. This could only be done when this is part of the central focus of the project. In the initiative phase a feasibility study is done and a program in brief and a project plan is made.

Wamelink *et al.* (2010) describes the managerial paradox in a construction project. At the start of the project the project team has major influence on costs, but there is little information to base the decision upon. While during the project the amount of information increase, but the influence on costs decreases. A feasibility study is therefor of major importance at the start of a project, a decision support tool could provide information to base the decision upon, for instance on the ambition in environmental sustainability. Leelarasamee (2005: 2) confirms this way of thinking: "*Decisions developers make in the predevelopment stage are very important. In many cases, the decisions affect significantly the future investment performance of the developed property.*"

4.8 Conclusion

This chapter has provided an answer to the first knowledge-related sub-research question:

> *What is presented in the theory of urban area development for the involvement of sustainability in the multi-actor decision-making processes to realize sustainable urban development projects from the viewpoint of the real estate developer?*

First, the theory also support the focus of this research on the real estate developer and the initial phase, because of its changing role in urban area development (Bentvelsen, 2014; Heurkens, 2012; Peek & Van Remmen, 2012) and the amount of influence during this first phase (Franzen *et al.*, 2011; Glumac, 2012; Wamelink *et al.*, 2010).

Second, the changing practise of urban area development has in most aspects a positive effect on the involvement of sustainability. For instance, the focus is changed to the actual demand of real estate, instead of the value jump from land acquisition (Putman, 2010). This offers the possibility to get sustainable housing if there is demand from stakeholders. Also the change to MEAT-procurement offers possibilities to involve sustainability instead of solely focus on the lowest price (Chao-Duivis *et al.*, 2010). A difficult aspect is the network society (Franzen *et al.*, 2011), because it fragments the mandate of various parties. A solution to align the involved parties is described by the qualitative and quantitative methods below.

Third, there are incentives for the real estate developer to involve sustainability: legislative requirement, marketing reasons, creating support of other parties and thereby, speeding up the development process or even increasing profits (Buskens, 2015; Franzen *et al.*, 2011).

Fourth, there are also barriers for the real estate developer to involve sustainability: fragmentation of decision-making and financial value (Cheng *et al.*, 2008; WBCSD, 2007). Fragmentation is also dealing with conflict of interests (Glumac, 2012; Golobic & Marusic, 2007). The information gab and spread knowledge over different parties are other barriers (Glumac, 2012; WBCSD, 2007). These are all barriers to get to a feasible business case, which is a precondition to start with the development (Franzen *et al.*, 2011).

Fifth, there are qualitative methods to get alignment in the interests of the involved stakeholders to get decision-making possible, such as the merger of interests approach of Van Hal (2014) and the usage of a concept as mediating strategy (Spijkerman, 2017b; Versteijlen *et al.*, 2010). This conceptual approach is also needed to successfully involve sustainability in the decision-making process of realizing integrated developments for the start of the project (Rovers, 2008; Schiltmans, 2013; Wamelink *et al.*, 2010).

In the end, real estate developer operates at its own expense and risk to increase and optimise their own value (Franzen *et al.*, 2011; Putman, 2010). From this it can be derived that the goal of the real estate developer is the optimal business case consisting of a quantitative financial value. Quantitative exploration and optimisation of the feasibility is therefore required. This can best be part of a quantitative optimisation of the 'creative interventions' of Figure 23.

5 Quantitative decision support with urban management instruments

5.1 Introduction

Quantitative decision support tools can help in overcoming the barriers in sustainable multi-actor decision-making, which are described in the previous chapter. This chapter explores a suitable methodology for creating a quantitative decision support tool and how it can be applied in this graduation thesis. It describes the principles of linear programming (LP) and considerations to use LP. Hereby, the chapter provides an answer to the second knowledge-related sub-research question:

> *What is a suitable quantitative optimisation method in urban area development to support complex, multi-actor decision-making? Why? And how can it be applied?*

First, the chapter gives insight in what quantitative urban management instruments are and which types there are identified. Second, it presents the Open Design methodology as opposite of the expert design approach. The approach of Open Design has the possibility to bring real decision power to all involved stakeholders and results into a solution space instead of a solution point. Fourth, the linear programming approach is presented, followed by its limitations. Sixth, the principles how linear programming can be used in multi-actor decision-making processes is described. The chapter ends with a conclusion.

5.2 Quantitative urban management instruments

Quantitative management instruments, also called quantitative urban design and decision-making techniques, make use of computer technology and can support the structuring of the design-decision process (Franzen *et al.*, 2011). Those instruments quantify design decisions and have the possibility to combine conflicting interests towards solutions (Franzen *et al.*, 2011).

Those quantification is possible on the scale level of a city (e.g. the 'smart cities' of Townsend (2013) and Hajer and Dassen (2014)) and on a local urban area development project (e.g. the urban decision room of Van Loon, Heurkens, and Bronkhorst (2008)). Four types of quantitative urban management instruments are identified by Franzen *et al.* (2011) for this lower scale level:

- Urban management instruments for supporting multi-actor urban decision-making
- Urban management instruments for urban design
- Process-oriented urban management instruments
- Urban management instruments for design based on cost vs. benefit

This graduation thesis seeks a combination of the first and last typology. An urban management instrument which can be used to prepare and support decisions taken by taking into account a consortium of actors and for calculation and estimation of the feasibility of an urban are development plan (Franzen *et al.*, 2011). These two aspects are discussed next.

5.3 Real decision power in multi-actor decision-making

The first aspect of the decision support tool is supporting multi-actor decision-making. In a complex urban area development project are, among others, the municipality, real estate developer(s), end-users and advisors involved. All the interests of those stakeholders have to be aligned, because decision power is scattered, which requires urban governance (Franzen *et al.*, 2011). According to Franzen *et al.* (2011) recognizes governance the existence of hybrid networks and the increasing role of private parties.

The classical approach for solving the design problem is to consult an expert or a group of experts (Binnekamp *et al.*, 2006). The researchers describe that in this approach, the experts propose a solution to the design problem that have to be 'sold' to the users of the building and/or the real estate developers. It is possible that these stakeholders are not at all satisfied with the proposed design alternative. The involvement of process experts has to counteract this dissatisfaction. Those experts devise a decision-making process that has to incorporates more wishes of the stakeholders into the final design, but this has as a consequence that a series of sub-optimal design decisions are made, which leads to a total sub-optimal design (Binnekamp *et al.*, 2006). Both appearances of this 'expert'-approach do not incorporate real decision power to all involved actors and, thus, lead to sub-optimal final designs.

The 'expert'-approach is ignoring other stakeholders who could be standing in the way of progress (Adams & Tiesdell, 2012; Binnekamp *et al.*, 2006). This is in line with how Adams and Tiesdell (2012: 126) look at the current political climate of neo-liberalism, which provide privileges to the development sector. The ignorance of stakeholders in the typical design process, this so-called 'expert'-approach, makes the approach unsuitable for citizen participation. According to Arnstein (1969: 216) citizen participation "*is the redistribution of power that enables the have-not citizens [...] to be deliberately included in the future*", but "*there is a critical difference between going through the empty ritual of participation and having the real power needed to affect the outcome of the process.*" An equal involvement of citizens in the decision-making process is comparable to stage 6 of Arnstein (1969: 217), see Table 5. The notion of 'citizen' in this ladder of citizen participation can also be read as another stakeholder. This equal involvement is thus not the allowance to give advice, but a real stake in the decision-making process. In this case the citizens are enabled to negotiate with the traditional power holders. The 'Open Design'-approach makes such real involvement possible (Binnekamp *et al.*, 2006).

Table 5: Eight stages of citizen participation (based on Arnstein (1969: 217)). Citizens

8	Citizen control	Degrees of citizen power	Have-not citizens obtain full managerial power.
7	Delegated power		Have-not citizens obtain the majority of decision-making seats.
6	Partnership		Have-nots are enabled to negotiate and engage in trade-offs with traditional power holders.
5	Placation	Degrees of tokenism	Have-nots are allowed to give advice, but the decision-power retains for the power holders
4	Consultation		Have-nots may indeed hear and be heard, but under these conditions they lack the power to insure that their views will be heeded by the powerful.
3	Informing		
2	Therapy	Nonparticipation	The real objective is not to enable people to participate in planning or conducting programs, but to enable power holders to "educate" or "cure" the participants.
1	Manipulation		

The focus of Open Design is on a collaborative approach to urban area development and in this approach all stakeholders (experts and layman) can influence the design as equal decision makers (Binnekamp *et al.*, 2006). Decision makers are stakeholders who have a real influence on the design, which is the opposite of parties who have only the right to express their views, but do not have formal power (Binnekamp *et al.*, 2006).

> "*The purpose of Open Design is to generate a design in which the interests of all stakeholders are reflected in an optimal way.*" (Binnekamp *et al.*, 2006: 17).

This optimal way is ensured by taking into account all wishes and preference of the stakeholders. During the decision-making process those stakeholders can equally influence the design outcomes. Outcomes is not a typo here, because this approach does not lead to one final design, but to several options (Binnekamp *et al.*, 2006). The final design can be selected by a democratic process (e.g. voting). The stakeholders have to accept this open-ended result.

5.4 Solution space vs. solution point

The open-ended result by multiple outcomes is possible due to the usage of a solution space instead of a solution point. A solution point is a single decision alternative (e.g. the points A-D in Figure 25) and a solution space the virtual space restricted by various interests of the involved stakeholders (Barendse *et al.*, 2012; Binnekamp *et al.*, 2006; Vlek *et al.*, 2016). This concept is also called the design space, which is described as "*a mental construct* *of an intellectual space that envelops or incorporates all of the potential solutions to a design problem.” (Dym and Little (2004: 97-98) in Barendse et al. (2012: 9))* A design space can contain very large amounts, possible even infinite potential design alternatives (Barendse *et al.*, 2012). The same author explains that in mathematical terms, a design alternative is represented by a combination of different values of design variables, which are design attributes like a buildings gross floors space or the ratio between public space and the amount to be developed in a neighbourhood. The solution space is shown by the striped part of Figure 24, which is restricted by the interests of various actors. A change of one of the restrictions, also called ‘constraints’, by one of the stakeholders also adjusts the solution space, which makes the solution space dynamic to the proposed input of interest values.

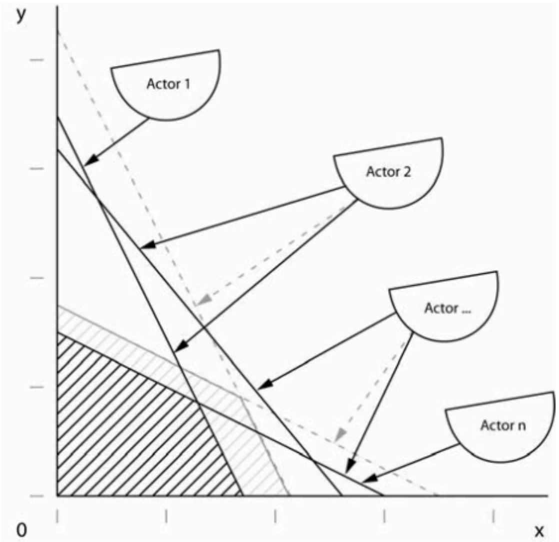

Figure 24: Dynamic solution space (Van Loon et al., 2008: 33).

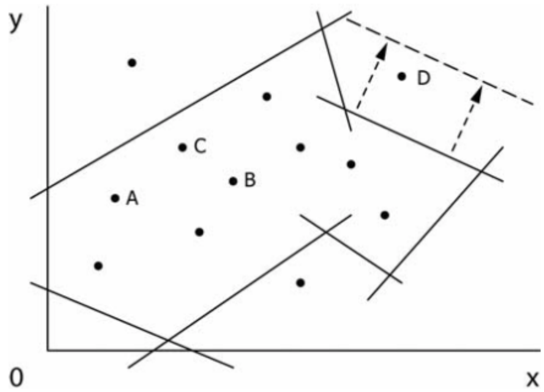

Figure 25: Common solution space (Van Loon et al., 2008: 11).

In Open Design the constraints are considered negotiable among stakeholders, which is the opposite to classical optimisation (Binnekamp *et al.*, 2006). This makes it possible to turn an infeasible result into a feasible result. For instance, Figure 25 shows that design alternative D is infeasible, but by means of negotiation a constraint can be adapted which makes the alternative feasible. Open Design is therefore useful in testing the feasibility of a project. Constraints have to be adapted in case there is no solution space which satisfies the interests of all stakeholders. All stakeholders have an equal stake in the decision-making to get the project feasible, as their interests are represented by the constraints.

Optimisation by means of Open Design offers the possibility to identify different plans within one solution space (Binnekamp *et al.*, 2006). This is explained with Figure 26 by the same writer. Part 1 and Part 2 represent different plans and within one part there are only small adaptations of sort of the same plan. In case a design alternative (a single solution point) is used as the starting point of an [incremental] trial-and-error process, it is unlikely that any solution in part 2 of the solution space will ever be found (Binnekamp *et al.*, 2006). Binnekamp *et al.* (2006) therefore concludes that thinking in terms of a solution space rather than a solution point significantly facilitates the realization of creative, unconventional architectural ideas.

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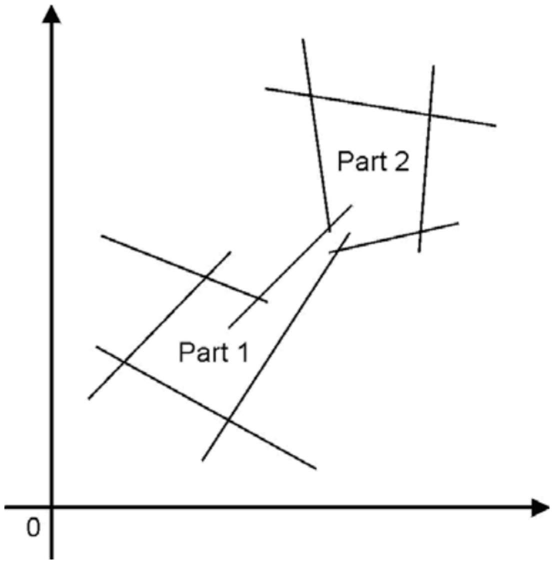

Figure 26: Solution space made up of two parts connected by a small 'corridor' (Binnekamp et al., 2006: 40).

These trial-and-error methods in the design of construction projects are also recognized by Milan, Bojesen, and Nielsen (2012)[27], who tried to optimise the energy supply installations for a 100% renewable energy supply on an hourly basics. The quantitative optimisation methods they identified where often based on generic algorithms or highly non-linear complex models. According to the researchers these types of models are well-suited in evaluating the trade-off between energy efficiency measures and renewable supply systems, but they are very computational intensive and a detailed calculation of a one-year performance would take up to two months of the newest processor engines. The researchers found this unsuitable for the design phase, which need a simplified and ready-to-use optimisation model (Milan *et al.*, 2012). Milan ***et al.*** (2012) founded in linear programming a simplified method for these optimisations. Linear programming is also used in the Open Design method (Barendse *et al.*, 2012; Binnekamp *et al.*, 2006).

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5.5 Linear programming

Linear programming (LP) is used as method for optimisation modelling. LP is a mathematical modelling technique aimed at optimisation calculation. In these calculations both the objective function and the constraints are reduced to linear functions. This makes it possible to optimise a certain objective or to check whether there even is a solution space (Barendse *et al.*, 2012; Vlek *et al.*, 2016). The concept of a solution space is already discussed before, but when looking back at Figure 24, Figure 25 and Figure 26 they all show that this virtual space is restricted by linear functions.

The LP-technique is labelled as a design methodology by Barendse *et al.* (2012), because the LP-technique explores the design space. The relevancy of this design methodology lies in the possibility to evaluate possible design alternatives before an architect has even draw them (Barendse *et al.*, 2012). This saves time and money. LP-modelling can also assist in decision-making, because each variable expresses the interest of a decision maker in the design (Barendse *et al.*, 2012). And because each variable is related to a constraints and a decision maker, these variables are considered to be negotiable, which offers the opportunity in practice that an infeasible outcome of the model can be changed to feasible after negotiation (Barendse *et al.*, 2012; Binnekamp *et al.*, 2006).

An important note is that all optimisation models can only produce single-criterion solutions, because, in mathematical terms, only one objective function can be optimised (Barendse *et al.*, 2012). That is why LP-modelling is not suited naturally to multi-actor decision-making. Barendse *et al.* (2012) gives some solutions with preference modelling, however, the selection of the values for the constraints is arbitrary and still relies on unstructured negotiation (Barendse *et al.*, 2012: 22).

[27] Chapter 6 continues on the model of Milan *et al.* (2012), as it is used as inspiration for the model created in this research.

According to D. R. Anderson, Sweeney, and Williams (2000) can any strategic decision-making process that is modelled by linear functions, requires the maximisation or minimisation of some quantity that, and is constrained by certain limits, be modelled into a LP-problem. This indicates usefulness of LP-modelling. Later on these actors indicate the same by acknowledging that LP is widely accepted as a robust quantitative problem solving approach. Salkin and Kornbluth (1973) showed that LP can be adapted to financial and accounting related problems. Gustafsson (2001), Bojic, Trifunovic, and Gustafsson (2000), Privitera *et al.* (2011) and more, which are named later on, applied LP-modelling to financial, renewable energy technology and building related optimisation problems, but none were related to residential neighbourhood developments.

That such a LP-model can be created is very likely based on its often used application, also in (renewable) energy-related issues for the built environment. Proof of concept is given by the recent publications of Milan *et al.* (2012), Mehleri *et al.* (2012) and Merkel, McKenna, and Fichtner (2015). More information about these research is given in chapter 8.3. Privitera *et al.* (2011: 842)[28] concludes in his research which used LP to optimising the installation costs of renewable energy technologies in buildings that "*applying LP to the practical analysis of early-stage feasibility for renewables in buildings can be a powerful tool for deciding on the optimum technology mix. It can demonstrate the risks of making the wrong selection, as well as provide strong indications of the key practical constraints that impact most on a renewable energy installation.*"

Appendix 13.9 continues on the LP-modelling technique by giving theoretical insight in how an LP-problem can be transformed mathematically to be useful in (sustainable) multi-actor decision-making processes.

5.6 Limitations of Open Design and linear programming

There are some limitations in the usage of the Open Design method and the related modelling technique of linear programming. The most influential ones are discussed, for instance the need for acceptance of all involved stakeholders, transparency and non-manipulation and the effect of the collaborative approach on decision-making.

In Open Design all stakeholders have to collaborate in a transparent and honest decision-making process (Binnekamp *et al.*, 2006). Manipulation in whatever from is counterproductive (Binnekamp *et al.*, 2006), because the other stakeholders will loss respect and trust in the outcomes, which is the essence of the Open Design process, the genuine acceptance of an open-ended outcome (Binnekamp *et al.*, 2006). The practitioner of the Open Design approach, called the open designer by Binnekamp *et al.* (2006), should therefore "*never change a constraints without the consent of the associated stakeholder.*" (Binnekamp *et al.*, 2006: 20-21). According to the author this is only allowed in case the open designer executes trial runs to find out which stakeholder to address and ask for adaptation of the value of the constraint concerned. This need for acceptance of the outcomes makes the management of the entire process more crucial to its success in relation to the development of an appropriate mathematical model (Binnekamp *et al.*, 2006).

Linear programming can only optimise one objective function and can therefore only produce single-criterion design alternatives, which fully satisfy only one of a single decision maker's interests. (Barendse *et al.*, 2012). That is why LP-modelling is not suited naturally to multi-actor decision-making. Barendse *et al.* (2012) explain the method of preference measurement as tool to overcome this limitation. However, Binnekamp *et al.* (2006) already discovered that this whole method is completely arbitrary and still relies on unstructured negotiation. LP is still useful for this research, as it investigates the optimal business case from a viewpoint of the real estate developer. The created tool will therefore produce single-actor optimisations, which can be used for its own strategy optimisation. The tool takes into account the interests and goals of multiple parties as constraints and that is why all feasible outcomes are acceptable to all stakeholders involved.

[28] Privitera *et al.* (2011) investigated how linear programming can be applied to optimise the investment costs of renewable energy technologies for a 100% renewable supply of an office building. The LP calculation of the researchers optimized the investment costs of the installed technology mix based on PV-panes, wind generations, solar thermal water heating and biomass heating and took into account key parameters as the geometry of the building, the investment costs of each renewable energy technology, the average annual meteorological conditions of the site and constraints for installation (e.g. available surface area of the roof).

One likely limitation of a collaborative approach is the tendency of group decisions to become uniform in order to provide the same benefit for all participants (Binnekamp *et al.*, 2006). In the Open Design method this is tackled by sharply distinguishing between central decision-making and individual choice. Individual choices are related to the values of the constraints set and central decision-making is related to the solution space.

5.7 Conclusion

This chapter has provided an answer to the second knowledge-related sub-research question:

> *What is a suitable quantitative optimisation method in urban area development to support complex, multi-actor decision-making? Why? And how can it be applied?*

Linear programming (LP) is a suitable method to support complex, multi-actor decision-making in urban area development projects. LP can be used to test the feasibility of the interests of all involved stakeholders and to identify the optimal solution from a single-actor perspective.

In first described usage method of the feasibility tests, all stakeholders have an equal decision power in the decision-making. In case that the modelling results show a feasible outcome, urban designers and architects can create design alternatives within the constraints set by the involved stakeholders. By this approach, all outcomes of the design process are acceptable to the involved stakeholders. A final design alternative can be selected by means of democratic voting. If all stakeholders have equally presented their interests in a honest and transparent matter, this outcome would be the result of an equal decision-making process, because no party benefits more than others.

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In the second described usage possibility, the result is optimal from a single-actor perspective. However, because the interests of all stakeholders are taken into account, this result must be acceptable to all stakeholders involved in the multi-actor decision-making process. This is not part of an equal decision-making process, because one party is benefits more than others. Although, the results are still acceptable to others, it should be possible with this approach to speedup complex decision-making processes.

6 Optimizing the business case of energy efficiency in urban area development

6.1 Introduction

The focus of this chapter is on the business case of energy efficiency in urban area development and provide an answer to the third knowledge-related sub-research question:

> *What is already known about the barriers and solutions in the decision-making about the aspects in a business case, which are presented in the research framework?*

The chapter starts with explaining the different energy ambitions and definitions for dwellings and is further based on the four aspects of the research framework, namely legislation, organisation, finance and physical solutions. These topics are elaborated after one another.

6.2 Energy ambitions and definitions for the residential built environment

There are many definitions used in stating the ambitions of energy efficient buildings, neighbourhoods or districts. This paragraph clarifies the main three categories of energy demand and describes the most used definitions of energy ambitions in buildings. It concludes by giving the definition used in this thesis.

6

The energy demand of a building can be divided in three main categories (Swinkels & Clocquet, 2010: 9):

1. Building-related energy demand
2. User-related energy demand
3. Material-embodied energy demand

The first category consists of the energy demand of the integral building-related installations (heating, cooling and ventilation climate systems, hot water and lighting systems in commercial buildings). User-related energy demand is the energy demand of the equipment brought inside by the users of the building (e.g. computers, television, kitchen appliances, etc.). And the last category about the material-embodied energy demand is the energy demand for the realization of a building (the materials production, transportation to the construction site, the building construction itself and the demolishing of a building) (Swinkels & Clocquet, 2010).

Dwars (2013) gives clarity by describing five different categories in dwellings with a high energy ambition. The definitions are explained in Table 6.

Table 6: Five different definitions defining the energy ambition of a dwelling (table based on Dwars (2013).

Term	Explanation
Passive House	Aims to reduce the building-related energy demand towards the minimum. The official requirement is set on a maximum energy demand of 15kWh/m^2. The concept is aimed at maximizing the building physics (e.g. great insulation, optimising the use of solar gain).
EPC=0	A mathematical approximation of the combination of installations and building physics aimed at realising a 100% sustainable energy usage of the building-related energy demand.
Near energy neutral building or nearly zero energy building (NZEB) (Dutch: '*Bijna Energie Neutraal Gebouw*', BENG)	The definition of the European Union stating that the building uses almost no energy. According to Dwars (2013) this is a definition with little guidance, because you do not know exactly the performance of the building. The EPC is between 0 - 0.2. The definition is often used for buildings that are connected to a collective system (e.g. heat grid).
Energy-bill-zero (Dutch: '*Energienotanul*')	The definition is based on the total energy costs for the consumer. The term is depending on the laws and regulations and the price developments. At the

	moment of agreement clarity is given about which arrangements have been made, but in financial sense it is unclear what the future will bring. It can be stated that an Energy-bill-zero building has an EPC around 0,2. The dwelling generates 500kWh less energy than the building (including the household/users) usages.
Zero-on-the-meter (Dutch: '*Nul-op-de-meter*')	This definition is conceived by the *Stroomversnelling*. This is a Dutch initiative to speed up the amount of renovations of social rental dwellings. It is a technical approximation in which the building generates as much energy as it usages in joules. The possibility is given for offsetting in the neighbourhood, within a radius of 10km. This offers the possibility to use district heating, biogas and collective systems. The EPC is around -0,4.

The passive house, EPC=0 and the nearly energy neutral building are focussed on the building-related energy demand. The energy-bill-zero and the zero-on-the-meter definitions originate from the total energy demand of the building (building- and user-related energy demand). The embodied energy of materials is not often incorporated. This is going to change, because of the MPG-legislation, which is more explained in the next chapter on legislation.

Athienitis, O'Brien, and Ayoub (2015: 1) add the notion of 'net' to the definitions: "*A net-zero energy building (Net ZEB) is normally defined as one that, in an average year, produces as much energy (electrical plus thermal) from renewable energy sources as it consumes.*" This notion can also be applied for a neighbourhood (NZEN) or a district (NZED).

The best practise in the Netherlands is zero-on-the-meter. In the development of Vauban, a neighbourhood in Freiburg, Germany the notion of the PlusEnergy building is developed. A PlusEnergy house is a dwelling with a net positive energy balance on a yearly basis. The building thus generates a surplus of energy from renewable sources. This surplus on electricity is sold back into the electricity grid (Freytag, Gössling, & Mössner, 2014; Gray & Zarnikau, 2011).

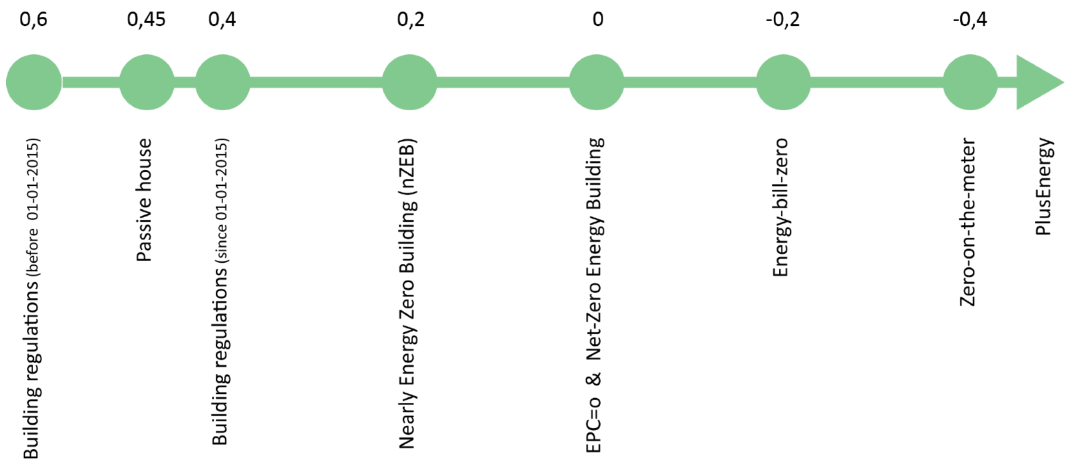

Figure 27: Energy definitions related to the EPC (own ill. based on Dwars (2013), Athienitis *et al.* (2015), Gray and Zarnikau (2011) and Freytag *et al.* (2014)).

The PlusEnergy building is the highest achievable ambition. However, in this thesis we define energy neutral when only the building-related energy demand is supplied by renewable energy on-site or in the neighbourhood. The EPC=0 or BENG definition is the standard, as this is going to be the minimum requirement by law in the Netherlands.

6

6.3 Legislation: Changing legislation about energy efficiency

6.3.1 Introduction

The coming paragraphs discuss the changing legislation about the energy efficiency of buildings. First, the change from the EPC to the BENG-legislation is discussed, second, the balancing agreement and last the Environmental performance of Buildings. Before the individual legislations are presented an introduction is given by the Trias Energetica of Duijvestein (1997) and an explanation about primary energy usage. This is required for the new BENG-legislation.

6.3.2 Basics of energy efficiency: The Trias Energetica and the New Stepped Strategy

The Trias Energetica and the New Stepped Strategy are strategies for reducing the energy demand.

The first three-ways-model to reduce the energy demand in the building industry was presented by Duijvestein (1997). This version was a slight adaptation of the strategy of Lysen (1996) for a general sustainable energy supply. Both strategies have the same three steps. The first measurement is the most favourable one and the last step has to be avoided. This strategy had led to the common used "*Trias Energetica*", which has three distinctive steps:

1. Reduce the energy demand by taking energy saving technologies;
2. Use sustainable, renewable energy as much as possible;
3. When there is still an energy demand left, then use fossil fuels as clean and efficient as possible.

The result is a closed cycle when all the demand is met in the first two steps. In a closed cycle non-renewables are no longer needed (Rovers, 2008). The balanced situation can be called sustainable. The Trias Energetica approach is therefore highly useful in developing energy neutral urban areas.

The Trias Energetica forms the guideline for a logical, environmentally conscious approach, but recent developments and new insights necessitate adaptation of the Trias Energetica to the '*New Stepped Strategy*' ('NSS') of Van den Dobbelsteen (2008) (Peek & Van Remmen, 2012: 34; Van den Dobbelsteen & Tillie, 2011: 6). The most important reasons for this are that the desired result has not been reached in practice and that the implementation of renewable energy technology is still minimal. The NSS integrates the Cradle-2-Cradle philosophy of McDonough and Braungart (2002) in the Trias Energetica by adding an intermediate step of incorporating waste streams between the reduction in demand and the usage of renewable resources. The NSS is not just about reusability, but also to strive for reuse at the same or even higher quality level. In that way, the entire life cycle is considered including the production and waste phase. The principles of the NSS (Van den Dobbelsteen, 2008) are shown below. Eliminating the need for the final step is the goal of this strategy.

- Save wherever possible without loss of comfort and health;
- Replace and use residual/ waste streams again. Upcycling wherever possible;
- Use renewable energy sources (a) and ensure that waste can be used as food (b)
- Minimum usage of finite sources and only with high efficiency (much for little).

The steps of the NSS are not only connected to buildings, but also to clusters or neighbourhoods, districts and the entire city (Van den Dobbelsteen & Tillie, 2011).[29]

[29] For instance, the New Stepped Strategy was the theoretical foundation of the Rotterdam Energy Approach & Planning (REAP) by Tillie *et al*. (2009). The REAP was developed as a structural approach for a sustainable energy supply in urban areas. This approach has been generalized with the LES (Dutch abbreviation for: 'Leidraad Energetische Stedenbouw') by Kürschner *et al*. (2011).

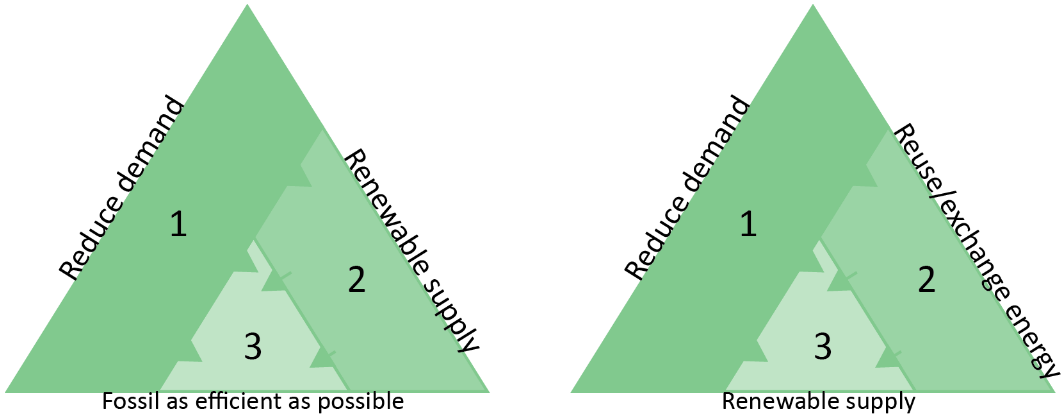

Figure 28: The steps of the Trias Energetica (left) and the New Stepped Strategy (right) (own illustration based on Duijvestein (1997) and Van den Dobbelsteen (2008))

Both strategies can be used at different levels of decision-making. Rovers (2008: 10) describes a clear example about sustainable material use when decision on the development of a new building. He states that when the decision is made to develop a new building, materials have to be used. However, decision-makers can also decide not to build (e.g. can the need for office space be met in another way), related to the first step of the NSS, or decide to renovate an existing office (second step of the NSS). According to the example should new construction only be considered in case these two options are unavailable. The strategies therefore can be used at the planning level. In this sense a well-organised management for sustainable building can realize more environmental benefit than the most efficiency technology in every scale level, from policy development to management to design (Rovers, 2008).

6.3.3 Primary energy use

The amount of primary energy is the total energy content of the natural resources used in energy conversion systems to supply usable energy like heat, cold or electricity. It represents the total amount of heat that can be produced by the complete combustion of the fuel without efficiency loss (Itard, 2011: 152). Of this combustion, for example, electricity is made. This generation is not effective, therefore, the amount of primary energy is higher than the amount of electricity used. The efficiency of electricity generation in a gas or steam turbine power plant is approximately 30-40% (Itard, 2011: 155). Renewable sources are not included in the primary energy, as they not use natural resources. Renewable sources for heat supply (e.g. a solar collector, a heat pump in combination with solar panels or district heating based on waste heat) can reduce the primary energy demand for space heating.

The primary energy demand can be calculated by taking into account the whole energy supply chain. The general energy chain consists of four main components (see figure 6). These are described by Itard (2011). First, natural resources (component 1, e.g. the primary energy of coal, natural gas, sun or wind) are converted into energy (e.g. heat, movement or electricity) in an energy conversion process (component 2). The generated energy is then transported or stored in an energy distribution network (component 3) to the demand side (component 4). The energy conversion process of non-renewable resources (e.g. fossil fuels) is mostly based on combustion, causing depletion of natural resources and environmental effects. Only non-combustible renewable resources do not have negative emissions to air, soil or water (Itard, 2011).

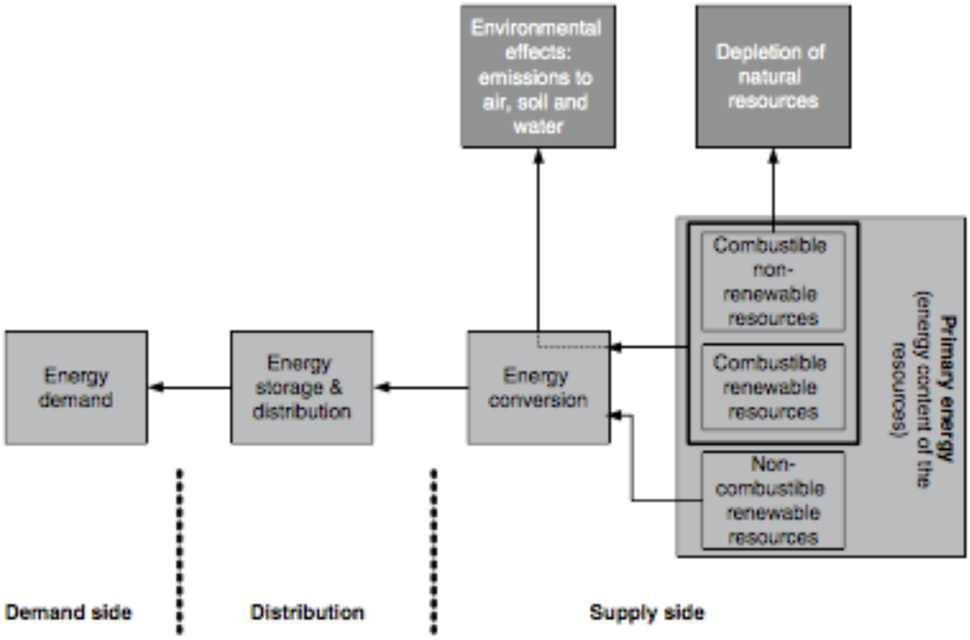

Figure 29: A generic energy supply chain (Itard, 2011: 120)

The primary energy usage is thus depended on the energy demand, the energy losses that happen in the energy distribution network and the energy conversion system used on the supply side. In current calculations a primary energy factor of 2,56 is used (Kruithof & Haytink, 2015: 10), this implies an average system efficiency of 39%.

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6.3.4 Energy performance measuring systems

Energy consumption in new buildings has been regulated in the Netherlands since 1975 (after the first oil crisis in 1973). The first regulations consisted only of limits on transmission losses based on the insulation values (Guerra-Santin & Itard, 2012).[30] Twenty year later, in 1995, the energy performance coefficient (EPC) became the indicator of energy efficiency of buildings (Guerra-Santin & Itard, 2012; Haytink & Valk, 2016). Nowadays, its successor is already known. The Energy Performance of Buildings Directive of the European Parliament and Council of the European Union (2010) requires all new buildings to be nearly zero energy from the end of 2020 onwards. The new regulations in the Netherlands will be based on BENG in order to comply with this directive. In the coming paragraphs the EPC and this successor BENG are discussed.

6.3.4.1 EPC

The EPC is introduced as a non-dimensional figure that expresses the energetic performance of a building, which was based on the energy consumption for heating, hot water, lighting, ventilation, humidification and cooling (Guerra-Santin & Itard, 2012). Some argue that the output value 1,0 is approximately the energy usage of an average house in 1990. That would mean that a new building in 2015 uses only 40% of the energy compared to the same house 20 years ago, since the required EPC-level is 0,4 in 2015 (PassiefHuisPlus, 2017; REV, 2017). Others state that an EPC of 1,4 for residential buildings more or less represented the standard building practice at that time (in 1995) and was therefore not considered difficult to achieve (Beerepoot & Beerepoot, 2007: 4817).

The required value is tightened over the years (see Figure 30). In addition to the EPC, the energy regulations in the Netherlands also further tightened the insulation values of external walls, roofs, ground floors, windows, doors and window frames (Guerra-Santin & Itard, 2012; Haytink & Valk, 2016). H. J. De Vries and Verhagen (2016) show that the obligation is always achieved with minimal effort in the period 1996-2003.

[30] For instance, roof insulation became mandatory since 1975, facade insulation since 1979 and insulation of the ground floor since 1983 (Ministerie van Volkshuisvesting Ruimtelijke Ordening en Milieu, 2002: 55).

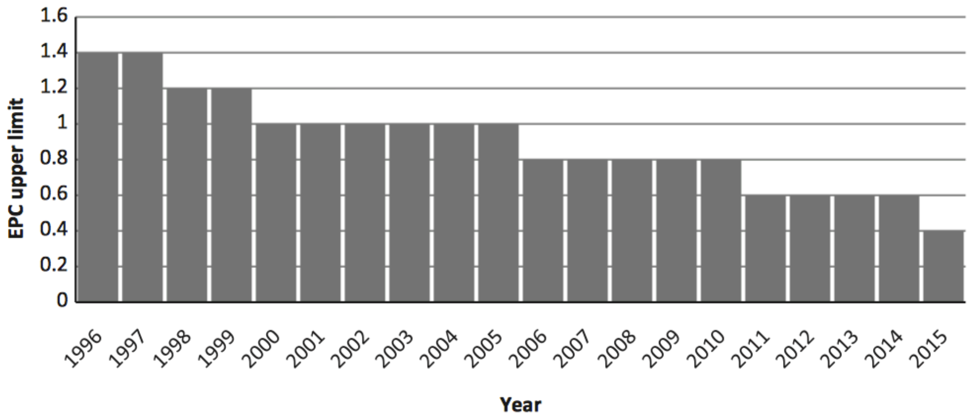

Figure 30: EPC upper limit in the Netherlands (H. J. De Vries & Verhagen, 2016: 59).

Guerra-Santin and Itard (2012) are giving a basic explanation about the calculation method of the EPC. The EPC is determined by dividing the calculated energy requirement of a building by a standardised energy performance, which is based on the heat-transfer surface and the total heated floor area of the dwelling. The correction by building size avoids penalising larger dwellings. Because of the geometrical correction, all buildings have the same EPC when similar energy features are applied (Beerepoot & Beerepoot, 2007). The EPC set a limit on the energy consumption, but because the correction can the estimated energy consumption still vary considerably for different housing types (Beerepoot & Beerepoot, 2007; Guerra-Santin & Itard, 2012). This allows designers and market parties to choose between applying energy-saving measures or renewable energy generation to meet the minimum requirements (Blok, 2015b; Guerra-Santin & Itard, 2012). For instance, if solar panels are cheaper in relation to a thicker layer of insulation, a heat recovery system or energy-efficient systems, the market party would most likely choose for adding more solar panels.

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The decrease in the maximum allowable energy consumption (by lowering the EPC) did not always had the desired effect. In 2006 the EPC was tightened to 0,8, but the theoretical expected energy savings of 20% were not reached. The effect on the energy consumption of dwellings were between 1 and 15% (Menkveld & Leidelmeijer, 2010). Besides lower savings than expected, residents had many complaints about the applied ventilation system, which caused noise pollution and health problems (Menkveld & Leidelmeijer, 2010).

The formulas for the determination of the energy performance of new buildings is established in NEN standards. These standards changed in July 2012. The NEN7120: 2011 replaces the NEN standards NEN5128 for residential construction and NEN2916 for utility buildings. The new standard is better known as the EPG, the method of determination for the energy performance of buildings (Dutch: '*De bepalingsmethode voor de energieprestatie van gebouwen*'). The new standard has been co-developed within the framework of the EPBD. In the old standards, the calculation of highly energy-efficient buildings was based on restrictions in the calculation method. In the new standard, an energy-efficient building can be modelled more in detail. As a result, the amount of input parameters has increased considerably, but the total energy consumption is roughly equivalent to the old standard for dwellings. However, there are differences between individual energy items, but these are limited. (Van der Loos, 2012)

6.3.4.2 BENG

BENG is going to replace the EPC-regulation. The European Performance of Buildings Directive (EPBD) requires that all new buildings must be nearly zero energy from the end of 2020 (Blok, 2015b; Bouwens & Bouwmeester, 2017; European Parliament & Council of the European Union, 2010). This directive applies for government buildings from the end of 2018.

In a letter to the Lower House of Parliament (Dutch: '*Tweede Kamer der Staten Generaal*'), the former minister of Housing and Civil Service Blok (2015b) presented his proposal to reach nearly zero energy buildings (nZEB), which can be literally translated to Dutch as '*Bijna Energie Neutraal Gebouw*' and is abbreviated as 'BENG'. BENG is inspired by the Trias Energetica of Duijvestein (1997): Reduce demand, use renewable resources and if needed, use fossil fuels as efficient as possible. The requirements of BENG are based on these steps, but in a different order (Bouwens & Bouwmeester, 2017). The EPBD requires separate requirements to be set for nearly zero energy buildings. As a result, the EPC was not suited anymore and is going to be substituted by this new energy performance measurement system BENG. The three new requirements of BENG are determined in the following way (Blok, 2015b)[31]:

1) The maximum energy demand of the building (in kWh/m^2.year)
2) The maximum primary energy consumption (in kWh / m^2.year)
3) The minimum percentage renewable energy (in % of the total primary energy demand)

For homes the boundary conditions will be set on a maximum energy demand and energy consumption of 25 kWh/m^2 annuarly for the first and second requirement and the minimum percentage of renewable energy generation is set on 50% (Blok, 2015b)[32]. It is not clear to which EPC these requirements met. According to Blok (2015b) the requirements are similar to an EPC of 0,2. However, Bouwens and Bouwmeester (2017: 3) state that it is approximately an EPC of 0.

Minister Blok (2015b) further argues that the heights of the above requirements is comparable to the requirements made in other Member States, such as, for example, Belgium and France. The requirements are already being realized in practice, but this is still in the top of the market. In 2018, before the requirements are laid down by law, they will be further tested for cost-effectiveness. If this test provides the insight that adaptation of the requirements is desirable, the minister of housing is going to consider an interim adjustment. This will be executed in consultation with market parties. However, the expectation of Blok (2015b) is that the requirements for the majority of the built environment are financially well-reachable in 2021. Only stacked constructions above five floors, studios and shops deserves special attention.

According to Blok (2015b), the requirements have as a consequence that new buildings need a better insulation and an increased air tightness. This is needed in order to drop the energy demand (the first requirement). Both measurements limit the amount of fresh air coming into the building. Therefore, the dependence on air conditioning facilities in buildings for maintaining a healthy indoor air quality will further increase. Comfort and health are important points of focus in the further development of nearly zero energy-concepts.

The new BENG requirements are tighter as the current EPC-requirement of 0,4, but besides that, because the BENG requirements focus on three different aspects even a housing concept with an low EPC or zero-on-the-meter does not necessarily have to meet the BENG requirements (Haytink & Valk, 2016).

6.3.4.3 BENG vs. EPC

The main difference between the EPC and BENG is that the EPC has one value to indicate the energy performance of a building (Bouwens & Bouwmeester, 2017). Within that single value a better score for one aspect can make up a worse score for another aspect. This happens in practise, because some renewable energy supply technologies are cheaper than extra insulation, so the first step of the Trias Energetica (reducing demand) is often skipped by real estate developers. In the BENG calculation this is not possible anymore.

A second difference is lighting. In the EPC calculation lighting is captured at the building-related energy demand. In BENG this is captured at the user-related energy demand (Bouwens & Bouwmeester, 2017). This only counts for dwellings.

Analyses by Bouwens and Bouwmeester (2017) show that the first requirement of BENG (reducing the energy demand) is the most critical. In the current practise even dwellings with an EPC below zero or zero-on-the-meter dwellings do not necessarily fulfil this requirement. In addition, Haytink and Valk (2016) state as main differences the increasing importance of design, importance of the coherence of measurements taken and the new requirement of a renewable energy supply on-site. The importance design-decisions are the shape and orientation of dwellings (Haytink & Valk, 2016). The researchers explain that is applies in particular to the size of glass openings in relation to the orientation. A solar orientated design can save 3-5 kWh / m^2 (Haytink & Valk, 2016). This implies, for example, an incentive for larger glass areas to the south and less to the north. Since the

[31] Appendix 13.9 gives an English summary on the components related to the calculation of the three principles of BENG based on Kruithof and Haytink (2015) Note that this method of calculation is still preliminary. In 2018/2019 the final calculation method will be presented (Bouwens, 2017a).

[32] These requirements are still preliminary. Once the final calculation method is largely completed (2018 Expectation), a cost-effectiveness study will begin on the feasibility of these requirements and based on the outcomes of this investigation shall the final requirements for the BENG indicators be determined (Bouwens, 2017a).

energy demand is not only determined in the winter but also in the summer period, attention should also be paid to summer comfort and the occurrence of overheating (Haytink & Valk, 2016). In addition, it appears that buildings with an unfavourable ratio between the usable floor area and the loss surface have a higher energy demand (Haytink & Valk, 2016). The orientation and shape of dwellings are therefore getting more importance within the BENG-legislation.

6.3.4.4 Energy Performance of a Location

Another tool of the government is the EPL. The Energy Performance Location (EPL) indicator is a measurement tool on the neighbourhood level, based on the assumption that an integral approach would be needed to improve the energy performance of a building (Rovers, 2008). Many technical installations are more efficient in larger volumes (Rovers, 2008). "*This EPL means that energy aspects can be introduced which are outside the scope of the house building and construction sectors, but which have a positive impact on the energy consumption of a building (e.g. energy-efficient heat and electricity generation, collective facilities, heat delivery, etc.).*" (Rovers, 2008: 25). Currently this a voluntary tool, mostly used by governments to set development targets (Rovers, 2008).

6.3.5 The balancing agreement

The balancing agreement (Dutch: '*Salderingsregeling*') makes it possible for small energy consumers (e.g. households) to balance the amount of generated electricity which is not used immediately and therefore returned into the electricity grid by the amount of electricity taken from the grid, when the PV-panels do not deliver a sufficient amount (Schootstra, 2016; Staats, 2015). This settlement occurs for the same cost as the electricity taken from the grid (in other words the producer's delivery rate), including energy tax, ODE and storage tax (Schootstra, 2016). In other words, the final energy bill of households states how much electricity they have taken from the grid deducted by the amount of electricity they have returned to the grid.

The balancing agreement results in shorter payback times for households, because they are not selling their overproduced electricity against market price, but instead it reduces the amount of kWh of electricity taken from the grid and therefore the overproduced electricity is valued at the consumer price (Staats, 2015). The balancing agreement is limited to the yearly energy usage of a household and in case more electricity is produced than consumed within one year, the returned electricity is valued at the market price or at the market price plus a suppliers premium (Staats, 2015).

The balancing agreement has contributed to a significant increase in the total installed capacity of PV-panels for small consumers since 2011 (PwC, 2016). In this period the average annual growth was 91%, compared with an average 13% growth over the period 2004 to 2011 (Kelder, 2017; PwC, 2016). The increase of the amount of installed PV-panels is also due to national and regional grants and the sharp fall in solar panel costs. In particular, the introduction of the balancing agreement reduces the payback period from 14 years to 7 years, which is an important incentive for individuals to invest in PV-panels (Kelder, 2017; PwC, 2016).

However, the evaluation of PwC (2016) also shows that the balancing agreement is very expensive for the government and that the scheme does not encourage solar panel owners to invest in storage batteries. The government therefore wants to adjust or even abolish the balancing agreement (Bouwens, 2015a; Kelder, 2017).

For the current situation, the scheme is a very effective incentive for decentralized generation of solar energy. But as the share of solar flow in the energy mix increases, the imbalance on the electricity grid also increases. This is a problem for the network administrator, for which the capacity of existing networks needs to be expanded and investments in smart grids are needed. It is also a problem for the electricity producer, which is due to fluctuations due to huge price differentials through supply and demand.

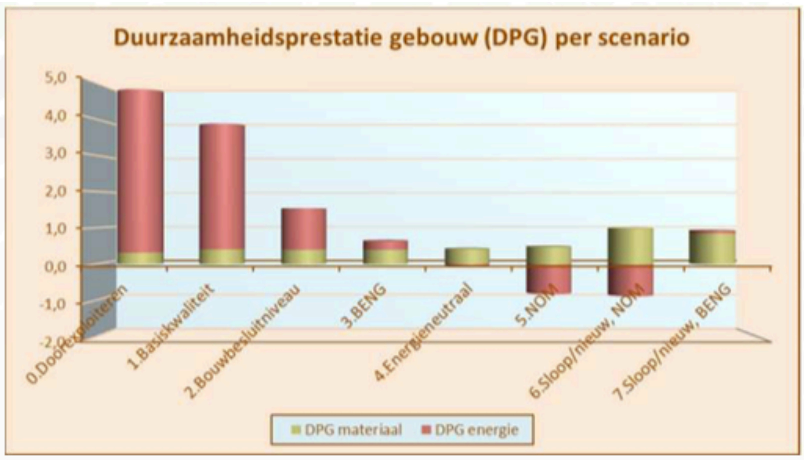
The temporary parking of power on the net by the solar panel owner, as if it were a storage medium, has consequences. Power can not be parked and must be used immediately, in balance with the amount of electricity produced and decreased elsewhere. It is logical that the solar flow prosecution contributes to those costs (Schootstra, 2016).

Staats (2015) has investigated possible technological solutions to mitigate the financial gap that results from the abolishment of the balancing agreement. The solutions concern (electrical) storage, demand control (using electricity when the sun shines) and a change in the orientation of solar panels.

6.3.6 Environmental Performance of Buildings

The Environmental Performance of Buildings (Dutch: '*MilieuPrestatie Gebouwen*', 'MPG') calculates the environmental impact of the materials used in a building (Kurstjens, 2017; TiMaX, 2015).

The combination of the MPG with the stricter energy legislation needs attention, because these two sustainability tracks are handled separate from each other in legislation, but they are effecting each other. For example, a PV-panel increases the energy performance, however, its scores relatively low on the energy performance because the production of a PV-panel costs a lot of energy (Luijkx, 2017c; Verlinden, 2017). Both trends will be restricted by even tighter regulations. Kurstjens (2017)[33] spoke about the change in legislation during the congress about the best energy ambition of new dwellings for housing association and explained that the MPG is active within the building degree since 1996, however, there were no harmonization methods for a reliable and verified calculation. This changed by the introduction of the National Environmental Database and the MPG became mandatory within the environmental permit in 2013. From the start of 2018, the MPG gets a limit value. This is comparable to how it went with the limit value of the EPC. It can be expected that this limit value will drop in the coming years. The MPG will ensure that the unilateral focus on energy is at least broadened to material use and CO_2-reduction. W/E adviseurs use an integrated score for the sustainability performance of buildings in which energy and materialization both take place (Kurstjens, 2017; Luijkx, 2017c). The results of such a calculation are shown in Figure 31. This figure shows the huge environmental impact of energy usage on the material balance of an old dwelling. Demolishing and rebuilding the dwelling with an increased energy performance will even cause less environmental damage in the long run. The figure also shows that renovation to zero-on-the-meter has the best environmental performance. This combination shows an interesting approach to realize the optimal solution for environmental performance. In addition, materials have to be used circular. the Netherlands was to be a circular country in 2050 and introduced a government-wide program to realize this objective (Dijksma & Kamp, 2016; Luijkx, 2016; Verlinden, 2017). In his presentation Verlinden (2017)[34] stated that the agenda about the circular economy exists of five main priorities, one of them is the construction sector.



RESULTATEN SCENARIO'S	
Scenario	DPG totaal
0.Doorexploiteren	4,80 100%
1.Basiskwaliteit	3,86 80%
2.Bouwbesluitniveau	1,54 32%
3.BENG	0,64 13%
4.Energieneutraal	0,38 8%
5.NOM	-0,33 -7%
6.Sloop/nieuw, NOM	0,12 3%
7.Sloop/nieuw, BENG	0,93 19%

Figure 31: Sustainability performance of a building for each scenario (Kurstjens, 2017: 23).

This new requirement in combination with the national calculation method and a nationwide database brings an end to the lack of clarity that is or is not sustainable (TiMaX, 2015).

6.3.7 Conclusion

The new legislations of BENG and MPG together with the adjustment of the balancing agreement require new solutions in the design of energy efficient dwellings. In particular, the BENG-legislation ensures a reduction of

[33] Senior advisor at W/E-adviseurs which is the company behind GPR-gebouw and GPR-stedenbouw. These tools were mentioned by the expert focus group as often used and widely recognized decision support tools (Nan *et al.*, 2017).

[34] Jos Verlinden is part of the managing board of the building and energy department within the Ministry of Home Affairs (Dutch: '*Ministerie van Binnenlandse Zaken en Koninkrijksrelaties*').

the energy demand and a renewable energy supply on-site. Currently, the MPG-legislation is still in his infancy, but when the legislation requires an increase of the total environmental performance also new solutions for the technologies used to realize BENG needs to be found.

The change of the balancing agreement also effects the business case of the energy efficient dwellings. In this way all three different legislations are related to each other.

6.4 Organisation: Involved parties and contractual agreements

6.4.1 Introduction

This theoretical part on organisational schemes for ENRND-projects is about the collaboration of the involved parties in urban area development in the Netherlands.

The part starts with basic insights of organisational schemes in urban area development projects and is followed by the main problem related to the organisational aspect. Third, three solutions for improvement of the organisational aspect of the business case for the development of energy neutral dwellings. The solutions can be seen as possible interventions for optimisation. The part ends with a conclusion.

6.4.2 Basics of inter-organisational agreements

The coming paragraphs discuss the possible public-private collaboration strategies and types of integrated contracts. The decision-making phases and involved actors already discussed. The paragraphs show in sight in the way how these types of actors are connected during the different development phases.

6.4.2.1 Public-private collaboration strategies

The public and private sector and associated actors can collaborate in different ways in urban area development projects or can chose to do the whole development by themselves (e.g. public or private development).

The applied collaboration strategy is based on the land policy of the municipality and the partnership between the sectors in the land- and real estate development phases. Heurkens (2012) describes that is it common to speak of partnership models, which is an "*institutionalized organizational project-oriented approach to 'join up' actors' interests, means and objectives.*" (Heurkens, 2012: 148). Many different theoretical types of public-private partnership models exists in Dutch development practice, although they are often slightly different used in practice. Heurkens (2012) uses the definition of a public-private partnership from Nijkamp, Van der Burch, and Vindigni (2002) in his research:

> "*A PPP is an institutionalized form of cooperation between public and private actors who, on the basis of their own indigenous objectives, work together towards a joint target, in which both parties accept investment risks on the basis of a predefined distribution of revenues and costs.*" (Nijkamp *et al.* (2002) in Heurkens (2012: 148))

This quote states some interesting aspects. First of all, the public and private actors work together towards a joint target, irrespectively of their own objectives. Secondly, the parties have agreed on the financial aspects on forehand. J. C. De Jong (2016: 39-41), Heurkens (2012: 148-158) and Ten Have, Nab, and Khandekar (2011) are explaining in-depth the theory of the traditional collaboration models, which is summarized in Figure 74 and in Appendix 13.11.1. The models differentiate in type involvement of public or private actors in each phase, in the distribution of risks, the amount of influence per sector on the end-result and the responsibilities for execution.

6

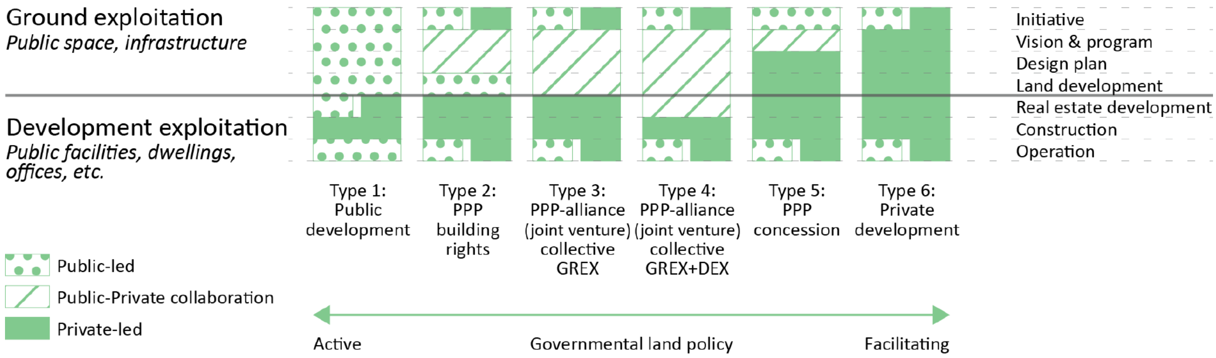


Figure 32: Models of public-private collaboration in the ground and real estate development combined with the roles of the public & private sector in each development stage within public-private-partnership models (own illustration based on J. C. De Jong (2016: 40) and Heurkens (2012: 149).).

The division of risks, responsibilities and decision power shift from the public sector towards private sector, when going to the right in Figure 74 (Heurkens, 2012). The models also indicate that the main differences are the power of decision-making in the vision, program and design phases. The decision-making in the vision & program phase determine if there is a public- or private development or a partnership between both. In case of the partnership, the division of risks and responsibilities in the land- and real estate development determine largely which type of partnerships are possible.

The type of partnership model also indicates the possible incentives for the real estate developer to incorporate higher energy ambitions. For instance, one of the biggest incentives of obtaining permits and complying with the legislations (Buskens, 2015), is only possible in case of an active role of the public sector and the other incentives are possible in all possible development strategies.

6.4.2.2 Procurement methods

Residential construction projects involve a large number of actors that interact in different phases of the process. The contractual relations, roles and responsibilities of the actors involved in this process (e.g. client, design companies, construction companies and maintenance companies) are jointly referred to as the procurement methods[35] (Rahola & Straub, 2013). Different relevant procurement methods can be identified for ENRND-projects: the traditional Design-Bid-Build (DBB), design team, Design and Build (DB) and Design-Build-Maintain (DBM)[36]. The first two methods have three tendering moments for design, construction and maintenance separately (Chao-Duivis *et al.*, 2010; Rahola & Straub, 2013). The other two need two or one tendering moment in which one party or a consortium of parties is tendered and are therefore called integrated procurement methods or integrated contracts (Chao-Duivis *et al.*, 2010; Rahola & Straub, 2013). The involvement of the different type of parties during the different phases and their contractual relations are shown in Figure 33.

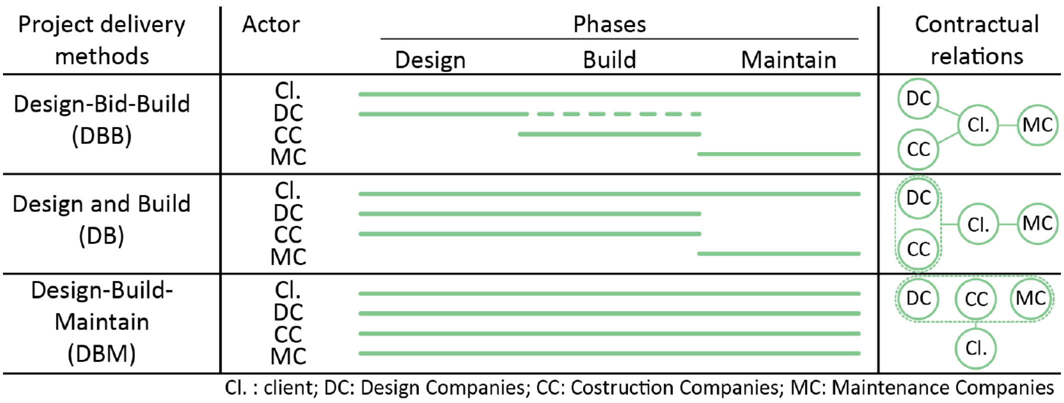


Figure 33: Actors' phase involvement and contractual relations (own illustration based on Rahola and Straub (2013: 221)).

[35] Called 'project delivery methods' in US literature (Rahola & Straub, 2013).
[36] The procurement methods are explained in Appendix 13.11.2.

The advantages of DBB are that it is the traditional procurement method and that all actors know their roles and what to expect from the process (Rahola & Straub, 2013). In addition, DBB is well suited to tender for the lowest price and tendering for the lowest price entails less administrative burden, because the tender procedure saves time and responsibility for demonstrating that the selection process is transparent and objective (Costantino *et al.*, 2012). The main disadvantage of DBB is the lack of collaboration between the design, construction and maintenance companies and it is therefore harder to manage liabilities (Rahola & Straub, 2013). For example, the design company may choose a particular heating system, whilst the construction or maintenance company knows that it does not perform as it should.

In case of an integrated contract there is better communication between the actors by the involvement of the construction companies in the design decisions and such examples are less likely to happen. In addition, the integrated contracts lead to shorter project durations and higher price certainty (Rahola & Straub, 2013). Therefore, clients perceive that DB delivers better value for money and causes fewer disputes (Rahola & Straub, 2013). In addition, the majority of the risk of design failure is transferred to the contractor or the consortium, as a single entity is responsible for design and construction and because design and execution are integrated it is possible to involve performance-based specifications (Pless, Torcellini, & Shelton, 2011; Rahola & Straub, 2013). In case of DBM is it possible to use energy performance guarantees by means of Energy Performance Contracting[37]. Disadvantages of integrated contracts are that it presupposes a change in the role of the actors and as a consequence, extra effort and time is needed to adapt to the new situation (Chang, Shen, & Ibbs, 2010).

6.4.3 Barriers from an organisational perspective for energy efficiency

The transition to BENG in the years from 2018 till 2020 will not be easy, because there is a fast transition time and a lack of sufficient pilot-projects and time to educate employees (Kantola & Saari, 2016). Kantola and Saari (2016) expect that there will be some problems and a period of adjustment even with for companies that are best prepared to make the transition. The impact of these problems related to BENG features, such as airtightness, renewable energy and building comfort, can be expensive (Kantola & Saari, 2016). This is caused by the increasing the complexity of residential development projects (Kantola & Saari, 2014, 2016). This complexity is associated with technology and the state-of-the-art HVAC installations[38] that pose additional risks. The likelihood and the magnitude of mistakes increase when the project size grows and the design becomes more unorthodox. In addition, the probability of costly mistakes in complex projects is high (Kantola & Saari, 2014). The main barrier is therefore the need of new, specialised knowledge, which is not available at the beginning of residential projects aiming at a high energy ambition.

In general, underperformance of projects is caused by among others project complexity, technological uncertainty and demand uncertainty (Flyvbjerg, 2012). According to Flyvbjerg, Garbuio, and Lovallo (2009) these factors are not the root cause of underperformance, which is the fact that project planners tend to systematically underestimate or even ignore risks of complexity, scope changes, etc. during project development and decision-making. This ignorance or underestimation of risks is often caused by optimism (also called the optimism bias) or strategic misinterpretation (Flyvbjerg *et al.*, 2009). Without going into depth about both root causes, the main problem is the planning fallacy in which managers make decisions based on delusional optimism rather than on a rational weighting of gains, losses and probabilities (Flyvbjerg, 2012). They overestimate benefits and underestimate cost and time.

Project complexity, technological uncertainty and demand uncertainty[39] are all relevant aspects in realizing ENRND-projects. These general causes of underperformance of projects and the planning fallacy to underestimate them makes the main barrier of the need for proper knowledge and skills in the beginning of the project even of higher importance.

[37] More about energy performance contracting and ESCOs in chapter 6.5.4.3.

[38] The state-of-the-art HVAC installations currently involve automated and integrated systems as standard features and problems observed in the past rose from the integration between automation, control systems and other HVAC solutions; therefore innovative systems may have an unmanageable degree of complexity (Kantola & Saari, 2014).

[39] Demand uncertainty is described in the part about the market value of energy neutral dwellings (see chapter 6.5.3.4), which is unknown in theory. Only the increased market value of A-labelled dwellings is known, however, this is required as minimum level in the building degree.

In addition, the structure of the construction industry in the Netherlands forms a significant barrier for the adaptation of sustainable technologies in residential development (Pinkse & Dommisse, 2009). According to Pinkse and Dommisse (2009) that is because the technological activities have been outsourced by the major construction companies and therefore it is difficult for a contractor to appraise and communicate about new technological innovations when they emerge. This seems to be particularly challenging for involving innovations for sustainability, because "*they are considered exceptionally risky as they often involve breaking loose from the prevailing technological lock-in.*" (Pinkse & Dommisse, 2009: 526)

6.4.4 Solutions from an organisational perspective for energy efficiency

The next section explains some solutions for improving the energy efficiency based on organisational aspects, such as who, when and how? First, the involvement of new parties in development processes is explained, followed by their moment of involvement. Third, the best suited contract method is explained and fourth, new collaboration schemes in the business model related to energy are presented.

6.4.4.1 Involvement of new parties

The involvement of new parties in urban area development is a topic of discussions. Some people (e.g. the Peek and Van Remmen (2012)) are in favour of the involvement as they see opportunities for the realisation of a feasible business case. Others (e.g. De Zeeuw (2011)) are critical whether this benefits the feasibility, because of almost inextricable contracts and blurring of the development industry by involvement of parties who lack knowledge and experience. First the argument in favour of the involvement is discussed, followed by the counter argument. After that the potential new parties in urban area development are discussed.

6.4.4.1.1 Debate on added-value of involvement of new parties

Peek and Van Remmen (2012: 10) describe an innovation in which the end-user takes a central position and where costs-savings and sustainability performance are realized. In the core of this new method they see a clever coupling of real estate, usage and flows. This new concept of 'flows' is defined as the representation of everything that enables the usage of real estate, which are the urban infrastructures of mobility, water, energy, waste, communication, health, safety, education and social development and also included the required information for managing these facilities. The parties that are managing the urban infrastructures of energy, communication, water and waste can actively be involved in urban area development. Early involvement of this parties in the planning phase enables the possibility for value creation in the operational phase, but demands other methods of collaboration. After all, real estate companies develop real estate with the ground exploitation as the financial basis. The parties of the urban infrastructures provide services and build installations, but have their own method for value creation. As the Peek and Van Remmen (2012: 10) sees it, this value can be added to the ground exploitation and thus, the ground exploitation can be supplemented with other financial business models.

De Zeeuw (2011) describes the involvement of new parties like the healthcare, energy and waste management sectors in urban area development as an unlikely, highly risky and a complex perspective. Even with the development of London King's Cross as an international example, he sees too many examples of failure in the Netherlands. As example for the statement that integrated contracts between public and private parties do not work for urban area development, De Zeeuw (2011) uses the Amsterdamse Zuidas. In this case is the linkage of public and private investment almost inextricable. De Zeeuw (2011) believes that DBFMO-like contracts are, in principle, applicable to fairly unambiguous products such as roads and buildings, but rarely on multiple area development. The second point of criticism of De Zeeuw (2011) is the blurring boundaries of the development industry by involvement of parties who lack knowledge and experience. As examples he named the real estate development activities of healthcare organisation Philadelphia which led to a bankruptcy, the transformation of the steamboat 'De Rotterdam' by housing association Woonbron, which led to a huge financial failure and the dramatic financial results of district heating companies. However, De Zeeuw (2011) agrees that the flows of energy and water are going to play a greater role in urban area development. These flows can act as value creators. And even integration of the municipal departments development and management can lead to cost savings. His opinion is very clear in the quote: "*But completely new 'earnings models'? Forget it, it's voodoo*" (De Zeeuw, 2011: 6).

Although not all parties who operate urban infrastructures (i.e. flows) can act as value creators, both Peek and Van Remmen (2012) and De Zeeuw (2011) see energy companies, installation companies and end-users as new parties in new style urban area development. The possible influence of these parties on energy efficient dwelling development is described next.

6.4.4.1.2 Energy grid operators

Households in the Netherlands mainly have three different connections for the energy supply, namely electricity, natural gas and heath. On average a Dutch dwelling only has a connection to the first two types of energy. The network of these energy sources is changing. This chapter provide a basic understanding of their development, working and to which direction they are changing.

The energy sector is in a transition to change from the traditional system with centralized generation and decentral consumption towards a system based on decentralized production of renewable energy and consumption (Peek & Van Remmen, 2012). In the current, centralized energy system electricity is transported from a central power plant to the consumer via three different network stages (Beggs, 2009; Itard, 2011; Vreeburg, 2016), see Figure 34. First, the electricity is transported over long distances by a high voltage distribution system (200-400 kV). Second, when getting close to industrial or built environments, a lower voltage distribution system is used (10–110 kV). Finally, electricity is transported to households using low voltage distribution (110–230 V). The high voltage part has little energy losses (±1%), the low voltage part has some more energy losses (±5%), however, the real energy losses are in transformers (4% up to 15%) (Itard, 2011). The low energy losses in the transmission grid makes it possible to transport electricity over very long distances (Itard, 2011). The central power plants makes the systems also more easy to control, which is important, because without a balance of supply and demand of electricity the system will black-out (Monti *et al.*, 2017; Vreeburg, 2016).

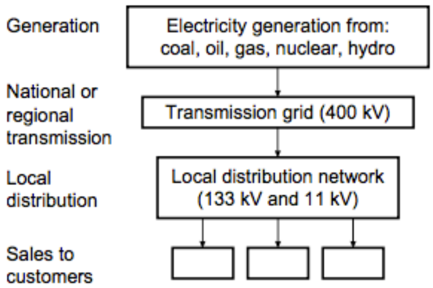


Figure 34: Typical structure of an electricity supply network (Beggs, 2009: 35)

The new, local (renewable) energy supply slowly changes the electricity grid to a decentral system in which consumers change to prosumers (producers and consumers). This change also requires several needs. First, a need for smart grids, because of the increasing difficulty of controlling the flow of electricity, more points of measurement are needed to get data about the real life flow of electricity. Second, a need for knowledge how to deal with peak moments of electricity generation by PV-panels, because those cannot be controlled from a central control system, as is the case with the power plants. And third, how get flexibility in the irregular energy supply of renewables. Chapter 6.6.3 further continues on these technological barriers.

It is difficult for grid operators to expand and optimise current energy grids. The description of Peek and Van Remmen (2012) about heating grid development shows a clear example. The operators of the heating grids are interested in expanding and optimizing them Heating grids are used in many cities to utilize residual heat from electricity generation, industry, greenhouses and waste incineration instead of the boilers in most dwellings that consume natural gas to provide this heat. The scale of many urban area developments is therefore interesting for heat companies. Early participation is required to utilize the opportunity to implement and adapt the infrastructure (Peek & Van Remmen, 2012). It is also possible to connect local renewable sources as geothermal heat to the heating grid. An important restriction, however, is the distance between the source and the connection points, because hot water cannot be transported over long distances without a lot of heat loss. Thus, there must be sufficient customers within a limited range of heat production. The required density is a second point of overlap between urban area development and the heating grid company. Peek and Van Remmen (2012) provides three reasons why the principle of investing in a heating grid does not differ much from that of traditional urban area development. First, it is a long-term investment of at least 30 years, which is largely dependent on the number of connections and heat extraction over the years. Second, the rapid realization of a large number of connections is important because the connection costs cover a substantial part of the investment. And third, heating grid companies face the same problems in their expansion during a declining housing demand as real estate developers, namely an increasing market risk.

Practitioners like the CEO of Alliander Molengraaf (2017) and Frouke Pieters of Liander during the congress of Bouwens (2017b) both indicate the urgency for the grid operator to be involved early on in the development process, because they as grid operator can help to facilitate the development of new dwellings and neighbourhoods without a natural gas connection and energy positive. In addition, they want to prevent large investments and blackout in case the energy grid has a too low capacity for become this decentral grid. This is supported by Vreeburg (2016).

Concluding, it can be expected that grid operators, especially the electricity grid operator, plays a role in the decision-making in the ENRND-projects to steer developments in such a way that large investments in the electricity grid to prevent possible blackouts can be prevented[40].

6.4.4.1.3 Installation technology companies

Companies from the installation technology can be involved more earlier in the developing process. Currently, they produce and maintain the devices that provide a healthy indoor climate. The companies install the required installations at the end of the development process. However, the knowledge of these parties can be used at an earlier stage to optimise the effect of the installations used in the building and on the scale of an urban area (Peek & Van Remmen, 2012). In addition, these companies can provide energy performance contracts that make buildings more energy efficient without effect on the budget (Peek & Van Remmen, 2012)[41].

Peek and Van Remmen (2012) indicate that apart from these performance contracts, which can last up to 20 years, the business model of installation technology companies has a short horizon. Their basis is selling devices and installing them, then it can also be the maintenance part of the business. Some companies may also hold or finance installations. Installation companies are not used to real estate risks, such as housing sales.

Concluding, by involving the companies who install the installation technology early on in the project, they can change their role to technological advisors and set boundary conditions for an optimal effect of the installations used.

6.4.4.1.4 End-users

In the new style of urban area development is the payment of end-user the basis for all revenue models (Peek & Van Remmen, 2012). The mix of users and utilities are determining if the area is attractive or not. Real estate users are individuals, mostly residents, institutions and companies. It is important to involve end-users during the development, according to the Peek and Van Remmen (2012), because the current and new users determine together the image of the area, they provide rental income and early involvement in the development and commitments of end users reduces the risk for all parties involved.

Putman (2010) indicates a changing financial process from getting land positions (focus on speculation of housing supply) to a focus on demand[42]. This can be executed by market research, but also by actually involving them in the development process.

It is difficult or costly for individuals to form accurate and precise expectations on the equipment performance (Howarth & Andersson, 1993). In addition, consumers predicate to lack full information regarding available energy-efficient technologies or simply lack the means to carefully evaluate the consequences of their decisions (Howarth & Andersson, 1993). This is in line with the huge performance gab between the actual energy consumption and the theoretical calculated consumption of energy efficient dwellings[43], as identified by Majcen (2016). This is among else caused by a lack of knowledge how to behave in an energy efficient dwelling. Education of future end-users is required to change behaviour and prevent the energy performance gab.

[40] Chapter 6.6.3.2 describes and Graph 7 shows graphs with the large impact a ZOM-dwelling has on the average electricity grid, which is during peak moments six times higher as a normal dwelling (Molengraaf, 2017).

[41] Chapter 6.5.4.3 explains more on energy performance contracts and ESCOs.

[42] More information on the changing focus of a real estate developer within real estate finance in chapter 4.3.4 and chapter 6.5.2.

[43] More information on the energy performance gab in chapter 6.6.3.1.

(Future) residents are taken initiatives leading to local energy companies, which in theory could be an effective approach, as the initiators are the end-users, acting in their own interests and therefore are already satisfied with a low return-on-investment (Peek & Van Remmen, 2012).

Concluding, end-users are the central spot of the main new business models in UAD 3.0. Involving them brings the opportunity 1) to get real information about the market demand, 2) to provide end-users more knowledge about the operation of energy efficiency dwellings to prevent the performance gab. And 3) to let them organise an own local energy company themselves, which is in line with their interests. Therefore, they accept a lower return-on-investment, which increases the likelihood of a feasible business case.

6.4.4.2 Early moment of involvement of advisors and new actors with knowledge

Complex decisions are made more earlier in the development process and therefore it is helpful to involve the knowledge of advisors and the described new actors in the early stages of the project.

This solution is endorsed by Peek and Van Remmen (2012) who state that the knowledge of these parties can be used at an earlier stage to optimise the effect of the installations used in the building and on the scale of an urban area. Spijkerman (2017b) also agree by stating that he identifies a changing role of advisors. Especially the technical advisors are giving restrictions before the design is made. By involving the people with the technical knowledge and the experience how to operate with the installations, complex decisions can be made more successfully already early on in the development process.

6.4.4.3 Integrated contracts or commissioning of energy efficient installations

Sub-optimal decisions in early phases of ENRND-projects by misinterpreting the complexity or the lack of knowledge have a large impact on time and investment. Because the impact is large, it is worthwhile investing money and resources in lowering the probability of those risks (Kantola & Saari, 2014). One of the solutions to prevent the optimism bias and planning fallacy is to get the knowledge early on in the project. Two suitable options are using commissioning and integrated procurement methods (Kenig, 2011)[44].

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First, commissioning is a comprehensive quality assurance method in new building projects that focuses on the energy efficiency and the related HVAC installations of a building and ensures that these buildings deliver or exceed the performance and energy savings promised by their design and intended operation (Kantola & Saari, 2014; Mills, 2011). Commissioning is executed by involving an objective third-party consultant who has to ensure that the advices and suggestions have unbiased background to all parties (Kantola & Saari, 2014), which helps to prevent the optimism bias. By involving the commissioning consultant throughout all the phases it positively affects many fundamental decisions early on in the project, which creates financial benefit later on (Kantola & Saari, 2014). The three most important phases of the project for commissioning consultants are the pre-design, handover and operation phases or the beginning and the end of the project (Building Commissioning Association, 2011). According to Mills (2011), commissioning is the single most cost-effective strategy for reducing energy, costs, and greenhouse gas emissions in buildings today. Commissioning is particular useful in traditional procured construction projects (i.e. design-bid-build contracts), because the essential part of commissioning is to bring close co-operation between parties (Building Commissioning Association, 2011; Djuric & Novakovic, 2009), which is required to bring knowledge of the construction and operation in the early decision-making moments. Therefore, commissioning is an affordable and effective way to prevent large-scale quality problems related to energy efficiency (Kantola & Saari, 2014).

Second, integrated contracts are the most suitable procurement method for complex and technologically challenging projects such as ENRND-projects, because those also support cooperation (Kantola & Saari, 2014). The DBM approach has the maximum potential to deliver energy savings of the described procurement methods, because it facilitates the collaboration between different actors of all phases from design, construction and operation and it promotes their commitment to achieving project goals (Rahola & Straub, 2013). In addition,

[44] Kenig (2011) uses different terms, namely Construction Manager At-Risk for commissioning and Integrated Project Delivery methods for integrated procurement methods.

DBM offers a higher certainty of price and less risk of design failure compared to the other procurement methods (Rahola & Straub, 2013).

The best choice between commissioning and integrated procurement methods is depending on the experience the involved companies have with integrated contracts, because integrated contracts presupposes a change in the role of the actors and as a consequence, extra effort and time is needed to adapt to the new situation (Chang *et al.*, 2010). For that reason, the transition period between 2018 and 2020 to get familiar with the EPBD-requirement can also be used as a transition period to get acquainted with integrated contracts (Kantola & Saari, 2014). Commission is a suitable method to bridge this period and get the advantages of commissioning. This would help to prepare the staff for the impending larger change of integrated contracts by first introducing them to a smaller change which is non-competitive with the later change (Kantola & Saari, 2014). After a successful implementation of integrated procurement methods, commissioning will get a negative impact on project costs. Kantola and Saari (2014) states this based on two reasons. First, the combination of commissioning and integrated procurement method lead to a lowered efficiency of the workers during the learning curve (Dewey, 2007) and because of learning anxiety (Warr & Downing, 2000). Therefore, because of the quality control function of commissioning agent, the employees of the client are no longer challenged to get the most out of the project. Second, by stating "*Any decision proposed by the commissioning consultant could just as well be made by an experienced owner*" (Kantola & Saari, 2014: 379), Kantola and Saari (2014) indicate that commissioning is redundant in case experienced people are involved in the early-phase decision-making. Therefore, Kantola and Saari (2014) continue, the benefits of commissioning have to be significant compared to a business-as-usual scenario. The idea is thus that commissioning can bridge the gap till the time that integrated contracts have become commonplace. Both bring a holistic perspective to design, construction, and operation that integrates and enhances traditionally separate functions (Mills, 2011). Therefore, both methods positively affect many fundamental decisions early on in the project.

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6.4.4.4 Collaboration schemes in the business model for renewable energy

Peek and Van Remmen (2012: 35-36) describe five possible collaboration schemes to realize a renewable energy supply on a neighbourhood level, of those three are relevant to this research. They are shortly introduced based on Peek and Van Remmen (2012) and provided from feedback.

First, a local energy company, which can be an independent energy service provider, but could also be related to an energy distribution company, housing corporation, real estate developer, investor or municipality. There actions are comparable to national energy service providers, because also these local energy companies have a profit target and invest risk-bearing in installations and infrastructure of sustainable energy systems. Van der Post (2011) investigated whether a local energy company could contribute to the value creation and/or risk reduction of an inner-city urban development. He concluded that the local energy company is no new party involved in urban area development and that the creation of a local energy company has the greatest chance of success in case a real estate developer / investor, whether or not in cooperation with the local government, acts as investors. This is because there is little willingness to invest by the new involved parties, such as energy companies or installation companies, before the financial feasibility of the business case has been demonstrated and this business case is highly dependent on the (phasing of) real estate development. In addition, Van der Post (2011) continues, stakeholders in local energy companies say they are satisfied if the energy business case can be made watertight. He identified no example in which a possible contribution to the real estate exploitation was possible. Therefore, the local energy company does not look a feasible business model for real estate developers in ENRND-projects.

Second, a local energy cooperative. This is a specific form of a local energy company in which a group of end users combine their power to make an innovative (renewable) energy system feasible. Such a cooperative provides for the marketing and / or generation, conversion and delivery of energy. The conclusion of De Lege (2016) about the collaboration between real estate developer and local energy companies is that it has only a potential added value for real estate developers in case they are difficult to develop or it is difficult to realize the energy ambition of the municipality. As possible barriers De Lege (2016) identified the need for sufficient space and a licensed supplier[45] and the possible lack of skills, experiences and/or knowledge at the residents to create and manage such a cooperation. Therefore, the local energy cooperative could be of added value for the real estate developer in ENRND-projects, but this is not very likely.

[45] This is only required in case the installation is not 'behind the connection' (De Lege, 2016).

Third, the energy Service Company (ESCO). An ESCO does not provide energy, but delivers an energy saving service. The company guarantees energy-saving on the basis of a performance contract and offers thereby the ability to get real estate sustainable in a budget neutral manner (Peek & Van Remmen, 2012). The ESCO is explained more in-depth later in chapter 6.5.4.3.

There are possibilities for new collaboration schemes within the business model for energy, however, those are highly dependent on the effort of the real estate developers and only one offers trustworthy possibilities to reduce the (financial) risks of the investment.

6.4.5 Conclusion

The previous part provided insight in the basics collaboration schemes within urban area development projects and the barriers and solutions for the optimisation of the organisational aspect of the business case for the realizing ENRND-projects.

The main barrier identified is the risk of underperformance of ENRND-projects by increasing project complexity, technological uncertainty and demand uncertainty, which cause the planning fallacy. The planning fallacy cause project managers and planners to systematically overestimate benefits and underestimate cost and time. This risks increases with the increasing complexity of the technological component of energetic installations, required by the rapid tightening of energetic legislations. The result of the main barrier is the need for proper knowledge and skills in the beginning of the ENRND-project.

In addition, the effect of the energy-related decision in the beginning of the project has a huge effect on the future operation of the electricity grid. This grid is transforming from a centralized to a decentral grid with prosumers instead of only producers and consumers. The increasing importance of design-decisions makes it likely that the grid operator plays a role in the decision-making, as desired by the CEO of the biggest grid operator in the Netherlands, Molengraaf (2017).

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The possible solutions are sorted based on: Who? When? How?
Who? Involvement of non-traditional parties such as the electricity grid operator, installation companies, energy advisors, end-users and ESCOs can act as value creators in ENRND-projects.
When? The knowledge of these parties can be used at an earlier stage to optimise the effect of the installations used in the building and on the scale of an urban area. Especially the involvement of (technical) advisors/ consultants can have added value by giving restrictions before the design is made and by guidance through all phases (e.g. by commissioning). By involving the people with the technical knowledge and the experience how to operate with the installations, complex decisions can be made more successfully already early on in the development process.
How? Integrated contracts or commissioning results in getting knowledge and responsibilities about the construction and operation in the early phase of the development process. In addition, can new collaboration forms help, such as the ESCO, which is likely to be of added value or possibly a local energy cooperative.

Lastly, the type of partnership model indicates the main differences in the power of decision-making in the vision, program and design phases. For a clear view on the decision-making from a viewpoint of the real estate developer, this should be taken into account. The type of partnership model also indicates the possible incentives for the real estate developer to incorporate higher energy ambitions, for instance, obtaining permits or a requirement in a public tender, or identifying some market demand.

There are multiple different solutions to overcome the barriers of ENRND-projects and to optimise the business case of those. The quantification of those aspects is hardly possible as real numbers on the effects are not presented in research. Only in case a party invests (partly) in the energy saving measures, those investments can be quantified and the effect can be measured and be optimised for the DST. This is the case for the ESCO.

6.5 Finance: New financing schemes/ business model

6.5.1 Introduction

The most important aspect of dwelling development for the real estate developer is to increase its own financial margin (J. C. De Jong, 2016; Putman, 2010). This chapter elaborates on the barriers and solutions in the decision-making about this financial part of the business case in realizing energy efficient dwellings and it has a focus on new financing schemes for energy efficiency.

The basics of real estate finance is explained as a first step. This part gives insight in how a real estate developer looks from a financial viewpoint to a development. The part ends with the financial consequences of two important trends in the new style of urban area development. Second, three main barriers of energy efficient developments are discussed. These are followed by four solutions are given for implementing energy efficiency measures in new dwellings. Lastly, the part concludes with a financial scheme showing the financial solutions. This indicates how the different parties are influences by the solutions selected.

6.5.2 Basics of real estate finance for the real estate developer

The basic principle in real estate finance is that the revenues should be higher than the costs in order to realize profitable or feasible project (J. C. De Jong, 2016). J. C. De Jong (2016) states that the individual mathematical calculations are not very difficult in real estate finance, however, the complex connections between the different calculations and the input for the many assumptions require a substantive amount of knowledge. The coming section introduces the basics of these complex connections within real estate finance.

The previously described development phases (initiative-design-construction) are not directly comparable to the calculation phases in real estate finance, but they show big similarities. One of the similarities with the construction process is the uncertainty at the start of the project. Global calculations are made in the initiating phase based on key figures (Dutch: '*kengetallen*') and high bandwidths (large uncertainties). In the realisation phase detailed and accurate calculations are made based on real numbers and small bandwidths (large certainties) (J. C. De Jong, 2016).

The biggest difference between the development process and real estate finance is that the calculations in real estate finance are executed backwards in time (from right to left in Figure 78, see Appendix 13.12), which is the opposite to the development process. This is called the residual approach, explained by J. C. De Jong (2016: 34): The starting point is the final product and from that point a line of reasoning is created backwards in time to see what is needed to achieve the desired result. A residual calculation means that assumptions are made about the revenues and costs.

In the theory of J. C. De Jong (2016), the residual calculation consist of three connected calculations, all related to a different aspect and phase of the development: the ground exploitation, the development exploitation and the real estate exploitation. In short these are related accordingly[46]: The real estate exploitation calculates the maximum value of the property by expected return on yearly rents minus the yearly operating costs. In case of owner-occupied dwellings, this calculation is not needed and the market value is used as input for the development exploitation. This calculation is simply the expected market price minus the costs of the development, which brings the residual ground price. This is the maximum price that the real estate developer can offer for the land. This is not the value of the land, because the land developer uses this as input in his ground exploitation. The expected earnings from the sale of the developed land minus the costs of public facilities (such as roads, parks) and urban infrastructures brings the residual value of land.

The development exploitation and real estate exploitations are focussed on one specific lot (J. C. De Jong, 2016). In the end, an investment decision is based upon an integral consideration between design and technical quality, function and user quality, location and ground acquisition and finance and exploitation (Wamelink *et al.*, 2010). Energy efficiency measures are included in increasing construction costs and/or increasing installation costs in the calculation model of the generic property exploitation of a real estate developer, shown in J. C. De Jong (2016: 172).

[46] Appendix 13.12 explains more in-depth the relationships between the different calculations and how those relate to different actors, costs and returns.

There are some general trends effecting this calculation, namely the shift from a focus on demand to a focus on supply and the demand for flexible programs and planning in urban designs. First, Putman (2010) describes that the focus in practise is shifting, this is also introduced in the introduction, but how does this effect the real estate calculation? Previously, parties were focussed on the supply of land. They speculate on a value jump that the land value would makes if the land-use plan was changed from lower valued agriculture land to higher valued building land (J. C. De Jong, 2016). The market parties could make profits of this rise in value. This started in the nineties during the VINEX-period when market parties decided to buy strategic ground positions on the edge of cities with the expectation that these agricultural grounds would be developed soon to housing (J. C. De Jong, 2016). However, there were also huge risks involved and a lot of own equity was needed, because often banks would not finance these risky investments. The speculated future rise in value was not included a valuation of the ground. The financial crisis exposed these huge risks and many parties had to write-off substantial amounts on their land positions. As result many municipalities had to deal with cuts and banks became distrustful to finance those speculations (De Zeeuw *et al.*, 2011; Mak & Franzen, 2014). The focus on the demand for dwellings reduces those risks and limited speculation activities. The second trend of the involvement of flexibility and the creation strategic development frameworks is in line with the demand to reduce the financial risks of urban area development and real estate development. The next section continues on how these trends relate to energy measurements.

6.5.3 Barriers for energy efficiency in real estate finance

The next part describes five barriers for energy efficiency, namely the notion that public subsidies are insufficient on the long run, the prevention of big pre-investments to reduce financial risks, the split incentive between the investing real estate developer and the profiting home owner, the market prices of energy neutral dwellings and the current price pressure on the residential markets.

6.5.3.1 Public subsidies are insufficient on the long run

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Classic public interventions (e.g. subsidies) are insufficient to realise massive and ambitious energy renovations (Bullier & Milin, 2013: 796). The authors investigate renovation projects, but their arguments are also valid for new construction projects. First, direct and indirect subsidies are limited resources and are not sustainable by nature. Second, Public subsidies only partially address to the needs of the real estate developers, which needs range from technical assistance to the financial structuring of the project. Third, subsidies are not always targeted to the projects for which they are most justified and may cause unjustified profits. And fourth, public subsidies do not solve the issue of financial credibility and solidity of the project promoters in front of financial operators (e.g. banks). Bullier and Milin (2013) conclude that on top of the traditional public subsidies (which have to be limited), there need to be other sources of financing and technical expertise to support the development of energy efficient building projects.

6.5.3.2 No big pre-investments in urban area development projects

The previous part has described the financial risks of big pre-investments in acquiring land positions, land development and constructing urban infrastructures related to fixed land use plans. Since the financial crisis it is harder for both the public as private sector to get financing and funding for projects, because banks are more critical for both investing parties as for consumers (De Zeeuw *et al.*, 2011). This is caused by the stricter rules and requirements for banks to loan money. For instance, more own equity is required from developing parties and the leverage-ratio of banks has to decrease[47], both reduces the possibility to get projects financed (Mak & Franzen, 2014).

This has the effect that projects are stagnating and currently are large-scale pre-investment in urban area developments only sporadically possible (De Zeeuw *et al.*, 2011). In order to continue urban area developments three solutions are offered: Spreading costs and income over the whole development, spreading the pre-investment over multiple parties and flexible programs and planning in the urban design (Mak & Franzen, 2014). The first solution has to do with cash flow management to overcome the big 'bathtub', as presented by the red line in Figure 35. Small investments during time reduces the depth of the 'bathtub' and thereby the coherent financial risks (Mak & Franzen, 2014). Besides the main infrastructures and public spaces are also pre-

[47] The leverage-ratio is the ratio between debt equity and own equity and a reduced ratio is causing a structurally reduced possibility for banks to provide loans (Mak & Franzen, 2014).

investments needed for energy grids (Mak & Franzen, 2014). This strategy makes it difficult to invest in such large-scale energy grid, which has to operate correctly from the commissioning of the first dwellings, such as a heating grid.

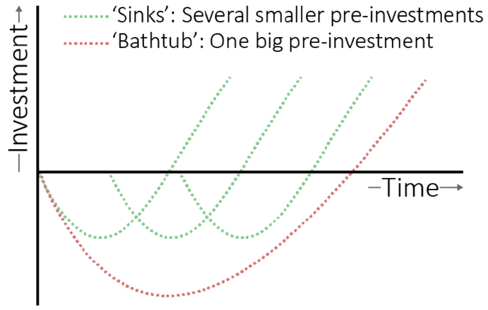

Figure 35: Cash flow management; Fictional representation of a cash flow and the effect of clipping (own illustration based on figure of De Zeeuw in Mak and Franzen (2014))

The second solution is spreading the risk-baring investment over multiple parties, which is already executed in practise by a variety of actors, such as real estate developers and large construction companies (Mak & Franzen, 2014). It can be expected that the real estate developer selects energetic solutions with a low financial risk profile. This can be checked by this research.

6.5.3.3 Complex financial business case of energy efficiency: Split incentive

One of the greatest barrier concerning investment in energy efficiency in residential buildings is the split incentive[48] (Ástmarsson *et al.*, 2013). In this case the interests of the building owners and tenants are misaligned, causing the landlord to not invest in energy savings if those investments only benefit the tenant (Ástmarsson *et al.*, 2013; Bullier & Milin, 2013). The articles are based on the rental housing sector, but also applies for real estate developers who sell their buildings to new homeowners after development (turn-key). The LCTPI (2015: 1) describes this as "*non-technical barriers that hamper the uptake of energy-efficient building solutions in both new and existing buildings.*" They argue that "*solutions have to be found by engaging the full range of stakeholders across the building value chain, in local markets. Only increased coordination and collaboration in local building markets can lead to improved market acceptance of energy-efficient building practices.*" (LCTPI, 2015: 1). The WBCSD (2007) comes with the same conclusion that the fragmentation of the value chain in the construction sector leads to a split in incentives to reduce the energy use and that incentives are not matched to the parties who can save the most through energy efficiency.

The split incentive occurs when the real estate developer provides the future home owner with the dwelling including installations, but the future home owner pays the energy bills. The real estate developer that makes the investment in the energy-efficient technology has no interest in doing so because the benefit – a lower utility bill – is for the end-user of the building (Howarth & Andersson, 1993; Pinkse & Dommisse, 2009), while this future end-user wants lower energy costs (IEA, 2007). There are few incentives for the building owner to invest in the energy efficiency of the dwelling, such as an increased value of the building (Ástmarsson *et al.*, 2013). This can be seen as a higher market value and the next paragraph checks whether this increased market value exists. The future home owner will get lower energy consumption and hence a lower energy bill, in addition the indoor air quality and comfort are likely to improve (Ástmarsson *et al.*, 2013).

The split incentive is seen as a classic principal (end-user)-agent (real estate developer) problem (Howarth & Andersson, 1993; IEA, 2007; Pinkse & Dommisse, 2009). Grossman and Hart (1983) speak about the principal-agent problem as two parties operating in an uncertain environment and for whom risk sharing is desirable and the action of the agent cannot be observed by the principal. However, the principal benefits from the outcome of the activity of the agent and pays the agent afterwards (Shavell, 1979). The optimal action for the agent depends on the extent of risk sharing between both parties and the attitude of the agent towards risky behaviour (Grossman & Hart, 1983). This division of costs and benefits and its relation to risk-bearing behaviour can be applied to energy efficient residential development. For example, in case there is a change of a higher gain (e.g. higher market price) for energy efficient dwellings, the agent (real estate developer) can undertake this

[48] For rental dwellings the term landlord/tenant dilemma is used (Ástmarsson *et al.*, 2013).

increasing risk-bearing activity. The principal (end-user) benefits from this dwelling and has to pay for this benefit, although he did not see the effort of the agent and therefore there is uncertainty about the size of the benefit. As both articles about the principal-agent indicate, this all happens in an uncertain environment and both parties have risks in the decision-making. The market price for energy efficient dwellings is one important aspect to reduce the uncertainty and gives the agent an indication about its possible benefits.

6.5.3.4 Market value of energy neutral dwellings

The market value of energy efficient dwellings is higher compared to average dwellings. The coming paragraphs will explain what market value is, the position of energy efficiency as a selling point, real numbers about the market value of energy efficient dwellings and concludes by the barriers for the market value.

Market value is the estimated amount at which a dwelling on the date of the valuation would be sold on the basis of a willing buyer and a willing seller with sufficient distance to each other after an appropriate preparation in which each of the parties with knowledge would have careful and uncomplicated traded (Van Gool *et al.*, 2013). Market value is also called direct return value (Van Groenestein, 2011).

The position of energy efficiency as a selling point has changed over the years. Van Eck (2008), Griess (2009) and Van Estrik (2009)[49] came to the same conclusion that dwelling type, size, orientation, outdoor space, location and price are the most important selling points for a new dwelling. Although, according to the same researchers, the aspect of sustainability and energy efficiency has gained position as an important selling point in recent years. Only 10% of the respondents of Van Eck (2008) has taken energy efficiency into account in the decision to buy their dwelling. J. W. J. De Vries (2010) concludes the same for starters on the housing market; they have often not enough savings and therefore select an increase of comfort by, for example, a more expensive bathroom instead of a sustainable energy concept. It will therefore be a major challenge for the construction industry to communicate the advantages of energy efficient technologies to (potential) home buyers and create market demand (Pinkse & Dommisse, 2009). A few year later Hooijschuur (2013) expected based on these theories a little change of market demand, however, the research indicated that consumers had energy efficiency more often in their top 3 of selling points, even before price and size. There appeared to be a shift in market demand for energy efficient dwellings.

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Since 2008 many research has been conducted on the willingness to pay for energy-efficient new build dwellings by the home buyer (Brounen, 2014, 2015, 2017a, 2017b; Brounen & Kok, 2011; J. W. J. De Vries, 2010; Griess, 2009; Hooijschuur, 2013; Van Eck, 2008; Van Estrik, 2009; Van Groenestein, 2011; Wilting, 2012). Hooijschuur (2013) concludes that people with a higher-income people are willing to pay extra for an energy-efficient dwelling compared to people with a lower income. J. W. J. De Vries (2010) concludes for the starters on the housing market, on average the people with a lower income, that they would consider the investment in energy saving appliances when it does not compete with other selling points, it has a clear increase in comfort and it has a cost benefit. Both higher and lower incomes thus consider energy efficiency.

Research of Van Eck (2008) shows that home buyers want to pay 5% extra for an A+ labelled dwelling and even 10% for an A++ property. The research also indicated that a price of 15% on top of the selling price was too much. However, Van Eck (2008) continues, the likelihood that people choose for these type of dwellings is decreasing, which means that it is important to pay close attention to the marketing strategy about the possibilities and qualities of the product to achieve the extra profit when placing energy-efficient homes in the market. Wilting (2012) concludes that the amount that individuals are willing to invest in an energy efficient dwelling is based on the annual energy cost reduction, which is in between the 5 and 10 euros per euro saved on the annual energy bill. This would imply a price difference of about €15.000 between an A- and G-labelled dwellings and €27.000 between a zero-on-the-meter and G-labelled dwellings[50]. Van Eck (2008) and Wilting (2012) used both a direct survey for individuals as research method. Wilting (2012) also used the indirect survey for real estate professionals about individuals as methodology for triangulation. Consumers can act different in reality and therefore, these numbers could be different in practise.

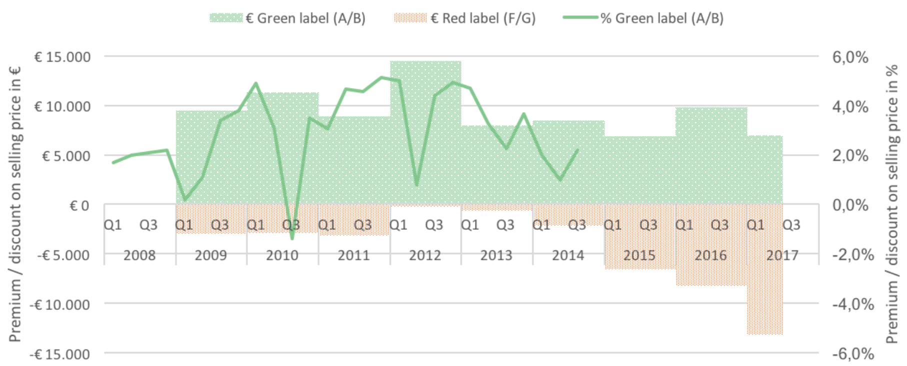
[49] Results are also published in Van de Griendt and Van Estrik (2010).

[50] This calculation is based on a monthly energy bill of €0 for a ZOM-dwelling, €105 for an A-labelled dwelling and €231 for an G-labelled dwelling. These are the same numbers as the later used example of Brounen and Kok (2011).

Brounen (2014, 2015, 2017a, 2017b) uses a different approach with real transaction figures of the Dutch Association of Real Estate Agents (NVM) and the related data on energy labels of the National Agency for Enterprising Netherlands (RvO). The price effects of the energy label are studied on the basis of a validated research model as described in Brounen and Kok (2011) and represented in Graph 4. Brounen and Kok (2011) expected that the variation in the price premiums for energy efficiency is related to the present value of future energy savings resulting from higher energy efficiency. As example the researcher state:

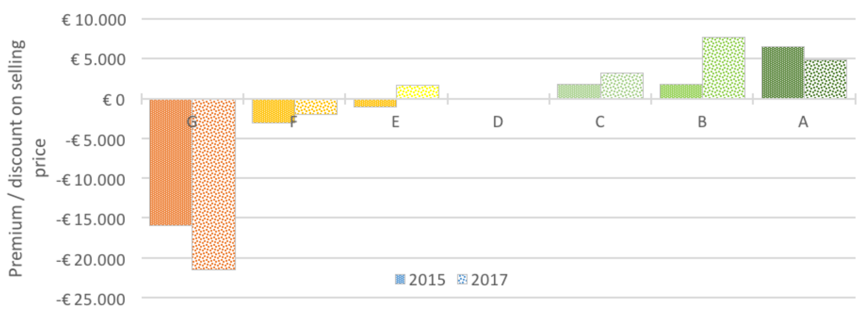
> *"In 2009, a standardized Dutch dwelling had an average monthly energy bill of €152, ranging between €105 for energy label A, to €231 for energy label G. Capitalizing the difference in the energy bill of an F-labelled dwelling, compared to a G-labelled dwelling, results in a present value of €4000."* (Brounen & Kok, 2011: 176)

According to the Brounen and Kok (2011) this calculation method explained the price difference of 1,8% between the average transaction price of F- and G-labelled dwellings in their sample, however, the difference present value in capitalized energy savings between A-labelled and G-labelled dwellings is about €16,000, or 7,2% of the average transaction price of €231,000. The 15% difference of price premium between A-labelled and G-labelled dwellings in the Q2 2015 sample seems to reflect more can just future energy savings alone (Brounen & Kok, 2011).



Graph 4: Premium / discount on selling price for different energy labels (own illustration based on Brounen (2014, 2017b)).

Especially G-labelled dwellings have a lower market value comparing to the other energy labels (see Graph 5). This market value is decreasing in the last two years from -€16.000 to -€22.000. All green labelled (A-C) dwellings have an increased market value compared to an average D-labelled dwelling.



Graph 5: Premium / discount on selling price for different energy labels (own illustration based on Brounen (2015, 2017a)).

Lastly, some concluding barriers of the market value. As first barrier, it is important to know that home buyers do not select their new dwelling rationally. Hooijschuur (2013) concludes that half of the respondents selected their dwelling based on comfort levels. Consumer willingness to pay for an energy-efficient dwelling appears to depend on four factors, namely comfort, environment, healthy indoor climate and costs (Hooijschuur, 2013; Wilting, 2012). This is opposite to the neoclassical models of competitive markets, in which perfectly informed, rational individuals consider the total costs of their decisions when purchasing energy-using equipment (Howarth & Andersson, 1993). If rational choice was the case and the value of the energy savings generated by improving the energy efficiency of a device exceeded the cost of the improvement, competitive producers could increase their profits by exploiting consumers' willingness to pay for the change (Howarth & Andersson, 1993). It could be that the rationality of choice will increase in case more home buyers get familiar with the total costs savings of energy efficient dwellings. In addition, according to Van Groenestein (2011) can the highest added value of energy efficiency measures be realized by selecting those measures on qualitative properties, such as lower housing costs, comfort, functionality, luxury and ease of use. Van Groenestein (2011) argues that consumer information to bring them knowledge and experience about energy efficient dwellings, could result in a higher market value of energy-efficient dwellings.

Another barrier is that in order to create a feasible business case should the average extra market value of the energy-efficient dwellings approach the additional cost of energy-efficiency measures (Van Groenestein, 2011). On that basis, it can be expected that a price increase equal to the extra market value of the energy efficient dwelling will result in actual transactions. In addition, Van Groenestein (2011) indicates that real estate developers expect that energy-efficient dwellings sell faster, because they are preferred by the consumer compared to the standard house at a similar VON price level. This expectation is confirmed by Brounen (2015, 2017a). The difference between the average selling time of an A-labelled and G-labelled dwelling was 118 days in the first six months of 2017 (Brounen, 2017a).

So concluding, consumers prefer more comfort (e.g. a new kitchen or bathroom) above energy efficient dwelling concepts, however this appears to be shifting. Currently, there is a higher market value for energy efficient dwellings and energy efficient dwellings sell faster, but actual numbers of the difference in market value between a A++++ (ZOM) and an 'normal' A-labelled dwellings.

6.5.3.5 Price pressure on the residential markets

Currently, the volume scarcity in the inner city area makes for a very high unnecessary price pressure. In 2016 and 2017 there were big price increases of more than 15% for owner-occupied dwellings in the bigger cities and the surroundings of Amsterdam (NVM, 2017). The transformation of vacant offices and outdated business areas will be achieved earlier, despite the high production costs and high land prices (De Blauw, 2016c). The price pressure are increases the value of land, which creates a barrier for the feasibility of energy neutral dwellings. However, in case the land was already owned by the developing company, the rising market values offers opportunities for delivering extra qualities, such as energy neutrality, to gain a market advantage.

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6.5.4 Solutions for energy efficiency in development of new dwelling

Energy efficient dwellings are more expensive as they need more insulation and more efficient installations. These higher costs can be calculated in a lower residential ground value or as a lower profit rate. However, if the real estate developer wants to have the best price for the ground and still make a good profit, new ways of financing are needed. The next paragraphs explain the basics of the new business models of energy efficiency and three possible solutions, namely 1) the additional borrowing capacity in a mortgage for energy efficient dwellings, which is increasing the buying capacity of future residents; 2) A third party investment or outsourcing: e.g. by energy service companies; And 3) Postponement of the investment by creating future proof dwellings and providing options for the future home owners

According to Gerrit Zalm these new financial instruments to make the built environment more sustainable, could also be used as opportunity to reconnect the Netherlands again and become an example for other countries (Bokeloh *et al.*, 2013). Bullier and Milin (2013) acknowledge this lack of financing schemes to achieve the European Union's energy and climate objectives. If the Netherlands succeed, our new knowledge could be a new export product.

6.5.4.1 New business models

There is a rising role of energy as value creator in urban area development (De Zeeuw, 2011). Energy efficient dwellings have specific economic profile, as the return of investment is not ensured by a direct cash flow such an increase in revenues, but in most cases, through energy savings by non-expenses (Bullier & Milin, 2013). However, this is only valid for energy saving measures, as the supply of renewable energy has direct revenue stream (Bullier & Milin, 2013).

The core of the new earnings models is in connecting the financial relationships between real estate, use and flows from one central construct and only if all three are connected there be the possibility of creating synergies between these elements (Peek & Van Remmen, 2012). An example of Peek and Van Remmen (2012), real estate and the flow of energy are connected through the connection costs. Between usage and energy is the energy bill. And real estate and usage are connected by the rent or ownership. By looking at those three aspects in a separate way, there are few incentives to make things cheaper and more sustainable. However, if we assume an alternative earnings model that includes all three elements, then there are opportunities to make real estate more energy efficiency in a financial feasible way (Peek & Van Remmen, 2012). In this way, it is possible to create added value in solutions for renewable energy and energy efficiency and create new earnings models.

Peek and Van Remmen (2012: 35) mention a number of solutions at the area level, of which the core is that energy and money flows should be maintained in the area by linking user profiles and production. In general, there are two new earnings models linked to renewable energy (Peek & Van Remmen, 2012: 6): performance contracts, and local cooperatives / (collective) private commissioning. The first one, a performance contract, makes it possible to increase the level of sustainability of real estate at no additional cost by investing in energy-saving measures. The investment is returned by savings on the energy costs. Second, a cooperative makes it possible to realize residents' initiatives, such as, distribution and generation of renewable energy, which should be cheaper and strengthen the social cohesion in the area. The first one is suitable to the real estate developer, because this one links energy efficiency to real estate.

Three related contract forms of the earnings models for renewable energy are described in Peek and Van Remmen (2012: 36-37). In one of them the real estate is an integral subject of the earning model, which is the ESCO. This one is explained later on as one of the solutions from the viewpoint of the real estate developer. The other two are more useful for local initiatives as for the real estate developer.

6.5.4.2 Additional borrowing capacity within mortgage

From the start of 2014, consumers with a certain may additionally borrow a certain amount of for the financing of an energy efficient dwelling (Dijsselbloem, 2013)[51]. A distinction is made between an energy efficient dwelling (energy label A++) and a zero-on the-meter dwelling (Dijsselbloem, 2013). The additional mortgage space is possible because no or less energy costs have to be paid to an energy company (based on research of the NIBUD-institute in Dijsselbloem (2013) and Blok (2015a)). The theoretical energy costs relate to the energy efficiency of the dwelling and for that reason the distinction is made between both dwellings.

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The extra borrowing capacity has been under pressure since this year. A letter from the NEPROM (2016) to the minister revealed that the minister wants to reduce the extra borrowing capacity for ZOM-dwellings. According to the letter, the NIBUD has recommended this, due to a lower electricity consumption in general and lower power prices, which has reduced the advantage of a zero-on-the-meter housing (NEPROM, 2016).

Besides that, Blok (2016) learns us that some members of the House of Representatives wants an investigation if an addition loan is also possible for dwellings with an A or B energy label. The argumentation is based on that those dwellings also have lower energy costs in relation to the average C-label dwelling and NIBUD has assumed that with those savings on the energy costs an additional € 3.000,- could be borrowed. However, the counterargument that is used in the same letter is that in practice, there is little difference in the energy cost savings between these labels.

In addition to the discussion of lower energy labels can also the borrowing capacity of BENG-dwellings be questioned. BENG-dwellings do relate to the energy label of A+++ (Bouwens & Bouwmeester, 2017). Why is there no intermediate category between A ++ and ZOM (A++++)? In that case the borrowing capacity can be around €15.000 - € 20.000.

The first discussion point appears to indicate that the amount of the additional borrowing capacities will change in the future.

6.5.4.3 Third-party investment: Energy service companies

Energy Service Companies (ESCOs) are companies that develop, install and possibly finance and maintain performance based projects aimed at increasing the energy efficiency of buildings (Ástmarsson *et al.*, 2013; Jensen, Hansen, & Nielsen, 2011a, 2011b). They are seen as private-sector delivery mechanisms for energy efficiency (Bertoldi & Boza-Kiss, 2017). The financing schemes used by an ESCO are called Energy Performance Contracting (Ástmarsson *et al.*, 2013; Bertoldi & Boza-Kiss, 2017; Bertoldi, Hinnells, & Rezessy, 2006; Bullier &

[51] Real numbers and changes over the years are presented in the Appendix.

Milin, 2013). In this research the notion of ESCO is used to prevent confusion with the Energy Performance Coefficient (also abbreviated as EPC). The coming paragraphs explain the difference between third party financing and third party investment, the basics about the business model of an ESCO, why it helps (opportunities) and how it is applied in the residential sector. The last part also includes some barriers why it is not applied in the residential sector. The section ends with some concluding remarks for the Netherlands.

The difference between third-party financing and third-party investment is that the latter investment schemes disconnect the burden of debt from the building owner to the building or the installations (Bullier & Milin, 2013). Several actors use the terms third-party financing and third-party investments as they are the same. Bullier and Milin (2013: 797) provided a clear distinction between the two by applying it to the relation to future energy savings. In case of third-party financing a third-party (usually a bank) provides the building owner with debt. The third-party financer has a claim on the owner. The owner keeps his usual role and takes the risk of not achieving the energy savings. The challenge for the third-party financer is to secure the repayment of the debt. In case of third-party investment, the investment is not carried out by the building owner, thus relieving him on the burden of debt. The third-party investor has a claim on the future energy savings, and may take on the risk of not achieving the expected savings. Third-party investment, for instance by an ESCO, therefore offers the opportunity for a building owner or real estate developer to improve the energy performance of a building with limited risks and without increasing its debt ratio (Bullier & Milin, 2013).

An ESCO does not provide energy, but delivers an energy saving service. The company guarantees energy-saving on the basis of a performance contract and offers thereby the ability to get real estate sustainable in a budget neutral manner (Peek & Van Remmen, 2012). In order to realize the savings, the ESCO invests not only in installations, but also in construction interventions, such as insulation of facade, floor and roof.
In this way, real estate is also an integral part of the earning model by connecting real estate, (energy) flows and the operation. The ESCO receives a monthly energy performance fee that results in a return on investment (Peek & Van Remmen, 2012). The end-user gets a lower energy bill with the realized energy savings. Part of the ESCO performance contract are agreements on how the guaranteed savings are demonstrated and agreements on how to prevent or correct the effects of use (e.g. on opening windows and keep on lighting bulbs). According to Peek and Van Remmen (2012) the ESCO contract is the most far-reaching business model for urban area development 3.0 starting from the (energy) flows.

An ESCO could help to address barriers to energy efficiency by providing knowledge, finance, installation, operation and maintenance under a long term contract (Bertoldi *et al.*, 2006). Therefore, the ESCO can help in minimising investments and financial risks for investing parties (Polzin, Von Flotow, & Nolden, 2016). In addition, the ESCO concept offers the resources to gain high energy savings without possessing the skills, knowledge or capacity to do it in-house (Ástmarsson *et al.*, 2013). In addition, some energy saving measures are getting more and more technically complex which require even more specialized knowledge which can be provided by ESCOs (Ástmarsson *et al.*, 2013). ESCOs in new build also have the opportunity to install energy efficiency at marginal cost (compared to levels of ex-post insulation or replacement of boilers that would have existed anyway) and there is also the opportunity for economies of scale for installation purchase (Bertoldi *et al.*, 2006). For the contractor or the real estate developer who wants to build and move onto the next project and retain no ongoing interest in a site, the ESCO allows a more sophisticated and integrated provision of energy and offers the opportunity to retain an operational billing and maintenance role (Bertoldi *et al.*, 2006). Skills, knowledge, finance, organisational capacity, economies of scale for the installation purchase and ongoing responsibilities in the operation phase are thus possibilities how the ESCO could help the real estate developer in achieving high energy ambitions.

ESCOs seem to be a suitable solution, however, in the practice of residential development ESCOs are a rarity. Applying the concept in the residential housing market poses many challenges. First of all, ESCOs are reluctant to guarantee savings in residential housing as it is hard and expensive to control human behaviour (Ástmarsson *et al.*, 2013). The behaviour of the end-users and the operation of the dwellings has to be taken into account to provide guarantees for achieving the desired energy efficiency. This causes the second challenge that the transaction cost of ESCO contracts are too high, because of these difficulties in guaranteeing the energy consumption as it takes away the occupant's incentives for reducing energy consumption (Ástmarsson *et al.*, 2013; Bertoldi *et al.*, 2006; Pätäri *et al.*, 2016; Pätäri & Sinkkonen, 2014).

Thirdly, decision-makers lack the knowledge about the ESCO model (Pätäri *et al.*, 2016; Pätäri & Sinkkonen, 2014)[52]. For instance, Polzin *et al.* (2016) concludes that municipalities under-estimated the risk reduction potential of an ESCO, which shows a lack of knowledge about the potential advantages of the ESCO model.

The increasing energy costs for households and the growing awareness of these costs and the ESCO-concept creates opportunities for the ESCO market, because this one was found to be driven on such market forces (Bertoldi & Boza-Kiss, 2017). Ástmarsson *et al.* (2013) also indicates that the knowledge about the ESCO concept is increasing and that the decision-makers, such as municipalities and private development companies, are gaining positive experiences. As result, the trust in the ESCO-concept is increasing.

There have been some attempts to adapt the concept to the residential market. One possibility is to guarantee a certain improvement on the energy label (Ástmarsson *et al.*, 2013). In that case the first two barriers are tackled, because it would decrease the transaction costs and transfer the risk of the actual energy consumption to the end-user. Essential for a successful compliance with the guaranteed improvement is to apply monitoring of the energy consumption (Ástmarsson *et al.*, 2013). The overview monitoring provides, gives both the ESCO and the end-user insights in whether or not realized energy savings are related to the building improvement or the changes in occupant behaviour. In addition, improving the visibility of energy consumption gives the end-user an increase awareness of how their behaviour influences the energy consumption. Monitoring therefore provides not only insights in the operation on household level, but it also provides proof to increase the level of trust in the ESCO-concept by showing how it is improving the energy performance of dwellings. This can be used increase amount of positive experiences and the degree of familiarity of the concept.

The ESCO market is preliminary in the Netherlands in relation to other EU countries and the market growth between 2010 and 2013 was only limited (Bertoldi & Boza-Kiss, 2017). This is either because of the amount of ESCOs, the number of pilot projects or because of the limited market size in comparison to the size of the country (Bertoldi & Boza-Kiss, 2017). The previous parts show the positive experiences with the ESCO-concept and how it can be used to increase the energy performance of residential dwellings by providing knowledge, finance, installation, operation and maintenance and thereby, minimising investments and financial risks for investing parties without the necessity to possess the skills, knowledge or capacity to do it in-house.

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6.5.4.4 Postponed by future-proof dwelling

It pays to postpone additional energy efficiency measures to create dwellings which perform better as required in the building degree, because energy prices are still rising insufficient and postponement reduces the probability of a financial loss in case the prices of energy would not increase as much as expected (Van Cann, 2011; Van de Griendt & Van Cann, 2012). This research eliminates the frequent assumption that an energy efficient dwelling has a higher market value. Instead, Van de Griendt and Van Cann (2012) continue, a dwelling which complies with the current building degree, is more valuable, but only in case it is provided with the flexibility to take additional energy saving measures when energy prices increase, but it can also postpone these investments in case energy prices decrease or increase less than expected (Van de Griendt & Van Cann, 2012). This implies that although it may be profitable to take these energy efficiency measures today, it is even more profitable to postpone these measures and wait until the energy prices have risen sufficiently (Van Cann, 2011). For the research of Van de Griendt and Van Cann (2012) perfectly rational trading parties are assuming, which taking into account uncertainties in expected energy price increase.

The real option theory of Dixit and Pindyck (1994) to support these statements, in this theory an option is the right, but not the obligation, to buy a good at a time of your choice. Unlike in the case of 'normal' investment decisions, real option theory of Dixit and Pindyck (1994) does not only look at the net present value of investment costs and returns, but also to the deferred value when an investment is not made immediately but postponed. Van de Griendt and Van Cann (2012: 46) describe the related calculation method.

[52] Pätäri and Sinkkonen (2014) and Pätäri *et al.* (2016) have executed their research in Finland. Finland has a good development market for ESCOs, especially compared to the Netherlands, based on the market size of ESCOs in relation to the size of the country (Bertoldi & Boza-Kiss, 2017). As the ESCO concept is little known in a good developed market, then it can be assumed that it is even less known in a preliminary market as the Netherlands. Therefore, the conclusion of Pätäri and Sinkkonen (2014) and Pätäri *et al.* (2016) is assumed to be valid for the Netherlands as well.

The best time to invest in energy-saving measures for new-build dwellings is defined by Van de Griendt and Van Cann (2012) as the energy price level where the deferred value is no longer significant compared to the net present value of a measure[53]. The optimal investment timing is an energy price level of about 200 percent relative to the price level during the research of Van Cann (2011), or a doubling of prices. Such a level is expected to be reached in approximately 10 to 15 years, based on historical energy price development (Van de Griendt & Van Cann, 2012).

Rationally seen, it pays to postpone energy efficiency measures to the year 2021-2026. Till that time future-proof dwellings should be developed according to the described research. This decision would also transfer the decision-making from the real estate developer to the end-user, which reduces the risks of the higher investment for the real estate developer.

6.5.5 Conclusion

The previous part provided insight in the basics of real estate finance and the barriers and solutions for the optimisation of the financial aspect of the business case for the realizing of ENRND-projects consisting of owner-occupied and single-family dwellings.

In short, the basic calculation for real estate finance uses the residual approach. This calculation of the residual value of land starts by identifying the market value of a dwelling. The market value minus the development costs of the dwelling (e.g. construction, installation and additional costs) brings the land value, minus the development costs of the land (e.g. demolition costs, land preparation, construction of the public space and additional costs) brings the residual value of land. The profit for the real estate developer are included in the additional costs of the development exploitation. If the residual value of land is larger as the selling price that the current owner desires, the development is feasible.

Five main financial barriers are identified to optimise the business case of energy neutral dwellings. First, the current public subsidies are insufficient on the long run, as subsidies are not economically sustainable and therefore other financial schemes are a necessity. Second, the financial crisis has had the effect that banks provide less funding and expect more private equity of developing parties. Among others, developing parties take less financial risk and spread large investments over time or over multiple parties and expect a flexible plan, which can be adapted to the changing market demand. As result, large pre-investments in urban area development projects are mostly infeasible and therefore, it is difficult to get a major area strategy for a large scale energy supply financial feasible. It is expected that developing parties will choose for smaller energetic solutions that spread the risk per phase of development. Thirdly, the complex financial scheme of real estate causes a split incentive between the real estate developer and the end-user, because the real estate developer has to invest in the energy saving measures and the end-user profits. Increasing the energy performance on forehand would increase the financial risks of not getting a return on investment if the market price is insufficient. This is in line with the fourth barrier that the market value of energy neutral dwellings is unknown. Research of the market value based on energy labels shows that an A-labelled dwelling has a huge financial advantage over the G-labelled dwelling. However, the A-labelled dwelling is required by the building degree and an energy neutral dwelling has an A++ energy label and the ZMO-dwelling A++++. In addition, energy efficiency is not the priority of home buyers, which prefer more comfort, such as a larger dwelling, a better location or a new kitchen/ bathroom. This is especially valid for starters on the housing market. The advantage of energy efficiency is visible by using rational thinking, because the extra market price can be returned to the end-user by a lower energy bill and thus, the total costs of ownership is lower for the energy efficient dwelling. However, it appeared that most home buyers are not thinking rationally, but emotionally. The last barrier is that currently the price pressure increases the market value of new dwellings in most parts of the Netherlands. This proposes difficulties when the ground first need to be bought, because also the residential value of land increases with increasing market values. However, rising market values offers opportunities for extra quality for gaining a market advantage, such as energy neutrality.

[53] Van de Griendt and Van Cann (2012) uses a margin of less than five percent of the net present value. In that case, the additional profit that can be achieved by postponing the investment is negligible in relation to the expected profit of executing the investment during the development of the dwelling.

There are opportunities to overcome these barriers. The main new business model for energy efficiency measures is based on the connection of real estate, usage and flows. This business model is based on a return of investment that is not ensured by a direct cash flow such an increase in revenues, but in most cases, through energy savings by non-expenses. The increased installation and construction costs for energy efficiency can be solved in all exploitation phases. In the first two phases of the ground and development exploitation the extra costs can be covered by a lower residual value of land or an increased efficiency/ lower profit price with the real estate developer. These solutions are not the most desired solution as they decrease the financial performance of the developing company and/or reduces the possibility to get the highest bid for the land.

The three main solutions identified are based on the real estate exploitation of the future building owner. First, since 2013 it is possible to get additional finance from the bank for an energy efficiency dwelling. In this case the energy efficiency measures are not competing with the comfort preferences. This solution is referred to in this research as the additional borrowing capacity within the mortgage. Second, a third party can invest in the energy saving measures and thereby lower the construction costs for the developing company. This is known as the energy service company (ESCO). The business model of the ESCO is that it invests in the energy saving measures and in return it gets a monthly fee from the end-user. The ESCO reduces the investments and financial risks for developing parties and also offers the opportunities to involve technological knowledge and skills, economies of scale by purchasing installations. ESCO only have a small market in the Netherlands. Lastly, research shows that it pays to invest later in energy saving installations when the energy prices has risen sufficiently and therefore it can be more profitable to develop future-proof dwellings instead of energy neutral or ZOM-dwellings. These financial solutions for handling the increased costs of energy efficiency are captured in the basic financial value scheme of Figure 36.

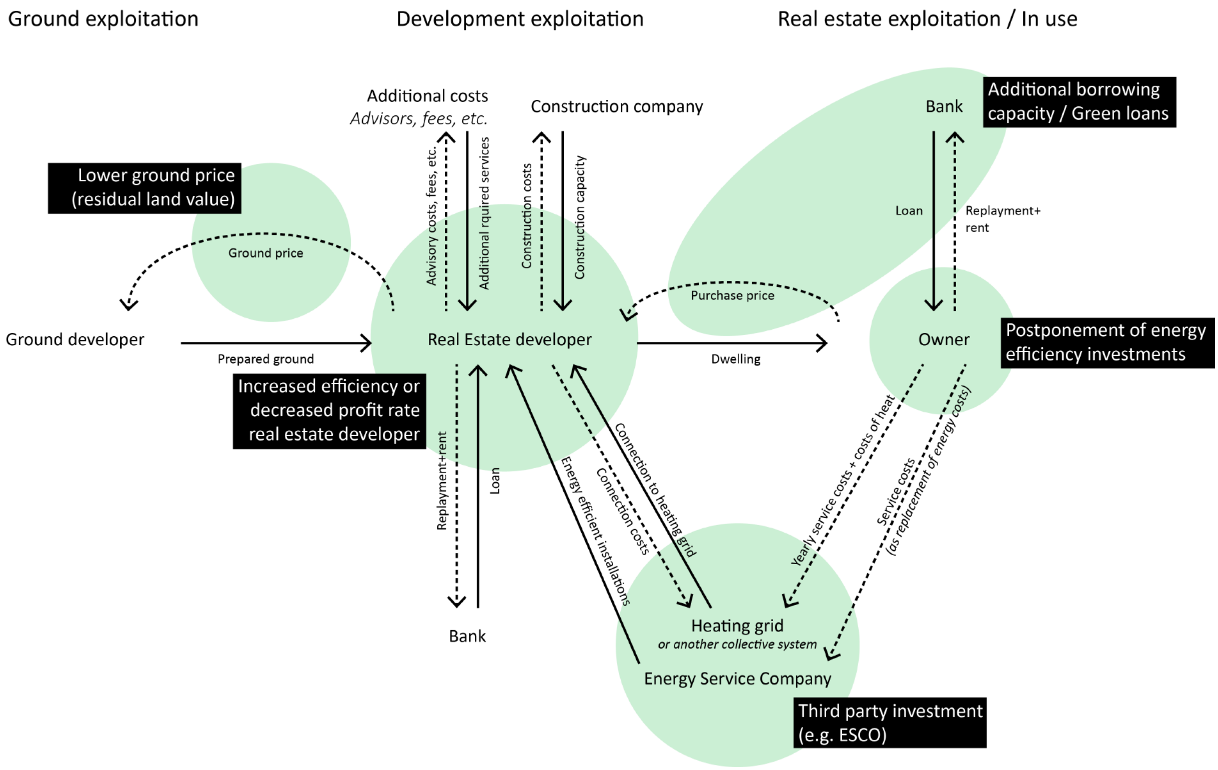

Figure 36: Financial solutions for handling the increased costs of energy efficiency
(own illustration, scheme is based on Putman (2010), Vlek *et al.* (2016), Bullier and Milin (2013), Bertoldi and Boza-Kiss (2017) and Van de Griendt and Van Cann (2012), solutions are based on the theory as described in this chapter).

6.6 Physical: Spatial / technical solutions for energy efficiency in the built environment

6.6.1 Introduction

This theoretical part on physical aspects is about the spatial and technical plans and designs within the business case of ENRND-projects. The part starts with basic insights of the calculation of the building-related energy demand. This provides understanding what the main decision variables are in reducing the energy demand. This is followed by two main barriers from the technological point of view. Third, possible solutions for improvement of the energy performance of the building design are presented. The part ends with a conclusion.

6.6.2 Basics: calculating the building-related energy demand of a dwelling

The building-related energy demand is based on the building-related installations (heating, cooling and ventilation climate systems, lighting systems in commercial buildings and hot water). The basic calculation is explained for the building-related energy demand of a single building.

The energy demand side is calculated by the energy balance of a building. The energy balance is the inventory of all energy (heat and cold flows, not electricity) flows through and into the building. If the sum of these energy flows is negative, the building needs heating to maintain its temperature at the required temperature. Itard (2011) describes the formulas needed to make an energy balance of the building. Her book chapter '*Energy in the Built Environment*' is the foundation of this chapter. If no other reference is given, it can be assumed that the formula comes from this chapter. This calculation is more basic as the official norm for energy efficiency in buildings, the NEN 7120+C2 (2012), but this less detailed calculation better for understanding the most important aspects.

The energy balance is described by equation 6.1, wherein if $Q_{balance} < 0$, heat must be supplied to the building.

$$Q_{balance} = Q_{trans} + Q_{inf} + Q_{vent} + Q_{sol} + Q_{int} \tag{6.1}$$

The five energy flows of transmission (Q_{trans}), infiltration (Q_{inf}), ventilation (Q_{vent}), solar gain (Q_{sol}) and internal gain (Q_{int}) are explained by equation 6.2-6.10. The first three described equations are related to the energy (heat) losses and the last two equations are related to the heat gains. This only counts for the situations in which heating is required. These formulas calculated the amount of power (P). When taking the time in consideration (e.g. one hour) the amount of energy used can be calculated.

Transmission is the energy flow of heat through the construction (e.g. walls, glazing, roof and floor) caused by a temperature difference between the indoor and outdoor temperature. The total amount of heat losses is calculated by equation 6.2. In this equation P_{bridge} represent the thermal bridges. For the sake of simplicity this is considered a constant percentage of the transmission losses, based on a quote of Itard: "*In more recent buildings, the proportion of heat loss due to thermal bridging is typically 10-15%*" (Itard, 2011: 128). In the official calculation by the NEN 7120+C2 (2012) transmission losses by thermal bridges are complicated and time consuming. $P_{trans,s}$ is calculated by equation 3. In this equation U is the overall heat transfer coefficient and based on the insulation value (the thermal resistance) of the material, A is the surface area, T_o is the outdoor temperature and T_i is the indoor temperature.

$$P_{trans} = P_{trans,s} + P_{bridge} \tag{6.2}$$

$$P_{trans,s} = U * A * (T_o - T_i) \tag{6.3}$$

The thermal losses by infiltration (equation 6.4) are based on the same difference in outdoor (T_o) and indoor temperature (T_i), the mass flow rate of air in kg s^{-1} (m_{inf}) and the heating capacity of dry air in $Jkg^{-1}K^{-1}$ (C_p). The mass flow rate of air is based on the density of air (p), which can be assumed to be 1,2 kgm^{-3}, and the volume flow rate of air in m^3h^{-1} (V). The volume or mass flow rate of infiltration air is not easy to determine as it depends on cracks in the construction and on pressure differences (and therefore on wind) between indoor and outdoor air. One general estimate can be made by the air change per hour (ACH). ACH is expressed in h^{-1} and is defined in equation 4b, using the volume flow rate of inflation air (V_{inf}) and the interior volume of the building ($V_{building}$). A typical ACH varies from 0.1–0.2 for air-tight large new buildings (floor area >10,000 m2), to 0.2–0.3 for smaller buildings and 0.5–1 or more for old buildings.

$$P_{inf} = m_{inf} * C_p * (T_o - T_i) \quad (6.4)$$

$$m_{inf} = \frac{p * V}{3600} \quad (6.4a)$$

$$ACH = \frac{V_{inf}}{V_{building}} \quad (6.4b)$$

The thermal heat loss caused by ventilation (equation 6.5) is based on the heat recovery efficiency of the ventilation system (η), the mass of the ventilation air (m_{vent}), the heating capacity of dry air (C_p) and the temperature differences in outdoor (T_o) and indoor temperature (T_i). The mass of the ventilation air can be determined by equation 4a.

$$P_{vent} = (1 - \eta) * m_{vent} * C_p * (T_o - T_i) \quad (6.5)$$

The heat gains through solar radiation depend on the orientation, size and the properties of the windows (equation 6.6). The total amount can be calculated by the sum of each orientation (i) for the solar heat gain coefficient of the window (g_{glass}), the surface area of the window (A_{window}), the solar factor of the shading (g_{shade}) and the total incoming power (direct and indirect) of the sunlight at the window area in W/m^2 ($P_{sol,w}$).

$$P_{sol} = \sum_i g^i_{glass} * A^i_{window} * g^i_{shade} * P^i_{sol,w} \quad (6.6)$$

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The internal heat gain (equation 6.7) is the energy produced inside the building and comes from people, lighting and appliances. The heat gains from people (equation 8) is based on the amount of people (n_{people}) and the heat gain per person (P_m)[54]. The internal gains for lighting is based on the fraction of installed power that is released to the room ($\zeta_{light,vent}$), the percentage of the building's floor area where the light is on (β_{floor}), the buildings total floor area (A_{floor}) and the lighting's electrical power (P_{light}) in W/m^2. If the luminaires are not ventilated, $\zeta_{light,vent}$=1 and for simple estimations take β_{floor}=1. A simpler version of equation 9 is to base the internal heat gains for light on the amount of lighting power which is transferred to heat and the total surface area. The equation for heat gains from appliances (equation 10) is almost the same as for lighting. It is based on the buildings total floor area (A_{floor}) and the appliances' electrical power ($P_{appliances}$) in W/m^2. For quick calculations of residential functions $P_{appliances}$= 5 W/m^2 can be used.

$$P_{int} = P_{int,people} + P_{int,lighting} + P_{int,appliances} \quad (6.7)$$

$$P_{int,people} = n_{people} * P_m \quad (6.8)$$

$$P_{int,lighting} = \zeta_{light,vent} * \beta_{floor} * A_{floor} * P_{light} \quad (6.9)$$

$$P_{int,appliances} = A_{floor} * P_{appliances} \quad (6.10)$$

By using this energy balance it can be calculated if a building needs heating or cooling to get to the required temperature level. The energy needed for the heating or cooling can be supplied in multiple ways. Majcen (2016: 59) shows a calculation of total energy consumption (Q_{total}) in equation 1 and how this relates to the energy index[55] of the dwelling by equation 2. This equation shows that the total energy consumption is divided by the UFA and the total area of transmission losses multiplied by some factors. This is done in order to not disadvantage larger dwelling types.

Additional to the building-related energy demand, there are also energy losses in the energy distribution system between the demand and supply and on the energy supply side in power plants (Itard, 2011)[56]. The energy losses in both of these systems also affect the quantity of energy that must be supplied to the building (Itard, 2011).

[54] Typical heat gains per person can be found on Itard (2011: 135).
[55] The energy index is used to determine the energy label of the dwelling.
[56] The operation of the electricity grid and how the current transition is taking shape is explained in chapter 6.4.4.1.2.

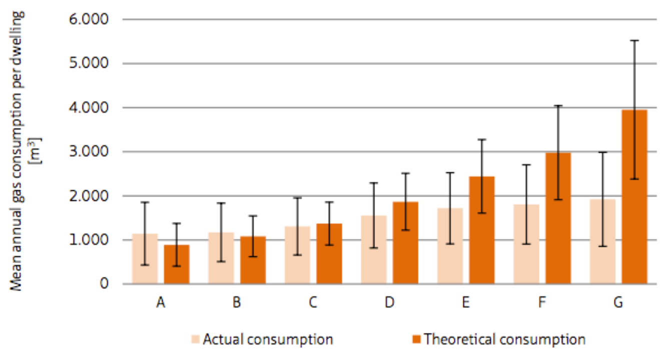
6.6.3 Barriers for the optimisation of the physical aspect of the business case

There are two main technological barriers possibility influencing the business case of ENRD-projects, namely the energy performance gab of theoretical calculations and the inflexibility of a renewable energy supply.

6.6.3.1 The energy performance gab of theoretical calculations

The energy performance gab is the misfit between the theoretical calculation of the energy performance and the actual energy use (Majcen, Itard, & Visscher, 2013; Visscher *et al.*, 2016). These theoretical calculation methods are based on models and parameters about the performance of construction types and materials, and on the expected or modelled occupancy behaviour of the inhabitants (Visscher *et al.*, 2016), of which the last one is affected by the heating, cooling and ventilation preferences, such as the described calculation method of the energy balance in the first part of this chapter. Visscher *et al.* (2016) identified several reasons why the performance gap occurs: "*the built artefact does not match the design (substitutions and poor built quality), the mechanical services are not commissioned correctly, the inhabitants do not understand how to operate the building, the inhabitants' behaviour and practices are not as expected, or the building does not fit the inhabitants' needs and capabilities.*" (Visscher *et al.*, 2016: 553)

The general pattern of the performance gab is shown in Graph 6. This graph shows that for dwellings with a green energy label (A-C) the actual energy use in general is higher than theoretically calculated and for dwellings with a red energy label (D-G) the actual energy use is lower. The explanation for this is according to Visscher *et al.* (2016) that the calculation models assume an average heating of the whole building[57], however, in reality occupants of poorly insulated only frugally heat the dwelling and only in the rooms that they actually use.



Graph 6: Actual and theoretical natural gas consumption in dwellings across label categories with ± 1 standard deviation, (from Majcen (2016: 115) based on Majcen *et al.* (2013)).

Based on the energy performance gab, Majcen (2016) argues that the energy label actually indicates little about the energy efficiency of a house, but instead, the energy performance depends entirely on the behaviour of the resident. In addition, she states that it is much more cost-effective to put time and money into changing the behaviour of residents instead of renovating the homes, especially when the goal is to reduce the energy demand.

Besides a frugal lifestyle in poorly insulated dwellings, the performance gab in energy efficient dwellings is also caused by the rebound-effect, which also related to the occupant behaviour. The rebound-effect is explained by Berkhout, Muskens, and Velthuijsen (2000) that if the inhabitants think that the building is more energy efficient, they become less careful in their energy use-related behaviour (i.e. they increase the temperature settings, heat more rooms, heat for longer periods, etc.). That is why the profit of the consumer, expressed by a lower energy bills and caused by energy efficient technology, is reduced relatively in comparison to the theoretical expected reduction. According to Berkhout *et al.* (2000) the rebound effect has two sides, namely 1) if the total amount of energy becomes cheaper, an individual will use more (for instance, to heat). And 2) if the income increases, an individual will spend more, also on energy uses. Both effects decrease the total effect on savings. The energy bill will become cheaper in case of an energy efficient dwelling and therefore, the usage of energy tends to go up. Although, according to the empirical evidence of Berkhout *et al.* (2000) the rebound effect for both SFD as MFD is probably small: between 0-15%.

[57] The official standard to calculated the energy performance of buildings, NEN 7120+C2 (2012), sees a dwelling as one calculation zone. This means that the dwelling is seen as one large area, while in reality the house is divided into several smaller rooms.

Besides the fact that the gab is caused by the occupant behaviour, there are also indications that the gab is related to design and construction faults, for instance that heating devices are operating very differently than assumed beforehand (Visscher *et al.*, 2016). Nieman (2007) even showed that within a sample of 150+ dwellings, 25% of the dwellings did not meet the EPC requirements in the design phase due to calculation mistakes and 50% was not constructed according to the design. Based on this and other research, Visscher *et al.* (2016) are doubting if further tightening of the energy performance regulations will lead to improvements in actual outcomes. That is why they suggest to improve the importance of monitoring the actual energy performance of the completed building. For energy neutral dwellings this would include a blower test to check the airtightness (related to the heat losses due to infiltration) and an infrared scan to find thermal leakages (related to the heat losses due to transmission) (Visscher *et al.*, 2016).

There are other solutions to decrease the actual energy consumption of newly built dwellings. According to Visscher *et al.* (2016) are important ingredients of the solution: ensuring that appliances and installation are correctly installed, monitoring the calculated performances in practice; enlarging the know-how and skills of building professionals; and creating an effective and efficient building control and enforcement process. Increasing the know-how and skills of professionals was also indicated as barrier with in the organisational aspect. This again indicates to get knowledge involved early on in the process. In this case to prevent the energy performance gab.

6.6.3.2 The inflexibility of a renewable energy supply

A second barrier is related to the inflexibility to time a renewable energy supply. Electricity from PV-panels is generated when there is solar power available and the sun cannot be timed. This barrier related to the necessity of peak shaving to time the energy supply, which is additional to the need to reduce the total demand (Beggs, 2009; Itard, 2011; Molengraaf, 2017; Monti *et al.*, 2017; Vreeburg, 2016). The next paragraphs create understanding of this problem.

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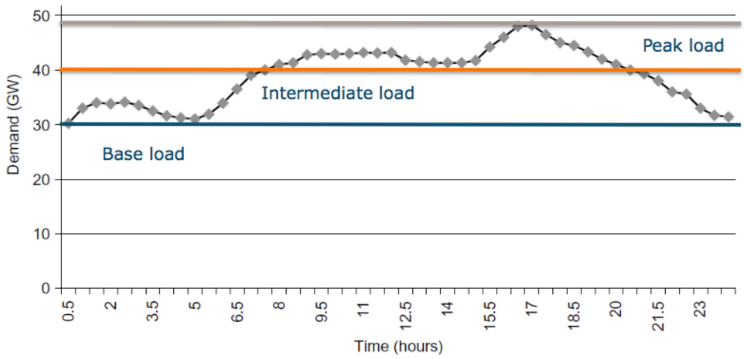
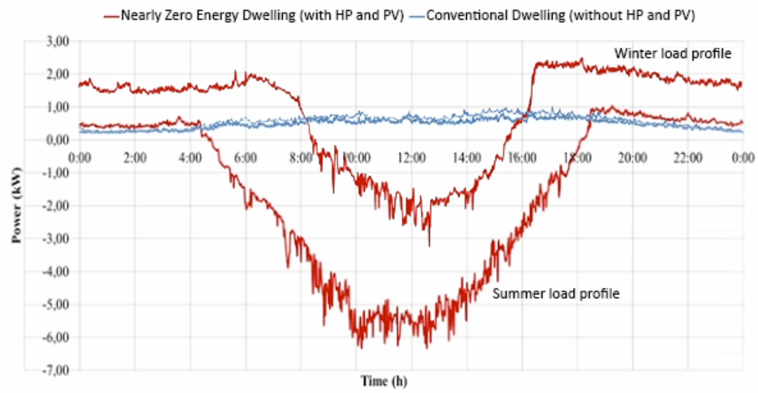


Figure 37: Different categories of load profiles during a typical day (Vreeburg (2016: 17) based on Beggs (2009: 37))

Generally, there are different load profiles of electricity flowing through the electricity grid throughout the day. These load profiles have a huge difference, according to Vreeburg (2016) the peak load can be 48GW and the base load about 30GW. The load profile of the grid is not identical with the load profile of an individual dwelling, because the peak factor flattens with more connections (Vreeburg, 2016). That is also why it is relatively expensive to develop an autarkic dwelling, because this has to supply the maximum peak factor of its own, which is not reduced by multiple dwellings.

The different load profiles are supplied by other energy sources, as electricity demand and supply has to be balanced each moment (Vreeburg, 2016). The base load is supplied by steady and reliable energy sources. Currently those sources are coal and nuclear power plants. It takes time for these power plants to adjust their energy output (e.g. it takes time before coal burns). The intermediate load is supplied by power plants that must be adjustable in output. Those power plants are based on coal and natural gas and renewable sources. The peak load must be supplied by a fast reacting energy source. In the Netherlands these are mainly natural gas power plants, but also stored energy (e.g. hydro or batteries) are suitable. Intermittent energy sources (e.g. wind and solar) are currently backed up by gas power plants.

The current electricity grid is designed to provided enough capacity to supply the peak demand. Consequently, a large part of the infrastructure and equipment are unused for longer periods. On average, only 55% of the total capacity is used (Vreeburg, 2016). Normally, some excess capacity is built into the system to make a growth in electricity demand possible. In the case that the electricity demand is higher than the grid capacity power puts will occur. This can happen as there is not enough generation capacity to meet demand or the cables in the transmission grid have become overloaded (Beggs, 2009).



Graph 7: Impact of a nearly zero energy dwelling on the existing distribution grid in winter, which is the average profile (3x peak) and summer (6x peak) (adapted and combined illustration of Molengraaf (2017: 11) and Molengraaf (2017: 12)).

The existing distribution grid is designed on average 20-30 years ago. Molengraaf (2017) explains how the new nearly zero energy dwellings (NZED) is hugely impacting the distribution grid, which is mainly because those dwellings make use of heat pumps and PV-panels. The peak capacity is on average three times the conventional dwelling where the grid is designed for (see Graph 7). In summer the peak capacity on the grid is even worse. On average the most people are on holidays and therefore less electricity is consumed, but the solar panels supply a lot of electricity into the grid (see Graph 7). This supply exceeds the peak capacity by a factor 6. The peak capacity is not the same as the volume. The blue line is the maximum demand capacity of a conventional dwelling on which the grid is designed for. The red line is what is actual happening in case of a NZED, either as demand or as supply format. The NZED need much more capacity of the grid than where the grid is actually designed for. Grid operators were used to design their grids for a combined peak of about 1,2 kWh. This is using the fact that 200 people in the same street are not at home at the same time and therefor, are not using electricity at the same time. Till now this system has worked, and is reliable since the second world war, but this will not work in the future. This system will not break down until 15-20% of the dwellings in a street are NZED. After that, more capacity is needed. This can be provided by new cables. The problem is the costs of these operations. Monthly bills for the connection costs will go up by the same factor. The grid operator has two major problems. First the costs cannot go up that fast, which will happen is the grid capacity needs to grow and second, the red line of the amount of the NZEDs is going up much faster than the grid operator can increase the capacity on the grid.

The inflexibility of the renewable supply of the PV-panels and the increased electricity demand due to the heat pumps cause capacity problems in the electricity grid. Huge investments are required to increase the capacity in case no cheaper solutions are identified and implemented.

6.6.4 Solutions for the optimisation of the physical aspect of the business case

The coming paragraphs described different solutions to optimise the physical aspect (i.e. the spatial design or the technological installations) for the business case. Passive (solar) design, renewable energy supply, renewable heat supply, demand side management, dynamic pricing and technological innovation are described in succession. Demand side management and dynamic pricing are combined in one part as these are both related to the barrier to tackle the inflexibility of renewable energy supply. All of these solutions are related to different scale levels, from the national policy, spatial neighbourhood design and technological interventions.

According to Van de Griendt (2011) are real estate professionals are very clear about which techniques they prefer. They realize the EPC 0.6 level (to 2015) with proper insulation and a natural gas-based heating system, the EPC 0,4 level (2015-2020) with soil energy based on individual heat exchanges and if needed supplemented by PV-panels or solar thermal water heaters. Real estate developers made these selections based on costs and risks. The coming paragraphs explain a broader view on the possible solutions.

Within the energy efficient adaptation of the existing building stock are replacement or deep renovations used as solutions based on the NZED renovation concept. This is an innovative, highly industrialized approach to retrofit houses from the 1960s and 1970s with a poor energy performance within less than two weeks by adding a new highly insulated skin, air-source heat pump heating and photovoltaic (PV) panels (Rovers, 2014). After the retrofit, there is a decrease of the living costs of the tenants, because the tenants only pay a higher rent but no energy bill at all (Visscher *et al.*, 2016). This only works if the theoretical estimations of the actual energy demand are correct, which is mostly not the case as described by the barrier of the performance gab (Majcen, 2016). This industrialized concept is also interesting for new build dwellings.

6.6.4.1 Passive (solar) design solutions for reducing the energy demand

Passive Solar Design (PSD) is the technique leading to passive buildings. For PSD both the urban form and building physics have to be taken into account. Passive (Solar) Design is useful to reduce the energy demand and thus in the realisation of BENG1. This explained in the next paragraphs.

PSD strategies are used to reduce the heating, cooling and lighting energy consumption of buildings and aim to use the natural energy flows of the sun to help establishing the thermal comfort in buildings (Stevanović, 2013). The term ‘passive’ was first introduced in the 1970s to describe “*those methods of employing solar energy that do not use mechanical power (e.g. pumps and fans) but instead use natural energy flows for the transfer of thermal energy into, out of, and through a building.*” (B. N. Anderson & Michal, 1978: 57). By using several design strategies PSD decreases the total energy demand of buildings. According to Stevanović (2013) an optimal combination of several strategies on different scale levels is required when targeted on very high levels of energy performance. Littlefair (1998) gives a first clear definition:

> “*Passive solar design involves arranging the form, fabric and systems of a building to increase the benefits of ambient energy for heating, lighting and ventilation, to reduce the consumption of conventional fuels.*” - Littlefair (1998: 303)

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In this definition Littlefair (1998) integrates the different scale levels of the urban fabric, the building form and its internal systems to optimize the reduction of energy demand of buildings. The result of PSD on the building scale is called a Passive House (Feist *et al.*, 2005) or Passivhaus (McLeod & Hopfe, 2015). The thermal demand of a passive house must be sufficient low in order to make it possible to be solely dependent on natural flows and still be possible to guarantee the thermal comfort and cover the entire peak heating or cooling load without any heating installations (Feist *et al.*, 2005; McLeod & Hopfe, 2015). Although, according to both Feist *et al.* (2005) and McLeod and Hopfe (2015), a small amount of supplementary heating of cooling can be added to the mechanical ventilation supplied air, but without using additional recirculated air. Thus, in order to reach minimal heat losses a Passive House must have great insulation and an optimal PSD to prevent overheating or undercooling. Otherwise mechanical heating or cooling appliances would be needed.

PSD incorporates both the urban form and the building physics. Corresponding the previous explanations, insulation of the building, providing thermal comfort and capturing the heat of natural energy flows are important factors at the building scale. However, Knowles (1974) and Littlefair (1998) argue that the urban form is a key factor in the viability of a passive solar building. Tall obstructions can block incoming solar light and heat and reduce passive cooling by blocking ventilation flows. They named it the concept of the ‘*solar envelope*’ (Knowles, 1974), or ‘*site layout*’ (Littlefair, 1998). The orientation of the building towards the south is incorporated in the site layout. This shows that individual building design and urban planning decisions regarding density and urban form are both relevant in PSD. Zirnhelt and Richman (2015) confirm this by stating that understanding PSD has significance potential to policy and planning decisions at the urban scale, regarding density and shading.
For the building scale several researchers identified many design criteria influencing the energy-efficiency of buildings. These criteria are based on the parameters of building orientation, shape, the envelope system, passive heating and cooling mechanisms, shading and glazing (Pacheco, Ordónez, & Martínez, 2012). The envelope system at the building scale is the optimal thickness of the thermal insulation material in the building envelope (Kaynakli, 2012). Glazing can be detailed in glazing type, window-to-wall ratio and shading on the windows (Raji, Tenpierik, & Van den Dobbelsteen, 2016). Zirnhelt and Richman (2015) state that the most important parameters are the thermal mass, the south window area and glazing type.

Concluding, passive solar design is an integrated design concept to reduce the energy demand by making use of natural materials. In that way transmission losses (by great insulation values and triple glazing) and infiltration losses (by a high level of airtightness) can be prevented and solar gain (by large south oriented windows) can enter the dwelling. Although, incoming solar gain has to be prevented in summer to prevent overheating. A good integrated concept can thus reduce the energy demand.

6.6.4.2 Passive vs. active solar design

The second building solar heating and cooling system next to the previous described passive solar design methodology are the active solar design methodologies. This part explains the different focus. Athienitis *et al.* (2015) explain the difference as:

> "*Passive systems integrate into the structure of the building technologies that admit, absorb, store, and release solar energy, thereby reducing the need for electricity use to transport fluids. In contrast, active systems include fans and pumps controlled to move air and heat transfer fluids respectively for space heating and/or cooling and domestic hot water (DHW) heating.*"
> - Athienitis *et al.* (2015: 10)

In passive solar systems only the natural energy flows of the sun and air are taken into account. In active solar systems electrical or mechanical equipment are used to increase the usable heat in a system (Chan, Riffat, & Zhu, 2010). For instance, solar collectors are used to adsorb the solar radiation energy, which is transported by a medium or fluid to a heat exchanger or storage tank that is providing in the heating demand. Passive buildings can never reach a ZOM-energy level, because electrical systems are not taken into account and thus the electricity to compensate the household-related energy demand cannot be generated. According to Boonstra, Clocquet, and Joosten (2006) is the difference between the passive building and the NZED methodology that the passive building design focusses on reducing the energy demand[58] and the NZED is solely based on the supply side. For the NZED a too high energy demand can be compensated by a better and more efficient installation or by adding generation facilities such as PV-panels. In passive building design that is not possible, both the demand and supply side have to be optimized.

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A third group could be based on PV-panels. Clarke and Strachan (1994) divide the groups as passive solar, photovoltaic and combined heat and power systems (active). PV-panels convert the incoming solar radiation to electrical power for local use or export to the grid.

According to Hestnes (1999) buildings are no longer designed to use just passive or active solar energy systems. The newer buildings combine several of these technologies and they are energy efficient, solar heated and cooled, and PV powered. She argues to call them simply "*solar buildings*" and to improve the design process into a holistic approach to solar building design.

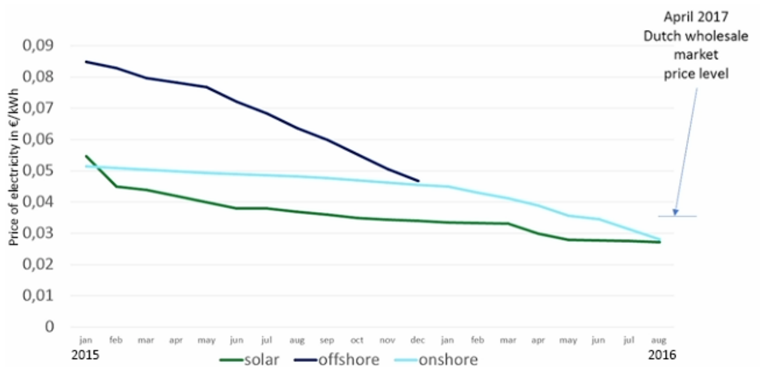
On multiple scale levels can passive solar design (focus on energy savings) and active system design (focus on a renewable supply) be applied. Active installations for reducing the energy demand are ventilation systems and systems for heat recovery. The energy consumption of a ventilation system is explained in Appendix 13.18.2.2. Active installations for a renewable electricity and heat supply are explained in the next sections.

6.6.4.3 Renewable electricity supply

The drop in price per kWh takes away any economic bottleneck or threshold in terms to make this transition possible. The timeframe is unknown for the Netherlands, but somewhere in the future energy from renewable sources will be cheaper than energy from fossil fuels (Molengraaf, 2017). Graph 8 shows the decline in energy prices of renewable sources of wind and solar. In this graduation these renewable energies based on solar and wind are incorporated[59].

[58] The requirements of the passive building design are set on the maximum thermal energy demand of 15 kWh/m^2 (Boonstra *et al.*, 2006), which is 40% lower as the BENG-legislation requires.

[59] The calculation of the amount of electricity gain by PV-panels can be found in Appendix together with the related costs and efficiencies. The calculation of the amount of electricity gain by windmills can be found in Appendix together with the related costs and efficiencies.



Graph 8: Costs of renewable power generation is going down on a global scale (slightly adapted illustration of Molengraaf (2017: 10))

Windmills have as main barrier that is hard to get ZOM, because the wind is not generated on-site. PV-panels have a conversion problem referred to the DC/AC-problem. This problem is caused by the different electricity types in the grid, namely alternative current (AC) and direct current (DC). AC is produced and distributed by through the grid by conventional power plants. DC is consumed by most household appliances which are equipped with inverters that convert AC into DC. Energy losses up to 7–8% occur during this conversion process (Itard, 2011). DC is also produced by PV-panels, however, because all appliances are equipped with a converter, the DC produced by the PV-panel must first be converted to AC, before being re-converted to DC current, which is doubling the energy losses (Itard, 2011). A solution would be to prevent these unnecessary energy losses to directly use the DC current in the appliances (Itard, 2011).

6.6.4.4 Renewable heat supply

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Renewable heat can be supplied in the all-electric concept by means of electric boilers, IR-lighting and heat pumps. Solar heating could also be possible to realize a high energy ambition, such as ZOM (Dirks, 2017), however, heating by solar collectors is competitive to PV-panels. PV-panels are more competitive, because they did rapidly decreased in prices (Sijpheer *et al.*, 2015).

First, electric-boilers operate by means of an electrical resistance[60]. They are only producing renewable heat in case they are connected to a renewable energy source. If they are connected to the electricity grid, the total efficiency of the system is very low due to the low average efficiency of the electricity grid of 39%[61].

Second, IR-lighting uses plug and play panels for heating. These are relatively easy installed, however, they heat by means of radiation and therefore a direct line between the IR-panels and the person or object that needs heating. In addition, these type of heating is still in its infancy, which is indicated by the fact that L. De Vos (2017) presented the first experiences with this heating concept. It is expected that this type is not present in the case studies and if that is the case, this option will not be available in the LP-model.

Third, heat pumps seem to be the most used device within the all-electric dwelling concept for heating purposes. The efficiency of a heat pump is expressed by its Coefficient of Performance (COP), which is defined as the ratio of produced heat by the electrical input to the compressor (Itard, 2011). A COP of 5 implies that 1 kWh of electrical energy is converted into 5 kWh of thermal energy. The COP is higher than 1, because a heat pump uses free heat from the environment (Itard, 2011). This free heat can be distracted from several sources. In general, a distinction is made between the air source heat pump (ASHP) and the ground source heat pump (GSHP). Of these types has the GSHP the highest COP, which can increase up to 7 in come practices (Staats, 2015). An GSHP has an average COP-value between 3-5 and ASHP has an average COP-value of about 2-3 (Furuno, Okushima, & Sase, 2016; Miara *et al.*, 2011; Thies, 2017). The COPs for different heating technological are difficult to estimate, because they are highly depended on ambient air, water and soil output temperatures (Thies, 2017). For instance, in case there is a very cold period during winter, the COPs level will be lower. The sizing of the heat pump depends on whether the heat pump covers part of the heating load or the whole heating load. In the latter, the heat pump system also includes a hot water heater and an electric booster, which provides the auxiliary heat

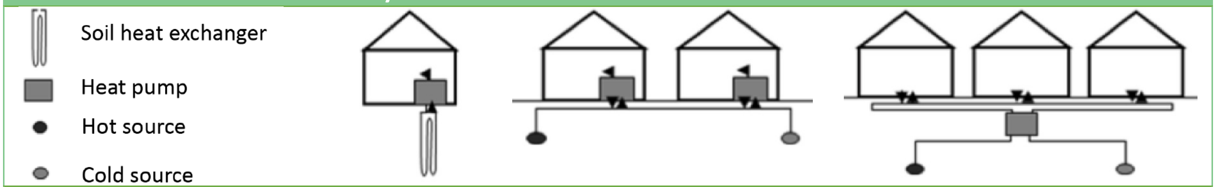
[60] The efficiency of an electric-boiler in current practise can be found in Appendix 13.23.1.

[61] This can be calculated by an inversion of the primary energy factor of 2,56, which is obtained in Kruithof and Haytink (2015: 10).

when the heating demand is larger than the heat pump can provide during cold (winter) days (Kjellsson, Hellström, & Perers, 2010). The GSHP thus has the highest energetic performance.

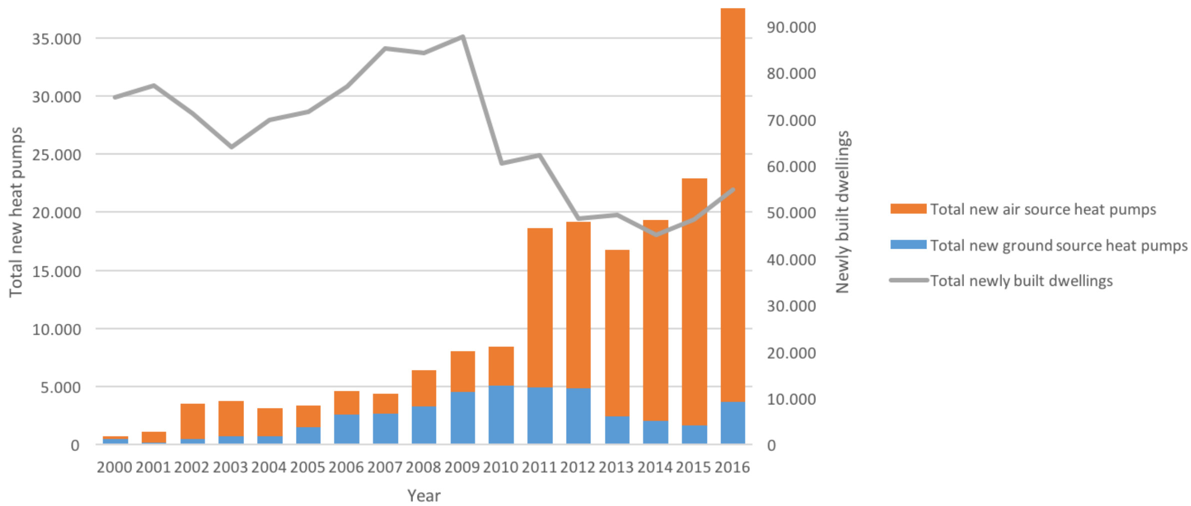
The GSHP can be installed on various scale levels (e.g. individual, block and neighbourhood, see Table 7) and as various appearances (e.g. open or closed system and ground-coupled or water-coupled, see Sarbu and Sebarchievici (2014: 444)). Especially the different systems on the various scale level is requiring different density constraints, a minimum number of connections and different organisational types for the operations (see Table 7). The selected scale level also affects the flexibility of the phasing and thus relates to the financial risks of the investor.

Table 7: Rules of thumb for when to use which ground energy source
(table based on Van de Griendt and Schilt (2010) in Van de Griendt and De Vries (2012: 55)).



	Individual system	Individual with collective source	Collective Hot-and-cold storage
Type of source[62]	Closed	Open	Open
Energetic yield	- / +	+	- /+
Flexibility of phasing	+ +	- /+	-
Required density	n/a	> 25 dwellings/ha	> 35 dwellings/ha
Required scale (number of connections)	≥ 1	≥ 25/ha	≥ 100
Operational type	Similar as HR-boiler	Small collective	Collective

Heat pumps are applied in many new development projects. Van de Griendt (2016) however was wondering if energy from ground source heat pump is not on its return. One year later on twitter he mentioned that trend breach was visible (Van de Griendt, 2017). Based on this idea to relate the amount of ground source heat pumps to the newly built dwellings Graph 9 is created. The figure clearly shows the increase of new ground source heat pumps starting from 2004, its decline since 2012 and the upswing in 2016. The usage of air source heat pumps got an upswing in 2011 and increases since. These air source heat pumps do not have to be applied in the newly built dwellings. Also large renovations projects, such as Stroomversnelling, use heat pumps (mostly air source heat pumps as they can easily be added to the existing stock).



Graph 9: Relation of the new heat pumps and the new dwellings (own illustration based on data of CBS (2017f, 2017g)

[62] Schematics and explainations of of different ground-source heat pumps are presented by Sarbu and Sebarchievici (2014: 444).

6.6.4.5 Tackling the inflexibility of renewable energy supply by dynamic pricing and demand side management

There are several ways to tackle the moments of peak demand and supply caused by the inflexibility of the renewable energy supply and the related heavy pressure on the electricity grid. First, to add more supply capacity by building more power stations and reinforcing the transmissions and distribution networks, which is a costly solution. Second, by restricting the amount of solar a dwelling can supply to the grid (reducing the demand of more capacity). And third, to shift a part of the peak demand to other moments of the day by discouraging customers to consume large amounts of electricity at times when electricity demand is at peak level (Beggs, 2009; Vreeburg, 2016). For instance, by charging the electric vehicle during moments of peak supply (Molengraaf, 2017). This last concept is named peak shaving, which requires demand side management on the household level and dynamic pricing within the grid level to value this flexibility of demand. These smarter solutions are based on flexibility and optimal usage of the available grid capacity and need to prevent huge investments in the expansion of the electricity grid.

The first solution on the household level is demand side management (DSM). DSM can shift loads profiles to moments when electricity generation is prevailing (Honolda, Wimmera, & Kandlera, 2015). This can be realized by the scheduling of devices in an optimized way (Honolda *et al.*, 2015). This must lead to smoother load profiles and in case of flexible energy tariffs DSM can lead to less energy cost in comparison to a reference case. The shifting demand profiles can also be used to mitigate the variations in production of renewable energy (Moura & de Almeida, 2010). That results in an increased effect on the reduction of fossil fuels, because the fossil fuel-based power plants need not be used as a backup facility. DSM also reduces the transport losses through the grid and the related primary energy demand (Spiegel, Kern, & Greenberg, 1997). The advantages of DSM are summed by Strbac (2008) and Castillo-Cagigal *et al.* (2011): 1) To reduce the generation margin (i.e. decreasing the need for backup generation), 2) to prevent transmission–distribution grid investment (i.e. adjusting the size of the lines to the increasing local demand), and 3) to increase the operation efficiency (i.e. decreasing the need for energy transport).

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The second solution is dynamic pricing of the energy demand and supply for households. The energy tariff is settled every 15 minutes. At peak supply, the electricity is cheap and at peak demand, the electricity is more expensive. The goal of this solution is that it causes peak shaving by a demand shift to periods with a big supply in renewable energies and that this is an incentive of peer-to-peer trading (Molengraaf, 2017; Monti *et al.*, 2017; Van Veller, 2017). Itard (2011) explains this as a kind of market guidance to given an financial incentive to the energy demander to shift some of his demand to a time with low demand. This way, the high investments in additional capacity of the electricity grid may be avoided.

Lastly, an emergency solution in case of an oversupply on the grid is congestion management. In this case the grid operator can direct steer on wind mills, solar panels, heat pumps and electric vehicle charging to prevent a black-out. This only goes further than the previous solutions and is seen as a solution in the distant future. However, this being a solution gives an indication on the urgency of the problem.

6.6.4.6 Innovation

Various innovative solutions for the reduction of the thermal energy demand, the thermal energy supply and the renewable electricity supply on a household level are worth mentioning: Photovoltaic/thermal (PV/T) panels and increased utilization of the ground as a heat source. These innovations were used by Kazanci *et al.* (2014) in the development of a plus-energy house and are explained next. Innovations in technology as for instance cars as battery packs, increasing the efficiency/COP of installations are neglected, because these are already discussed or their effect is obvious.

6.6.4.6.1 Innovation by cooled solar panels and hybrid photovoltaic/thermal panels

The increase of the operating temperature of PV-panels causes an almost linear decrease of their performance (Schiro *et al.*, 2017). Research revealed that an increase of around 1 °C leads to a decrease in efficiency of about 0,45% (Debra, 2017; Zhu, Raman, & Fan, 2015) and that controlling the operational temperature of PV-panels by adding a water-based cooling system can increase its efficiency (Kazanci *et al.*, 2014; Krauter, 2004; Peng, Herfatmanesh, & Liu, 2017; Schiro *et al.*, 2017; Teo, Lee, & Hawlader, 2012).

The PV-panels require cooling, because the operational temperature of PV-panels increases more rapidly in relation to the outdoor temperature (Schiro *et al.*, 2017). With an outside temperature of 20 degrees and cloudy weather, the PV-panels reaches a temperature of 27˚C. However, without clouds the PV-panel reaches even 40˚C (Schiro *et al.*, 2017: 7). Schiro *et al.* (2017) shows that an active cooling method can improve the electrical efficiency up to 22% and reduce the PV module temperature up to 30˚C. This cooling method also consumes electricity. The net energy production percentage as percentage of the non-cooled energy is estimated be 3,5% (Schiro *et al.*, 2017: 10). Krauter (2004) estimates even a potential 9% net energy production gain. The researcher sees two important effects in the presence of the water film. First, the operation temperature of the PV-panels can reduce up to 22˚C and second, the light reflection is decreased, allowing more solar radiation to enter the PV-panel. Peng *et al.* (2017: 1) even suggests that "*the annual PV electric output efficiencies can increase up to 35%, and the annual total system energy efficiency including electric output and hot water energy output can increase up to 107%*". In practice this research used ice on the back of the PV-panel to provide the cooling function and the efficiency rate of the PV-panel increased by 47% with this cooled condition.

Researchers thus provide a wide range of possibilities to increase the efficiency of PV-panels. The most interesting is the new concepts proposed in the literature study of Schiro *et al.* (2017): the so-called hybrid photovoltaic and thermal (PVT) collectors. This system simultaneously produces electrical and thermal energy. The water used for cooling is heated and used in the supply of the hot water demand, while it also increases the overall system performance. However, the hot water needs to be used by a thermal user. This brings us to the next innovation, combining this hybrid PV/T-panel with a heat pump.

6.6.4.6.2 Innovation by connecting ground pumps to solar collectors

In heating-dominated climates, such as the Netherlands, the single GCHP-systems can cause a thermal heat depletion of the ground (Sarbu & Sebarchievici, 2014). According to these researchers this largely decreases the heat pump systems performances. Their solution is to connect solar thermal (ST) panels to the ground-couplet heat pump (GCHP)[63]. The result is named a hybrid ground-couplet heat pump (HGCHP) (Sarbu & Sebarchievici, 2014). In this case the GCHP is sized to meet the cooling load and the ST-panels are added to meet the heating load that cannot be supplied by the GCHP. An additional advantage is that the use of a supplemental heat supply system can significantly reduce the size of the ground heat exchanger (GHE) and the borehole installation costs. The basic operating principle of this hybrid GCHP with a solar collector is shown by Figure 38. Kjellsson *et al.* (2010) gives three major reasons for adding solar collectors in a GCHP-system: 1) to decrease the use of electricity, 2) to raise the temperature in the borehole. And 3) to decrease the net heat extraction.

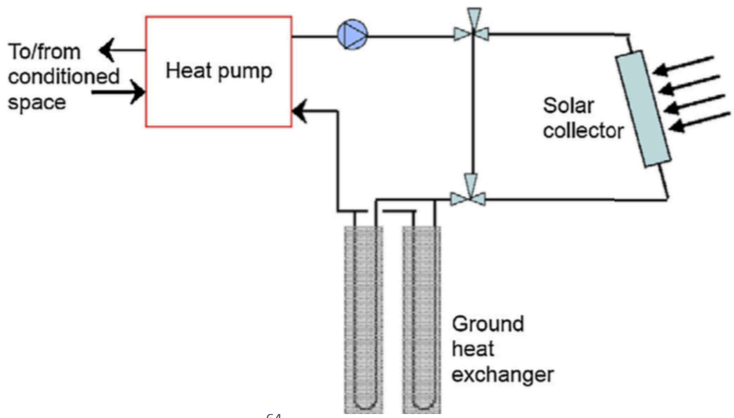


Figure 38: Schematic diagram of a HGCHP[64] system with solar collector (Sarbu & Sebarchievici, 2014: 451).

Kjellsson *et al.* (2010) investigated different operational method of the HGCHP and concluded that in case the solar heat is used for recharging the borehole, the lowest monthly average and the seasonal performance factor are higher in comparison to the other system operations (see Figure 39) and that the optimal design for reducing the use of electricity is when the ST-panels produces domestic hot water during summertime and recharges the borehole during wintertime (November–February) (Kjellsson *et al.*, 2010). The reason for this is given by Kjellsson *et al.* (2010) and can be summarized as that during the summertime, the heat demand in the summer is low and little heat is distracted from the borehole and the ground temperature is higher and complemented naturally by heat from the surrounding area. Recharging is not necessary. However, during the winter time the heat demand

[63] The GCHP is a specific GSHP, namely an individual ground-source heat pump with a closed loop (Sarbu & Sebarchievici, 2014).

[64] The hybrid ground-couplet heat pump (HGCHP) is an individual ground-source heat pump with a closed loop system connected to the solar collector (Sarbu & Sebarchievici, 2014).

is high and many heat is distracted from the borehole, causing a drop in temperature of the borehole. The heat pump is now working during the worst conditions. Both are reasons why recharging during this time has the most impact. In the winter the ST-panel can only produce heat at a low temperature and high temperatures are required for domestic hot water. Therefore, it is more efficient if this heat is used to recharge the borehole.

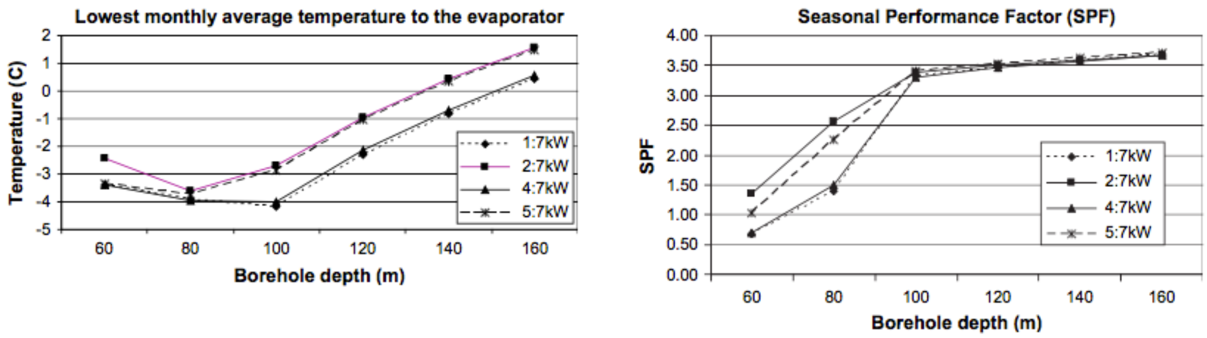


Figure 39: Seasonal Performance Factor for the HGCHP (Kjellsson *et al.*, 2010: 2671).
1 – no solar heat; 2 – all solar heat recharging the borehole; 4 – all solar heat for domestic hot water; 5 – all solar heat recharging the borehole in November-February, the rest of the year for domestic hot water.

Both innovations are related to system innovations by connecting different components to create a more efficient system. The PV/T-panels simultaneously produce electrical and thermal energy and enhance the efficiency of the electricity production. The hybrid GSHP connects the solar collector to the borehole to maximize the performance factor. Maybe in the future can these systems even be combined to a PV/T-panel with a connection to the borehole, which combines the advantages of both innovations into one system.

6.6.5 Conclusion

The conclusion profits insights in the main barriers and solutions for the optimisation of the physical aspect of the business case of ENRND-projects.

There are two main technological barriers possibility influencing the business case of ENRD-projects, namely the energy performance gab of theoretical calculations and the inflexibility of a renewable energy supply. The energy performance gab is the misfit between the theoretical calculation of the energy performance and the actual energy use, which is caused by different occupancy behaviour and the rebound effect related to home owners and design and construction faults related to the construction sector. Solutions are found in the education of the future inhabitants by showing them the monitored results of their behaviour and how the appliances should be used and in increasing the know-how and skills of professionals. Both were also indicated as solutions within the organisational aspect. This again indicates to get knowledge involved early on in the process and involve end-users somehow to teach them how their energy efficient building should be operated. Both helps to prevent the energy performance gab.

The second barrier identified is the inflexibility of the renewable supply of the PV-panels and the increased electricity demand due to the heat pumps that cause capacity problems in the electricity grid. Huge investments are required to increase the capacity in case no cheaper solutions are identified and implemented.

Solutions are found to optimise the physical aspect (i.e. the spatial design or the technological installations) of the business case: Passive (solar) design, renewable energy supply, renewable heat supply, demand side management, dynamic pricing and technological innovation. First, passive solar design is an integrated design concept to reduce the energy demand by making use of natural materials. A good integrated concept can thus reduce the energy demand. In addition, the NZED methodology and active solar design are based on the supply side. Newer dwellings combine these approach and as result they are energy efficient, solar heated and cooled, and PV powered. The design process of these buildings can be improved into a holistic approach to solar building design. The integrated design approach is thus important for several methodologies of the energy efficient dwelling with a low energy demand.

Of these active systems are PV-panels, windmills electric boilers and heat pumps identified as the current best available technologies to generate renewable electricity and renewable heat.

Demand side management is helpful for peak shaving purposes on the household level to shift the electricity demand to times of (high) renewable electricity production. In addition, flexible tariffs be used on the grid level as an incentive to shift the usage of consumers to times of renewable electricity production.

Many innovations possible by integration of different parts of the system, for instance, the PV/T-panels and the HGCHP system with solar collector. First, PV/T-panels who provide hot water and electricity and even have an increased efficiency for the electricity generation due to the cooling by the water. Second, the HGCHP system with solar collector has an increased efficiency because the hot water of the solar collector heats the ground source during winter time. This is more efficient, because it can be used within the heat pump and it limits the heat distraction from the source.

Concluding, there are many opportunities to optimise the business case and make the whole electricity grid more reliable. The most important aspect is to involve knowledge and skills of expert professional in the first phases of the ENRND-projects. They are informed about all these technological possibilities and have to ensure an integrated design process with a holistic approach to solar building design by combining passive and active solar design concepts. For the optimal energy efficient dwelling is an integral concept in which all energy-related components collaborate as a system key.

6.7 Conclusion

The coming paragraphs show barriers and solution that are influencing the business case of energy efficiency in multi-actor decision-making processes of ENRND-projects. Thereby this chapter has provided an answer to the second knowledge-related sub-research question:

> *What is already known about the barriers and solutions in the decision-making about the aspects in a business case, which are presented in the research framework?*

There are many barriers to overcome in the decision-making about ENRND-projects. First, the new legislations of BENG and MPG together with the adjustment of the balancing agreement require new solutions in the design of energy efficient dwellings. In particular, the BENG-legislation ensures a reduction of the energy demand and a renewable energy supply on-site. Second, the organisation aspect. The main barrier identified in the literature review is the risk of underperformance of ENRND-projects by increasing project complexity, technological uncertainty and demand uncertainty, which cause the planning fallacy. The planning fallacy cause project managers and planners to systematically overestimate benefits and underestimate cost and time. This risks increases with the increasing complexity of the technological component of energetic installations, required by the rapid tightening of energetic legislations. The result of the main barrier is the need for proper knowledge and skills in the beginning of the ENRND-project. Third, the finance component of the business case. The basic calculation for real estate finance uses the residual approach. Five main financial barriers are identified to optimise the business case of energy neutral dwellings: 1) The current public subsidies are insufficient on the long run, as subsidies are not economically sustainable and therefore other financial schemes are a necessity. 2) Large pre-investments in urban area development projects are mostly infeasible and therefore, it is difficult to get a major area strategy for a large scale energy supply financial feasible. It is expected that developing parties will choose for smaller energetic solutions that spread the risk per phase of development. 3) The complex financial scheme of real estate causes a split incentive between the real estate developer and the end-user, because the real estate developer has to invest in the energy saving measures and the end-user profits. 4) The market value of energy neutral (A++ and A++++) dwellings in relation to A-labelled dwellings is unknown. Research of the market value based on energy labels shows that an A-labelled dwelling has a huge financial advantage over the G-labelled dwelling. 5) The current price pressure within the residential market increases the market value of new dwellings in most parts of the Netherlands. This proposes difficulties when the ground first need to be bought, because also the residential value of land increases with increasing market values. And fourth, the two main physical barriers are related to technology, namely the energy performance gab of theoretical calculations and the inflexibility of a renewable energy supply. The main barrier is how to combine all those into feasible business case and which barriers are involved in the decision-making and which are not.

There are theoretical solutions found for the optimal business case of a real estate developer to realize ENRND-projects. First, for the organisational aspects is specific knowledge required more earlier on in the project and theory proposes to use an integrated procurement method or commissioning. In addition, the involvement of non-traditional parties related to energy can act as value creators in the business case. Second, the financial business case focus on a new business model based on a specific economic profile, as the return of investment is not ensured by a direct cash flow such an increase in revenues, but in most cases, through energy savings by non-expenses. Two solutions are found to prevent a lower residual value of land or a lower profit rate for the real estate developer, namely an increased market value, made possible by an additional borrowing capacity in mortgages for energy efficiency dwellings and an investment by a third-party (e.g. an ESCO). In the last case the ESCO get its return on investment by a periodically energy fee of the end-user during the operational phase. Besides the solutions, it appeared that postponement of the energy efficiency measures pays and in that case the dwelling has to made future-proof, which prevent larger investments during the development of the dwelling. This also transfer the risk and decision-power to the end-user. These financial solutions for handling the increased costs of energy efficiency are captured in the basic financial value scheme of Figure 36. Third, the physical aspects, a conceptual approach for an integral system design of the dwelling and the procedure of the trias energetica are recommended. The conceptual approach ensures optimal system benefits in which the result is more than the sum of its parts. The trias energetica can be complied by two steps: 1) Reducing the energy demand with passive solar design and applying insulation. And 2) Generating renewable energy by using installation technology, such as PV-panels and heat pumps. Installation technology is required to realise the highest energy ambition.

PART 3
EXPLORATION

Energy ambition	Zero-on-the-Meter
Project	‘Prof. Schoemaker Plantage’, phase 1
Location	Delft
Real estate developer	AM

7 Exploring cases studies: Current practices in ENRND-projects

7.1 Introduction

This chapter explores the business case of ENRND-projects in current practises and provides an answer on the first sub-research question:

How is an ENRND-project realized by the real estate developer in current projects?

A case study is used to investigate on an empirical basis the current state-of-the-art in practise. The business case of this urban area development projects is researched on how the organisational and financial aspects impact the physical end-results and how the important decisions are made by the involved actors with a focus on the role of the real estate developer. The results are presented in this chapter. The review of literature and policy documents is supplemented by a semi-structured interview with the involved real estate developer. During this interview it is not asked how they would do it, but it checked how they did it by identifying which decisions related to energy the real estate developer made based on which information and how it affected the business case. In this way can several things be identified: 1) how decisions about energy efficiency are made by the real estate developer, 2) the implemented solutions used for the financial, organisational and physical aspects of the business case. And 3) the requirements of a decision support tool.

The chapter is structured as follows. First, the headlines of the sampling process are described, followed by the case studies themselves. The description of the case study starts by presenting the context of the case, then providing insight to the aspects of the business case and how the real estate developer integrated these aspects and in the final part preliminary conclusions based on the case are given. In the last part of the chapter conclusions in the form of lessons learned for the optimisation model are presented.

7.2 Sampling

7

The cases are strategically and non-randomly sampled (see chapter 3.5.2.2). In that way all cases are relevant to the research questions. First the selection criteria for the cases is discussed, followed by the different search strategies applied and lastly the selected cases are introduced shortly.

7.2.1 Selection criteria for the cases

The used selection criteria are based upon the aspects of the research framework (energy legislation, organisational, financial and physical solutions). The selection criteria are presented in Table 8 together with the argumentation and the concrete implemented values.

Table 8: Selection criteria for case studies

Selection criteria	Reason why	Concretely implemented as
Increased energy ambition	Central subject of thesis	Select projects of different energy ambitions: - Zero-on-the-Meter - Energy neutral (EPC=0/ BENG) - Higher as required by building regulations (EPC<0,6 in 2011 and EPC < 0,4 in 2015)
All-electric energy concept	Demarcation of subject thesis	Only select all-electric energy concepts (thus, exclude heating grid, etc.)
Development of owner-occupied and single-family dwellings	Demarcation of subject thesis	Only select owner-occupied and single-family dwellings

Decision power of the real estate developer in the energy concept/ solutions for energy efficiency	Demarcation of subject thesis	Focus on private realization or public realization Public-private partnerships are difficult, because of the equal role of the developer in relation to the municipality. However, still interesting if there is enough time.
Project size is bigger as 25 dwellings	Possibility to implement collective energy solutions	Project size is bigger as 25 dwellings (based on Van de Griendt and Schilt (2010)).
Recent projects which already finished the development phase and/or are starting construction	Possibility to evaluate real results to the results of the LP-model in the next chapters. And results need to be valid in the new legislation.	Projects after 2011, since the maximum EPC-level decreased to 0,6 from the start of that year (Agentschap NL, 2011).
A variety in projects in locations and thus market situations and real estate developers	Broader exploration of possibilities	Only 1 case per location and 1 case per real estate developer
Multiple financial solutions	Exploration of possibilities	At least one project with an Energy Service Company (ESCO) involved.
Not in the spotlights of current research	Exploration needs to have added value next to the literature research	No cases in which universities are involved or content is published in peer-reviewed journals.

Several search strategies were used and in the end the cases were selected based on the ZEN database of RvO (2017a), which offered the best cases[65]. ZEN is the abbreviation of '*Zeer Energiezuinige Nieuwbouw*', which is translated from Dutch as 'Very Energy-efficient Newly Built'. Since 2015, ZEN has been follow-up program of the Lente-akkoord (Bouwens, 2015b). A development can become ZEN if the energy-performance is between energy-neutral (BENG) and energy-producing and takes the residents as starting point (Bouwens, 2015b). Therefore, close attention is required to living comfort, healthy environment and affordability. The central thesis of the ZEN-program is how to match technical highlights with the consumer requests, which increasing the living comfort and reducing the energy bill (Bouwens, 2015b). The ZEN-program of the Lente-akkoord is a cooperation between representative associations of (semi-)market parties[66] supported by the government (Bouwens, 2015b). Projects in the ZEN-database are therefore highly relevant for this graduation lab as the database only consists of projects with a high energy performance and lots of decision-making power for market parties.

In total 57 projects from the database of RvO (2017a)[67] are taken into account. Most of the projects consists of rental dwellings and in only 42% of the projects is the main focus on owner-occupied and single-family dwellings (see Figure 40). Hereof, 43% of the projects, thus 16% of all projects, have a projects size bigger than 25 dwellings. These projects are relevant for this graduation research and are shown in Graph 10.

[65] The other search strategies are explained in Appendix 13.13.
[66] Housing associations are meant by the semi-market parties.
[67] The database of RvO (2017a) showed 61 projects at 2017, June 20, however, some small subprojects are merged and double mentioned projects are only included once.

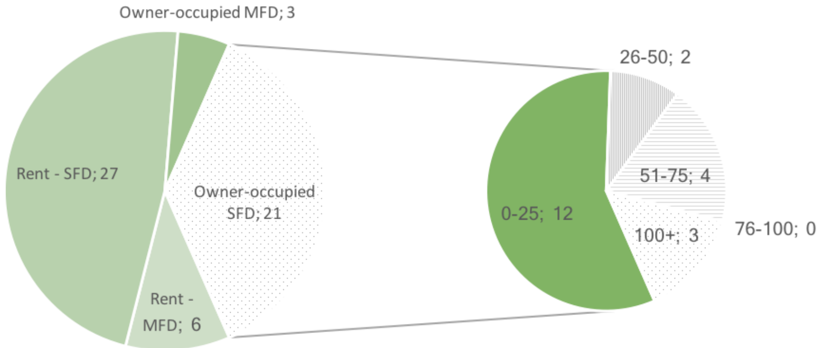
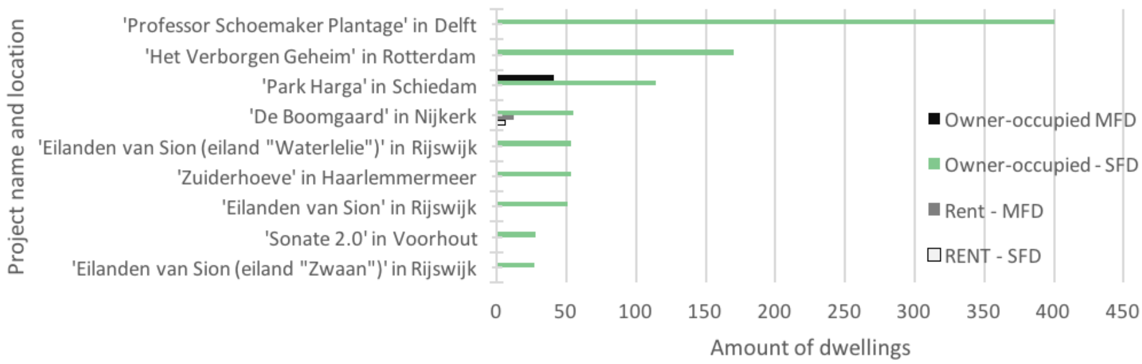


Figure 40: ZEN-database disaggregated by project types and sizes. Numbers are the amount of projects in the ZEN-database (own illustration based on project data in RvO (2017a)).
(SFD: Single-Family Dwelling & MFD: Multi-Family Dwelling/ Apartment)

All projects in Graph 10 meet the selection criteria. 'Prof. Schoemaker Plantage' in Delft and 'Het Verborgen Geheim' in Rotterdam are selected as most interesting cases, because these projects have the largest project size in amount of dwellings, the highest energy ambition (zero-on-the-meter, see RvO (2017f, 2017g)) and both projects only focus on the development of single-family dwellings. In addition, the projects in Rijswijk are close to the location of the project in Delft and both locations and the 'Zuiderhoeve' project in Haarlemmermeer are developed by AM (RvO, 2017b, 2017c, 2017d, 2017h)[68], that is why only one of them can be selected.



Graph 10: Project size of the projects in the ZEN-database with mainly owner-occupied and single-family dwellings and a project size bigger than 25 dwellings (own illustration based on project data in RvO (2017a)).

7.2.2 Selected Case studies for exploration of development strategies

Seven cases are suitable for this graduation research[69]. Four cases are selected for further investigation. This have to be two cases in which the real estate developer has decision power from the first initiative of the project (thus private realization) and two projects in which the decision power of the real estate developer was involved later on in the project, thus in which the municipality did the initiative. Figure 41 shows the projects with the related energy ambition and their realisation method.

First, 'Het Verborgen Geheim' and 'Prof. Schoemaker Plantage' have the highest energy ambition currently realized in projects, namely zero-on-the-meter. Both cases have a different development partnership method and a different financing method, as one of them collaborated with an ESCO. Therefore, these projects are selected first.

Second, one project has to be selected for the public development method. Project Locatie Valkenburg was still in the feasibility phase and therefore excluded from further research. Hoge Weide (Wonen op Smaak, Synchroon) and Veemarkt (Oase, VORM) are both located in Utrecht and both struggled with the heating grid (Gemeente Utrecht, 2016, 2017a, 2017b). It is assumed that both projects will give similar results and for that reason only one of them is selected. Project the Veemarkt gets this priority, because of its increased focus on sustainability/ energy efficiency and its published reports on the exploration of possible energy concepts (Gemeente Utrecht,

[68] Some projects in RijswijkBuiten are developed by a collaboration of AM and VolkerWessels (RvO, 2017b, 2017c).
[69] These seven cases are shortly introduceed in Appendix 13.13.

2017a; Harting, 2015; Mooij, 2011, 2012). Research of the project RijswijkBuiten state that it is not always possible to unravel which party has delivered exactly what advice, because of the intensive cooperation (Mensink & Franzen, 2013: 15). For that reason and because an ESCO is used in project Veemarkt, co-design had its part in the project and because of the struggles with the heating grid, project Veemarkt is selected and RijswijkBuiten gets a third position.

Thirdly, one project with private realisation has to be selected. This is project Helsdingen, because it is expected that its co-design approach gets interesting results for the research questions and this project is finished within one year. However, Nieuw Kortenoord still provides interesting knowledge and insights and its research is included in the further study.

The selection is summarized in Figure 41.

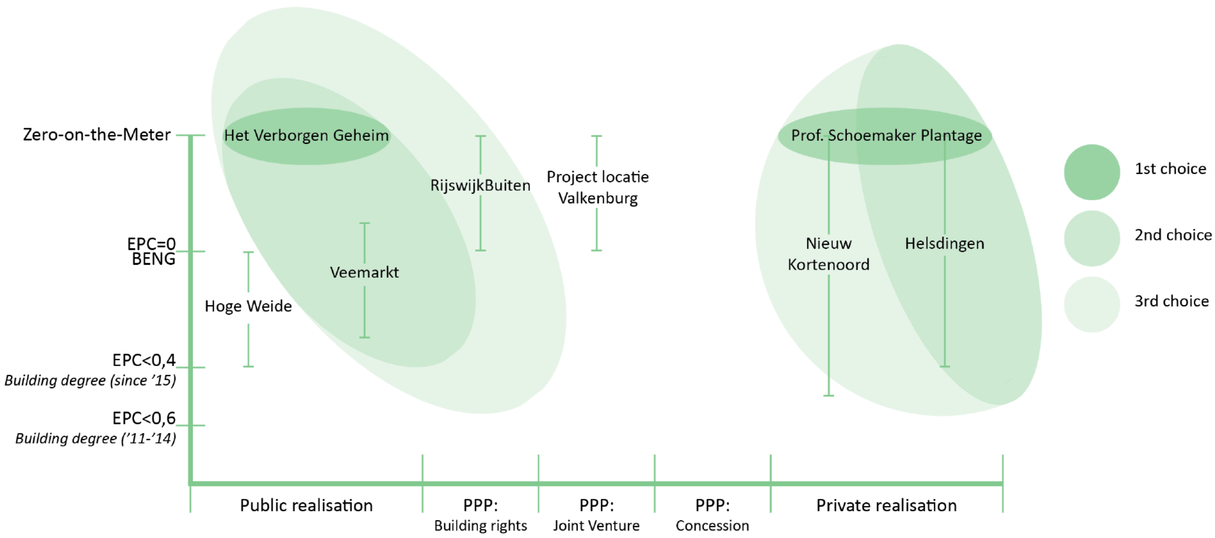


Figure 41: Pre-selection of case studies based on energy ambition and public private partnership (own illustration).

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All 1st choice and 2nd choice cases are brownfield locations on the edge of the city and spread over the Randstad, as can be seen in Figure 42.

Figure 42: Final selection of case studies and locations (own illustration).

The projects also differ in expected market values due to the different locations (see Figure 43). In this figure the projects on the left (prof. Schoemaker Plantage and Het Verborgen Geheim) had insufficient data, but as can be seen has Delft mostly dwellings in the high segment and this part of Rotterdam in the low and middle segment. The projects on the right side (Veemarkt and Helsdingen) are in the highest segment and just below the middle segment.

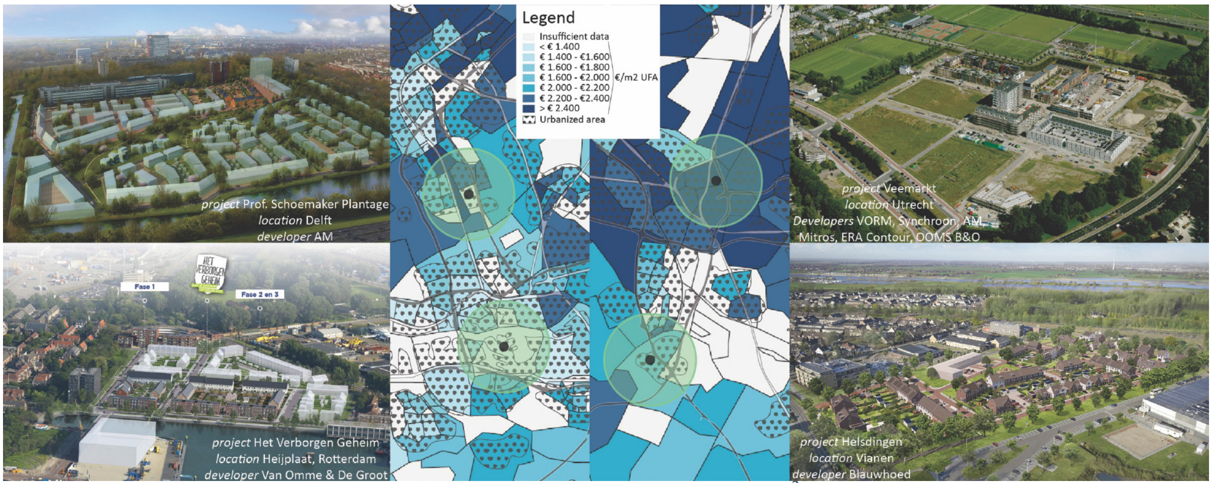

Figure 43: Bird's eye view impression and market prices per m^2 UFA (own illustration).

The projects are investigated by desk research (reading policy documents, new articles, promotion webpages, etc.) and semi-structured interviews with the real estate developers.

In the next paragraphs the first choice project of ‘Het Verborgen Geheim’ is discussed. Due to time reasons, the other projects are excluded from the in-depth analyses the report. ‘Het Verborgen Geheim’ offered insides in the involvement of the ESCO and was therefore preferred over ‘Prof. Schoemaker Plantage’.

7.3 Het Verborgen Geheim, Van Omme & De Groot

7.3.1 Introduction

Het Verborgen Geheim in Rotterdam consist of 170 newly built dwellings for the owner-occupied market. All dwellings will be developed as zero-on-the-meter-dwellings. Van Omme & De Groot Projectontwikkelaars en Bouwers (VO&DG) is developing and realizing the project. Het Verborgen Geheim is part of the ZEN-program (RvO, 2017f). Marco Dijkshoorn, project manager at Van Omme & De Groot, is interviewed for this case (Dijkshoorn, 2017).

The case is selected, because the real estate developer made the decision about the energy concept, an ESCO was used and the project size of 170 dwellings offers possibilities for advantages by economies of scale (e.g. collective systems).

The description of Het Verborgen Geheim at the website of the ZEN-program:

> *“[Het Verborgen Geheim] is unique in Rotterdam. In terms of architecture, the houses fit perfectly with the building style of the houses in the original garden village. The neighbourhood is spacious with lots of greenery, plenty of room for children to play and plenty of parking.”*
> – quote of RvO (2017f) is translated from Dutch

7.3.2 Context of the case

The context of the case is given by a description of its location, the dynamics of the decision-making process and surrounding projects.

7.3.2.1 Location and history

Het Verborgen Geheim can be translated as '*the Hidden Secret*' and is located at Heijplaat. Heijplaat is a little village in the middle of the Waal- and Eemhaven harbours on the south banks of the river Maas in Rotterdam (see Figure 44). The neighbourhood is characterized by its small-scale development in a garden village setting and the village is surrounded by large scale harbour activities. The village is relatively far from the city centre and mainly consist of social rented dwellings owned by Woonbron. The village is a little oasis within the big harbour, 'the hidden secret'.

The village was constructed in two phases. From 1914, the number of employees of one of the largest yards in Europe, the Rotterdam Droogdok Maatschappij (RDM), grew so fast that the RDM decided to develop around 850 dwellings behind the RDM-site (Ooms, 2017). This was the origination of the garden village Heijplaat. The second phase was constructed just after the second world war (Vereniging Wijkbewoners Heijplaat, 2014). This origin also explains Heijplaat's location in the midst of all port activities.

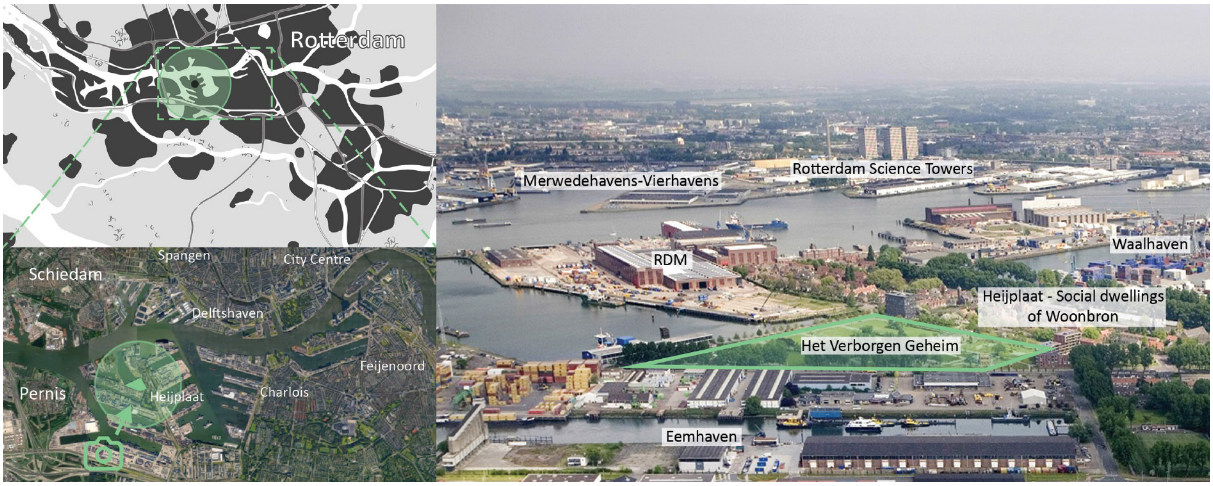

Figure 44: Location of Het Verborgen Geheim (own illustration based on Google Maps and Ooms (2017)).

The port and the village have always been strongly linked, not only economic but also cultural and social (Stadshavens Rotterdam, 2009). Stadshavens Rotterdam (2009) give a clear explanation about this relation between port and village and the (physical) differences. The link is reflected in, among other things, the characteristic architecture of RDM's headquarters and the development of the village. On the other hand, they are two very different environments: the village is small, quiet and green while the RDM site is large, busy and rocky (Stadshavens Rotterdam, 2009).

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In the 1970s, the entire dwelling portfolio of the RDM was sold to the housing association Onze Woning (currently Woonbron), because of the bad financial situation at RDM (Gemeente Rotterdam, 2013). The RDM went bankrupt in 1983 (Gemeente Rotterdam, 2013) and the property at the RDM site is currently owned by the Port of Rotterdam N.V (Stadshavens Rotterdam, 2009).

7.3.2.2 Dynamics of the decision-making process

The development process has encountered quite a few difficulties. This part elaborations on the most important decision moments and the role of energy. It makes clear which partly had the decision power and on which information they based their decisions. A short summary is shown below, the full text can be read in Appendix 13.15.

In September 1990, the city council decided to demolish the post-war dwellings on Heijplaat, because of the poor building and living quality (Gemeente Rotterdam, 2013). The owner Woonbron will be leading the process and replaces the demolished dwellings by new dwellings. In December 2013, Woonbron ceased to be able to fulfil the role of land development company for the project due to the new, tighter governmental regulations for housing associations (F. De Jong, 2015; Gemeente Rotterdam, Havenbedrijf Rotterdam, & Move On communicatie, 2015; Raets & Aboutaleb, 2015). At that time, Woonbron prepared already most of the land for development (Gemeente Rotterdam, 2013). In November 2014 the city council decided to take-over the control the development under some strict conditions (Raets & Aboutaleb, 2015: 2):

- The tender has to be completed with a positive result regarding a signed development agreement with a market party.
- That market party has to bid at least the ground price of € 19.419 per dwelling and has to buy at least a fixed amount of lots per year.
- The made costs by Woonbron has to be counted as loss by Woonbron
- The municipality gets the ground from Woonbron without costs
- Woonbron pays the municipality for the unprofitable projects in the ground exploitation.

At the start of 2015, the municipality of Rotterdam and Woonbron organized a tender for the selection of a creative market party who wants to take on the development of the project on Heijplaat (VKZ, 2015). This market party has to develop, sale and construct approximately 170 single-family dwellings (VKZ, 2015). The tender gives the extra information that the municipality is owner of all the land and the land-use plan has been completed and became irrevocable. At June 1, 2015, the municipality of Rotterdam, housing association Woonbron and real estate developer Van Omme & De Groot signed the development agreement 'Heijplaat Nieuwe Dorp'. The real estate developer has drawn up a plan that complies with the spatial ambition and preconditions, made a bid of € 21.450 per plot, which is higher than the minimum land price of € 19.419 from this project and agreed to realizes the dwellings with a speed of 25 units each year (Gemeente Rotterdam *et al.*, 2015; Raets & Aboutaleb, 2015: 2). The municipality will develop the public space. At the same time, the agreement was signed between the municipality and Woonbron. With this agreement, the municipality takes over the urban area development of Woonbron. The ownership of the ground is transferred free of charge to the municipality (Gemeente Rotterdam *et al.*, 2015; Raets & Aboutaleb, 2015). With the consent of these partners, the agreements from the SOK relating to the development will be transferred by Woonbron to the municipality. The municipality monitors that the market party performs its real estate operation in accordance with the agreements of the SOK (for example, adaptive construction and energy neutral development). The steps taken for the development also implement the motion of Van der Lee *et al.* (2014) about the facilitation of sustainable new constructions in Het Nieuwe Dorp (filed in the city council on 2014, November 14). Therefore, the board proposed to dismiss this motion (Raets & Aboutaleb, 2015).

The decision timeline is shown in Figure 45. The timeline also shows some moments that are not included in the decision-making process as described above. They are not directly related, but do indirectly effect the results. These events are also discussed in Appendix 13.15.

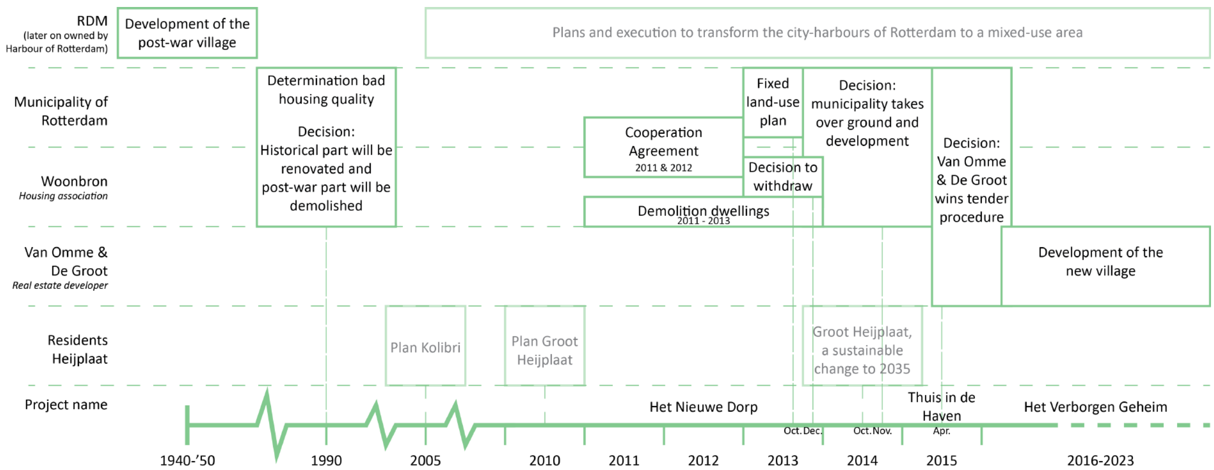

Figure 45: Decision timeline and involved stakeholders (own illustration based on Gemeente Rotterdam (2013, 2017); Gemeente Rotterdam *et al.* (2015), Stadshavens Rotterdam (2009), Vereniging Wijkbewoners Heijplaat (2014), Top010 (2015) and Ooms (2017)).

7.3.3 Business case behind energy efficiency

The business case behind the energy efficiency of 'Het Verborgen Geheim' is described in the coming paragraphs. First, the baseline is set by the program of dwellings and the development planning. This is followed by the components of the research framework: legislation, organisation, financials and physical solutions. The part concludes by the method of integration.

7.3.3.1 Dwelling mix (program) and planning

In total 170 single-family dwellings are going to be developed by Van Omme & De Groot. Most of them are terraced dwellings, some are quay dwellings (single-family dwellings next to the harbour/water) and some are semi-detached dwellings. The proposed dwelling program is shown in Table 9, based on a letter about the land-use plan and the ground exploitation of the Mayor and Alderman to the city council. The dwelling typologies have a different design, UFA and selling price (see Figure 46). When comparing those dwellings of Figure 46 and Table 9 some difference about the UFA can be notified. When comparing the planned amount of dwellings to the dwelling that are already sold according to information of the website about the project in Ooms (2017), a slight difference can be notified. There are more larger sized single-family dwellings developed as on-forehand, before the selection of the market party, was proposed and more quay dwellings are developed as proposed.

Table 9: Dwelling mix as planned by Raets and Aboutaleb (2015: 4) and realized in the real life case (Ooms, 2017)

Dwelling typology	**UFA planned (m^2)**	**UFA realized (m^2)**	**Number of dwellings planned**	**Number of dwellings realized in phase 1-3**
Single-family dwelling	110	114	126	12
Single-family dwelling	130	121	9	35
Semi-detached dwelling	150	150	12	6
Quay dwellings	160	160	23	24

Figure 46: Dwelling typologies with their design, usable floor areas and pricing per phase (own illustration based data and pictures from Ooms (2017) and KuiperCompagnons (2016a).

The projected is phased in seven stages (see Figure 47). In the same figure the designs of the dwelling types are shown for the first three phases.

Figure 47: Phasing of the development and the design of the first three phases (adapted illustration of Ooms (2017).

The aim is to develop the project in a period of three to six years (Gemeente Rotterdam, 2013). This planning is dependent on the deposition rate. Agreed is a minimum deposition rate of 25 dwellings annually (Raets & Aboutaleb, 2015), which implies a planning of 6-7 years. Starting in 2016, this means a planning towards 2022-2023. The website of the project also announces the same planning from 2016 to 2023 (Ooms, 2017). However, since March 2016 already three of the seven phases containing a total of 77 dwellings went on sale (see Figure 48). This would imply a development progress of approximately 50 dwellings annually. If this development speed can be retained, the project will be finished in about 3,5 years.

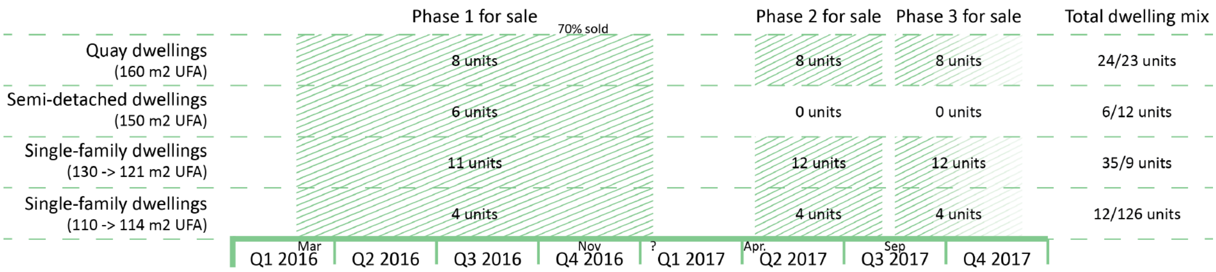

Figure 48: Sales progress (own illustration based on Ooms (2017) and Raets and Aboutaleb (2015)).

7.3.3.2 Legal boundary conditions

The dwellings which are currently under development have to comply with an EPC-level of 0,4 (Nieman RI, 2014). The dwellings developed after 2020 have to comply with the new BENG-legislation (Bouwens & Bouwmeester, 2017; Haytink & Valk, 2017).

With the current speed of the project (50 dwellings annually), the project will be finished in at the end of 2019 or beginning 2020. This is also accordingly to the planning of the real estate developer. Dijkshoorn (2017) stated in the interview that BENG does not have to be considered in this project, if the last permits for the project are granted before the end of 2020. So, if the current development schedule is met, all dwellings have to comply to the same legislation.

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The environmental permit still has to be granted to the real estate developer. However, the land-use plan offers a lot of space for a slightly changing in the planning and design of the dwellings, because a strategic development framework is used (see Figure 49).

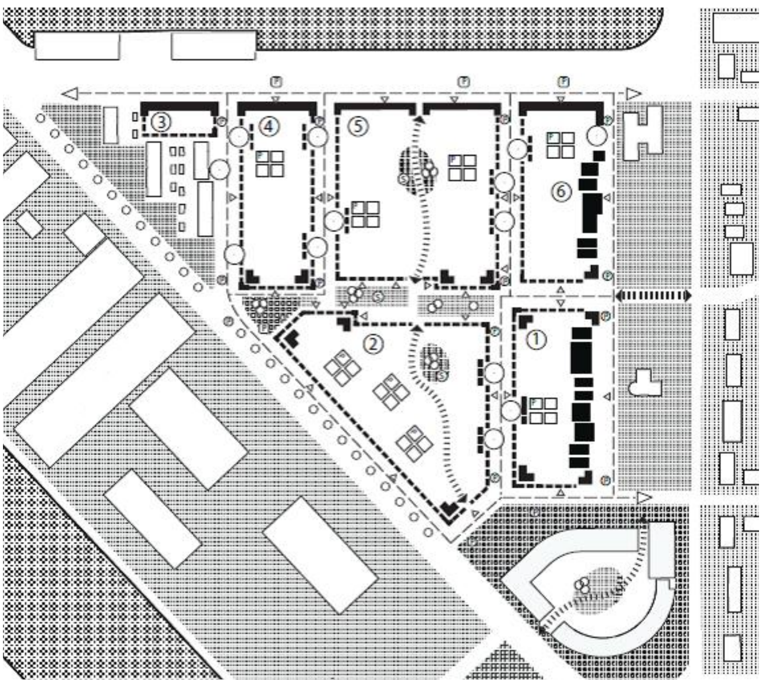
Figure 49: Strategic development framework in the land-use plan (Gemeente Rotterdam, 2013).

The land-use plan also has a fixed paragraph on sustainability and the energy efficiency (Gemeente Rotterdam, 2013). For that reason, the development of 'Het Nieuwe Dorp' has to contribution to the increasing sustainability level of the whole of Heijplaat. The requirements for this specific development are:

- Good thermal insulation (high energy labels) and high noise protection (noise-proof measures also contribute to thermal insulation).
- A step towards energy-neutral Heijplaat, using local energy sources (sun / light, wind, soil) and reducing and regulating the energy demand.
- A water-proof area (see adaptive building) and good rainwater drainage.
- Green in the neighbourhood.
- Use sustainable and / or recycled materials.

The municipality sees the land-use plan together with the separate paragraph of the amenities committee (Dutch: '*welstandsparagraaf*'), as the method to realize the sustainability ambitions (Gemeente Rotterdam, 2013).

This degree of sustainability is also mentioned in the structural vision (Stadshavens Rotterdam, 2011: 39). The structural vision state that the whole area has to function in such a way that it is frugal with energy and usages renewable energy sources as much use as possible, partly generated in the city ports themselves. The generated energy must be sustainable and can arise from a large number of sustainable sources: the residual heat of industries in the area, the geothermal energy, water cooling, wind, sun, biomass, tides and fresh-salt transitions in the surface water. The structural vision does not provide solutions, but formulates the requirements for the developing parties. They can decide on how to reach the ambitious goals when drawing up their plans.

Besides the environmental permits, also permits for the 170 ground source heat pumps have to be granted to its future owner of the energy service company Klimaatgarant (EERB[70]). These are granted in May 2017 (Gemeente Rotterdam, 2017). There is only one limitation according to Dijkshoorn (2017), because the last dwellings are closely located to an open hot-and-cold storage in the ground. This is the hot-and-cold storage of the big (apartment) building in the southeast part of Figure 49. That is why municipality will not allow for deep ground source heat pumps of 150m. The pipes are only allowed to 80m, however, it that case the power output will not be enough to heat the whole dwelling during cold days. A solution would be to dig two wells per dwelling, but this would be more expensive (Dijkshoorn, 2017). At the time of the interview, they were still investigating the possibilities.

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7.3.3.3 Organisational

From the organisational aspects four collaborations are discussed. The one between the municipality of Rotterdam as client and the real estate developer VO&DG as contractor, the one between the real estate developer, architect, construction company and advisors, involvement of (future) inhabitants and the collaboration with non-traditional, energy related companies.

First, the collaboration municipality-developer. The municipality created a strategic document for the development of the city harbours. In this document 'creating on the edge' of the Stadshavens Rotterdam (2008) can be read that the municipality wants to create decision space for the market parties and how they propose to do this. For instance, the government is taking a stimulating role and makes clear choices for decisive programs. These choices are clear by the pre-investments taken to create the acceleration and increases the investment willingness of market parties. In that way the municipality and the Harbour of Rotterdam N.V. create a perspective for value creation and decreases the payback period for market parties. That is why the municipality searches for market parties with guts, who want to make a real quality improvement and are 'creating on the edge' (Stadshavens Rotterdam, 2008: 20).

The case of 'Het Verborgen Geheim' went differently. The municipality did facilitate the housing association, but the municipality took over the development when Woonbron ceased the project. Since then the municipality took a leading role in close collaboration with Woonbron and closely controls the agreements made in the SOK2 (Gemeente Rotterdam, 2015). However, by creating a strategic development framework in the land-use plan, they still leave decision space for the market parties. They defined their goals and leave the details thereof to the creativity of the market. That is why VO&DG could come up with the own solutions, for instance, for energy efficiency.

[70] Energie Exploitatie Rijswijk Buiten. One of the sub-companies within Klimaatgarant.

Secondly, the collaboration real estate developer - architect – building company – client. The real estate developer Van Omme & De Groot is a developer and a construction company. For that reason, they operate design and build within their own company (Dijkshoorn, 2017; Van Omme & De Groot, 2013). This can be seen as a collaboration within design and build contracts. The real estate developer wants all relevant parties to be involved from the start of the project. They like to work with the same parties in different projects. The project is planned and designed with collaboration of parties from each discipline appropriate to the project (Van Omme & De Groot, 2013). They state that in this way they avoid duplication and failure costs and ensure that the lead time is shorter and the quality increases.

The energy ambition set in the tender of the municipality was high. That is why VO&DG involved the ESCO Klimaatgarant already early on in the project 'Het Verborgen Geheim' (Dijkshoorn, 2017). According to Dijkshoorn (2017) Klimaatgarant functioned as energy advisory and as third party investor, because they invest in the energy installations (e.g. ground source heat pump and ventilation).

The goal and strategy of Klimaatgarant are elaborated by Wansink (2015): Klimaatgarant was established in 2012 to realize economically viable and technically sound energy-neutral dwellings and residential areas with an EPC-level of 0 or lower. The expertize of its managers makes it possible to create creative connections between technology and financing. Klimaatgarant has cooperated in various tenders with municipalities and real estate developers. Klimaatgarant particular focus on tenders with a high energy ambition, and because of their knowledge and experience, Klimaatgarant can make the difference. In addition to the high energy ambition, Klimaatgarant also has the ambition to win the tenders. That is why they want to be an equivalent (sparring) partner for the real estate developer or municipality. In this collaboration innovative concepts can be drawn that make the difference. This general strategy fits the description for the project of 'Het Verborgen Geheim'.

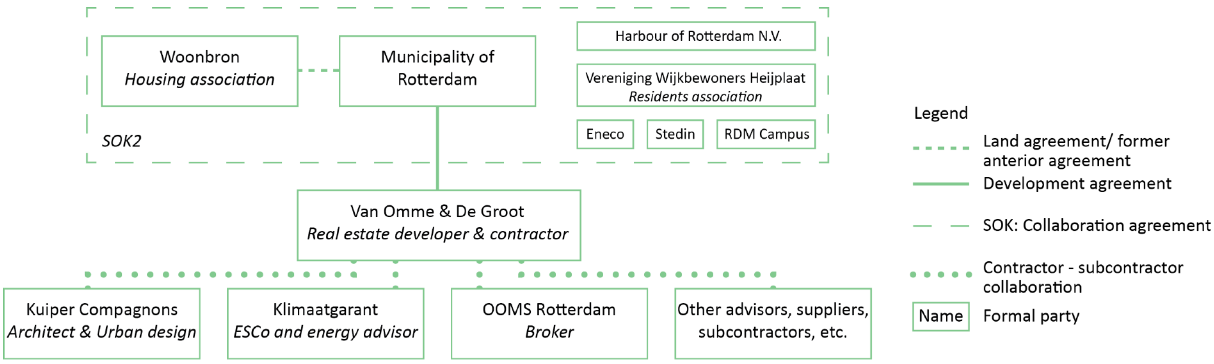


Figure 50: Involved parties and their (formal) relations (own illustration based on Dijkshoorn (2017); Gemeente Rotterdam (2015); KuiperCompagnons (2016a); Ooms (2017); Raets and Aboutaleb (2015); Van Omme & De Groot (2013); Vereniging Wijkbewoners Heijplaat (2014)).

Third, the involvement of (future) inhabitants. High ambitions for the involvement can be read in the land-use plan from the viewpoint of the municipality (Gemeente Rotterdam, 2013). The remaining part of the paragraph is a summary of this text. It states that on Heijplaat, a climate neutral example district is being realized with the project '*Klimaatneutraal Heijplaat: van theorie naar de praktijk, met de bewoner centraal*' (translated as '*Climate neutral Heijplaat: from theory to practice, with the inhabitant central*'). Within this project the role of inhabitants and users of the area is centralized. This is agreed within the framework of '*Duurzaam Heijplaat*' by the parties involved in the SOK2[71] and to realize it before 2020. The Ministry has provided a financial contribution to guide and facilitate this process within the framework of the Innovatieprogramma Klimaatneutrale Steden (IKS) (translated as '*Climate Neutral Cities Innovation Program*'). In the context of 'Duurzaam Heijplaat', the parties of SOK2 have chosen to let residents and their questions be the guiding factor, because without support of residents, sustainable development is not possible. The professional world is thus serving the residents. This concerns the current residents of Heijplaat, but also applies to future residents. In the development of 'Het Nieuwe Dorp', future residents will be helped and encouraged by the professional partners to choose measures that contribute to a sustainable Heijplaat. Energy conservation measures (homes with very low energy demand)

[71] These parties were the municipality of Rotterdam, the Port of Rotterdam, housing association Woonbron, Programmabureau Stadshavens, Eneco, Stedin, RDM Campus and residents' association 'Verening van Wijkbewoners Heijplaat'.

and the provision of renewable energy generated locally (on-site or in the immediate vicinity) are considered (Gemeente Rotterdam, 2013).

The land-use plan described an approach for the current and future inhabitants. Did it work? Research of Machielse and Frederiks (2013) into whether the IKS-Heijplaat had led to a process that had its roots with the current residents. The conclusion of their investigation was that the IKS has gone through a difficult process that failed to achieve the high ambitions in terms of sustainability. However, the difficult process had let to more unity and attention among an increasing number of inhabitants and professional parties. The professional parties, such as the municipality, the housing association and the energy company had moved to an approach that is less determined by the logic of the system world, but more about the logic of the living world. In the end, the basics with the necessary space and possibilities are created to grow the district towards an energy-neutral and more sustainable Heijplaat.

The current inhabitants were not involved in the planning of the project 'Het Nieuwe Dorp'. Only after VO&DG had won the tender, they had a meeting with the residents association on Heijplaat (Dijkshoorn, 2017).

The opposite is valid for the future inhabitants. RvO (2017f) named the extra attention for the communication towards future residents, the monitoring energy use during the operation phase and the stimulation of a decrease of household electricity consumption as special points of attention, which had been executed. According to Dijkshoorn (2017) this was because the zero-on-the-meter energy standard is something new, which has to be communicated and motivated. Otherwise future residents do not know how to use it.

In summary, the municipality had huge plans for the role of the current residents in the decision-making process. However, in reality the current residents had hardly any steak in the development of the plans. Future residents were involved from the start. It was expected that the new aspect of zero-on-the-meter needs extra communication and motivation.

Fourth, the involvement of non-traditional, energy-related actors. In the whole project Stedin, Eneco and Klimaatgarant were involved. Stedin and Eneco were involved in the development of the SOK2, however, during that time VO&DG was not involved yet. During the interview with Dijkshoorn (2017) it appeared that the ESCO Klimaatgarant was the most important energy related, non-traditional actor. Stedin and Eneco are formally informed of the future energy patterns of the dwellings, so that they can construct the appropriate cabling. The role of Klimaatgarant is already explained. The grid operators hardly had influence during the project.

Concluding, the high energy ambitions of the municipality set in the tender documents required a creative approach of the market parties, which led to the early involvement of Klimaatgarant. All parties within the design and development team collaborated closely from the start of the project.

7.3.3.4 Financial

The four possibilities of the theoretical framework are shortly addressed; the involved of an ESCO, a lower ground price, a lower profit rate by developer and higher selling price.

First, the involvement of an ESCO was critical in this development (Dijkshoorn, 2017). The ESCO Klimaatgarant was involved in the decision-making already early on in the project and invests in the energy installations of all dwellings. They guarantee a 25-years zero-on-the-meter performance towards the future inhabitants, based on a normal, reference family operation (Wansink, 2015). This can be offered, because Klimaatgarant has gathered information by monitoring already more than 6.000 dwellings which contain their energy concepts (Wansink, 2015).

The future residents repay this investment of the ESCO by a monthly fee. The monthly fee is lower as the energy bill would be in the reference scenario that the ESCO did not invest (see Figure 51) and the energy bill stays lower in the future (see Figure 52). Willem Bastein from Klimaatgarant explains how this works in an interview on Het Verborgen Geheim (2016). In this interview Basteins names four benefits. First, the dwelling is cheaper from the start, because of its energy efficiency. Second, the energy costs remain cheaper, because the prices of electricity are increasing less rapidly as the ones of natural gas and the rent of the installation of Klimaatgarant only increases by the inflation. Third, people can buy the installations from Klimaatgarant to have maximum costs savings. This is possible by the additional mortgage space of a zero-on-the-meter dwelling. And fourth, the zero-on-the-meter dwelling is future proof and will be more valuable in 20 years from now.

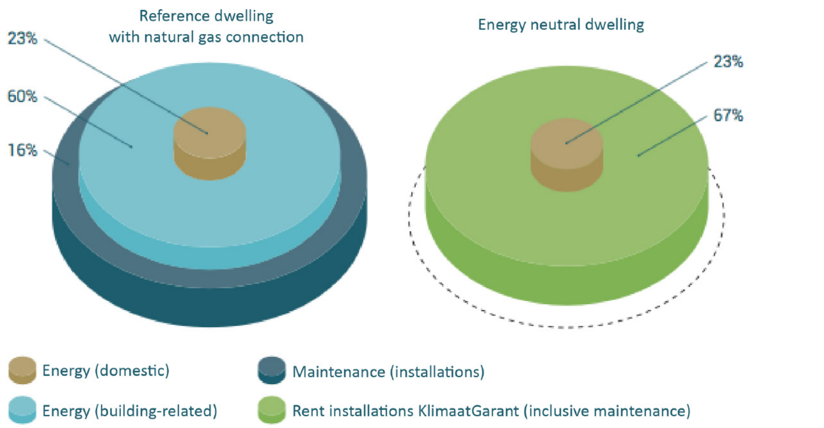


Figure 51: Exploitation costs terraced-dwelling in RijswijkBuiten (translated from Schilt (2013: 3)

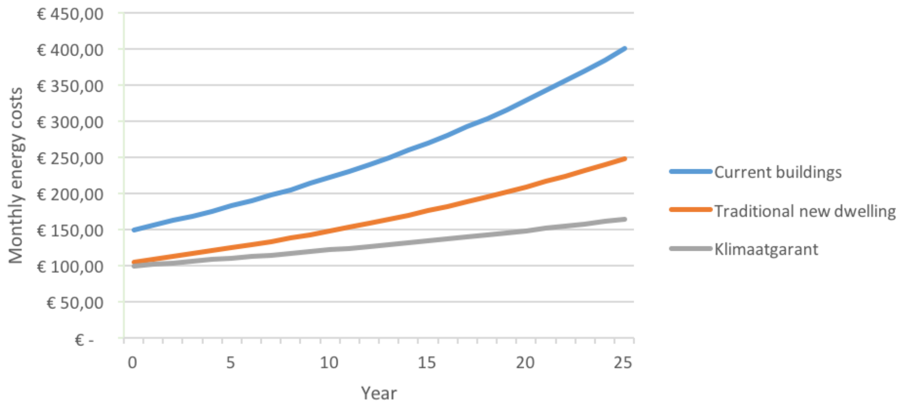


Figure 52: Comparison of monthly energy costs over time (graph translated from Van den Bogerd (2016: 11)).

Klimaatgarant base their price levels on the monthly costs of a traditional new dwelling and ensure a little discount (Dijkshoorn, 2017; Het Verborgen Geheim, 2016; Van den Bogerd, 2016). From the graph of Van den Bogerd (2016: 11) the key figures are extracted. With the current inflation rates (1,25%) the users of the installations of Klimaatgarant are even more cheaper in the long run. The difference between the current buildings and the traditional new buildings is based on the fact that the traditional new building are more energy efficient, especially for space heating and usage relatively less natural gas. It is primarily natural gas that causes price rises (see Appendix 13.25).

Table 10: Key figures used in Figure 52 (based on Van den Bogerd (2016: 11)).

	Monthly starting tariff	Annual increase of tariff
Current buildings	€ 150	4,00%
Traditional new dwelling	€ 105	3,50%
Klimaatgarant	€ 100	2,00%

Second, a lower ground price. The municipality set a minimum land price of € 19.419 for this project and the real estate developer finally bid € 21.450 per plot (Raets & Aboutaleb, 2015: 2). When relating this ground price to the selling price of each dwelling on the project website (Ooms, 2017), it appeared that the ground costs are in between the 6 and 10%. This is very low according to a Dutch average of around 30% (Nederlandse Grondmaatschappij, 2009). Dijkshoorn (2017) also stated in the interview that the developer had accurately balanced the extra investment in energy efficiency with the additional ground bid. Each time, the option that yielded the highest number of points for the MEAT tender was chosen. Ultimately, the final plan did not yield the highest bid, but the most points. Therefore, this tendering approach can be seen as hidden subsidy from the municipality.

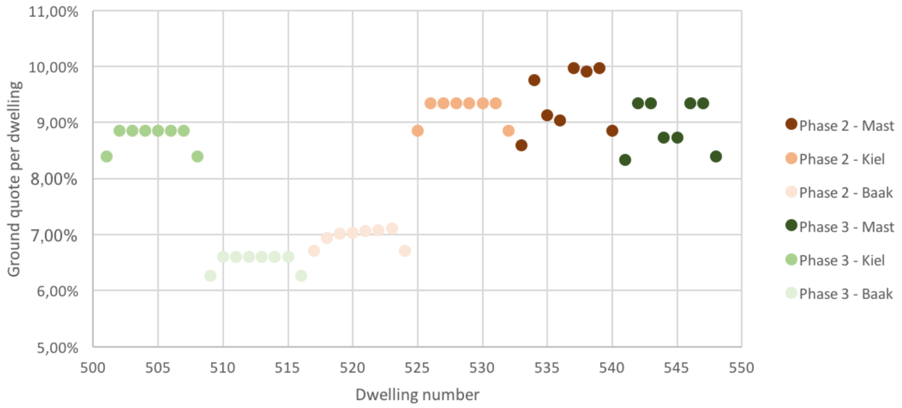


Figure 53: Ground quote per dwelling (based on ground price in Raets and Aboutaleb (2015) and selling prices on the project website (Ooms, 2017); see appendix **13.9** with the price information per dwelling)

The finance of the '*Innovatieprogramma Klimaatneutrale Steden*' (IKS) was used for the broader location of Heijplaat. No (direct) relation can be found to the tender of the municipality in the published lessons learned of Machielse and Frederiks (2013).

Third, a lower profit rate by developer was also the case according to Dijkshoorn (2017). The development manager stated that large tenders cannot be won if real estate developers calculate with a normal profit margin.

Fourth, the higher selling price. According to Dijkshoorn (2017) the selling price was not increased, because of the bad market conditions caused by the isolated location of Heijplaat. However, a higher mortgage is still possible due to the level of energy efficiency (zero-on-the-meter). This allows people with lower income to qualify for a dwelling within this project.

Concluding, the solutions of the ESCO, ground price, profit rate and higher mortgage all are used to a greater or lesser extent in this project. The ESCO Klimaatgarant is involved and had an important role with the knowledge and experience in realizing energy efficient dwellings and by its financial input. The ground price could be dropped by the municipality, due to its free of charge delivery of the already prepared lands by Woonbron. The profit rate was lower, because the real estate developer wants to win the tender. And at last, the selling price was not increased, but because of its energy efficiency, people with a lower income could still buy a dwelling, because they can be granted an additional borrowing space within their mortgage.

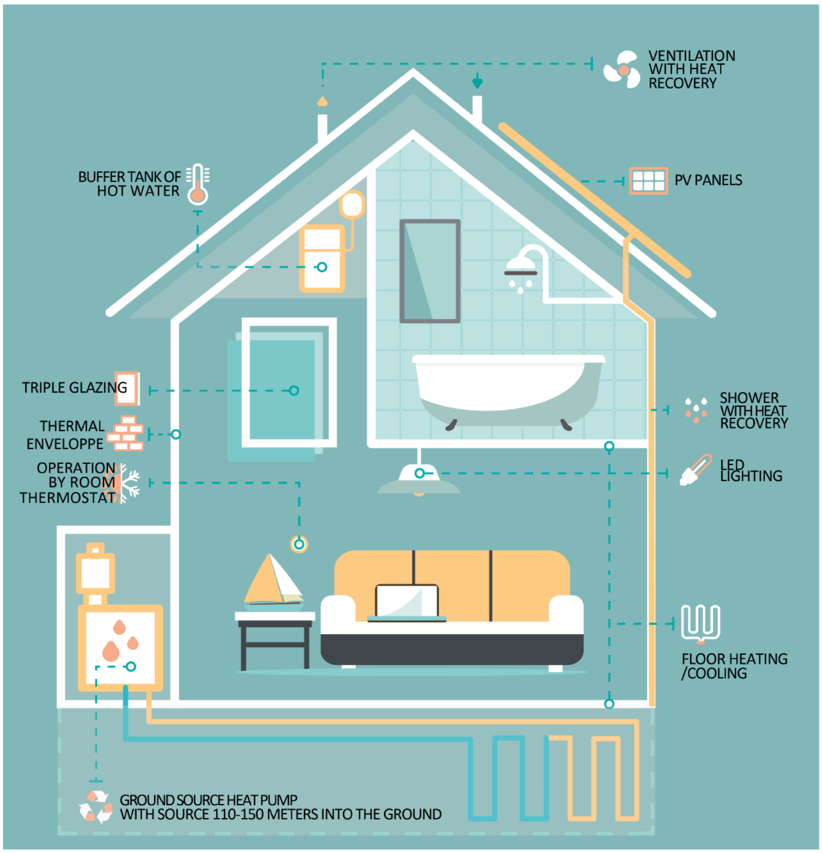
7.3.3.5 Physical energy solutions

This part elaborates on the final energy concept selected. First, the scale level of design is discussed and later the concrete energy concept is explained.

The energy concept is implemented on a building scale and based on the energy installations. This can be reasoned from the multiple explanations about the applied concept to reach zero-on-the-meter. Basteins from Klimaatgarant in Het Verborgen Geheim (2016), Stadshavens Rotterdam (2015) and the description on the project website (Ooms, 2017), all explain an fully energy neutral dwelling based on an all-electric technical concept in which the PV-panels on the roof generate sufficient power for both the building related energy demand and the energy demand of all household appliances. In each dwelling an individual heat pump with soil loop through the ground heats the dwelling during winter and cools in during summer. Also cooking is done by electricity. In addition, the houses are extra energy efficient, because of the triple glazing, other insulation measures and heat recovery units used for ventilation air and shower water. In these units the heat air or water runs besides the cold incoming air or water and preheats it.

An energy efficient design was not mentioned as influencing factor in the urban design. Besides, the urban design needed to get the qualities of the adjacent and former garden village (according to the urban designer and architect Robert Mentink of KuiperCompagnons in Heijplaat Rotterdam - Het Verborgen Geheim (2017); KuiperCompagnons (2016b)) and be a climate proof design (Stadshavens Rotterdam, 2011: 62). Climate-proof in the sense of the protection to flooding, because the neighbourhood is located outside the dikes (Gemeente Rotterdam, 2013).

The energy concept is thus based on its building physics. But how did they realize it? Klimaatgarant and Het Verborgen Geheim (2016) made a poster to explain the working to future inhabitants. In this poster they mention some features, summarised in Figure 54. To start with the excellent insulation. For that reason, the dwelling needs only little heating during winter time. This heating is done by floor heating. The ground source heat pump (GSHP) only works with such low-temperature heating systems. An additional advantage of the GSHP is that it can cool the dwelling during hot summer days. This ensures a comfortable warm dwelling during winter and a pleasantly cool dwelling in summer. The system operates best if the same temperature is set for the whole year, because it takes a while before the low-temperature heating is on the desired temperature. This system is entirely fed by the solar electricity generated by the PV-panels on the roof of the dwellings. The system is maintenance-friendly and user-friendly. Maintenance is included in the energy bill towards Klimaatgarant and all the inhabitants have to do is occasionally check the water pressure of the low-temperature heating system.



Heat pump with closed-loop ground source
The heat pump takes care of your home for heating, cooling and hot water. You operate the heat pump with the room thermostat, with room temperature settings, a menu for the preparation of hot tap water, time and date. Once the thermostat is set, you never really have to change the settings again!

Ventilation system with heat recovery
The ventilation system ensures a constant CO2-level in any area. The system controls and adaps where necessary. Fresh outside air is pre-heated first, so that the indoor temperature is maintained.

PV Panels
The PV panels generate enough electricity for heating, cooling, hot water and ventilation, but also for lighting and household appliances. The houses are therefore zero on the meter.

Boiler
The house has a 150 liter boiler (optional 200 liters). You can set the desired warm water comfort yourself with the room thermostat. There is plenty of hot water for a shower or a bath.

Floor heating and cooling
Your new home has floor heating and cooling. Such a system is based on relatively low temperatures. This means in practice that changes in temperature are slower than with normal heating. The best results are achieved when the thermostat is at the same temperature day and night. The system will do the rest.

Underfloor heating has great advantages:
- No ugly radiators at home and more useful space
- An even temperature throughout the house
- No more hot air streams, so less of airborne dust (good news for people with respiratory disease!)

Figure 54: The zero-on-the-meter energy concept of Klimaatgarant as applied in Het Verborgen Geheim (illustration slightly adapted and translated from Klimaatgarant and Het Verborgen Geheim (2016)).

Table 11: Characteristics of the thermal envellope (RvO, 2017f).

Feature	Value
Airtightness ($Q_{v;10}$-value)	0,40 $dm^3/s \bullet m^2$ UFA
U-value glass (incl. window frame)	1,0 W/(m^2 UFA•K)
Average R_c-value solid walls	4,5 $m^2 \bullet K/W$
R_c-value roof	6,0 $m^2 \bullet K/W$
R_c-value ground floor	3,5 $m^2 \bullet K/W$

Table 12: Characteristics of the energy related installations (RvO, 2017f; Van den Bogerd, Bastein, & 't Hart, 2016).

Feature	Value
Space heating and hot tap water	Combi heat pump
Heating device/ mode	Floor heating and/or wall heating and/or concrete core activation
Space cooling	Hot-and-cold storage
Renewable energy supply	PV-panels

Ventilation type	Balance ventilation with heat recovery (type D)
Ventilation principle	CO_2-controlled, also in the bedrooms
Window type	Triple glazing

If we take a closer took to the energy concept it appeared that the thermal envelop (see Table 11) is according to the minimum insulation levels as required in the building degree (Nieman RI, 2014).

This is opposite to the publication of Bouwmeester (2015: 9), in which several real estate developer state that it is not sufficient to apply these minimum requirements. They, Onno Dwars of VolkerWessels Vastgoed and Nico Blaauw of Trebbe, state that an optimal is around an R_c-value of 5-6 in the walls and that an even thicker insulation package requires too much space in the façade and becomes expensive. In the same publication Renz Pijnenborgh of Archi Service calculated that an optimal insulation package has R_c-values of 5 (floor), 8 (facade) and 10 (roof). With this knowledge in mind, Van Omme & De Groot made something possible that was not expected possible a two years before.

The optimum Qv;10-factor was expected 0.3 to 0.35 for dwellings with a sloping roof (Bouwmeester, 2015: 10), however, also Qv;10-levels of 0,4-0,6 were measured. The Qv;10-factor for this project is into this range.

Two types of ventilation systems are possible, when zero-on-the-meter is the energy ambition (Bouwmeester, 2015: 11). These are systems with a mechanical exhaust and a natural inlet and systems with a balance ventilation including heat recovery. However, according to Onno Dwars in the same publication of Bouwmeester (2015: 11) only the system with balance ventilation is possible. He states that it is inefficient to have high insulation values for the thermal envelop and thereafter, bring cold outside air inside through grids in the façade or above windows. In the project of 'Het Verborgen Geheim' this system of balance ventilation with heat recovery is used.

Some features of passive solar design can be discovered. First, the dwellings all have a compact design (see Figure 46). This ensure little loss surface. However, the secondly, the figure also shows no overhangs to prevent overheating. Thirdly, it can also be argued that the north-south oriented streets look wider as the west-east orientated streets, it enhances passive solar gain. However, the window-to-wall ratio does not look suited for this and this argument cannot be found.

The main issue is possibly the conceptual approach of dwelling development (Bouwmeester, 2015: 6), as described in the publication as the optimisation of the process of creating the dwelling (product). In this approach the concept is improved after every project. The concept consists of a combination of engineering and installation solutions and details and can be executed by a variety in architectural details (e.g. size, floor plan, façade design). Practice shows, according to the same Bouwmeester (2015: 6), that conceptual building is indeed the key to continuous improvements and it is also the key to boosting the energy performance of homes. This is in line with the approach of Klimaatgarant, who is improving its energy efficient installation concept in time by continuously monitoring all dwellings (Van den Bogerd, 2016). According to Van den Bogerd (2016), monitoring is their key success factor. They have online surveillance of about 6.500 dwellings, which determine which systems work and do not work, report errors and failures automatically and proofs to consumer that 0 is really 0.

In line with the monitoring, the dwelling is tested after completion to test whether the theoretical expectations are realized in practice. This energy efficiency test is executed by a blow test measurement, infrared heat measurement and ventilation test (RvO, 2017f). Based on the energy demand calculation of Itard (2011) it can thus be notified that with these tests the losses by infiltration, transmission and ventilation are verified. These tests are also needed to improve the concept on airtightness for next developments, according to Bouwmeester (2015: 10).

Concluding, there are multiple methods possible within the energy concept of the ground source heat pump to get towards a zero-on-the-meter dwelling. The thermal envelop of the project requires to the minimum standards. Only the triple glazing is above the requirements. The energy installations applied are the most effective ones currently possible within the concept (balance ventilation has heat recovery and the ground source heat pump has the biggest COP of all heat pumps).

7.3.3.6 Integration
The integration is done on the three scale levels of the urban design, building specifics and energy installations and within the three disciplines of the research framework: organisation, finance and design specifications.

The conditions for the urban design were already decided by the municipality via the land-use plan, which was already irrevocable (Gemeente Rotterdam, 2013). This was done in collaboration with the developer of that time, Woonbron. The detailing and building design-decisions were made in collaboration between KuiperCompagnons (as architect and urban designer), Van Omme & De Groot and the ESCO Klimaatgarant. The integration between the three aspects and the energy installations are made by the ESCO Klimaatgarant. Dijkshoorn (2017) explained that Klimaatgarant made an ultimatum by requiring the usage of their energy concept to get them on board.

7.3.4 Conclusions
Van Omme & De Groot, the municipality, Woonbron, Klimaatgarant and the residents' association all played their role within the decision-making process.

- The municipality of Rotterdam initiated the energy ambition of this project by setting the requirements within the tender specifications. The low ground price can be seen as hidden subsidy from the municipality by deciding to putting the focus down on the energy ambition within the MEAT-tender. In the end, this is mainly paid by Woonbron. They had to deliver already prepared lands to the municipality without costs and taking over their risks. This created the financial possibility for a low ground price. In addition, the municipality enhanced creativity of market parties by using a strategic development framework and requirements, instead of fixed solutions.
- The ESCO Klimaatgarant played a critical role in realizing the energy ambition of zero-on-the-meter by having input on knowledge and investments.
- The resident association kept pushing for a fast development with a high quality. This has affected the city council, who came up with the motion about energy neutral Heijplaat. This became a boundary condition within the tender.
- Real estate developer Van Omme & De Groot was indispensable for the integration of all possibilities offered by the design company, ESCO and municipality, the real estate developer had the leadership within the tender, development and realisation and they dared to take the risk within this development.

Together this created a unique project in sense of the location and the realized energy ambition.

7.4 Conclusions/ Lessons learned for the optimisation model

The main lessons learned for real estate developers on how to realize ENRND-projects is discussed in this part. Both the tangible products and the decision-making process are dealt with. The conclusion gives answer on the first sub research question:

How is an ENRND-project realized by the real estate developer in current projects?

But first, why do real estate developers involve in ENRND-projects? The motivation is asked during the four exploratory interviews and the motivation was different. The real estate developers were stimulated by the tender (Dijkshoorn, 2017; Van der Wolf, 2017), stimulated by the expected market demand/ future clients (Delnoij, 2017; Van Seumeren, 2017) and by the expected change in regulation (Delnoij, 2017; Dijkshoorn, 2017; Van Seumeren, 2017).

The business case is discussed based on the aspects of the research framework (Figure 8).

7.4.1 Legislation
In the in-depth case the legislation did not stimulate the increased energy ambition, but the requirements in the tender. The upcoming legislation of BENG does speed-up the development, because the real estate developer would like to be finished before the BENG-legislation is valid.

7.4.2 Organisation

The project organisation was based on a design and build-contract with an early involvement of all advisors. This was required to realize the multiple tasks about sustainability, such as the energy ambition. The ESCO Klimaatgarant was critical in this team. This party added their energy-concept for an all-electric concept as fundamental basis of the dwelling design. The contractor was also involved during the design phase, this made it possible to exchange knowledge of the technical requirements of the high energetic ambition.

The analysis for the sampling method showed that the energy ambition was possible to realize within different partnership models between the real estate developer and the municipality. Only the concession model was not founded throughout the selection procedure.

The grid operator is asking in general for involvement in the development of such neighbourhoods due to the impact it can have on the electricity grid (Molengraaf, 2017). In this specific project they had hardly any involvement different than in other development projects. This is a mismatch in the desires of the grid company.

Three learning aspects: 1) Integrated contracts to realize the high building standards (e.g. for airtightness), 2) Early involvement of advisors. And 3) Multiple possibilities within the public-private partnership.

7.4.3 Financial

Several methods are possible for financing the extra investments. In the in-depth analysis of the case study showed the application of the third investment by an ESCO. The higher selling price[72] was not deemed feasible due to the difficult market conditions of the isolated location. The real estate developer even raised the price quoted of the municipality and lowered its desired profit rate to win the tender.

The energy service company does not want to invest in all energy saving measurements. For instance, an electric boiler consumes more electricity to generate the same amount of heat as both the heat pumps. For that reason, the electric boiler needs more PV-panels to get towards BENG or ZOM, which increases the investment. In the cases appeared that the ESCO wants to invest in solar panels and ground source heat pumps.

The Zero-on-the-Meter ambition made it also not possible for two other strategies which make the end-user responsible for the realization. The first one was the postponement of the investment. In that case the real estate developer constructs future-proof dwellings. The second one involves additional energy options during the sale of the dwelling. The end-user can decide on the desired energy ambition. In the analysed case the end-use could decide if they wanted to buy the system from the ESCO Klimaatgarant or not.

7

7.4.4 Physical

The first exploration of the case studies show that the urban form is not an important variable for energy efficiency. Although an optimal urban envelop can reduce the energy demand by increasing the amount of solar gain (as explained in the theoretical framework section about passive solar design), other factors like the input of the client (in the Blauwhoed-case) and the noise of the highway (in the AM-case) were found to be more important, or the urban design envelope was already fixed by the municipality (in the case of VORM and Van Omme & De Groot). Therefore, the design on a building scale level and technologies unrelated to the urban design have to be the important variables in the optimisation model.

In the in-depth case the energy concept of Klimaatgarant was applied, because the ESCO only collaborates if their concept is selected. This concept consists of a GSHP powered by PV-panels and a CO_2-balanced ventilation system with heat recovery. In addition, the thermal envelop was airtight and triple glazing was added.

In short, the realization of the zero-on-the-meter ambition was required by the tender of the municipality. Early on in the process the real estate developer involved the ESCO. The ESCO required a certain energy concept based on the GSHP and the PV-panels. The ESCO had already proof of concept and guaranteed a 25-year operation of the installations within the ZOM-ambition. This party brought knowledge and invested in the installations. The ESCO was therefore key in the decisions about the organisation, financial and physical aspects of the energy concept.

[72] Motivated by the additional borrowing capacity and more and more by the lower future living expenses.

8 Development of the decision support tool

8.1 Introduction

This chapter results into the overall design of the decision support tool and provides an answer on the second sub-research question:

> *How can a decision support tool optimise the results for the real estate developer in residential neighbourhood development to realize at least an ambition of energy neutrality?*

The structure of the chapter is based on the first steps of a design process, as described by Dym and Little (2004) in Barendse *et al.* (2012: 3). *First*, the reasoning behind and the objective of the decision support tool is described by defining the need of the client, the negotiable constraints from other stakeholder perspectives and the function of the model in the decision-making process. Hereafter the design of the model starts. The alternatives for the conceptual design of the model is described as *third* step. Multiple alternatives are researched and one is selected. This design is further constructed during the *fourth* step in the detailed design phase. The preliminary design phase is not described, because this was integrated with the detailed design phase in an iterative process. This model is designed and analysed based on theory and general knowledge. The result of the chapter is a first version of the model, which is tested and evaluated in the next chapter.

8.2 Optimisation objectives and constraints from a multi stakeholder perspective

According to Dym and Little (2004) the first step is to clarify the client statement, objectives, user requirements, constraints and the function of the design. These topics are discussed in succession.

The viewpoint of this thesis is the real estate developer who can be seen as the client. From the beginning of 2021 the real estate developer must develop almost energy neutral dwellings, which comply with the BENG-legislation. More energy efficiency measures are needed to comply with this increased standard, which cause an increase of development costs. Selecting the best configuration of energy efficient installations is not part of the core business of the real estate developer and this party should get fast advice on the different options at hand to comply with the legislation. Linear programming can help in finding the optimal configuration of the dwelling mix and energy efficiency measures which realize the highest profit for the real estate developer. Herein the model gives decision support in the selection of the dwelling mix, the energy installations and the appropriate way of financing leading to the highest profit.

LP can incorporate the viewpoint of multiple stakeholders into account by using negotiable constraints (Barendse *et al.*, 2012; Binnekamp *et al.*, 2006). All stakeholders have their own goals, which are related to a different objective. The objectives of different involved stakeholders are shown in Table 13. As the focus is on owner-occupied houses, the real estate investor and the housing association are neglected.

Table 13: The perspectives of the different stakeholders in the LP-model

Actor	**Objective**
Real estate developer	The maximum yield of the total development
Future owner of the dwelling	The minimum total costs of ownership (TCO)
Environmental agency	The maximum renewable electricity production
Bank	The maximum interest rate
Third party investor in energy (ESCO)	The maximum %yield over the investment
Municipality	The minimum dwelling mix in the urban program

All parties have lower or upper limit (depending on the direction of the objective). If that value is violated, the result is no longer acceptable to them. Those values are added as constraints to the LP-model. This are constraints are the minimum and maximum number of certain dwellings in the urban design, the dwelling dimensions and related development costs, the requirements for energy efficiency in the BENG-legislation, the financing method and the total cost of ownership of the end-user. If constraints are set too tight, the LP-model will return 'unfeasible'. The beauty of this mathematical model is that 'unfeasible' solutions can become feasible by renegotiating the constraints (Binnekamp *et al.*, 2006).

The function of the LP-model in the decision-making process is that it can show the optimal solution for the given constraints to the real estate developer with respect to the limit values of other stakeholders. In this case the model can save a lot of time by not having to manually search for a solution. The relation of the model to the interactor design space (see Binnekamp *et al.* (2006)) is described in the concluding part of this chapter.

8.3 Conceptual design alternatives leading to a preliminary design

Several alternatives are explored for the development of the LP-model. In the explorations questions were asked like what is the model going to optimise exactly and why is that useful? How can this be executed by linear programming? This part presents the conceptual design of the selected alternative. The other alternatives are shortly introduced in Appendix 13.15. During the development of the conceptual design feedback was given by expert during unstructured interviews. The results of this feedback and how it influenced the development of the DST is summarized in Appendix 13.17.

In the selected alternative the lessons learned in the previous three alternatives are combined. First, a combination to drawing in SketchUp is not possible and not needed when focussing on the first financial feasibility of the optimal dwelling mix and energy efficiency measures. Secondly, the official calculation of the energy demand reduction contains many nonlinear relationships, which are not suited to linear programming. Third, the precision of the official calculation method and hourly data requires too much computational power and nonlinear applications. And fourth, it is too time consuming to develop a model which also includes heating grids as an alternative. And in many locations heating grids are not present. Therefore, the focus is put on a renewable energy supply as set by the BENG2 and BENG3-requirements. Further, only all-electric concepts which use electrical boilers and heat pumps as heat generators and solar and wind as renewable energy supply are taken into account. Those installations can be added to the basic structure of the real estate developer dilemma as described by Barendse *et al.* (2012: 13-22). The optimisation model optimises amounts of installations per dwellings, which can easier be connected to costs instead of design adjustments. Amounts are linear connected and can be optimised by Whatsbest.

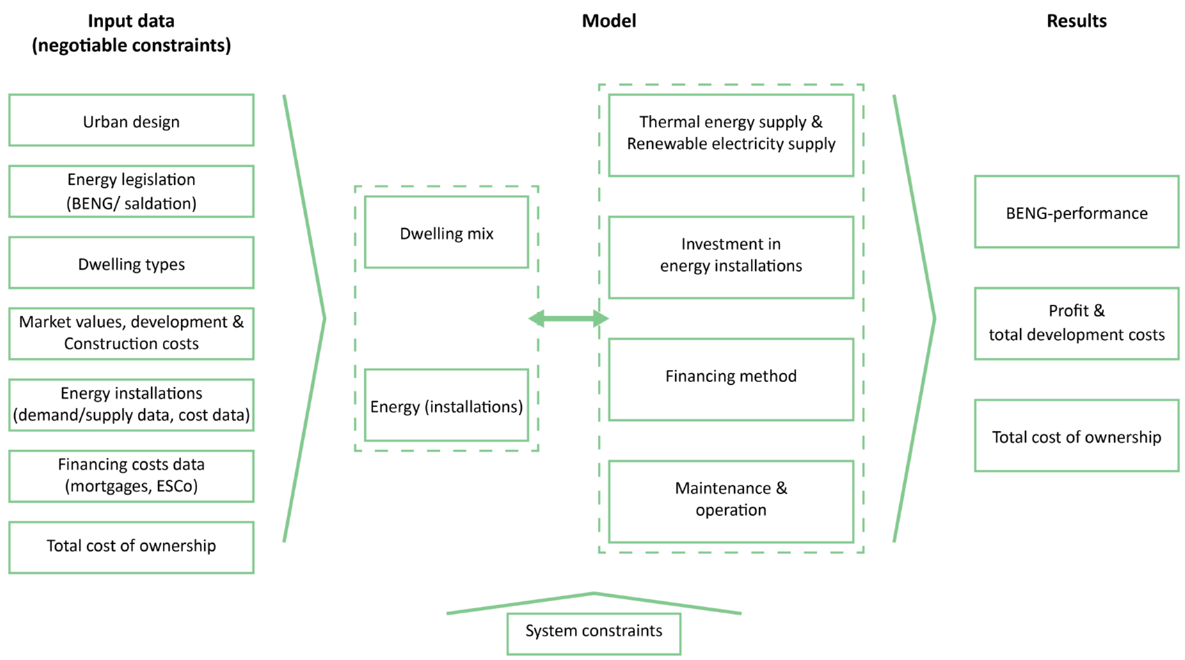


Figure 55: Schematic overview of the conceptual design of the linear programming model (own illustration).

The selected alternative optimises the amount of different dwelling types and the best suited energy installation to maximise the amount of profit and realize the desired energy ambition. The model uses the separation of energy demand (BENG1) and supply (BENG2+3) in the model by using a fixed input of BENG1 and optimisation of BENG2+3. The model uses aspects of the urban design as the availability of land for construction and the required diversity in the dwelling mix, the requirements in the BENG-legislation, the characteristics of the available dwelling types as the amount of south-facing roof surface and usable floor area, market values and construction costs for those dwelling types, possible energy installations with their related efficiencies, costs and maintenance requirement, possibilities to finance the extra investment in energy saving measurements and input for the TCO. How those aspects are used in the model is described in the next paragraphs and an overview of the structure between the aspects is shown in Figure 55.

8.4 Detailed design of the decision support tool

Everybody who have designed something can acknowledge that design is an iterative and creative process of going back and forth again and again, from sketches to details and back to literature. In the end of the development of this optimisation model additions are made to the parts which are created at first and errors were corrected. Those errors became visible during the continuously analyses and tests if the model operated properly and if the results are logical, as illogical results are often accompanied by errors. This part does not describe those design struggles for the reason of comprehensibility, but the headlines of the functioning of the model. All mathematical formulas and the technical description of the model is presented in Appendix 13.18. The assumptions made for the model are presented in Appendix 13.19.

The mathematical structure is based on endogenous (fixed input) variables and exogenous (output) variables. First, the real estate developers' dilemma is introduced with the objective function on profit and the endogenous dwelling types. Second, the energy installations are introduced with the possibilities for the thermal and renewable energy installations. The amount of installed installations are endogenous variables. Third, the constraints for BENG are introduced based on the size of energy dwelling type and the energy installations applied in each type. Fourth, the calculation of the total investment is added as endogenous variable. Fifth, the total investment must be financed in some way and this is made possible by the endogenous variables about finance: two for mortgage types, one for the ESCO and one for the financing by the real estate developer. This one is connect to the amount of profit made, as will be explained in that section. Seventh, the dwelling type, installations and financing methods used relate to the TCO. This part introduces energy costs, maintenance costs and costs related to the additional investment and financing method. Lastly, multiple possible objective functions from other stakeholders' perspective are given. In the end a model is created which maximizes the amount of profit made by the real estate developer, but constraint by all previous mentioned aspects.

8.4.1 Real estate developers' dilemma: the dwelling mix and profit

The underlining structure of the whole LP-model has the objective function to find the optimal mix of single-family dwellings the real estate developer must develop to get the maximum profit. This structure is based on the real estate developer dilemma as described by Barendse *et al.* (2012: 13-22). Twelve dwelling types are created as the endogenous variables. Those types are based on four unique architypes in single-family dwellings, namely corner dwellings in terraced dwellings, mid-terraced dwellings, semi-detached dwellings and detached dwellings (see Figure 82). The critical reader will see six different types in the figure, however, the corner dwellings of terraced dwellings and semi-detached dwellings can be mirrored and therefore those dwellings are not unique. The four architypes differ in the market value per m^2 UFA and in the lot size per dwelling.

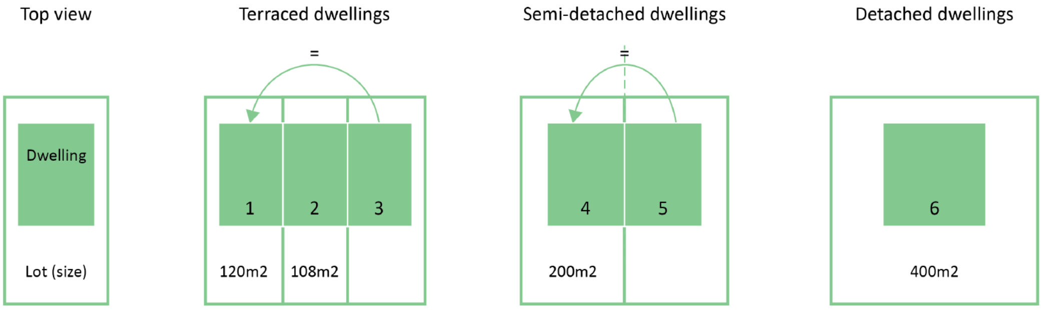


Figure 56: Four unique architypes of single-family dwellings are included in the optimisation. All differ in the market value per m^2 UFA and the lot sizes per dwelling (own illustration).

Each of the four architypes has three sub-types, which differ in the amount of UFA (and thus in the related total market value and construction costs). In total 12 types of dwellings can be selected in the optimisation (see Figure 83).

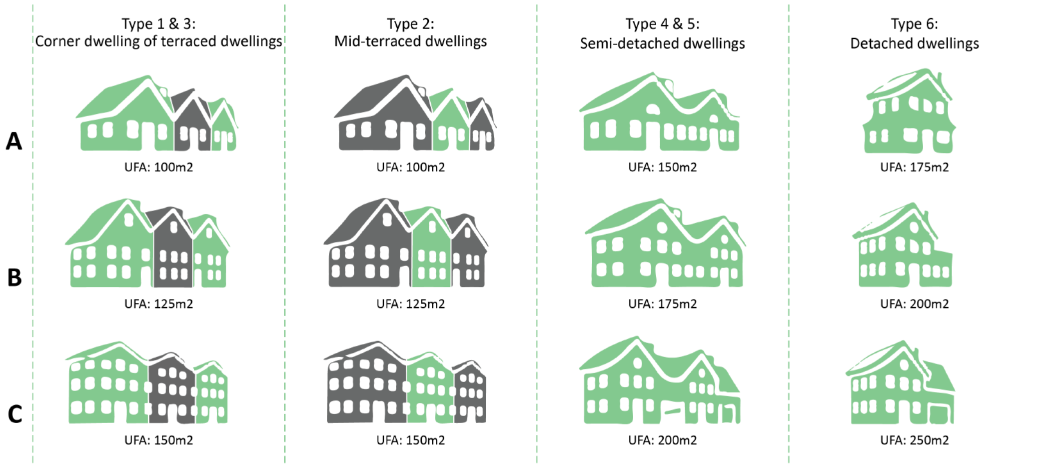


Figure 57: Three sub-types for each architype gives 12 dwelling types in total. Sub-types differ in the amount of UFA (own illustration).

These twelve possible dwelling types are the decision variables in the LP-model. The objective function is to maximise the amount of profit made.

However, the objective function is subjective to several constraints. First, the amount of available land for dwelling development cannot be exceeded. Second, the total amount of dwellings developed must fit the bandwidth of the density requirements. Third, the individual dwelling types must fit the bandwidth set.

8.4.2 Energy measurements: thermal and electrical supply installations

Part of the optimisation is to solve the energy problem. For each dwelling an installation is selected to supply the thermal energy demand. The all-electric concept offers electric boilers and heat pumps as solutions. This selection is described in the first part. Secondly, installations for the renewable electricity supply are selected. PV panels and wind are offered as possibilities. Third, the household energy usage is calculated. This is needed to calculate to total energy consumption of the dwelling for the energy bill in the TCO and the needed renewable supply methods to get towards zero-on-the-meter or even energy positive.

8.4.2.1 Thermal energy demand: Domestic heat pumps and electro boilers

The thermal energy demand per m^2 UFA is an exogenous variable. Only the supply gets optimised. Each dwelling type has two packages of energy saving measures. One that complies to the BENG1-requirement of 25 kWh thermal energy/m^2/annum and one that does not comply to the BENG1-requirement. This is chosen for the sake of simplicity, however, more levels can be added. The calculation of the needed energy saving measurements per dwelling type is described in Appendix 13.7.

8

The supply of the thermal energy demand in the all-electric concept can be done by electric boilers, air source heat pumps (AHSP) and ground source heat pumps (GSHP). The operation of those systems is described in the theoretical framework. Heating by infrared is left out of consideration, because these systems are still under development for domestic application and little is known about their correct application. In total 36 unique dwellings can be developed by the real estate developer (see Figure 85).

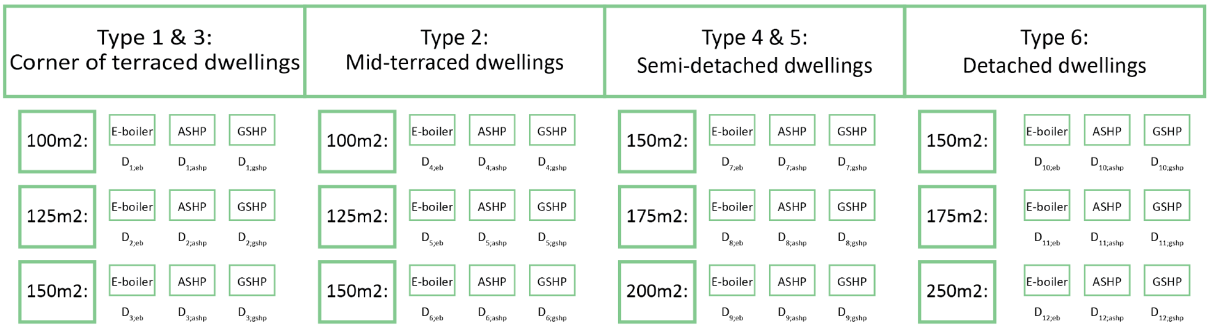


Figure 58: 36 endogenous dwelling types are created by offering three thermal energy supply installations per dwelling type (own illustration).

The three thermal energy supply installations have different efficiencies, as described in Appendix 13.23.1.

8.4.2.2 Energy demand of the ventilation system

The primary energy usage of the ventilation system is calculated based on the method described in Itard (2011: 131).

8.4.2.3 Renewable energy supply

The supply of renewable electricity is possible by windmills and PV-panels.

The model calculates per dwelling type the optimal amount of PV-panels based on three different types. The used PV-panels, their efficiencies, their Wp-output and degradation rate can be found in Appendix 13.23.2 together with the used conversion factor to convert the amount of Wp to kWh generated.

8

The model calculates the amount of renewable energy generated by wind (in kWh) by multiplying the amount of full load hours for wind mills and the capacity installed in kW. The maximum amount of wind power is constrained by the amount of windmills allowed and the maximum capacity per windmill.

8.4.2.4 Household energy demand

The household energy demand is needed in the calculation of the total energy costs and the TCO. This determines if the zero-on-the-meter ambition is cheaper or not over the operational time.

The calculation of the energy demand for household appliances is provided in NEN 7120+C2 (2012: 74). Based on this formula fixed value can be calculated of 3,2 W/m^2 (NEN 7120+C2, 2012: 75), which makes the total yearly energy demand of household appliances only dependent on the usable floor area of the dwelling.

8.4.2.5 Check zero-on-the-meter

The dwellings are zero-on-the-meter (ZOM) when on a yearly basis the renewable electricity supply is higher as the amount of electricity consumed by the heating installations and the household appliances. ZOM is important for two things. First, these dwellings can get a higher mortgage at the bank (see 13.24.1) and second, the renewable energy they generate above this level is worth less, because of the balancing agreement (see the theoretical framework).

The LP-model checks whether the supplied renewable electricity is higher than the required electricity for the building-related electricity usage (i.e. the energy consumed by the thermal energy installations and the ventilation system) and the household-related electricity usage.

8.4.3 Comply with BENG-legislation
The possibilities of the previous described energy components are constrained by the BENG-legislation. This legislation requires the amount of primary energy usage to be lower as a certain amount (in BENG2) and the renewable energy supply higher as a certain percentage of the total primary energy consumption (in BENG3).

8.4.4 Extra investment in energy measures
The extra investment in energy measures is calculated by the amount of PV-panels, the amount of kW of windmill power installed and the cost per dwelling type for each heating installation. The costs for the energy saving measures are pre-calculated for every dwelling type and added to the costs for the heating installations. See Appendix 13.7 for the method how these measures are calculated.

8.4.5 Financing the extra investment
The calculated extra investment of the previous part has to be financed in some way. Three possibilities are offered by the model to finance the extra investment:
1. By an increased mortgage of a bank;
2. By third financing of an energy service company;
3. By the real estate developer (deducted from the amount of profit).

All options influence the TCO for the end-user. The interest rate has to be paid in the first two options and the investment is lower in the last one, which is reducing the selling price of the dwelling.

A fourth option of direct financing by own equity of the individual buyer was explored. However, in that case the selling price and the related market value would increase. At this moment in time, the market value is not directly related with the required additional investment in energy saving measurements, because the energy concept will not be bought by a majority of buyers when this spending complies with other living requirements (J. W. J. De Vries, 2010). In addition, this option is not affordable for everyone. The extra market value is assumed the same as the extra mortgage, because this additional borrowing space is in line with energy cost savings (Blok, 2014a, 2015a, 2016; Dijsselbloem, 2013) and the living expenses remain within the existing reference building with energy label C (J. W. J. De Vries, 2010). In case buyers select this fourth option, the price is still market conform and only the TCO would be lower as they do not pay the interest rate. That is why this fourth option can be seen as comparable to the mortgage option for the viewpoint of the real estate developer.

The cheapest way for consumers to finance the extra investment is to invest in more mortgage (J. W. J. De Vries, 2010). That is why other consumer financing options are not considered. The investment is thus spread over three options. The amounts that can be financed by the mortgage and the ESCO are constraint and the real estate developer has to finance the remaining part.

First, the constraints related to the mortgage. Since a few years it is possible to borrow an additional amount for the financing of a zero-on-the-meter dwelling and for a dwelling with an energy label of at least A++. In this part the calculation for the maximal extra borrowing capacity is given. More information on the amounts of extra borrowing capacity and fluctuations over the past few years are given in Appendix 13.24.1. The amount of money financed by the BENG-mortgage must be smaller as the borrowing capacity. ZOM-dwellings add extra borrowing capacity on top of the amount of the extra borrowing capacity for BENG.

Second, the constraints added for the ESCO. The cases showed that the ESCO does not want to invest in all energy saving measurements and only invest in PV-panels and all-electric concepts based on ground source heat pumps (see lessons learned in chapter 7.4). The rapid upswing of the usage of air source heat pumps in Graph 9 is promising for innovation and improvement of those systems. The possibility is created to manually select the options in the LP-model in which the ESCO wants to invest, because the ESCOs readiness can change in the future.

8.4.6 Total costs of ownership (TCO)
The future owners do not only have an interest in choosing the optimal solution in terms of investment costs, but also in the costs of energy and maintenance during the lifecycle of the project. These are the so called total cost of ownership (TCO) and are an important input indicator for the decision-making process of the future owners (Dijkmans & Klerks, 2013). In the proposed LP-model the TCO of ownership takes into account the investment costs, financing costs, maintenance costs and the energy costs.

8.4.7 Objectives functions from other stakeholders' perspective

The LP-model can also be used to view the design problem from another stakeholders' perspective, such as the future owner of the dwelling, the environmental agency, the bank or the ESCO. The variety of the dwellings cannot be optimized. The model lacks therefore the viewpoint of the municipality as objective function. However, all viewpoints are also taken into account as constraints.

- The future buyer wants to have the minimum TCO.
- The environmental agency wants the maximal renewable energy production.
- The bank wants the maximal mortgage (rent is exogenous and cannot be optimized).
- The ESCO wants the maximal financing (rent is exogenous and cannot be optimized).

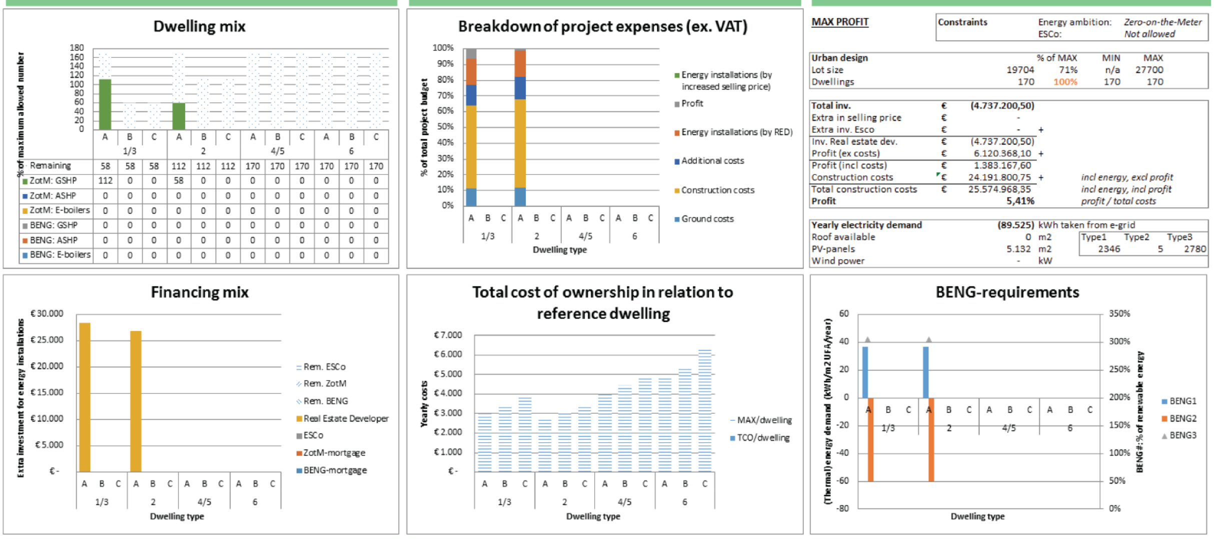
8.5 Model output

The model output is summarized by a dashboard. This dashboard shows all the outputs of the endogenous variables. The most important constraints are also indicated (e.g. the amount of dwellings allowed per dwelling type, the density, the development space as lot size, the energy ambition and the allowed methods of financing. Other exogenous variables are used as described in the Appendices or if indicated in the attached description of the dashboard.

Dwelling mix
Graph gives the results of the optimial dwelling program (e.g. to generate the maximal amount of profit) and the results of the energy installation for the thermal energy supply. It also includes the energy ambition (e.g. zero-on-the-meter or not).

Breakdown of project expenses
Graph gives the results the costs categories for every dwelling type. It easy shows the amount of profit made or the costs for the ground. Only remark; the energy installation by the increased selling price should be above the 100%.

Key figures
The tables show the key figures and constraints (e.g. lot size, amount of dwellings, roof size availability). Side note; the maximum amount of PV-output is reached if there is zero roof availability and type 1+2 is also zero.



Financing mix
There are four types of financing. The striped parts showed the 'unused' part of the financing capacity. The ESCo as third party financer, the mortgages as higher selling price and the real estate developer as less profit/lower ground price.

Total costs of ownership
The striped part shows the reference dwelling (average Dutch dwelling of the same type and size). This is an input variable. The filled bar shows the TCO for dwelling type as result of the optimisation.

BENG requirements
Graph gives the results for the BENG-calculation. BENG1 is a fixed, input variable. BENG2 and BENG3 are calculated by the model. BENG2 gets negative and BENG above 100% if energy is supplied to household appliances or the grid annually.

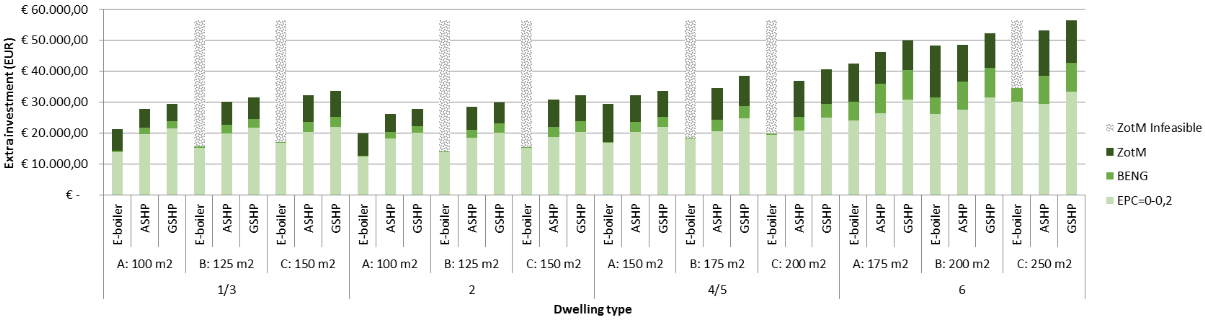
Figure 59: Dashboard as output result of the model. The example used shows the results for the case study of 'Het Verborgen Geheim' to realize a zero-on-the-meter energy ambition (see 'energy ambition' within the constraints in the top right). In this case the possibilities to increase the selling price or involve an ESCO were disabled (see 'financing mix'). It also looks like if there is a negative energy demand, however, this means that energy is supplied to the grid annually. This counts for the time of installation. The amount gets lower during the years due to degradation of the PV-panels. (own illustration).

8.6 Assessment and verification

The model is continuously analysed and tested during its development and with this feedback the model is continuously redefined and optimized model. This leaded to the final, detailed and described design. This final result of the model is applied to real life situations. The results of the assessment are shortly addressed in general. In Appendix 13.26 more data and descriptions can be found on the assessment. The coming section only describes the headlines. The model is assessed the following topics:

- Correct operation of the objective function
- Correct energy demand calculation (of BENG1) with a model, which used prior the designed model
- Construction costs in relation to profit rate
- Construction costs of BENG and ZOM
- Energy outputs

Only of the important headlines are the output of the construction costs of BENG and ZOM, shown in Graph 11.



Graph 11: Extra investment for realizing energy ambitions as output of the LP-model. The output is optimised on minimum costs (own illustration).

The terraced dwelling can be realized within a range of €20.000 to €30.000, the semi-detached dwellings have a range of €30.000 to €40.000 and the detached dwellings a range of €40.000 to €55.000. These are high prices compared to the case of a detached dwelling: € 31.863,- to realise BENG in Bouwens and Bouwmeester (2017: 19) and according to Beek (2015) the additional costs for a new dwelling are about € 15.000 to realize a zero-on-the-meter standard.

The reason for these high prices is that all energy saving and supplying installations are taking into account. However, the current building degree requires an EPC=0,4 and in order to realize this level also energy saving and/or supplying installations are required. It is hard to determine from which level additional costs are required. Kuijpers - van Gaalen (2014) calculated different solutions to realize an EPC=0,4. In all concepts are PV-panels included. In that case would not all PV-panels have to be taken into account to realize BENG or ZOM. A difficulty is that the EPC requirements can be obtained without PV-panels.

Therefore, an exact reference image for costs is hard to get. The two price-levels from the sources indicate that the costs of a detached dwelling are twice the costs of a terraced dwelling. That is according to our prices. The price levels are checked within the appendices on price levels. For the reason that all the extra energy installations can be financed by the mortgage and most of them can be financed by the ESCO, no additional measures are taken to decrease the presented costs levels.

The second headline is the one of the energetic performance. Graph 12 shows the energy usage of all dwelling types. The reference dwelling is the average energy usage of series of five terraced, ZOM-dwellings located in RijswijkBuiten and installed with a ground source heat pump (Sijpheer *et al.*, 2015). The size of the dwelling is around 150 m^2 UFA (Kadaster, 2013), this is a bit higher as our terraced dwelling type C. In the figure a minimal building-related energy usage can be seen, but it appeared that in the used reference case the COP of both hot water (3,8) and space heating (7,0) was higher as used in our case (Staats, 2016: 12). When adopting this exogenous variable, the energy usage was the same bit too low. The building-related energy output of the model looks valid, considering the little margins of the reference dwellings. However, the household-related energy usage has a huge difference. This low energy usage by household appliances in our reference case has it reasons.

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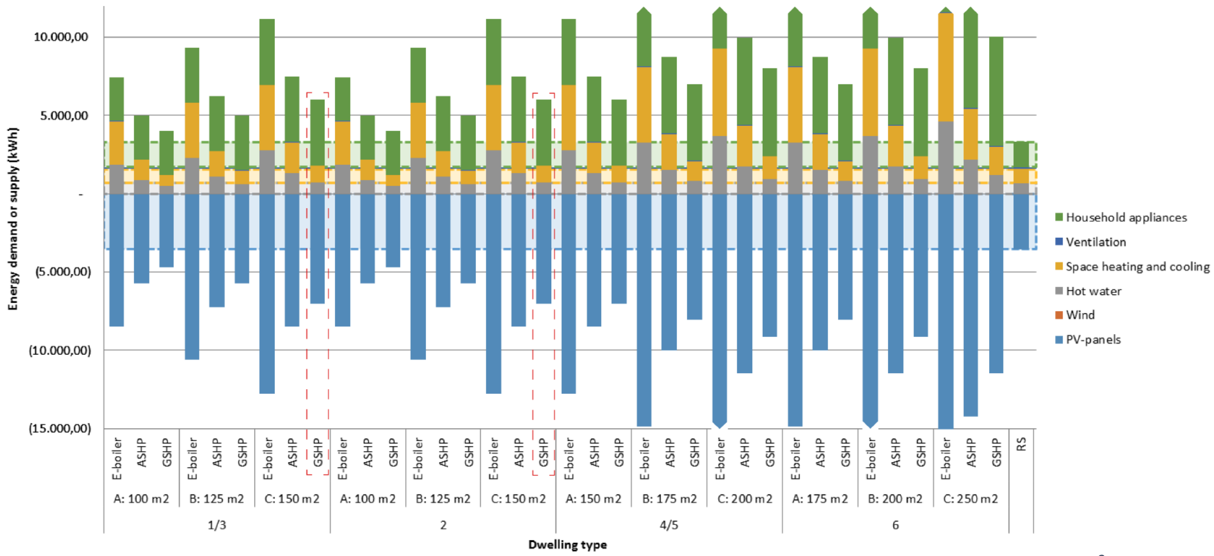
According to Sijpheer *et al.* (2015: 7) are the residents stimulated by making vouchers available for the purchase of LED-lighting and other A+++ appliances to buy these energy efficient appliances during this pilot project. These types of measurements also translate into a real measured low household electricity consumption. Our model uses the official requirement for the household-related energy usage of NEN 7120+C2 (2012).



Graph 12: Energy usage profile of different dwelling types in first year (including energy demand of 37 kWh/m^2/a) (own illustration).

Concluding, the LP-model gives a good indication of the building-related energy performance of the dwellings compared to the reference case used. It is hard to determine what the added costs are for energy saving appliances based on the current building degree. In the end, these costs can be attributed to the additional borrowing capacity or the ESCO and therefore no additional measures are taken.

8.7 Conclusion

The design of the model shows that the design problem of energy efficient neighbourhoods can be modelled by means of linear programming and used for the structuring and optimisation of the design space. In this conclusion, the first SRQ is answered.

> *How can a decision support tool optimise the results for the real estate developer in residential neighbourhood development to realize at least an ambition of energy neutrality?*

The answer is given in threefold. First, a description is given about the goal-oriented system of the LP-model. Second, a reflection is given on how this goal-oriented system and the optimisation problem can be applied in multi-actor decision-making process and how it shapes the possibilities within the interactor design space. And lastly, the model is explained by the structure of the modified Ackoff-Sasieni utility function in Binnekamp *et al.* (2006: 213).

The results of the real estate developer in the problem in question can be optimised by applying the LP-modelling technique. This technique can create a decision support tool showing the best possible outcome within the given constraints. For the creation of this LP-model, all involved variables within the business case have to be converted to linear relationships. In this case that means that the physical, financial, organisational and legislation oriented aspects of the business case are included. The physical aspects are related to the amount of dwellings and installations techniques, which are constraint by the limits of physics. The financial aspects are related to the total investment, the financing method and the TCO. The organisational aspects are related to the interests of the involved stakeholders and these design-decision variables are set as constraints. The legislation aspects are the BENG-requirements, also set as constraints. The design-decision problem that bounds all these aspects are the (amount of) dwelling types to be developed, the energy installations to be used and the financing method. The goal is to get the optimal configuration of the design-decision variables for the maximal profit, the maximal energy performance or the minimal TCO. The maximal and minimal results are limited by given constraints, for that reason maximal and minimal can be changed for optimal. In this case the collection of alternatives is based on the amount of dwellings, energy installations and financing methods used.

However, the result of this LP-model is product oriented. The decision-making process cannot be captured by the LP-technique. Now the notion of the design space comes into play, because this one makes it possible to use the model in multi-actor decision-making processes. The design space is the collection of all possible design alternatives and is restricted by the linear constraints. Some of the constraints relate to design-decision-making variables, which again relate to a stakeholder. If the stakeholder changes its decision, the design space can be adapted. That is way the decisions of the multiple involved stakeholders about the values of the design variables determine the size and shape of the design space. In that way the optimisation problem and its related constraints relate to the inter-actor design space and the LP-model can be used in these multi-stakeholder decision-making processes to shape the design space. However, only one objective function can be optimised. For that reason, the LP-model always produces single-criterion solutions. The constraints make it possible to incorporate the demands of other stakeholders. In such a way, a feasible solution needs to be acceptable by all stakeholders, because their demands are incorporated.

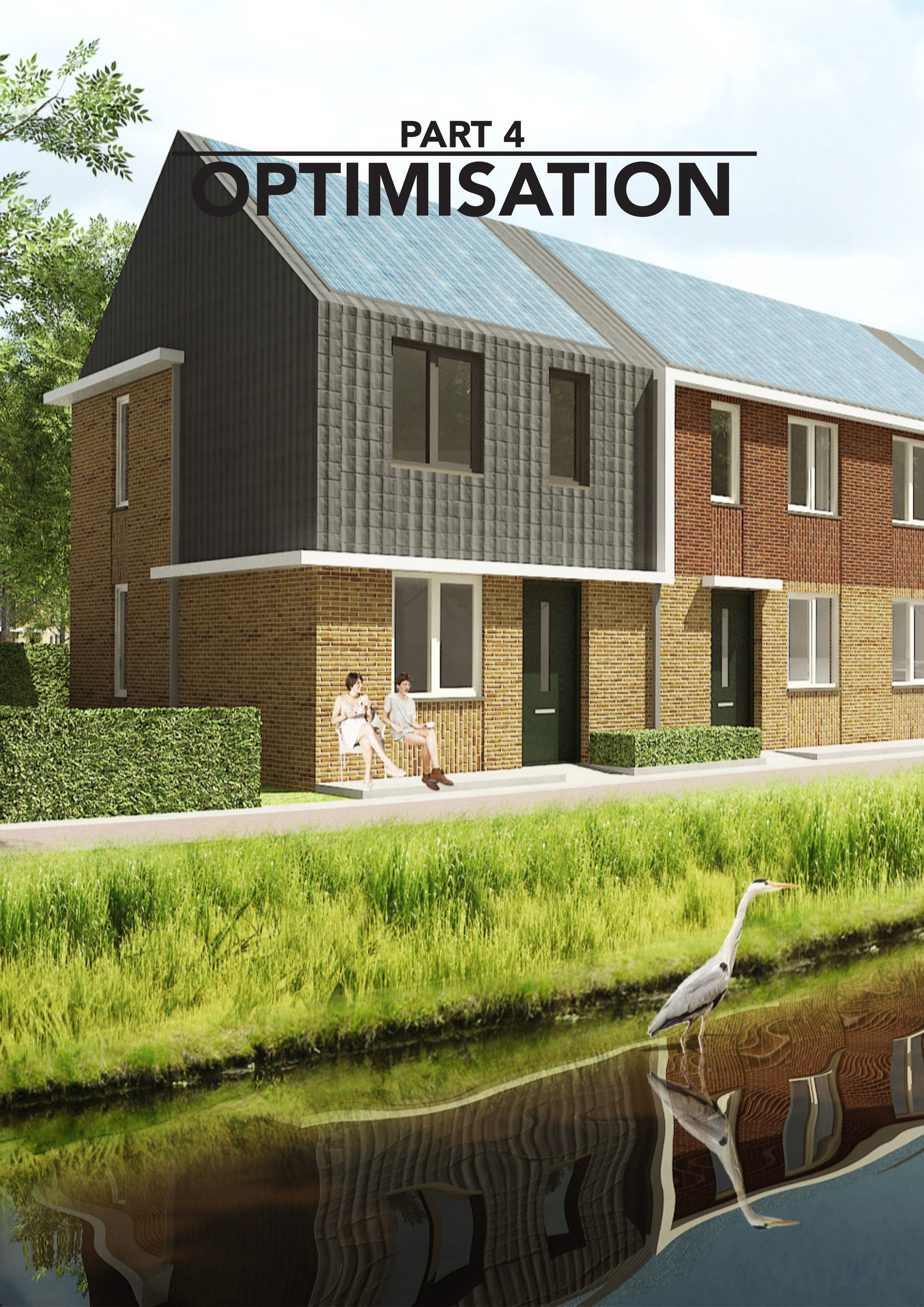
The LP-model is also structured by the modified Ackoff-Sasieni utility function of Binnekamp *et al.* (2006: 213), see formula 6.59. The optimized utility (U) is dependent on the relation (function f) between the decision variables (D_i), the result (output) variables (R_k) and the fixed (input) variables (F_j).

$$U = f(D_i, R_k, F_j) \tag{6.59}$$

All these five types of elements are used in the model. *First*, the value of the decision variables is determined outside the model. The results of the described LP-model are effected by some important decision variables (e.g. the possible UFA of the dwelling types, the amount of roof surface related to each dwelling type due to its design, the density and dwelling mix, the operational period, the interest rate of the mortgage and ESCO, etc.). All these decision variables relate to one stakeholder. The different decision variables are clearly recognizable within the LP-model, which offers the opportunity to make them open and comparable. These variables define the solution space or the design space and these variables can be open discussed, negotiated and changed by the involved stakeholders during the use of the model in a transparent decision-making process. In case this approach applies, one can speak of the Open Design Approach (Binnekamp *et al.*, 2006). *Second*, the result variables are optimized inside the model and gives as output the optimal alternative for amount of dwelling D_i to develop and which related energy installations to apply. These are also named the endogenous variables. *Third*, the fixed (input) variables are for instance the market value of dwellings, energy prices, efficiencies of energy installations and the TCO for reference buildings. Although, the fixed input variables are not bounded by the limits of physics. Change of these variables is possible, but it is outside the decision power of the stakeholders. For instance, the market value and energy prices change of time, but can hardly be changed by a single stakeholder and the efficiencies of energy installations increase by innovation, but these cannot be required. That is why a sensitivity analysis should be included in the next parts to show the effect of a change of these input variables on the result variables. *Fourth*, the optimised utility is dependent on the objective function used. This could be the amount of profit, the electricity production or the TCO. And *last*, all these stated variables are related to each other by linear functions.

In short, the LP-model is a goal oriented system and can be used from the viewpoint of a single actor to optimizes his objectives within the defines constraints. All relationships in the model are linear and the design-decision-making variables within these relationships are related to different stakeholders. In that way an unfeasible solution can be change to feasible by renegotiating these decision-making variables. In case of this LP-model the profit for the real estate developer is the objective function and energy ambition together with other input variables from various stakeholders are set as constraints.

PART 4
OPTIMISATION



Project	Part of ‘RijswijkBuiten’
Location	Rijswijk
Real estate developer	Dura Vermeer

9 Added value of the decision support tool

9.1 Introduction

This chapter elaborates on the added value of the decision support tool designed in the previous chapter and provides an answer on the third sub-research question:

> *What is the added value of the decision support tool in decision-making processes for the realization of ENRND-projects?*

The determination of the added value is executed in two ways. The first one is the application of the DST to the in-depth described case of 'Het Verborgen Geheim'. This results into the optimal theoretical results. A sensitivity analyses has to determine which decision variables have the most influence on the outcome. In the end, the theoretical results of the model are compared with the results in practise of the case of Van Omme & De Groot. The second method is executed by means of letting an expert focus group reflect upon the final design of the DST. The expert focus group indicated that a viewpoint from another stakeholder would be interesting, namely the municipality. The added value of the tool for this stakeholder is the third part of this chapter. The chapter ends with a conclusion which answers the sub-research question based on the application of the model and the expert focus group.

The first approach is a quantitative approach that wants to maximize the validity of findings and standardize approach as much as possible to generate answers that can be coded and processed quickly (Bryman, 2012: 470). This was required in the analysis of the more as 300 runs. In second approach, the researcher is interested in the interviewee's point of view. The outcomes are not bounded by the quantitative restrictions. The qualitative interviewing approach fits best within this approach (see Bryman (2012: 470)).

9.2 DST applied to 'Het Verborgen Geheim'

The proposed results of model are compared to the decided results in practice. The difference learns us how the business case can be improved or what the limitations could be from the model. A sensitivity analysis presents the more effective variables in the decisions about energy neutrality. The DST is applied to the case of 'Het Verborgen Geheim' of Van Omme & De Groot. First, the input variables are presented, which are followed by the results as output of the model. Third, the results of the sensitivity analysis are represented and lastly the conclusions are given.

9.2.1 Input

The input variables for this case are large determines by the land-use plan, which was already fixed (Gemeente Rotterdam, 2013). The specifics for this case are shown in Table 14. The general input for this case is already discussed in Chapter 6 and the related Appendices.

Table 14: Input variables for the optimisation of 'Het Verborgen Geheim'.

Variable	Value	Source/description
Area size	58.472,5 m^2	Appendix 13.26
Development space	51% of the area can be developed - Plot 1: 4.202 m^2 - Plot 2: 7.964 m^2 (-25%) - Plot 3: 649 m^2 - Plot 4: 4.168 m^2 - Plot 5: 8.672 m^2 (-25%) - Plot 6: 4.119 m^2 From Plot 2 and plot 5 25% must be excluded due to the green path and community garden inside the plot.	Appendix 13.26, based on Gemeente Rotterdam (2013)
Density	170 dwellings	Land-use plan (Gemeente Rotterdam, 2013) Tender (Raets & Aboutaleb, 2015; VKZ, 2015: 5)
Energy ambition	Zero-on-the-Meter	Energy gives most points in tender (Dijkshoorn, 2017) Ambition in land-use plan (Gemeente Rotterdam, 2013) and structure vision of area (Stadshavens Rotterdam, 2011)
Dwelling mix	Corner terraced-dwelling: 0-170 Mid-terraced dwelling: 0-170 Semi-detached dwelling: 0-170 No detached dwellings	Appendix 13.22.3
Market values	Corner terraced-dwelling: € 2.100 Mid-terraced dwelling: € 1.969 Semi-detached dwelling: € 2.115 Detached dwelling: n/a	Appendix 13.22.3
Ground quote	€ 19.419,-	Ground exploitation of tender (Raets & Aboutaleb, 2015: 4)
Usage of ESCO	Yes, only pays for PV-panels, GSHP's and ventilation system.	(Dijkshoorn, 2017)
Additional mortgage as extra selling price	No	(Dijkshoorn, 2017)
Wp -> kWh	0,8645 = 0,91 (location) * 0,95 (orientation)	Appendix 13.23.2 (Figure 94 and Figure 95)

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With these input data the following runs have been executed[73]:

- 8 runs for the best output (see next section)
- 268 runs for the sensitivity analysis
- 2 runs for the municipality (ground price, see 9.4)
- And many test runs

9.2.2 Output

Two runs represent the boundary conditions set by the municipality. These are shown in Figure 60 and Figure 61. The possibility to involve an ESCO is not included in the first run. In the second run this option is included.

[73] The energy ambition and financial possibilities have been adjusted. This is indicated as such in these situations.

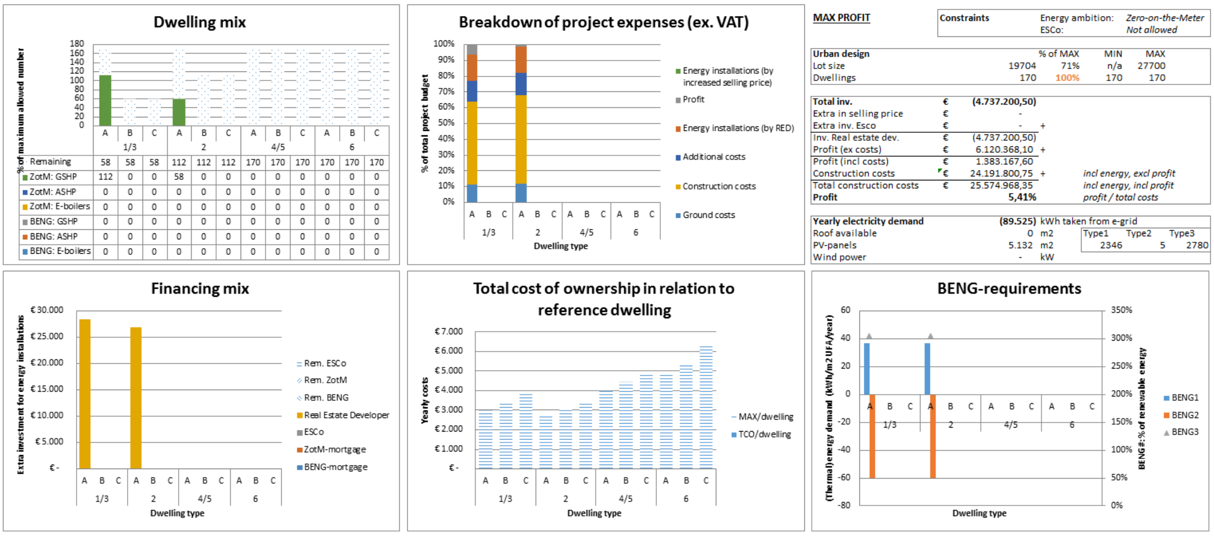


Figure 60: Print screen of dashboard run 1

The noticeable aspects in the first run are the selection of only small terraced dwellings with an GSHP. The model strives for the most corner-dwellings as a ratio of almost 2:1 (2-corner to 1-mid-terraced-dwelling) is the output. Also the real estate developer has to pay the total investment in the energy installations. This leads to almost zero TCO for the home buyer. A profit rate of 5,41% is kind of low, however, it is likely that the real estate developer knows some methods for optimisation.

This profit rate increases in the second run to 18,18%. This increase is cause by the involvement of the ESCO. The financing mix shows that the ESCO pays most of the investment in energy installations. These investments cover the ventilation system, the heating system with the GSHP and the PV-panels. Other investments in energy saving measures are paid by the real estate developer. The usage of the ESCO is also visible in the TCO. The costs for the home buyer increases, however, these costs are still a lot lower as in the reference situation[74]. In this run the model also selects the smallest terraced dwellings with an GSHP.

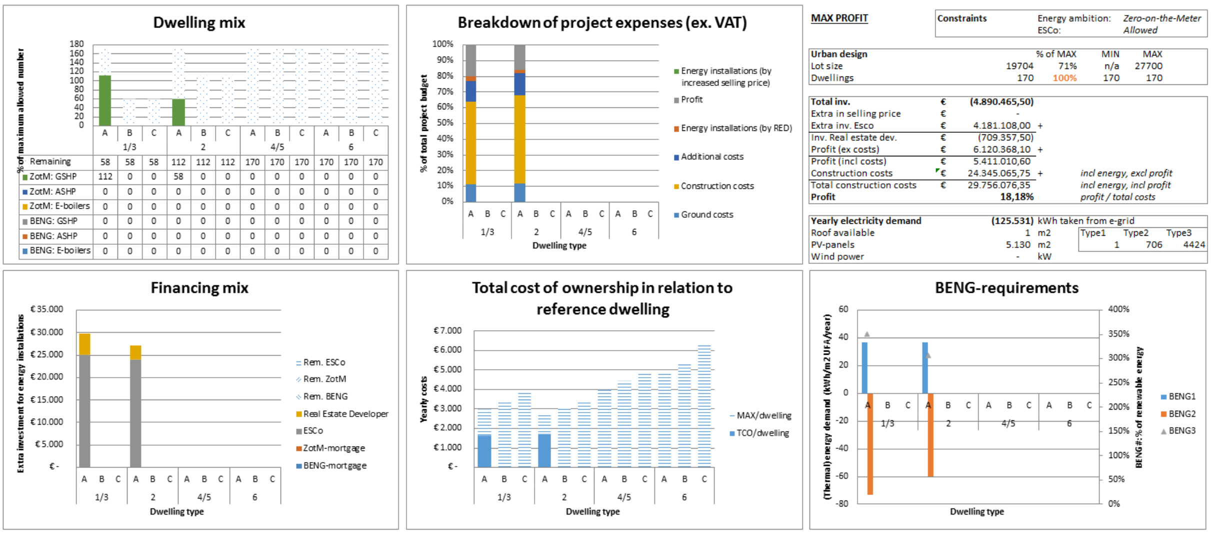


Figure 61: Print screen of dashboard run 2, with the possibility to involve an ESCO

In the next runs the effect of the involvement of the ESCO is further investigated and also the effect of changing the legislation and energy ambition is added to this. The resulting profit rates are presented in Figure 62. The associated dashboards can be found in Appendix 13.28.

[74] The reference situation is reached when the striped bar is filled with the solid coloured bar. An example, the TCO of run 2 (in Figure 61) are for dwelling type 1&3A about 50% of the reference dwelling.

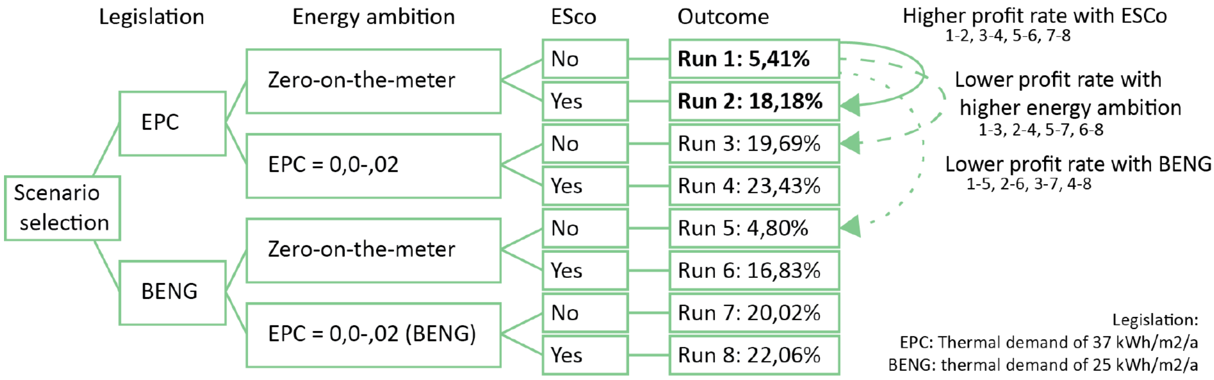
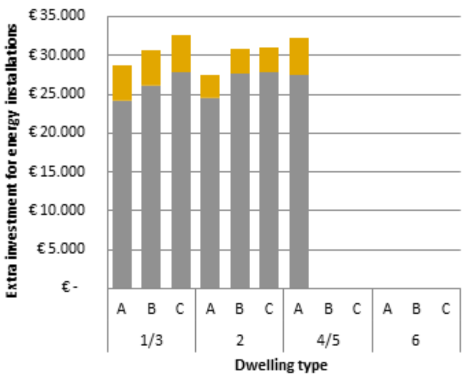
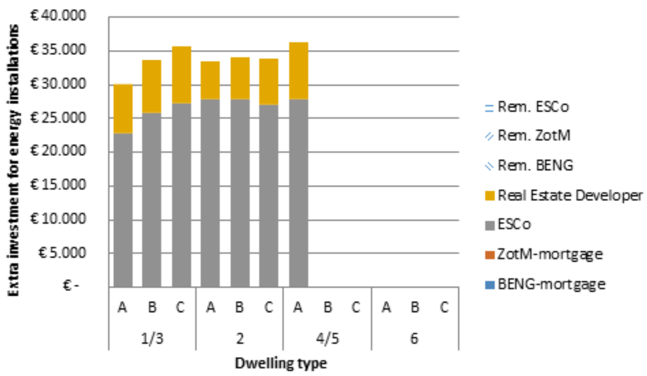


Figure 62: Results of runs with changing legislations, energy ambitions and usage of the ESCO, see Appendix 12.18 for the dashboards of the runs 3-8 (own illustration).

Some trends look like to appear. First, the runs indicate that the solutions with the involvement of the ESCO have an increased profit rate (4 out of 4 cases). Second, a higher energy ambition looks to have a negative effect on the profit rate (4 out of 4 cases). And last, the BENG-legislation also looks to have a decreasing effect on the costs (3 out of 4 cases, one case it has a positive effect of 0,33%). These three issues are further explored in the sensitivity analysis. For this case, all the BENG-dwellings are more expensive as the EPC-dwelling (see Graph 13 and Graph 14). This is caused by the increasing measurements needed to meet the requirements of BENG1. These graphs also indicate that dwelling type 4&5A-4&5B and 6A-6C are infeasible according to these simulations. This is indeed fixed for the detached dwellings (6A-C), because the market analysis showed that there is no market for these dwellings (see Appendix 13.22.3). The reason for the infeasibility of the larger semi-detached dwellings needs further research.



Graph 13: Costs per dwelling within EPC-legislation (own illustration).



Graph 14: Costs per dwelling within BENG-legislation (own illustration).

There are also some additional findings based on the dashboards of the runs (see Appendix 13.28):

- The model selects larger dwellings if energy ambition is lower. The plausible reason behind this is that PV-panels are likely to be more expensive than the increased market value returns.
- The TCO for the home owners are near to zero if no ESCO is involved. The reason for this is that the real estate developer pays for it and does not reflect this in a higher selling price.
- The involvement of the ESCO is always used to its maximum capacity and because the ESCO requires the usage of GSHP, these are always used in 100% of the dwellings if an ESCO is involved.
- GSHP are also selected in case the energy ambition is set at ZOM. Some difference appears with the usage of the ESCO. In case it is not possible to involve the ESCO, some dwellings have less efficient installations. This is possible, because the model allows for heat exchange between the same type of dwellings. This is the theoretical optimal solution. In the discussion this topic returns if this is realistic as an outcome.
- The model selects the usage of ASHPs and electric boilers in case the energy ambition is not ZOM and no ESCO is involved. The expected reason for this is that extra PV-panels are cheaper to realize the regulatory requirements in comparison to the update to the GSHP. Within the BENG-legislation the model even selects 100% e-boilers and larger dwellings.

These findings are further analysed in the sensitivity analysis.

9.2.3 Sensitivity analyses

The sensitivity analysis investigates the sensitivity of the main decision variables based on the components of the research framework to influence the business cases. These were the legislation, organisation, finance and physical aspects. In this case the organisation aspect is about the involvement of the ESCO, because this was the one aspect that could be quantified. The physical solutions are about the result (output) variables of the dwelling type and energy installations and about the decision variables as the ridge of the dwelling to influence the amount of roof surface and the kWp output of the PV-panel and input variables such as the COP-efficiency of both the ASHP and the GSHP. The sensivitiy analysis involves six different aspects, namely:

1. Position of the ridge[75], normally 0,5 (halfway)
2. Maximum possible kWp of a PV-panel, normally 0,3 kWp
3. COP of the GSHP, normally 3,8
4. COP of the ASHP, normally 2,6
5. Higher selling price by mortgage possible (yes/no)
6. Involvement of ESCO possible (yes/no)

In total 268 runs are executed for the sensitivity analysis. The next paragraphs explain the headlines of the findings from the sensitivity analysis. Appendix 13.29 shows more information and includes the graphs related to the statements. The sensitivity analysis uses the abbreviations of BENG for both the legislation and the energy ambition. For sake of clarity ZED was added. ZED is the Zero Energy Dwelling. This is about the energy ambition (EPC=0,0-0,2). BENG refers to the legislation used.

9.2.3.1 Legislation

Based on the sensitivity analysis it can be stated that BENG is not always more expensive, but the current EPC-legislation is more profitable for lower energy ambitions financed by the ESCO and that BENG-legislation can lead to an increase of dwelling size.

The first statement is valid in case of an energy ambition with energy neutral dwellings and a financing method with the ESCO, the EPC-legislation is always more profitable (see Graph 40). This is caused by the used installations. More PV-panels are required in case of the EPC-legislation and those are paid by the ESCO. More energy saving installations and investment in the thermal envelop are required in case of the BENG-legislation and those are paid by the real estate developer. That is why the EPC-legislation is more profitable in those runs. In runs without the ESCO the EPC-legislation is slightly more expensive. Therefore, it depends on the energy ambition, physical measurements taken and the method of financing which type of legislation is more expensive.

The second statement that BENG-legislation can lead to an increase of the dwelling size in case of a ZOM-energy ambition within these 256 runs is indicated by Graph 41. The graph shows that the ZED-ambition does not have an effect on the dwelling size.

9.2.3.2 Organisation

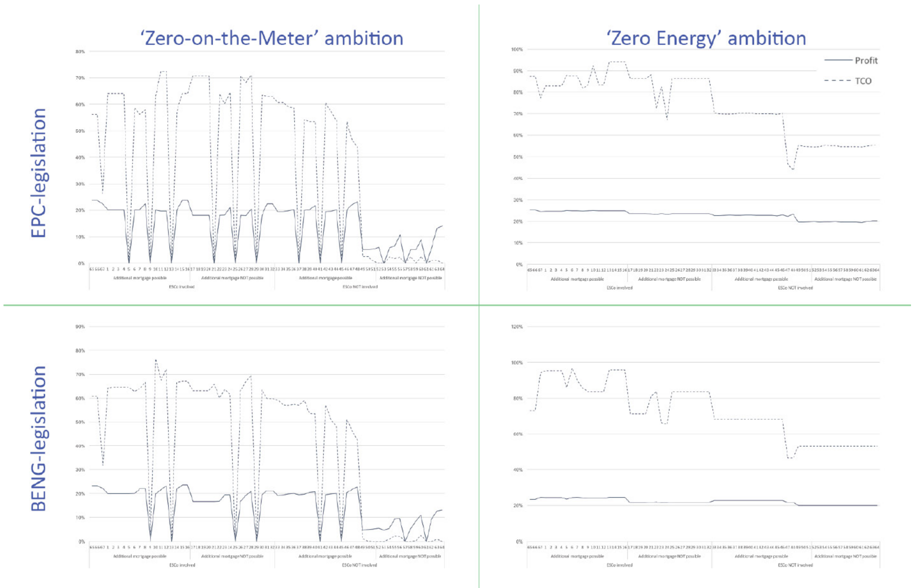
The second aspect of organisation is about the ESCO involvement. As explained before, the organisational aspect involves much more, but only the ESCO involvement is quantified in the model. For the real estate developer has the involvement of an ESCO a positive effect on the profit rate in almost all cases (shown by Graph 43). The effect of the ESCO is the biggest in case of the ZOM-energy ambition without the availability of the addition mortgage space. This increased profit rate was between 8,2pp - 13,1pp[76]. Only if both financing solutions (ESCO+additional borrowing capacity) are used and the energy ambition is ZOM, the effect of using the ESCO or not will not be big. For the home buyer has the usage of an ESCO an increasing effect of the TCO. All runs shows an increase of the TCO when the ESCO is involved (see Graph 44). Though, even with the involvement of an ESCO are the TCO lower as the reference dwelling. That is known because only feasible runs are presented.

[75] See Figure 110 for explanation.
[76] pp is the abbreviation of procentage point.

9.2.3.3 Finance

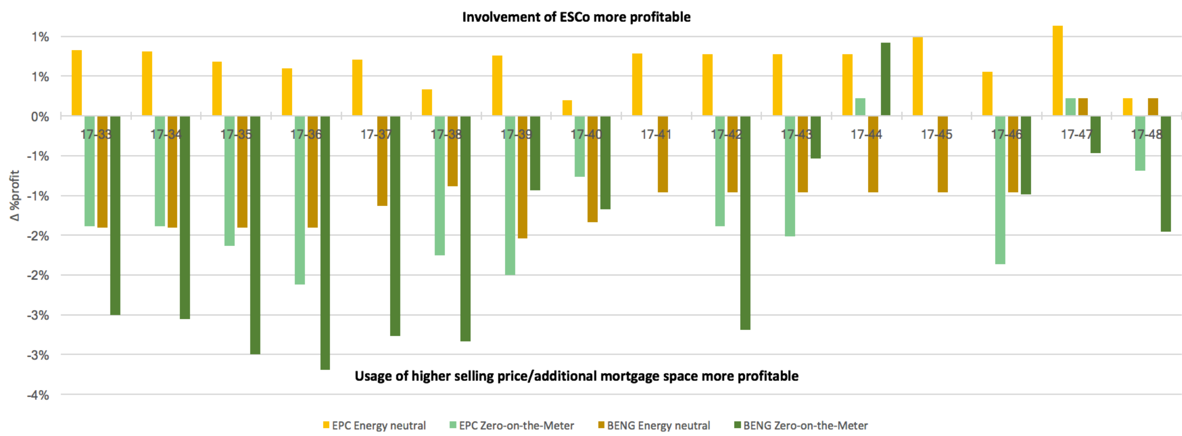
A comparison of the effects of legislation and energy ambition is shown in Graph 46. Some insights became visible:

- The profit rate is relatively stable within the ZED-energy ambition. Most profit is made in case both financing options are the lowest profit is made in case no additional financing options are used.
- The TCO vary in between 45-95% within the ZED-energy ambition. If both financing options are used, the dwelling often has almost the same extra living costs for energy purposes as the reference dwelling. If no financing options are used, the TCOs are the lowest. Except for one, the increase in type of PV-panel reflected by the maximum amount of kWp possible.
- The ZOM-energy ambition is more effected by the method of financing and the input variables about physical solutions. The infeasible runs within this ambition also present larger fluctuations.
- The ZOM-energy ambition is hardly financial feasible in case no extra financing options are used and has really low TCO. Only nine runs (out of 32) had a profit rate above 7%. These are the runs in which the newest 400Wp PV-panels or a change of the position of the ridge to 80-100% was applied.



Graph 15: Effect of the different input variables on the amount of TCO and profit (own illustration).

The comparison of the ESCO involvement and the mortgage possibility leads to interesting insights (see Graph 50). For most comparisons the additional mortgage possibility is more profitable. The ESCO is more profitable for all comparisons within the ZED-energy ambition and the EPC-legislation. The differences are mostly bigger in case of the ZOM-energy ambition. This is even more valid in case of the BENG-legislation. This difference can be explained that in that case the investment is higher, but the ESCO does not pays for this differences and the additional mortgage space does finance all solutions.



Graph 16: Comparison of profit rate between the usage of an ESCO and the usage of addition mortgage space by an higher selling price (own illustration).

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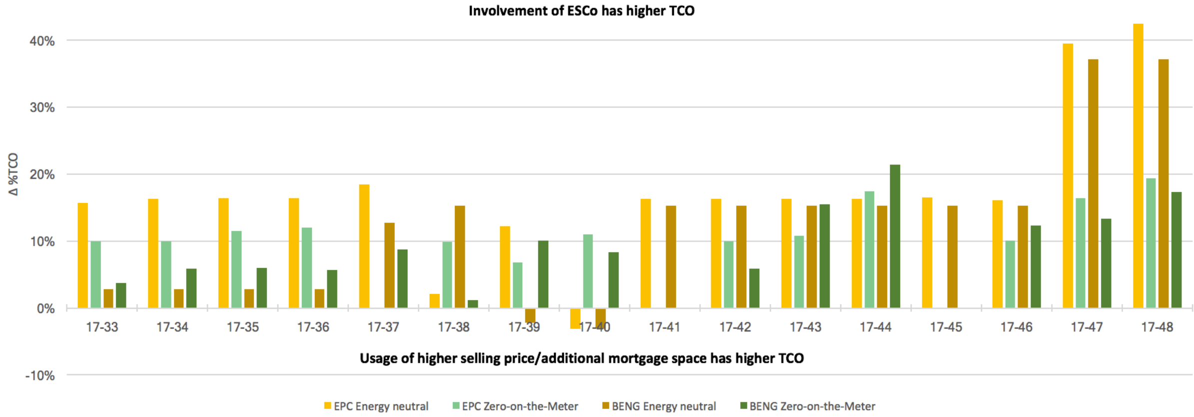
The TCO are in most comparisons higher in case the ESCO is involved (see Graph 51). This is the case for all the comparisons with an ZOM-energy ambition.

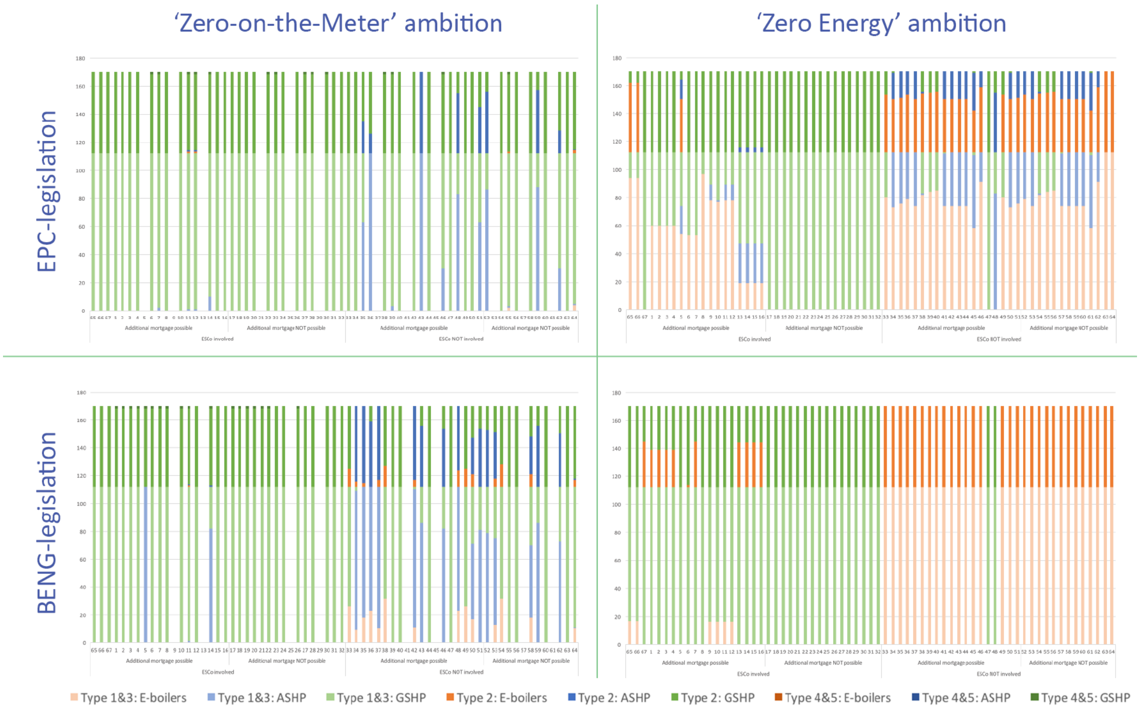


Graph 17: Comparison of TCO between the usage of an ESCO and the usage of addition mortgage space by an higher selling price (own illustration).

Concluding, increasing the selling price with the amount of additional borrowing capacity for a mortgage of an energy efficient dwelling is profitable in all but one comparison. The profit rate increased most (+8,9pp - 14,6pp) in case of the ZOM-energy ambition and without the involvement of the ESCO. However, this last one would lead to an increase of the selling price by €29.000 (see Appendix 13.24.1). In most comparisons the higher selling price leaded to increased TCO. The financing method with the increasing selling price also leads to an increased profit rate in most comparisons to the involvement of the ESCO (38 out of 59) and it also leads to a lower TCO in most comparisons (56 out of 59).

9.2.3.4 Physical

This paragraph discusses on the thermal supply installations selected by the model (output variables) and the effect of some physical input variables (COP efficiency of the ASHP and the GSHP, max kWp possible per PV-panel and the position of the ridge). First, a general overview of the effect of the energy ambition and legislation on the thermal energy supply installations selected is shown. And second, insights based on Graph 6 are presented.



Graph 18: Thermal energy supply installations selected within dwelling types (own illustration).

The financing options and the legislation has effect on the optimal thermal supply installation (see change in colours in Graph 52). More detailed, the GSHP is selected in all runs with only the financing possibility of the ESCO involved. In the other financing option mix does the legislation of BENG lead to a decrease of amount of GSHP selected. In addition, BENG-legislation leads to an increase of the electric boilers. This goes up to a 100% selection of e-boilers in case of the ZED-energy ambition and the absence both financing options. The e-boiler is the cheapest solution to meet the energy ambition. The feasibility of this option is limited by the amount of roof surface available to cover the electric demand.

Insights on the effect of the input variables is gathered from the different runs in Graph 6. *First,* the effect of the COP of the ASHP. In all 8 runs with an ESCO the GSHP was selected and therefore the changing COP of the ASHP had no effect on the profit rate. The profit rate is slightly increased (+1pp) without the ESCO involvement and the TCO decreased a bit (-2,5pp max). *Second*, the effect of the GSHP. The runs are infeasible for COP=3. If the run was feasible, an increase of the COP of the GSHP leads to an increased profit rate. This was even up to 5pp in case no additional financing option was selected, for the other 3 comparisons this was around 2,5pp of extra profit. COP=9 results into one size bigger dwellings, which increases profit, but increases also the TCO, because larger dwellings use more energy and need more installations to get ZOM. *Third,* the effect of the max Wp per PV-panel. In all runs the 250Wp PV-panel lead to an infeasible result. The rest of the results has different effects. In three of the four comparisons the best PV-panels (400Wp) leads to bigger dwellings and therefore increased profit rates. The profit slightly drops (-0,5pp) in the comparison with both financing options involved. In the same comparison the TCO increased with big numbers (+9,5pp), in case the PV-panels are paid by the extra mortgage the TCO drop by around 7pp. In the other two comparisons the TCO fluctuates with 2,5pp, first down and with the bigger dwellings up. *Fourth*, the effect of the roof surface influenced by the position of the ridge. In all cases at with the ridge positioned at 40% (less roof space) the result is infeasible. In the case with the ridge almost located at the northern part of the dwelling (at 80% and 100%), the roof offered enough space to create the biggest size dwellings. This ensured a rapid increase of profit level (3-4pp with additional financing measures and even 8pp without additional financing measures). The big increase was caused that four dwellings were installed with an e-boiler and heat exchange was possible within the block. In case of the ESCO the TCO increased 7pp with the mortgage and the TCO was stable without mortgage. In the case with the mortgage and without the ESCO, the TCO dropped rapidly (-10pp).

9.2.4 Results

The results of the model are compared to the real-life situation. Run 1 and Run 2 represent the situation of the real life case in sense of energy ambition and regulatory requirements. In both situations the smallest possible terraced dwellings with a GSHP are selected. Run 2 fits better, because the ESCO is allowed.

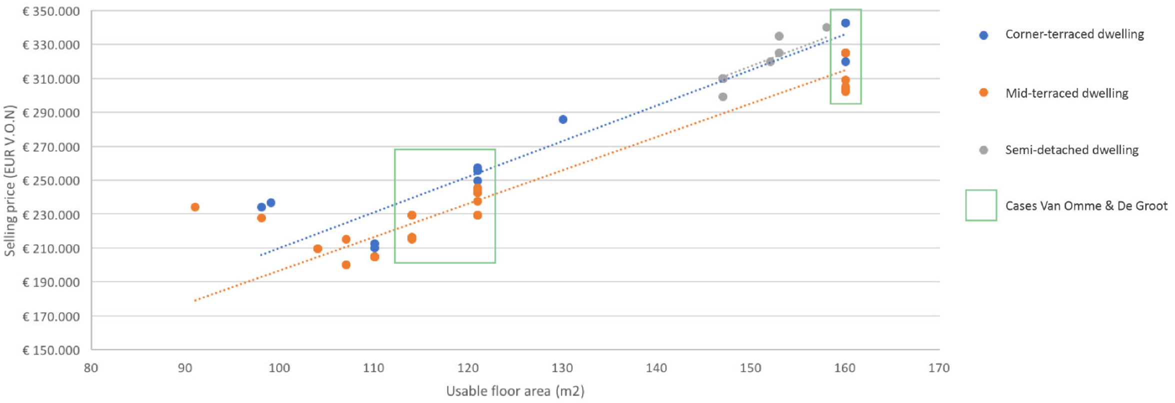
Table 15: Comparison of real life situation to the results of the LP-model.

	Real life situation[77]	Run2
Dwelling mix	12 semi-detached of 150m^2 24 terraced dwellings of 160 m^2 134 terraced dwellings of 114 or 121 m^2 2:6 (corner : mid-terraced)	170 terraced dwellings of 100 m^2 2:1 (corner : mid-terraced
Heating installations	170 GSHP	170 GSHP
Financing	Energy installations financed by ESCO	Energy installations financed by ESCO

The comparison shows that the model proposes to use the same heating installations and financing method. Only the dwelling mix is different, because in the real life situation twelve semi-detached dwellings are developed and all the dwellings have a larger size. First, why does the model propose no to develop semi-detached dwellings? The answer can be found in Graph 19, which shows that the market value of a semi-detached dwelling is almost the same as for a corner-terraced dwelling, but the construction costs are larger. Proportionally the corner-terraced dwelling more profitable. Why are these dwellings developed in the real life situation? The answer is unknown, but the land-use plan shows a staggering building line (see Figure 103, right side of plot 1 and 6) on the locations of the development for the semi-detached dwellings. The researcher could not find the explicit requirement for this in the land-use plan (Gemeente Rotterdam, 2013), but it could be a desire of the

[77] The whole dwelling program of the development has uncertainties. The presented numbers are based on the urban design on Ooms (2017).

municipality. This number was also presented in the letter to the city council of Raets and Aboutaleb (2015), however, that letter was written after the real estate developer was selected as winner of the tender. It is unknown who desired the semi-detached dwellings on that spot. This needs future research for the real reason.



Graph 19: Housing market saturation (own illustration, see Appendix 13.22.3).

The other aspect was the size of the dwellings, why does the model propose to make different dwellings, while in reality the most dwellings are around 130 m^2 UFA. The semi-detached dwellings and the quay dwellings are a bit bigger, respectively 150 m^2 UFA and 160 m^2 UFA. A reason could be the number of terraced dwellings for sale with a size around the 100 m^2 UFA (see Graph 19). In the real life situation dwellings are developed with bit larger size as the ones for sale. This could be a focus to another market segment. The model does not take this into account, but it can be added as a decision variable. If the constraint is added that 0 dwellings of 100 m^2 UFA can be developed, the model returns infeasible. The sensitivity analysis had shown that the COP of the GSHP and the maximum Wp of the PV-panels influences the feasibility. For the new runs the COP of the GSHP was increased to the level of the reference dwelling in RijswijkBuiten with the same system of the ESCO Klimaatgarant (Staats, 2016: 12) and the maximum Wp of the PV-panels was increased with 20Wp for €200 extra per kWp. These numbers are based on a own calculation with the numbers presented of MetdeZon (2017) and Schwerhoff *et al.* (2017). The new input variables are shown in Table 16.

Table 16: Input variables for the optimisation of 'Het Verborgen Geheim'.

Variable	Value	Source/description
COP GSHP	Space heating: 7 Hot water: 3,8	(Staats, 2016: 12).
New PV-panel **Wp** **€/kWp**	 320 1800,-	Own calculation based on MetdeZon (2017); Schwerhoff *et al.* (2017)

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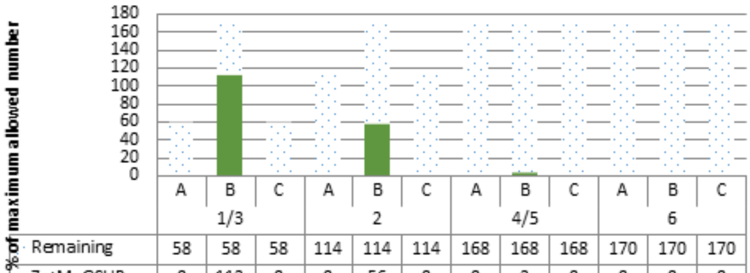
The new runs have a feasible result. The profit rate would be around 10,15% without the ESCO and around 20,70% with the involvement of the ESCO. The individual reflection with experts explains that this is not the profit rate but the profit rate including the residual land value. The real estate developer can decide to raise the ground bid or to add extra quality to the plan. In the real life situation, the ground bid was increased (Dijkshoorn, 2017; Raets & Aboutaleb, 2015) by 10% (Raets & Aboutaleb, 2015) and extra plan quality was required for water adaptation, because the location was located outside of the dikes (Gemeente Rotterdam, 2013). Both runs realized bigger dwellings (125 m^2 UFA, see Graph 20). These sizes are in the middle of the ones developed in the real life situation. The model does not take into account market forces and therefore it maximizes the dwelling type that brings the most profit. In real life multiple different dwelling types are brought to market to overcome market saturation of one type and to spread risks.



	A	B	C	A	B	C	A	B	C	A	B	C
	1/3			2			4/5			6		
Remaining	58	58	58	114	114	114	168	168	168	170	170	170
ZotM: GSHP	0	112	0	0	56	0	0	2	0	0	0	0
ZotM: ASHP	0	0	0	0	0	0	0	0	0	0	0	0
ZotM: E-boilers	0	0	0	0	0	0	0	0	0	0	0	0
BENG: GSHP	0	0	0	0	0	0	0	0	0	0	0	0
BENG: ASHP	0	0	0	0	0	0	0	0	0	0	0	0
BENG: E-boilers	0	0	0	0	0	0	0	0	0	0	0	0

Graph 20: Dwelling mix proposed by the LP-model with the new input variables of Table 16 (own illustration).

9.2.5 Discussion

There are four points of discussion for the outputs of the LP-model for this case study and the related sensitivity analysis.

First, the results are only valid for this specific case and the particular runs. It could be that other decision variables offer new results, such as the energy scenario used, the market value, the ground price, the interest rate of the mortgage or the monthly fee of the ESCO.

Second, as mentioned before in the sensitivity analysis, the model offers the possibility of heat exchange within the same dwelling types. In reality this is not very likely. A solution could be that only one type of thermal supply installation can be selected within each dwelling type by adding a constraint related to a binary variable. This is not done because of time reasons and because the model now shows that in some cases it is interesting to look at shared options. This limits the value of the outcomes with a mix of thermal supply installations. This can be checked by future research.

Third, only one energy scenario is used within the sensitivity analysis. The inclusion of the others would multiple the amount of runs with 4, which was not feasible within the time. The energy scenarios are explained in Appendix 13.25.2. The energy scenario ‘High’ is used (see Table 44)[78]. This scenario was a bit lower as the base-scenario of J. W. J. De Vries (2010). This scenario was selected, because the expectation of the researcher was that the base-scenario would lead to many infeasibilities caused by high investment costs and long payback times. This would have harmed the amount of data gathered for the sensitivity analysis. The TCO of the reference scenario are also based on the ‘High’-energy scenario and therefore, the comparison to the reference scenario could be a bit exaggerated. The relations of the different runs to each other are still valid.

Four, the orientation of the dwellings is now fixed within a certain range (see Appendix 13.23.2). This means an average value of the efficiencies of the PV-systems. Difference and infeasibilities in single dwellings can occur. This needs future research.

9.2.6 Lessons learned based on application of the DST

This part builds on to identify the leasons learned on the added value of the designed DST. First, the results of the comparison of the LP-model and the real life situation are summarized and the main outcomes of the sensitivity analysis related to the results of the case are presented. Thereafter some critical questions are answered on the usefulness of the DST and last the lessons learned are presented.

In the first runs the LP-model proposed to develop smaller dwellings as in the real life situation. Larger dwellings were infeasible to the energy constraints. The proposed dwelling type, financing method and heating

[78] The ‘High’ scenario of the rising energy prices calculated within this research contains a natural gas price increase of 5,0% and an electricity price increase of 3,0%. The base-scenario of J. W. J. De Vries (2010) contained a natural gas price increase of 6,0% and an electricity price increase of 4,0%. The ‘Base’ scenario of this research contains a natural gas price increase of 3,0% and an electricity price increase of 0,5%, lower as the expected inflation rate.

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installations were almost the same as in the case. The model proposed larger dwellings after widening the energetic limitations of the power output of the PV-panel (max Wp) and GSHP (COP). The limits were increased till values which were proven and guaranteed in practise in other projects. The model did not show large differences to optimise the business case.

What have we learned from the LP-model? Have we identified new solutions for this case? No, the model proposes the same energetic concept with the GSHP and proposes to develop the largest dwelling size possible within the possibilities of the roof surface, PV-panels, COP of the GSHP and all the other input and decision variables.

What is the added value of the model for this project if it does not bring optimisations to the business case? It brings fast exploration of the possible solution space and shows if the constraints set offer a feasible solution. No trial and error methods are needed with architects and urban design who incrementally design new design alternatives. However, in this case the LP-model would not have speedup the development. The slow start of the project had different reasons as explained in the in-depth description about the process. Since the municipality started the tender the project got flow. By the involvement of the ESCO Klimaatgarant by the real estate developer Van Omme & De Groot knowledge about ZOM-dwellings was brought into the design team. The ESCO had learned from previous projects what the most important decision variables are and how the energy concept of a dwelling can be optimized. The added value of the model was already added by the knowledge of the ESCO.

Value is added by quickly showing none-informed people the effects of the decision variables on the business case. This has been executed by the sensitivity analysis. For instance, Graph 43 clearly shows the effect on the profit rate of the involvement of the ESCO in case the selling price was not increased. This effect was in between the +8 - +13pp in all feasible runs. It also shows the effect to not increase the selling price, which was decided by the real estate developer because of different market location (Dijkshoorn, 2017). Within that boundary condition the model shows that involvement of an ESCO is a smart decision to make. The model also shows that this financing method influences the selection of a heating installation. Though, this is not really an added value, because that became very clear without the model. The model does show the added value of other insights in the physical constraints, such as the effect of the COP of the GSHP, amount of roof surface and the maximum Wp per PV-panel. The model teaches practitioners how these variables as technological constraints influence the outcome of the business model.

The application of the DST learned us that it not only shows information to improve the insights of the skilled and experienced professional, it also teaches the other practitioners about the effect of their decisions by showing it.

9.3 Expert focus group

The expert focus group is a suitable method to address a particular fairly tight defined topic (Bryman, 2012), which is in this case the added value of the LP-model. The participants within the expert focus group can interact with each other to construct a shared opinion. Planmaat is selected by a non-probability sampling method. This was most accessible, due to the researchers' student job at Planmaat. Planmaat is an independent financial consultancy firm in the field of (urban) area development and applies the open design approach of Binnekamp *et al.* (2006) in practise. This background makes Planmaat very suitable for reflecting upon the application of the decision support tool. One disadvantage of the used sampling approach is that the results cannot be generalized to the whole population of experts within the field of urban development. More information about Planmaat can be found in Appendix 13.29.

The method used during the expert focus group was according to the description within the research methodology chapter and the chapter of Bryman (2012: 500-520) about focus groups. The session can be seen as an open dialogue around a main question: "*What is the added value of the created model for various stakeholders?*" An introduction of the research and the model was given before the interaction started within the focus group. More information about the methodology applied in the focus group can be found in Appendix 13.29.

The main conclusions of the expert focus group are described in the next paragraphs and are split in the following topics: Single-actor or multi-actor application of the tool, the value of the tool for different types of stakeholders, application of the tool during different decision moments and other decision support tools. These are addressed in succession.

It is most likely that the model will be used for single-actor explorations of the solution space instead of in multi-actor decision-making processes. The reason for this is that the model is very transparent on profit and development costs. This transparency is not desired by private stakeholders. The model gives clear and fast insights in the different possibilities and can therefore be used for exploration of the solution space from the viewpoint of different kind of actors.

The added value of the model is present for real estate developers and the municipality. However, this is not equal all real estate developers. The focus groups identified two different types of real estate developers. These days many large real estate development firms use predesign (conceptual) designs. This implies that most of the design and installation technology has already been fixed on forehand. This model will not be very useful for them in their decision-making. However, those conceptual dwellings are developed incrementally. The model can be used to assess the current quality of those dwellings. That would be on a building scale and there are more sophisticated detailed decision-design support tools that would be more useful. The second group of real estate developers consists of the ones with a more traditional approach, those design all their dwellings from the ground for every project. The focus group sees opportunities for the model for those developers. Which installations do I need in my dwellings for the most profit? Which program of dwellings is best in this development? The second stakeholder who can have added value from the model is the municipality. Municipalities have to define ground prices and energy ambitions for public-led developments. However, according to the focus group, they found it difficult to set the right price level for a high energy-ambition. The model can help municipalities to define the optimum between ground price and energy ambition, without having the risks of setting a too high or too low price. This observation is new to the research process and tested in a quantitative method later.

The identified actors can apply the model during different decision moments. First, the model can assist the municipality in defining the minimum energy ambition or ground price in the program of requirements, before a project is tendered to the market. Second, the model can assist the real estate developer and/or municipality in the composition of the dwelling programme before the urban design is created. And third, the model can assist the real estate developer in exploring the possibilities with the decision about the final installation technology and dwelling size used even after the dwelling program is fixed. This means that the typology (e.g. terraced dwellings, semi-detached dwellings and detached dwellings) is fixed and not the usable floor area. The model can determine the optimal dwelling sizes in relation to profit and installation technology used.

The expert focus group concluded with that there are many other decision support tools and that currently GPR Stedenbouw is often used for quantification of sustainability ambitions (e.g. energy, comfort and health, future value). This tool has a wider approach and is commonly recognized. It is not likely that the created model can compete with that tool.

In addition to what is said and concluded, Bryman (2012) also states that is interesting to look at the group interaction and observe what is said non-verbally or occurred during the discussion. In this case new knowledge was shared about the upcoming energy legislation and extra borrowing capacity for highly energy efficient dwellings during the session. The model thus also teaches experts in the field about new possibilities and changing legislation.

Concluding, the model has added value in the exploration of the decision problem from a single-actor viewpoint. Its high level of transparency makes it less interesting for multi-actor decision-making. The relevance is bigger as only for the real estate developer, although, the model is initially design for that actor. The model can assist during different decision moments, for instance about the energy ambition, ground price, dwelling program and installation technology needed. The model can also serve as a learning tool for new possibilities within new legislation.

9.4 Application of DST from viewpoint of other stakeholders

The expert focus group had the shared opinion that the decision support tool also could be used for the viewpoint of the municipality to determine the optimal balance for the energy ambition and the ground price (Nan *et al.*, 2017). In this part this idea is quantitatively tested by several runs within the model. The results are discussed.

The runs used the same input data as the first runs of the model (see Table 14 for the input and Figure 62 for the outputs). In these runs the possibility to increase the selling price is excluded as compared to the real case. Two runs are executed, one with and one without ESCO. The profit rate is fixed at 7%.

The dwelling mix consists in both cases of small size terraced dwellings with a GSHP[79]. In the first run without ESCO, the extra profit made is €106.612,60. This is 0,47% of extra profit (based on total construction costs), however, this profit is made on the corner-terraced dwellings, while the mid-terraced dwellings make losses. If the profit rate is fixed at 7%, the ground price could be increased with about €630 per plot. In the second run with ESCO, the extra profit made is €4.286.776. This is 14,38% of extra profit (based on total construction costs). If the profit rate is fixed at 7%, the ground price could be increased with about €25.216 per plot. That is a huge difference. It must be notified that this would be the maximal ground price. It does not take into account extra plan quality or the extra costs required due to the innovative characteristics of the development (first time ZOM). It also made the implicit decision that the real estate developer has to collaborated with a third party investor like an ESCO. In general, the model gives the municipality an indication about the feasibility of an energy ambition in combination with the ground price and therefore the model has added value to the municipality.

9.5 Conclusion

This chapter explained a quantitative and qualitative investigation to identify the added value of the created DST by applying it to the in-depth described case study and comparing the outcomes of the LP-model to the real life situation and by reflecting upon the final design by means of an expert focus group. In that way an answer is provided to the third sub-research question:

> *What is the added value of the decision support tool in decision-making processes for the realization of ENRND-projects?*

The added value of the DST is that it can help in decision-making processes of ENRND-projects. The DST incorporates the interests of different stakeholders and optimizes one aspect of a single stakeholder. Thereby it indicates if there is a feasible solution space which is satisfying to the interests of the different stakeholders. In this way the DST has several advantages:

- The DST can bring fast exploration of the possible solution space and indicate if the constraints set offer a feasible solution. In that way no trial and error methods with architects and urban design who incrementally design new design alternatives are needed anymore. Therefore, the DST can speedup decision-making, because the actors are not required to spend time and money on architectural design which have infeasible boundary conditions.
- The DST can quickly show the effects of the decision variables on the business case. In that way the DST can improve the insights of the skilled and experienced professional and it also teaches the other none-experiencied practitioners about the effect of their decisions by showing it. Thus, the DST has an educational component.
- The DST can rapidly confirm or reject the statements of different stakeholders. In that way the barrier of the information gab can be reduced. In this way the other team members can also be convinced about the feasibility of certain proposes.
- The DST can be used to rapidly explore the results of other perspectives and in that way the solution space can be mapped.
- The DST integrates the different financial explotations and gives only results in case the business case is feasible. In this way the barriers of the split incentives and the difficulty to get a feasible business case are reduced.

[79] The output was the same figure as the presented dwelling mix (upper left graph) in Figure 60 and Figure 61.

With all those advantages could the DST help as guidance and as a means to provide insight in the various possibilities by exploring the solution/ design space in multiple decision moments from first feasibility of urban design to installation technology within building design. The DST helps to optimise the results without requiring any dependence on the computer model. The DST brings fast results and could also be useful in showing laymen the extent of the effects of changing the decision variables.

The DST is useful for more than one actor to explore their optimal solutions. The DST has succesfully been tested from the viewpoint of both the real estate developer and the municipality.

The DST is also useful in different decision moments within the initiating phase of the development to explore the possibilities. The DST can be used for exploration or determination of: 1) the feasibility of the energy ambition or ground price in the program of requirements, 2) the composition of the dwelling programme before the urban design is created. And 3) the possibilities of the final installation technology and dwelling size used after the dwelling program is fixed. During all these moments, the model can determine the optimal dwelling programme and dwelling sizes in relation to profit and energy-related installation technologies used.

The DST has some limitations. The first one is indicated by the expert focus group. It is highly likely that the usage of the DST in a multi-stakeholder decision-making processes is little, due to its transparency. Therefore, the stakeholders with a financial focus would feel a loss of power to the benefit of the less experienced actors. A high level of transparency would negatively influence the bargaining position of, for instance, the real estate developer. The second one was indicated during the development of the DST by the unstructured interviews. In 2018 the new MPG-legislation will play a part in construction projects and it is expected that these regulations will become stricter, which is increasing its stake. That is why it would be useful to take this into account. This can be done in future research. Lastly, the DST only works for the demarcated focus of this research, thus for the all-electric energy concept applied on neighbourhoods consisting of single-family and owner-occupied dwellings. In addition, the input variables have to be adapted to the specific situation, because results are not generalizable for all dwellings or project types. The expansion of the demarcated focus can be executed in future research.

Concluding, the DST as many advantages to speedup the decision-making process by rapidly showing actors the feasibility of their combined interest, teaching them the effect of their decisions and more. The DST can be used from the viewpoint of various actors. However, in the end the LP-model can only optimise one aspect related to one actor and is therefore not naturally suited for multi-actor decision-making processes. The DST can be usefull for exploration of the solution space of ENRND-projects from the viewpoint of a single actor.

PART 5
SYNTHESES

Energy ambition	Future proof
Project	‘Nieuw Kortenoord’
Location	Wageningen
Real estate developer	BPD

10 Conclusion

The conclusion provides an answer to the problem of the increasing legislative requirements for the energy performance of all-electric, single-family and owner-occupied dwellings on a neighbourhood scale level from the viewpoint of the real estate developer in the realization of energy neutral residential neighbourhood development (ENRND)-projects and how this market party can optimise the business case of these ENRND-projects. Energy neutral in this research incorporates only the building related energy demand. The term ZOM-dwelling is used in case the energy performance also incorporates the household related energy demand.

The conclusions of the optimal business case and the developed decision support tool (DST) are based on the case study, expert focus group and the linear programming (LP-)model. The outcomes of these different research methods show that:

- It is feasible for a real estate developer to realize the highest energy ambition of present-day, zero-on-the-meter, within current available methods and means.
- All aspects of the business case influence the feasibility to realize ENRND-projects.
- The designed DST has added value for the multi-actor decision-making processes within urban area development on a smaller scale level of a neighbourhood for the optimisation of dwelling program and energy systems

These general conclusions are further explained in the next paragraphs, which are separated in four parts based on the used components of a business case, namely organisation, finance, physical and legislation. Thereafter the conclusion about the added value of the designed DST is further explained.

First, the organisation aspect. The main barrier was the lack of knowledge and experience in the explored cases. In all cases integrated contracts (at least design-and-build) were applied and no indication of commissioning was found. In the in-depth case the ESCO was involved early in the project (in the pre-design phase), which had first the role of energy advisor and later of third-party investor. Both, the integrated contract and the involvement of the ESCO, brought knowledge of the construction, operation and financing of the ZOM-concept early on in the project. It was also expected that end-users and grid operators were involved early on in the projects. This was not always the case. The grid operator was often just informed about the project and it was hard for the real estate developers to get information from them. Cases were identified with all kinds of public-private partnerships, however, the partnership model gives an indication of the incentive for the real estate developer to achieve such high energy ambitions, which is explained in the last part of the conclusion. In the DST the organisational aspect was only optimised for the ESCO, because that was the only one with a direct financial effect. Therefore, integrated contracts and involving knowledge early on in the project found to be of key importance in the optimisation of organisational aspect of the business case.

Second, the optimisation of the financial aspect of the business case was done in the cases by either the involvement of third-party investment (i.e. an ESCO) or an increased selling price was required to realize the ZOM-ambition. The increased selling price was made possible by an additional borrowing capacity for the mortgage for A-labelled and ZOM-dwellings. According to the results of the LP-model it is hardly possible to create a feasible business case without one of those solutions. These results also indicated that the ESCO is useful in the Netherlands, especially to keep selling prices low. However, the ESCO-concept is more expensive on the long run in sense of TCO for the future home owner. In most runs of the LP-model the TCO of the energy efficient dwelling was below the TCO of the reference dwelling, which indicates that energy neutral or ZOM-dwellings are profitable for the future home owners. This is further stimulated by the increasing price of natural gas. The additional borrowing capacity has growing possibilities (ZOM, A++), however, there are signs that the national government wants to change these possibilities and the calculation method. Besides both financial solutions, investment could also be postponed by developing future-proof dwellings. The decision is then postponed to the (future) home owner. However, in that case the energy performance of the dwelling is not realized as energy neutral. Postponement of investment in energy saving measures was not found in the described case study and also not incorporated in the LP-model. In addition, all real estate developers of the explored cases stated that they had little profit, due to the tender to win, due to the location or due the extra costs of the increased energy ambition. Verification is hard, but in case the ESCO was involved, the level of profit increased. Altogether, both the ESCO and the increasing selling prices with the additional borrowing capacity seem to be valid solutions to get a return on investment for the real estate developer on the extra invested capital and to get lower TCO for the future home owner. The increased selling price is financially most profitable, however, the specific market situation is leading in which solution is best, because those have to indicate if there is a market for an increased selling price.

Third, physically it is recommendable to apply a conceptual approach within the dwelling design and to the installation technology. This helps in a good integration of energy efficiency measures. The physical implemented solutions in the case study are on the scale level of a single-building because of the risks related to large pre-investments and a sense of ownership for the future home owner. All energy concepts were based on ground source heat pumps and PV-panels. These heat pumps have high investment costs, but are costs-effective in the long run, due to the high COP-level. Heat pumps require the usage of low temperature heating systems for optimal efficiency. All explored cases solely depend on PV-panels for on-site generation of electricity. The whole dwelling is powered by the electricity supplied by the PV-panels and therefore the amount of roof surface is gaining importance in the dwelling design. The LP-model indicated that in some runs, the amount of roof surface was the limiting factor to make larger dwellings possible. In addition, some features of passive solar design are used on the scale level of a dwelling, especially the parts of passive design to insulate the dwelling (e.g. extra insulation, airtightness and ventilation) and the parts of passive solar design to prevent overheating in summer, however, theory had already indicated that passive solar design will not solve the problem. It was also not found that passive solar design was applied on the scale of a neighbourhood. The described measures taken are not all energy efficiency measures implemented in the ZOM-dwellings. However, these are the most important ones. All measures are related to each other, which shows again the importance of the conceptual approach.

Fourth, the aspect of legislation. In BENG-legislation it is not possible anymore to compensate between demand and supply, therefore the tightening legislation demands more as only adding a few more PV-panels. The modelled output showed that BENG-legislation could lead to bigger dwellings, which consume less energy per m^2, but consume more energy in absolute sense. During the test runs the LP-model selected wind energy as preferred solution, because this is cheaper per kWh as solar energy. However, it is not possible to construct a windmills next to every block of dwellings.

Altogether, the outcomes of the different research methods show that it is feasible for a real estate developer to realize the highest energy ambition of present-day, zero-on-the-meter, within available methods and means.

The designed DST has added value for the multi-actor decision-making processes within urban area development on a smaller scale level of a neighbourhood for the optimisation of dwelling program and energy systems. The DST could help as guidance and as a means to provide insight in the various possibilities by exploring the solution/ design space in multiple decision moments from first feasibility of urban design to installation technology within building design. The DST brings fast results and could also be useful in showing laymen the extent of the effects of changing the decision variables.

Lastly, the reason why the real estate developers in the explored cases realized a higher energy performance as required different per case. However, a consistence is found in the incentives and the used public-private partnership models. First, in case of the public realization, the real estate developers realized a higher energy ambition because it was required to win the tender or it helped in winning the tender. Second, in case of the private realization, the real estate developers found a market for those increased energy efficient dwellings and expected an increased return in market value. Also, in these cases the real estate developers used the project to learn for future projects when the legislation is further tightened. In all cases the real estate developers used the project to brand their own company.

This research provided proof that it is possible to realize in a financial profitable manner ZOM-dwellings on a neighbourhood scale level. All projects did not develop a complex district energy system requiring huge pre-investments and an increased risks profile. In some cases, the knowledge, skills and financials were provided by third parties (i.e. ESCOs) and therefore, it is not required to have all this expertise and possibilities in-house. Both implies that the identified strategies to optimise the business case of ENRND-projects can also be applied in smaller scale projects and that it is possible for smaller real estate developers who lack the specific knowledge and skills. There are different possibilities to optimise the business case, but a coherent strategy between them is required, which makes the decision-making in the first project phases of fundamental importance for successful realization of an increased energy ambition in the realization of energy neutral residential neighbourhoods by the real estate developer.

11 Discussion

This research investigated the optimal business case of the real estate developer in developing energy neutral residential neighbourhoods consisting of all-electric, single-family and owner-occupied dwellings. It shows that it is financially viable for both the real estate developer as the end-user to develop such dwellings. There are some key elements that have to be incorporated to realize such dwellings, these are: 1) an integral energy concept based on many integrated installations, 2) early involvement of knowledge about the construction and operation of such concepts and 3) new financing methods.

In the coming paragraphs a reflection is given on the relation of the research outcomes to the reviewed theory, the level of sustainability on the long run of the outcomes. That indicates if the current ZOM-concept is a good strategy from the viewpoint of sustainability to recommend to real estate developers and municipalities. Thereafter limitations and advantages of the used research methods are presented. The discussion ends with a view upon future directions of ENRND-projects.

11.1 Reflecting on theory

The reflection on theory is described in three parts based on the chapters of the literature review, namely complex decision-making in (sustainable) urban area development, quantitative decision support systems leading to the LP-modelling technique and the optimisation of the business case of ENRND-projects. For reasons of brevity only notified deviations of the presented theory in the literature review and possible additions to the current body of knowledge are discussed. The part ends with the key moments to involve the designed DST.

There are two topics of discussion on complex decision-making in (sustainable) urban area development, namely the incentives of real estate developers as discussed by Buskens (2015) and private sector-led urban development projects, which looks the most like the concession model as discussed by Heurkens (2012). First, Buskens (2015) indicates in Figure 18 the most distinguished incentives for real estate developers to involve sustainability in their projects. All these incentives are recognized in the interviews, however, as also can be seen in the figure, the financial incentive is often not presented. The figure speaks about financial profits based on the investors perspective. This research indicated that there is a feasible business case for the current highest energy ambition of ZOM-dwellings and because of the additional borrowing capacity home buyers does not have to decide between emotional arguments (e.g. comfort, larger dwelling size, new kitchen or bathroom) and rational thinking in sense of the TCO. The expectation is that new research would indicate an increasing importance of this financial incentive to involve in sustainable urban area development and that it has become relevant for the real estate developer instead of only for investors. In addition, the incentives seem to be related to the partnership model applied. In public realization the incentive was to obtain the permits, to comply with the regulations and to be distinctive with respect to the competition. The private realization showed incentives such as an expected market value of energy efficient dwellings and to create support among customers. Incentives such as marketing advantages and taking corporate social responsibility was found present in all projects, but of less importance. Second, the changing practice with the shift from public to private sector involvement, discussed by Heurkens (2012), Peek and Van Remmen (2012), Franzen *et al.* (2011) and more, was indeed notified. The private sector (i.e. the real estate developer) is taking initiative in their developments and get a more important role in public agenda setting. Heurkens (2012) speaks of a trend towards private sector-led urban area development projects and compares it to the PPP-concession model. However, during the whole research process, especially during the execution of the purposive sampling method, no case with the concession model was found. Till the mid-term presentation of P3 this research still involved private sector-led[80]. The lack of this collaboration scheme and the focus of on the real estate developer in all kind of development models made that this concept has been omitted from the research focus. In two of the four cases for which explorative interviews were held, the municipality had a decisive role in the realization of the energy ambition. Altogether, the real estate developer is important in the decision-making for the realization of ENRND-projects, although there is no focus on a public-private partnership scheme. This PPP-scheme has influence on the incentive for the real estate

[80] The title of the P3 report was even 'energy neutral and private sector-led residential neighbourhood development'.

developer and those incentives are changing by the growing feasibility of the business case behind ENRND-projects.

The second theoretical part involved quantitative decision support systems. This chapter resulted in the usage of the LP-modelling technique. The developed LP-model showed that LP-modelling can be used from a multi-actor perspective by incorporating all interests of the different actors by adding them as constraints to the model, but in the end the LP-model optimises the objective of one single actor. It is expected that the usage of the created LP-model in real life situations of multi-actor decision-making processes is little, due to its transparency (Nan *et al.*, 2017). This in line with the argumentation in Binnekamp *et al.* (2006) about transparency, which is still valid after more as ten years. Binnekamp *et al.* (2006) describes that the expert stakeholders of the urban planners and real estate developers perceive a loss of power to the benefit of for instance future inhabitants. The former dislike transparency, for instance, what if the future home buyer sees the amount of profit the developer makes on their house? That would negatively influence the bargaining position of the real estate developer. However, and this is additional to the knowledge presented in Binnekamp *et al.* (2006), the LP-model brings fast results and could also be useful for laymen and professionals in the education of new skills and insights. In that case no real numbers have to be used, but insight can be gained in the possible extent and the effect of changing decision variables in complex subjects, such as ENRND-projects. The information gab[81] can be reduced by using LP-modelling as educational device. In that way it is prevented that different parties use wrong arguments during decision-making processes and it is likely that this leads to other decisions.

The conclusion shows that many possibilities are possible in the optimisation of the business case of ENRND-projects. Some differences and future opportunities can still be identified when comparing the research findings to the theory. Organisationally not all expected non-traditional parties were involved and only one type of the contractual integration methods was applied. First, of the non-traditional parties was the grid operators the least involved, which is strange when comparing it to the impact on the electricity grid. Both projects have 100+ dwellings with the ZOM-concept. This was expected otherwise. Also end-users were only involved during the decision-making process in some cases[82]. Second, the application of commissioning is not found in any case. All explored case studies applied integrated procurement methods, which was the best solution according to Chao-Duivis *et al.* (2010). Financially both solutions to cover the extra investment in energy saving measures were applied. Postponement was not described within the in-depth case study, but it was founded in one explored case[83]. From the physical component are the main theoretical barriers of the inflexibility of the grid or the performance gab of Majcen (2016) neglected. Also theory indicated that more innovation is possible with enhanced integration of different components of the installation systems used in the ZOM-concept[84]. Some of the following parts of the discussion hint to a further improvement of the ZOM-concept, but this part already gives a first indication that the ZOM-concept could be improved, because of the lack of solutions to some barriers and the failure to utilize a few opportunities.

Lastly, a model was presented in chapter 4.7 to control the multi-actor decision-making processes during the initiative phase of urban area development projects by means of stakeholder management and creative interventions and optimisation. This model was based on J. C. De Jong (2016: 19), Spijkerman (2014: 7), Versteijlen et al. (2010) and Dym and Little (2004) in Barendse et al. (2012: 3). The created DST can be used within this process as guidance and as a means to provide insight in the various possibilities. The DST helps to optimise the results without requiring any dependence on the computer model.

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[81] Described by Glumac (2012) and WBCSD (2007) in chapter 4.6.2.

[82] See description of the project Helsdingen in Vianen of real estate developer Blauwhoed in Appendix 13.13. They used co-creation, which also provided information about the real market demand of energy neutral and ZOM-dwellings.

[83] See description of the project Nieuw Kortenoord in Wageningen of real estate developer BPD in Appendix 13.13.

[84] See the description of technological innovations in chapter 6.6.4.6.

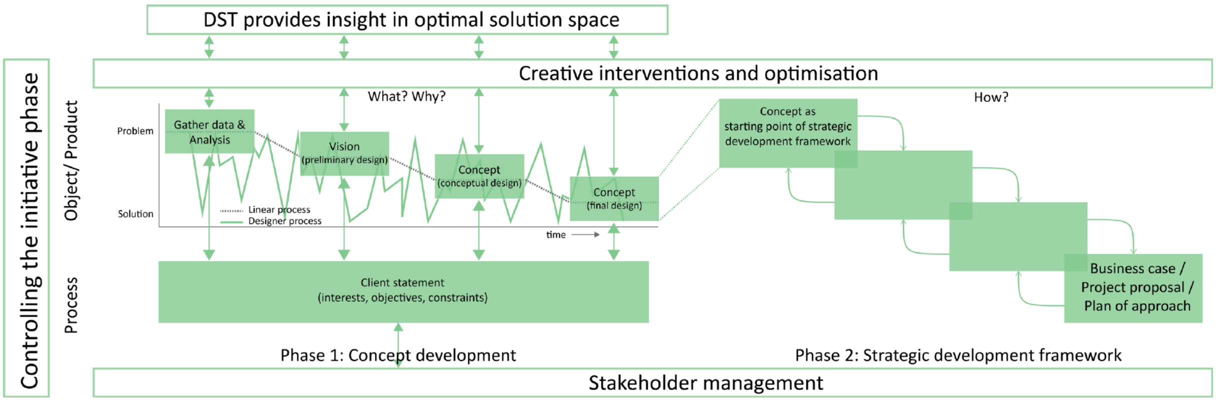

Figure 63: The position of the DST in the multi-actor decision-making processes during the initiative phase of urban area development projects. The LP-model can be used as tool for guidance and as a means to provide insight in the various possibilities (own illustration, adapted version of Figure 23).

The identified actors can apply the DST during different decision moments during the initiation phase of the development process (Figure 63 is part of the initiation phase), namely in determining the feasibility of the energy ambition or ground price in the program of requirements, in the composition of the dwelling programme before the urban design is created and by exploring the possibilities of the final installation technology and dwelling size used after the dwelling program is fixed. During all these moments, the model can determine the optimal dwelling programme and dwelling sizes in relation to profit and energy-related installation technologies used.

11.2 Reflecting on the level of sustainability of the ZOM-concept

The research outcomes present ZOM-dwellings as the highest energy ambition currently realized in residential development projects, but how sustainable are they on the long run? Several points indicate that a lot of improvements can be done in the current energy concept. First of all, in comparison to the dwellings constructed 10 years ago that only had a natural gas-boiler for the hot water supply, the ZOM-dwellings needs a lot of installations for the reduction of energy losses and for the generation of thermal and electrical energy (e.g. PV-panels, heat pump and a ventilation system). These technologies have a short life span compared to, for instance, additional insulation or the design of the house. Those technologies have not the lowest environmental burden, especially when the extra environmental burden that these technologies have in their manufacturing process is taken into account. However, the electricity supplied by the grid in the Netherlands is very inefficiency generated with an average efficiency of ±39%[85] and therefore the environmental burden of dwellings using electricity from the grid is bigger compared to ZOM-dwellings, because of the indirect consumption of large amounts of primary energy resources[86]. Of the various commercial alternatives, the ZOM-concept seems the least bad alternative.

However, this alternative cannot be recommended to be implemented by real estate developers and municipalities without any doubt. Two reasons from different stakeholders are presented. First the end-user is faced with an increase of TCO on the long run in comparison to the alternative ZOM-concept with the increased insulation (i.e. based on the passive building standard), because the concept based on installations, such as the heat pump and the PV-panels, has higher maintenance, replacement and usage costs[87]. It is very likely that the real estate developer will not select the alternative with the lowest TCO, because of the increasing construction costs, which reduces the residual land value. Besides future costs, some end-users currently complain about the lack of hot shower water in the ZOM-dwelling[88]. The solution for this would be to increase the output of the heat pump, however, this requires an increase of electricity usage and a related increase of annual electricity costs. This also effects the level of sustainability when taking into account that the electricity from the grid has a high

[85] This can be calculated by an inversion of the primary energy factor of 2,56, which is obtained in Kruithof and Haytink (2015: 10).
[86] The difference in environmental pressure of dwellings with a high annual energy demand, dwellings constructed according to the building degree and ZOM-dwellings is visible in Figure 31 and Kurstjens (2017: 23).
[87] This is supported by research of Valk (2013).
[88] See Van Delft (2017) as example. The energy concept with the heat pump needs (more) time to increase the water temperature in comparison to a HR boiler and that is why it is possible that end-users get a cold shower.

environmental burden in sense of primary energy. Second, the grid operator is faced with an increased impact on the grid. The balancing agreement allows the ZOM-dwelling to use the electricity grid as a free battery pack and the grid needs to be adjusted if more than 10-15% of the dwellings in a street became ZOM-dwellings[89]. That is not (financially) sustainable on the long run and other incentives for this are necessary. For instance, by abolishing the balancing agreement. In that case end-users are stimulated to use their own generated energy. This can be done by battery storage or by peak shifting, which is shifting the electricity usage to times of own electricity generation. This reduces the dependence of end-users on the grid, and thus reduces the dependence of the central power plants that generate energy based on natural gas and coal. Currently, these polluting power plants are still needed as full backup for times when there is no wind and no sun, and therefore no renewable energy. Therefore, it can be states that ZOM-dwellings still use grey energy. They only compensate it by ‘dumping’ renewable energies into the grid in case they have a moment of over generation. As long as the ZOM-concept remains in their present form, the need these polluting power plants will remain. That is why, from a sustainable point of view from different actors, there are further optimizations of the ZOM-concept possible.

The ZOM-dwelling does relate to other topics of sustainability. The ZOM-dwelling provides a more comfortable and healthy indoor environment and lower energy costs. This is especially valid in case an older dwelling is upgraded with the ZOM-concept, in that case undesired air flows and moisture can prevented and the lower energy costs combats energy poverty. This combination of the technological-economical optimisation with the desires of the end-user, such as comfort and health, is the focus of the current applied research of the ZEN-platform. Furthermore, the ZOM-concept has little links with other sustainability measures. Sustainability is broader than energy, as stated in the chapters on sustainability[90]. Energy savings are directly noticeable in the wallet of households and that is why market parties involve the topic of energy, because of the related business case. However, the other sustainability measures on social (e.g. health, social cohesion, etc.) and environmental (e.g. water, biodiversity, etc.) should not be forgotten.

Concluding, are ZOM-dwellings a smart strategy from an energetic / sustainability point of view? Yes, for now, but sustainability is much more. The current ZOM-concept could be the basis for further improvements. In the next versions, the negative effect on the electricity grid and the environmental burden of the manufacturing process of the installations can be decreased. This has to be done by taking the social and financial viewpoint into consideration for the realization of a concept that improves on all aspects of sustainability.

11.3 Reflecting limitations and advantages of research methods

The coming paragraphs reflect on the validity, reliability and generalizability of the research findings based on the used research methods and reflects on the limitations of the DST.

There are some limitations for this research based on the validity and reliability of the research results in both the qualitative first part and quantitative second part. First, for the explorative qualitative first part an extensive search has been executed into policy documents and all kind of other documented data. These insights were verified and extended by semi-structured interviews with the related real estate developer. This addresses the topic of triangulation of data sources. There is one limitation of this approach. There is no validity control executed with other stakeholders on the answers given by the representative of the real estate developer, because only one interview per case is executed. A lack of available time and data saturation were the reasons that this was not executed. The document review and the interview shaped a holistic view about how the business case of the energy concept was developed and there were no contradictory findings. Therefore, the qualitative results are found to be valid and reliable. Second, the outcomes of the LP-model were continuously compared to known projects, as assessment of the reliability of the quantitative part. In this way the LP-model has been calibrated and adapted till it gave reliable results. However, the real input numbers of the real life case were unknown, therefore, the outcomes of the LP-model must have been different. That is why presented outcomes of the LP-model cannot be presented as real numbers, they only give an indication about the relationship of certain aspects and the size in which it effects those. Lastly, the expert focus group had useful outcomes, although, the expert focus group contained of people with the same background knowledge due to

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[89] Molengraaf (2017) discussed the impact during this presentation. This impact is visualized in Graph 7.
[90] See chapter 2 and Appendix 13.3.

time reasons. An involvement of professionals with different background knowledge would have enhanced the research. The findings are valid from their point of view. Altogether, the research produces valid and reliable results, although, the quantitative outcomes of the LP-model cannot be presented as comparable to reality, because of the lacking input data.

The conclusions of the case study and the model outputs cannot be generalized to the whole population of ENRND-projects, because of the used case study method, which objective is not to confirm or to quantify, and the applied sampling methodology of purposive sampling[91]. The objective of the exploring case study was to gather an in-depth and holistic insight in how different aspects of the business case and the development context have affected the optimisation and realization of the increased energy ambition. Those aspects can be different in other circumstances and therefor the identified solutions within one case study are not generalizable to other contexts. In addition, the sampling approach looked for cases which are best suited to answer the research questions. These are not necessary the cases that best reflect the typical case within the whole population. The results are specific for the projects and bound to the locations and therefore, the best solutions for one case/location are not per definition the best for other cases. However, the outcomes of this results provide useful lessons for other cases.

The LP-model can be used for exploration of the initial phase of the ENRND-project after the decisions have been made to focus on an all-electric concept with single-family and owner-occupied dwellings. The LP-model incorporates assumptions and simplifications of the official calculations and can therefore not be used for the optimisation of detailed, official calculations[92]. The impact of the limitations is only little and therefore the outcomes of the model are still valid and reliable. The level of reliability depends on the input values, if those are wrong the outcomes are not reliable as well. The LP-model is not applied in a real life decision-making process and it is therefore unknown how the model functions as DST in real life. For the optimisation of the business case the LP-methodology is founded to be useful as it is relatively easy to learn, demands the computational power of an average laptop, gives fast results and the model can relatively easy be adapted to add new constraints (i.e. of new stakeholders).

Concluding, the research findings cannot be generalized to the whole population of energy neutral residential developments. Though, interesting lessons learned are produced for practise. These lessons learned are based on multiple explorative case studies, one in-depth described case study and quite reliable outcomes of the LP-model. The LP-model can be used as DST in the explorative initial phase of an ENRND-project. The LP-model optimises the results from a single-actor point of view and incorporates the interests of multiple stakeholders in this optimisation. That is why feasible results should be acceptable to all involved actors in the decision-making process[93].

11.4 Future directions of ENRND-projects

Rapid changes can be expected in the close future. This change is encouraged by new legislation, higher possible ambitions and increasing technological advancement.

The combination of the new legislations has to ensure a higher level of sustainability of energetic dwelling-concepts. The balancing agreement (Dutch: '*Salderingsregeling*') is fundamental for the current ZOM-concepts. Adjustments of this agreement is expected in the near future. The new norms in the legislation about the Environmental Performance of Buildings (Dutch: '*Milieuprestatie Gebouwen*') will affect the materials used in zero energy building concepts. The introduction of BENG together with these changes demands for a further improvement of the ZOM-concept, which is in line with the first part of this discussion. However, it is likely that the amount and the calculation method of the additional borrowing capacity is going to be changed[94]. In the worst case scenario that this amount will be reduced and the new dwelling concepts which comply with all three

[91] Chapter 3.7 on validity, reliability and generalization of the research methodology explains the reasons why.
[92] Appendix 13.31 gives insight in the limitations of the LP-model by a technical description of operation of the model and the impacts of the limitations on the outcomes of the LP-model.
[93] The municipality, real estate developer and end-user are incorporated in the DST. They are represented by the quantification of the urban dwelling program, financial feasibility and the TCO.
[94] This is based on the discussion notifiable in the House of Representatives, as described in Blok (2016).

regulations are still as expensive as the current ones, end-users have to make a more rational choice in the decision-making for their new dwelling, otherwise it is likely that the market value of the new ZOM-dwellings will be too low in relation to the development costs. The lawmakers should therefore come up with an integral solution regarding these upcoming new laws and legislative changes. Perhaps these changes start stimulating higher energy ambitions that also have a lower overall environmental burden, a lower pressure on the electricity grid and which are more affordable.

This higher energy ambition than ZOM is not the far future, as it is already within reach to create energy positive neighbourhoods. These can be realized with interventions on the level of the electricity grid and on the scale of individual buildings[95]. Solutions are based on flexible pricing to provoke peak shaving at the consumer level. The price of energy will be based on time slots of five minutes. The price will increase at times of peak demand and decrease when demand is low. This would encourage flexible usage of electricity by the consumer, which can be executed by demand side management for peak shaving and it is even possible for him to lower the energy bill and be less dependent on the electricity grid. In addition, the increasing usage of electric vehicles could stimulate a higher energy ambition for dwellings; what if a dwelling produces the amount of energy required for the building-related, household-related and personal transport-related energy demand?

Electric vehicles, smart grids and smart buildings are future steps in the improvement of the electricity grid and are related to the individual dwelling. Electric vehicles can serve as battery packs to help with peak shaving the electricity demand from the e-grid. However, they can also have a negative effect on the electricity grid, because recharging the batteries request a lot of electricity. Molengraaf (2017) state that it should be forbidden for an grid operator to expand the capacity of the grid for the peak demand of charging electric vehicles, if those vehicles are connected to the grid for 20h a day. Smart charging during off-peak moments can solve the issue[96]. Financial incentives should stimulate the charging at off-peak moments. If that succeed, large grid investments are not needed for charging those EV's. Smart grids are needed for a solid operation of the decentralized electricity grid. They have to deal with the increasing complexity[97] of the electricity grid to combine different electricity production processes and therefore they have to increase the flexibility to deal with the peaks of renewable energy supplies and demand (Itard, 2011; Molengraaf, 2017; Vreeburg, 2016). The role of the consumer is to apply demand side management in their home to shift load profiles of, for instance, electric vehicles, the dishwasher, the dryer and other appliances which timing can be changed. This DSM-systems transform dwellings to smart buildings. The smart grid and smart homes in the decentralized grid share all kinds of information to optimally match the renewable energy supply to the demand for electricity, and thus local renewable energy generators, batteries, for example in electric vehicles, and household appliances work together to maximize to use of the available renewable energy and prevent overloading the grid.

All these developments will affect the method for developing ZOM-dwellings. Legislation, financial incentives and technological enhancement make higher energy ambitions than ZOM possible which have a lower environmental burden and are financially more attractive.

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[95] Monti *et al.* (2017) proposed in his book 'Energy Positive Neighbourhoods' modelling techniques and business plans to make energy positive neighbourhoods financial viable and technological possible.

[96] There is a difference between regular charging and smart charging on the peak load. When regular charging is applied, peak demand is high from 18 o'clock till 20 o'clock in the evening (when people are coming home and thus also other appliances are starting to use more electricity due to usage). Smart charging uses peak shaving to charge the electric vehicle during the off-peak moments (i.e. during the night).

[97] "*Future electricity grids are expected to increase in complexity by combining different electricity production processes: electricity from power plants, but also from wind or solar energy produced by the consumer itself, must be fed to the grid and the supply must be matched to the demand: what source should be used when? […]. Electricity produced by wind is used when there is wind. If there is no wind, other sources like a central power plant are used.*" (Itard, 2011: 150)

12 Recommendations

This last chapter summarized the recommendations mentioned throughout the report. The recommendations are based on the conclusions of the main research question, the sub-research questions and the discussion. They are split for research, practise and policy.

For research:

- Exploring the implementation of additional functions within the DST, such has higher scale levels, other functions (e.g. retail and/or offices), other energetic solutions (e.g. heat grid, IR-lighting, biomass and/or geothermal) and/or multiple layers of (sustainable) urban development.
- Exploring the involvement of comfort for the end-user within the optimisation. The current tool optimises a technical-economical problem. Adding comfort would add the social component of sustainability and is in line with the current research within the ZEN-platform. This platform implements applied research for market parties on this subject.
- Implement the MPG-legislation as improvement of the current DST. This updated version calculates the optimal cost-environmental solution by including the total environmental burden of the used energy installations. This total environmental burden includes among others the energy burden of the construction of the energy installations. This improvement would make it a life cycle optimization.
- Testing the application of the DST in a real decision-making process.
- Explaining the market value of energy efficiency in dwellings. Research is already done, but the market value is changing rapidly (J. W. J. De Vries, 2010; Hooijschuur, 2013; Van Groenestein, 2011; Wilting, 2012). This research needs an update and recommendations are needed in how the market value could be improved.
- Exploring the role of institutional investors and housing associations in ENRND-projects. The current research was focused on owner-occupied dwellings. The research question would be like; how can the business case of energy neutral developments be optimized for rental dwellings? Research for housing associations is already executed, but the institutional investors are getting an increased market share in the Netherlands (CBS, 2017d) and their role is interesting. These parties have a vision and strategy for the long run. Their role could be vital.
- Exploring and explaining the role of the ESCO in the Netherlands. They are currently hardly known, but this is different in other places in Europe (Bertoldi & Boza-Kiss, 2017). How can its role be increased in the Netherlands?
- Exploring and explaining the effect of a new calculation method for the mortgage capacity. Currently, there is the possibility for additional borrowing capacity within the total mortgage for dwellings with a high energy efficiency (Blok, 2014a, 2015a, 2016; Dijsselbloem, 2013). In 2016 the government proposed a research to change the calculation based on mortgage costs to living costs (mortgage + additional energy costs). What would this effect be for the development of energy neutral dwellings?

For practise:

- Using additional financing methods can make zero-on-the-meter dwellings financially feasible and can improve profit rate.
- Apply the DST in the decision-making processes for a fast exploration of the feasibility of the solution space and the optimization of the business case for energy neutral residential developments.
- Apply the DST on training activities for professionals for to get them to understand the effect of their decisions concerning utilization of energy saving and supply installations.
- Involve energy advisors early on in the process to show the energetic possibilities for the location, the selection of an energy concept and its optimal implementation.
- Involve residents during the development of their energy neutral dwelling. Majcen (2016) showed that many energy efficiency social rental dwellings in the Netherlands do not perform much better as theoretically expected. Education and motivation can have a huge effect on the energy demand (Staats, 2016).
- Keep a permanent eye on the rapidly increasing possibilities of technology. This is of key relevance, because the quick increase of efficiency of GSHP and PV/T-panels (Sarbu & Sebarchievici, 2014; Schiro *et al.*, 2017), which are having a huge effect on the possible design of the dwellings. In addition, IR-

lighting can become competitive to a GSHP, due to the lower investment costs and direct responds in temperature increase (L. De Vos, 2017).

For policy:

- Develop a nationwide plan of action to stimulate and streamline the energy transition. This needs to be on a nationwide scale, because provinces with a lower population density and only little industries have to compensate for the provinces with the larger population densities and big industries. Another element to consider is to tighten the energy legislation after 2021 in such a way that real estate developers are stimulated to develop zero-on-the-meter dwellings.
- Reconsider the formulation of the BENG-legislation, because currently in some cases it stimulates the development of bigger dwellings. Bigger dwellings consume more energy, which is counterproductive to the objective of BENG.
- Keep the additional borrowing capacity in green mortgages for ZOM in place. This additional borrowing capacity makes it possible to get ZOM-dwellings financially feasible and without it would require the involvement of a third investor or it would drop the residual value of land. The last effect creates a negative competitive position in relation to other dwelling types with a higher residual value of land.
- In relation to the above mentioned recommendation it is also recommended that policy makers suggest to explore the optimal amount of this additional borrowing capacity and the way it is calculated (see topic in research and discussion in the Parliament in Blok (2016)).
- Consider additional investments on the scale of the individual dwelling in case the balancing agreement will be abolished. This recommendation is relevant, because of the huge positive effect the balancing agreement has on the business case of home owners.
- Consider on the long run an adjustment of the MPG-legislation to stimulate the innovation of an installation system in an energy neutral dwelling that have a less environmental burden. This is relevant, because the model outcome proposes the most installation intensive solution, namely a roof covered with PV-panels, a GSHP, balance ventilation and more. This needs environmental improvement in the future. The current DST can be improved with this additional MPG calculation to define the optimal cost-environmental solution.

APPENDICES

Energy ambition	Zero-on-the-Meter
Project	‘Het Verborgen Geheim’
Location	Rotterdam
Real estate developer	Van Omme & De Groot

13.1 Appendix 1: Trends in Dutch energy prices for households

The depletion of natural gas cause increasing energy prices, which creates an incentive for Dutch residents to invest in energy efficiency. Van de Griendt and De Vries (2012), both working on sustainability for a large housing developer in the Netherlands, expect that the energy prices would continue to rise, but in order for home buyers to decide on energy efficiency, it has to be profitable and possible to pay for.

It is questionable if the energy prices really are increasing. The energy prices for households consists of a summation of the delivery price and taxes. The delivery price is the price of electricity for the households minus the governmental tax. Tax for electricity and natural gas consists of three parts: tax on electricity/ natural gas, the raise renewable energy and VAT (Dutch: '*Opslag Duurzame Energie*') (Belastingdienst, 2017). The raise renewable energy is a levy charged on natural gas and electricity to stimulate the production of renewable energy. The levy is introduced in 2013 and can incrementally be increased till 2028 (Kamp, 2012; Rijksoverheid, 2011). The RvO (2017e) gathered data on energy prices. The following statements on price changes are derived from these data. In the period before the crisis in 2008, both natural gas and electricity were subject to a sharp increase in price. Between 2001 and 2009 the total costs of electricity per kWh for households increased on average by 4,4% annually and in the same period the price of natural gas for households increased on average by 5,1%. But after 2009, the trend stalled. Between 2009 and 2016 the price of electricity decreased by 2,8% on an annual basis and the price of natural gas almost stabilizes by a growth rate of 0,64% annually. The decrease of the price of electricity was caused by a steep drop of the delivery prices by 50% (between 2008 and 2016). The delivery prices of natural gas were also highly fluctuating. Between 2001 and 2008, there was an average increase of 8,16% annually and between 2008 and 2016 the delivery prices decreased by an annual rate of 4,75%. For natural gas the biggest decrease in delivery prices (-22,98%) happened between 2014 and 2016. These fluctuations are being strengthened (in the case of electricity) and reduced (in the case of natural gas) by taxes. In 2016 the tax on electricity dropped 15,8% to €0,10/kWh for small scale consumers (<10.000 kWh), the tax on natural gas increased by 31,7% to €0,25/m3 for small scale consumers (<170.000 m3) and the raise renewable energy increased by a small step (Ministry of Finance, 2015).

On a worldwide scale level, fossil fuels have a high price elasticity. The oil is heavy fluctuating, indicated by a drop of 71% between June 2014 ($112/barrel of oil) and January 2016 ($32/barrel of oil), after a price increase of 188% (from $42 to $121/barrel of oil) since 2009. Coal stays cheap and natural gas is related to the price of oil (CBS *et al.*, 2016). The price elasticity is more related to the production and geopolitics than to scarcity in supply, because global supplies in the form of fossil fuels are equivalent to another 150 years of oil consumption, 360 years of gas consumption and 1320 years of coal consumption at the 2004 consumption rate (CBS *et al.*, 2007). However, since 2004 the global energy consumption has been increasing annually. In the period 2004-2014 the world consumption of natural gas increased by 25,8%, of coal by 36,7% and of oil by 13,1% (BP, 2014). However, the proved reserves increased as well (BP, 2014). It cannot be stated that the proved reserves are depleted sooner.

In other words, there are enough fossil fuels to supply energy to the world for more than a century. However, besides climate change, two aspects of the future resources supply demand for change. First, the supplies are limited. New (sources of) resources are required in the long run. Second, these resources are disproportionately divided over the world, causing dependencies on other countries for the supply of energy. It is questionable if the Dutch government would go along with these geopolitics.

The graphs on the next page show how much the prices of energy for Dutch households were fluctuating last decade. Data is based on RvO (2017e)[98].

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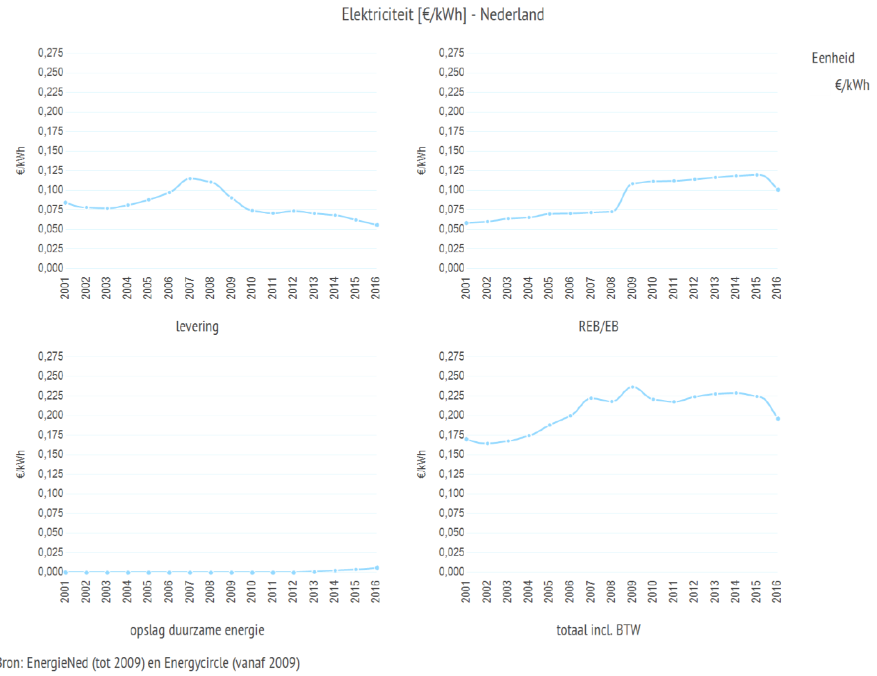
[98] RvO (2017e) got it from EnergieNed (till 2009) and Energycircle (from 2009).



Graph 21: Trends in prices of electricity for Dutch households. Clockwise explanation starting at the upper left figure: the delivery price of electricity per kWh; the taxes on electricity per kWh; the total costs of electricity per kWh; the extra tax on renewable energy surtax per kWh (RvO, 2017e).

Graph 22: Trends in prices of natural gas for Dutch households. Clockwise explanation starting at the upper left figure: the delivery price of natural gas per m3; the taxes on natural gas per m3; the total costs of natural gas per m3; the extra tax on renewable energy surtax per m3 (RvO, 2017e).

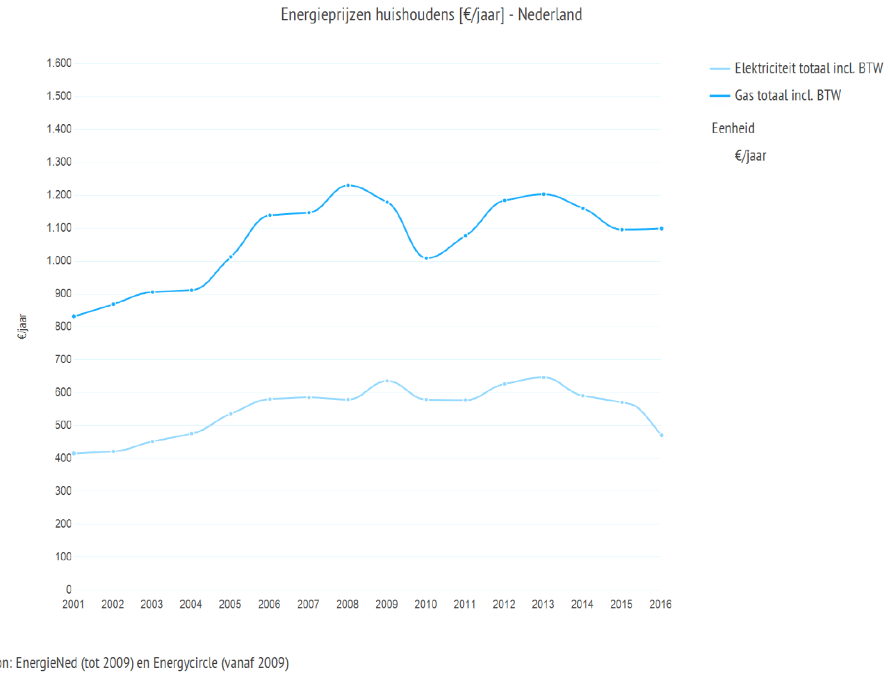


Figure 64: Average energy bills of electricity and natural gas for Dutch households in €/year (RvO, 2017e).

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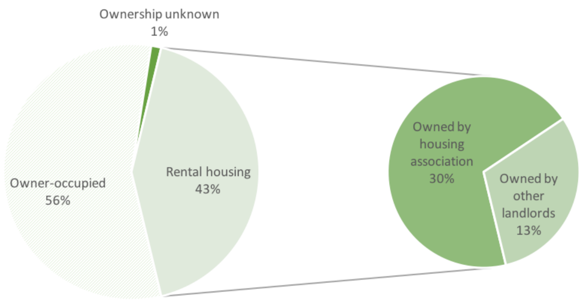
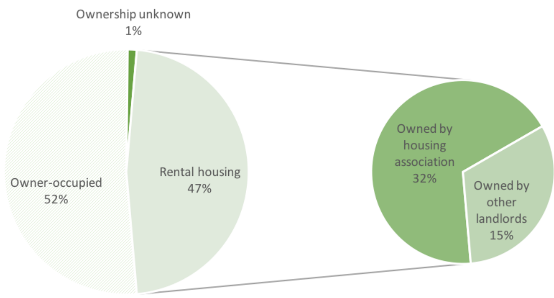
13.2 Appendix 2: Data on ownership of dwellings and dwelling types

This Appendix gives more information on the ownership of dwellings and the dwelling types within the building stock in the Netherlands and the Randstad.

Over half of the building stock in the Netherlands and in the Randstad consist of owner-occupied dwellings (see Graph 23, Graph 24).



Graph 23: Ownership of dwellings within the Netherlands in 2016 (own illustration based on data of CBS (2017d)).



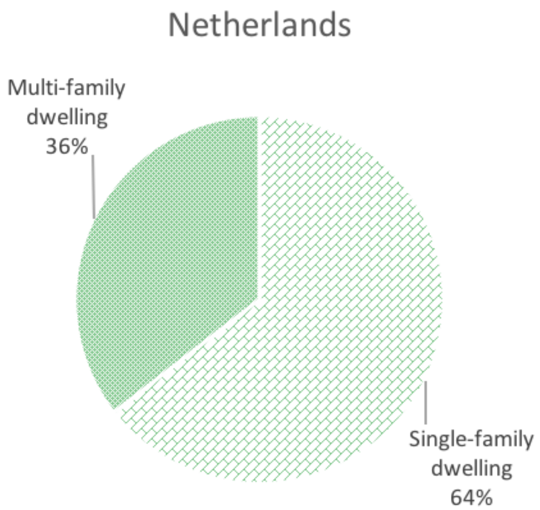
Graph 24: Ownership of dwellings within the Randstad in 2016 (own illustration based on data of CBS (2017d)).

Graph 25: Ownership of dwellings within the Netherlands and the Randstad over a longer time period. Note: Data before 2012 was not available (own illustration based on data of CBS (2017d)).

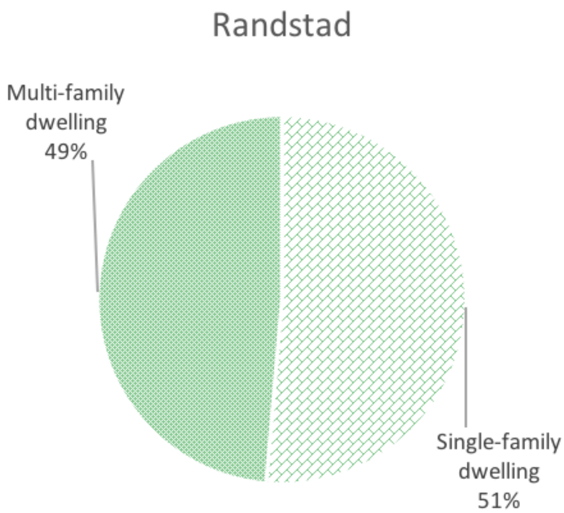
Table 17: Data used in for graphs about the ownership of dwellings within the Netherlands and the Randstad (own table based on data of CBS (2017d)).

Location	Year	Owner-occupied	Owned by housing association	Owned by other landlords	Ownership unknown
Netherlands	2012	4182889	2269883	852097	81874
	2013	4215587	2270528	898434	64749
	2014	4237007	2273976	939732	84600
	2015	4265934	2262930	966215	92885
	2016	4296719	2252640	994464	97500
	Change 2012-2016	2,72%	-0,76%	16,71%	19,09%
Randstad	2012	1744238	1148659	455507	38687
	2013	1761914	1145314	477992	30804
	2014	1773267	1142762	498538	39141
	2015	1790242	1135445	509866	43013
	2016	1807233	1127411	528815	41983
	Change 2012-2016	3,61%	-1,85%	16,09%	8,52%

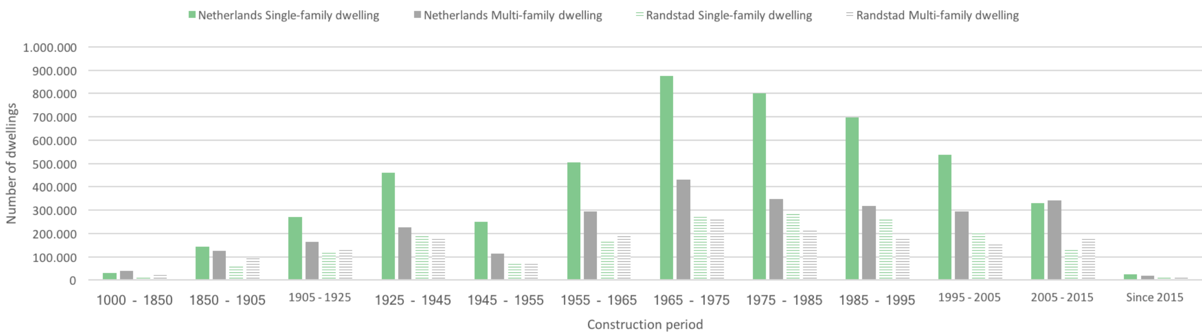
SFD are the majority of the dwelling stock in the Netherlands and in the Randstad (see Graph 26-Graph 28). The text in the report shows that this type is also the most constructed type at the moment.



Graph 26: Ratio single-family dwellings and multi-family dwellings in the Netherlands in 2016 (own illustration based on data of CBS (2017e)).



Graph 27: Ratio single-family dwellings and multi-family dwellings in the Randstad in 2016 (own illustration based on data of CBS (2017e)).



Graph 28: Amount of single-family dwellings compared to the amount of multi-family dwellings developed during different construction periods in the Netherlands and in the Randstad (own illustration based on data of CBS (2017e)).

13.3 Appendix 3: Need for sustainable development

This appendix discusses the major problems demanding sustainable development, its history and application as the triple bottom line.

13.3.1 Climate change

The first trend is climate change, the climate is changing and research showed that humans are causing this rapid change (Imbrie & Imbrie, 1980; IPCC, 2007a). An indication of how rapid is rapidly can be found in the report of the Intergovernmental Panel on Climate Change (IPCC, 2007b), which showed that eleven of the twelve years between 1995 – 2006 were the warmest observed years since the instrumental records began in 1850. The same organization (IPCC) states that "*anthropologic greenhouse gas emissions have increased since the pre-industrial era, driven largely by economic and population growth, and are now higher than ever.*" (IPCC, 2014: 4). The atmospheric concentrations of greenhouse gases (GHGs) are currently at the highest point in at least the last 800,000 years. The IPCC concludes it is extremely likely that GHGs are the dominant cause of the observed global warming (IPCC, 2014). In that way humans are causing climate change, which implies that humans can counteract this trend. This is a huge challenge. The effects could be devastating. For instance, more than two third of the cities are situated in a delta and thereby vulnerable to the indirectly consequences of climate change, namely the risk of flooding (Aerts et al., 2009). Flooding is caused by heavy rainfall and a rising sea level, which again is caused by the rising temperature. Global warming is part of climate change (Blackmore, 2010; IPCC, 2007b). There are still discussions if climate change is caused by humans. Schmidt and Wolfe (2009) computed that the odds of this being a natural occurrence are one in a billion! So, the change that these people are right, is very small.

It seems contradicting that on the one hand cities needs to adapt to climate change, and on the other hand, cities are a major contributor to climate change as well. This contradiction is due to the high density of all kinds of activities that come together in urban areas. A main contributor to climate change is the GHGs emitted by traffic, industry and domestic heating (EPA, 2016). Since this is happing substantially in urban areas, these are the places to implement measures to reduce the GHG emissions. The need of mitigation and adaptation in the built environment is clear, this is a huge problem to be tackled in urban (area) development.

In addition to climate change are the CO_2-emissions also causing other problems like health problems, the heat island effect and increasing the cooling demand of buildings. Reducing these GHG-emissions, and especially our CO_2-emissions related to the energy supply sector and building sector, helps to mitigate the effects of climate change. Without a drop in CO_2-emissions, the current society is effecting the possibilities of future generations, which is the core definition of sustainable development (also called the '*Brundtland definition*' of sustainable development):

> "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*" - Brundtland (1987: 43)

Robertson (2014) believes something is going to change in the planet we call our home. The change she envisioned is from a world "*situated either at the threshold of a planetary disaster of unprecedented magnitude or at the beginning of a new sustainable era. Whatever, the outcome, the new state of the world will not be like it is today.*" (Robertson, 2014: 3) This implies the need for a transition of our whole society in order to survive. One of these transitions is the energy transition, which is discussed later in this chapter.

13.3.2 Resource depletion

The second trend is the challenge of resource depletion. Even 30 years after the publication 'Limits to Growth' of Meadows *et al.* (1972)[99], the same writer still state "*the flows of energy and materials required to sustain industrial growth are depleting non-renewable stocks.*" (Meadows *et al.*, 2004: 129). Economic growth is generating environmental pressure and there are limits to ongoing economic growth, for that reason economic development needs to be realized within the limits of the carrying capacity of the earth (Meadows *et al.*, 1972; Meadows *et al.*, 2004; Tellegen, 2011). Worldwide cities are responsible for almost 75% of the global resource consumption, while covering only 2% of the earth surface (Madlener & Sunak, 2011). Concepts are introduced

[99] More about the history of the concept 'Sustainability' can be found in Appendix 2

to change the linear mind-set to a circular one, like Cradle to Cradle (McDonough & Braungart, 2002) and the circular economy (Ellen MacArthur Foundation, 2012), but further steps have to be made. "*We will have to develop fundamentally different production processes that organized in a different way and use different raw materials.*" (Kroeze *et al.*, 2010: 7) Resource depletion happens on worldwide and national scale levels.

In the Netherlands resource depletion is affected by their main resource for the Dutch energy supply: natural gas. The key role of natural gas in the Dutch energy supply sector is developed by having their own natural gas resources. Currently, the country is depending on this supply. Almost 100% of the household have a connection to the gas infrastructure and more than 50% of the countries' electricity demand is supplied by gas-fired stations (Bazelon *et al.*, 2010). This makes gas a major direct and indirect source of energy for most households in the Netherlands, but what is the future? In 2015 the Dutch government lowered the maximum allowed volume of gas to produce in Groningen. This measure should lower the risk of earthquakes. (CBS *et al.*, 2016) Van Rossum and Swertz (2011: 251) state in a report of the CBS that if new, economical feasible, natural gas reserves are not found, the current production rate of gas cannot be sustained for long. The Groningen gas is of low caloric value and therefore mainly used in households for heating and cooking. High caloric gas is used for electricity generation and imported from Russia and Norway (CBS *et al.*, 2016). This type of natural gas cannot be used without modifications in households. The prospect is that our natural gas reserves are empty in a few decennia (Van Rossum & Swertz, 2011). This prospect functions as window of opportunity for the society to create buildings that are not using gas.

13.3.3 The concept of sustainability

"*At its core, the word 'sustainability' refers to systems and processes that are able to operate and persist on their own over long periods of time.*" (Robertson, 2014: 3)

"*Sustainability is about seeing and recognizing the dynamic, cyclical and interdepend nature of all the parts and pieces of life on earth, from the soil under our feet to the whole planet we call home, from the interactions of humans with their habitats and each other to the invisible chemical cycles that have been redistributing water, oxygen, carbon and nitrogen for millions of years. [...] [Sustainability] is about the emergence of a new dynamic state of the world in which there is room for everyone, in which every living being can purse its right to live and to thrive, in which the great systems and cycles of the planet once again find their own state of durable yet dynamic equilibrium in patterns, form microscopic to local to global, that will endure over long periods of time.*" (Robertson, 2014: 3)

Sustainability is a term to bridge the gap between development and environment. Originally it came from forestry, fisheries and groundwater companies to deal with quantities, such as "maximum sustainable cut," "maximum sustainable yield" and "maximum sustainable pumping rate." (Rogers *et al.*, 2008: 22)

13.3.4 Getting sustainability on the political agenda

The attempt is now to apply this concept of sustainability on all aspects of development (Rogers *et al.*, 2008). The first awareness of the need for sustainability was created by the report 'Limit to growth' of Meadows *et al.* (1972). These MIT systems scientists applied dynamic system modelling techniques to calculate the result of the ongoing economic growth. Results were devastating. Figure 65 shows that increasing industrial output would deplete our resources on earth and increase pollution, while in the long run population would decline as direct effect of a decrease in food production. The research was commissioned by a think tank called 'The Club of Rome'. (Meadows *et al.*, 1972; Robertson, 2014)

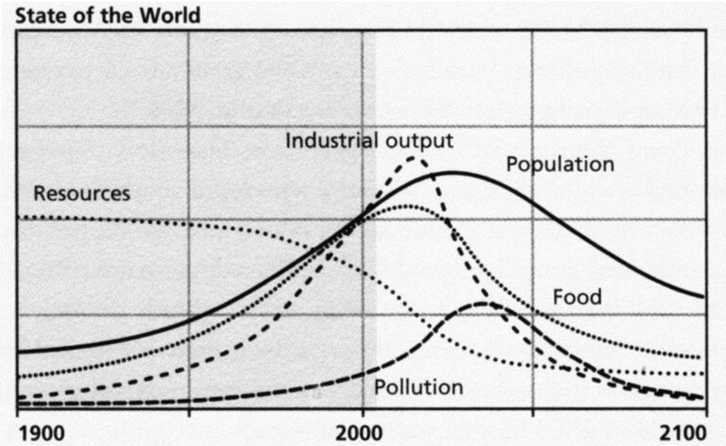


Figure 65: One of the scenarios of the report 'Limits to Growth' (Meadows et al., 1972).

In the same timeframe the first in a series of international initiatives was taken to counteract the deteriorating global environment. Ghosh Roy (2011) sums up the most important ones till 2002, shown in Table 1.

Table 18: Landmarks of international initiatives in the view of the deteriorating global environment (Ghosh Roy, 2011: 6)

Year	Landmark
1972	Stockholm Conference under United Nations Environment Programme (UNEP);
1985	Montreal Protocol on depletion of Ozone layer under the Vienna Convention;
1987	Brundtland report on 'Our Common Future' under the World Commission on Environment and Development under the U.N.;
1988	Establishment of Intergovernmental Panel on Climate Change (IPCC) jointly by the UNEP and World Meteorological Office;
1992	Earth Summit at Rio de Janeiro enunciating the famous 'Agenda 21' for sustained development;
1997	Kyoto Protocol under the Framework Convention on Climate Change 1992;
2002	World Summit Johannesburg, proposing Millennium Declarations on improving the quality of life.

In 1987 the World Commission on Environment and Development (WCED, headed by Gro Harlem Brundtland of Norway, submitted a report 'Our Common Future' in 1987, popularly known as the Brundtland Report, which presented the concept of sustainable development as an alternative to the policy of only economic growth (Ghosh Roy, 2011):

> "*Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*" - Brundtland (1987: 43)

The definition contain two key concepts (Ghosh Roy, 2011):

1. The concept of needs in particular the essential; needs of the world's poor, to which the overriding priority should be given;
2. The idea of limitations, imposed by the state of technology and social organisation on the environment's ability to meet the present and future needs.

The concept of sustainable development merges environment and economics in decision-making. "*This definition established the need for integrated decision-making that is capable of balancing the economic and social needs of the people with the regenerative capacity of the natural environment.*" (Rogers *et al.*, 2008: 42) "*The core idea of sustainability is that current decisions should not impair the prospects for maintaining or improving future living standards. This implies that our economic systems should be manager so that we can live off the dividends of our resources.*" Repetto (1986) in Rogers *et al.* (2008: 22)

13.3.5 The Triple Bottom Line

Early in the twenty-first century the research field of sustainability focuses on interactions among different systems. Robertson (2014: 38) state that "*sustainability sciences strives to understand the dynamics of ecological systems, social systems, and their interconnections as a framework for sustainability, bringing scientific rigor to the triple bottom line.*" This is one of the most often heard ideas in discussions about sustainability, or better known as triple P: people, planet, profit or economy, ecology, equality (triple E). In the Johannesburg Treaty in 2002 profit changed to prosperity and the triple P become: People planet profit/prosperity.

13.3.5.1 Environment (ecology/planet)

"*It refers to preserving and restoring the health of living systems. All life on the planet depends on ecosystems to purify air and water, pollinate crops, provide food, recycle waste, and to circulate atmospheric gases, chemical elements and energy; these processes are sometimes referred to as ecosystem services. [...] In order to create a planetary condition that is sustainable we must understand how these processes work, not just as individual pieces but as systems. We must see our own species as neither victims nor masters but as active members of the interconnected web of living being. We need to learn to live within our means ecologically, to recognize that there are built-in limits to any system known as its carrying capacity.*" (Robertson, 2014: 5)

13.3.5.2 Economics (profit/prosperity)

The Profit aspects concern about economic vitality and future values, such as local employment, flexibility and robustness. "*People need economic motivation to change. No person willingly chooses poverty if they know that other people are living comfortably and easily.*" (Robertson, 2014: 6) "*We must aim to a world that can deliver long-term prosperity to everyone, where people in every region live well.*" (Meadows *et al.*, 2004: 41)

13.3.5.3 Equity (social equity or equality, people)

The people aspects are related to liveability, like air, soil contamination, safety and quality related aspects as available green and social inclusion. "*Equity includes freedom from unhealthy living conditions and equal access to food, water, employment, education and healthcare. Equity means providing opportunities for all people, not just a privileged few, to grow and flourish in their own way.*" (Robertson, 2014: 6)

13.3.5.4 Fourth pillar: Spatial

Some researchers address a fourth pillar: spatial. According to Spangenberg (2002) this is especially important in the urban and neighbourhood context, because of the various forces and entities influencing the decision-making process.

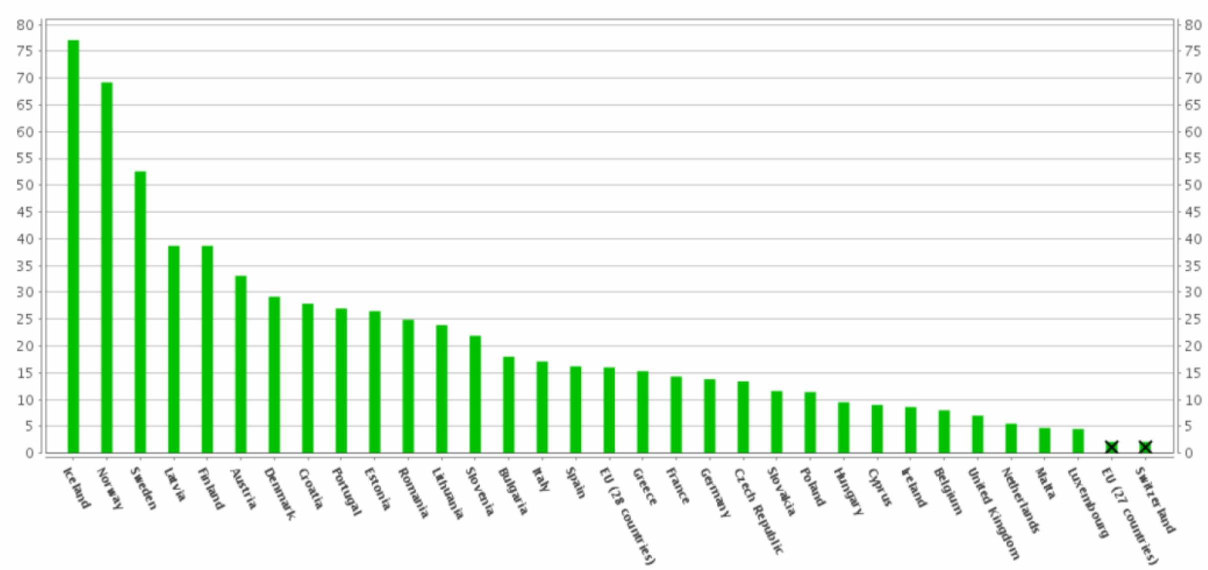
Table 19: Facets of sustainable urban area development (Buskens, 2015: 27)

Profit / Prosperity (Economics)	Creating a favourable business climate
	Stimulate local employee ships
	Stimulate local employment
	Attract long-term investments
People (Social, Equity)	Social security
	Social interaction
	Comfort and healthy living environment
	Social cohesion
	Human scale
	Demand driven development
	Good accessibility
Planet (Environmental)	Good public transport services
	Stimulate healthy transportation options (biking, walking)
	Interwoven components
	Self-sufficient (circular economy)
	Renewable energy sources
	Prevent environmental pollution
	Respect ecological structures
Spatial quality	Varied density
	Mixed-use
	Preserve historical quality
	Place making/create an own identity
	Flexible
	Robust
	'Stewardship'

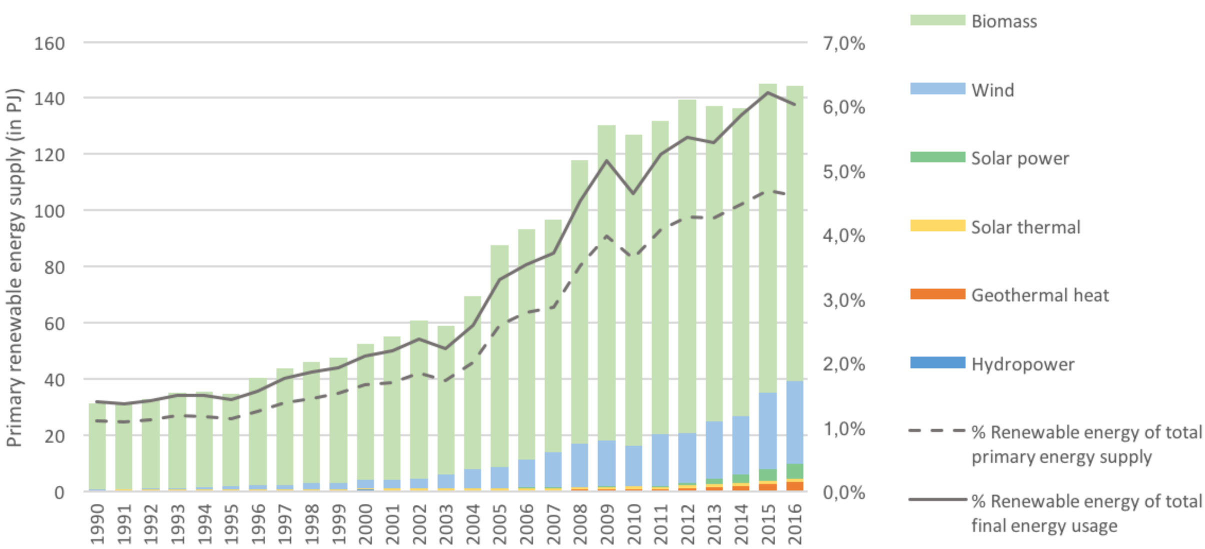
3P are effecting each other. Rovers, Kimman, and Ravesloot (2010) react to the importance of the 3P's. The basics for society are food, energy, water and raw materials. Without those a society cannot exist and can certainly not grow. These basics are used to create people's affluence and wellbeing. With abundance, society and culture and drive, without those resource, adaptation is need. This part is covering 2P's: people and planet. In the opinion of Rovers *et al.* (2010) the P of Profit only exist to facilitate and to give direction to the other Ps. They say that: "*Economy and policy can be adjusted, since they are not natural phenomena.*" (Rovers *et al.*, 2010: 18)

13.4 Appendix 4: Data on energy usage through Europe and within the Netherlands

The Netherlands performs very bad when comparing the renewable energy consumption and the reduction of CO_2-emissions to other European countries. Graph 29 shows the share of renewable energy compared to the gross final energy consumption (also called 'total final energy usage' within this report), only Malta and Luxembourg perform worse. Graph 30 shows an increase of the renewable energy production, which is mainly caused by increasing usage of biomass and electricity from windmills. The graph also shows that the share of renewable energy has grown 3-4%-point in 25 years in the Netherlands. The Netherlands performs better on the reduction of CO_2-emissions, however, in 2013 this was only about 8-9%-points compared to 1990 (see Graph 31).



Graph 29: Share of renewable energy in gross final energy consumption in % in 2014 (EEA, 2016)[100].



Graph 30: Primary renewable energy supply in the Netherlands in PJ/year and its share of the total primary energy supply and the share of the final energy usage (own illustration based on data of CBS (2017a)).

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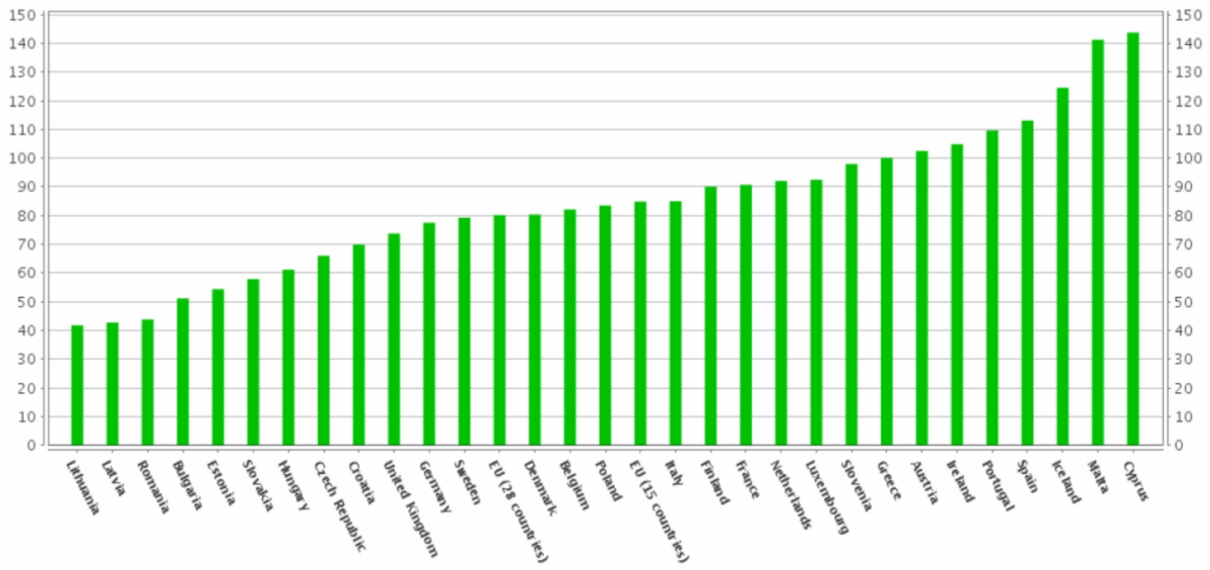
[100] Image can be found by using code: t2020_31, data is published by the European Environment Agency (EEA) and collected by Eurostats.



Graph 31: Greenhouse gas emissions (in CO_2-equivalents) in 2013, indexed to 1990 (EEA, 2016)[101].

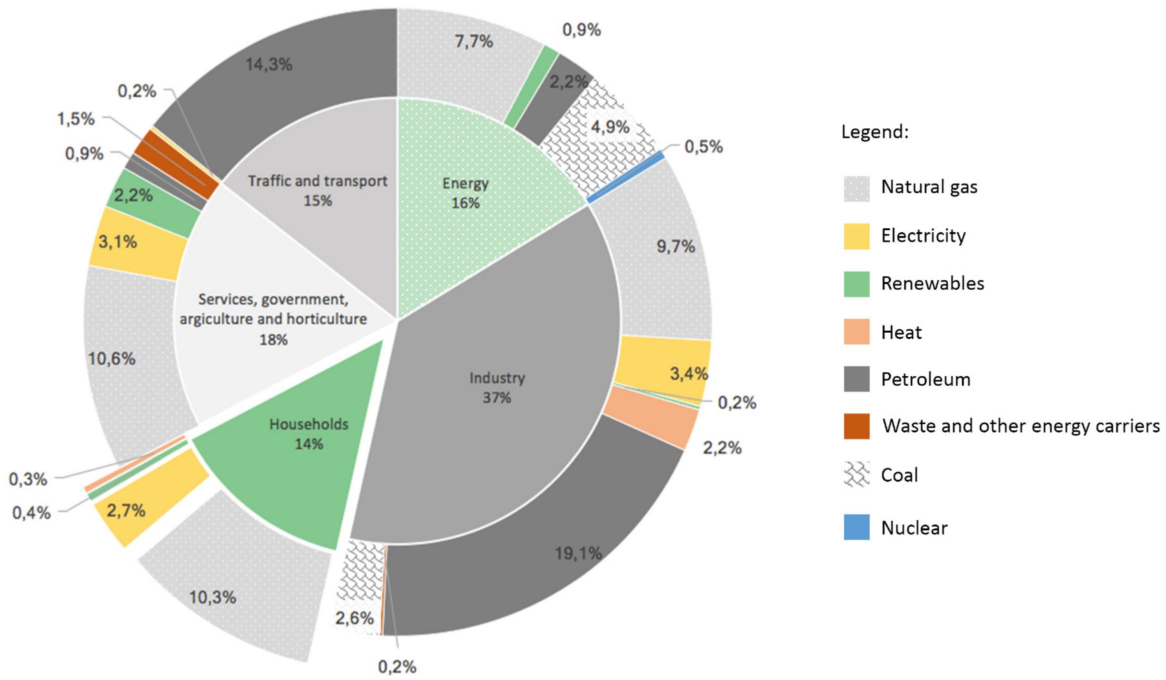


Figure 66: Primary energy usage per sector in the Netherlands in 2013 (own illustration based on data of CBS (2014a)).

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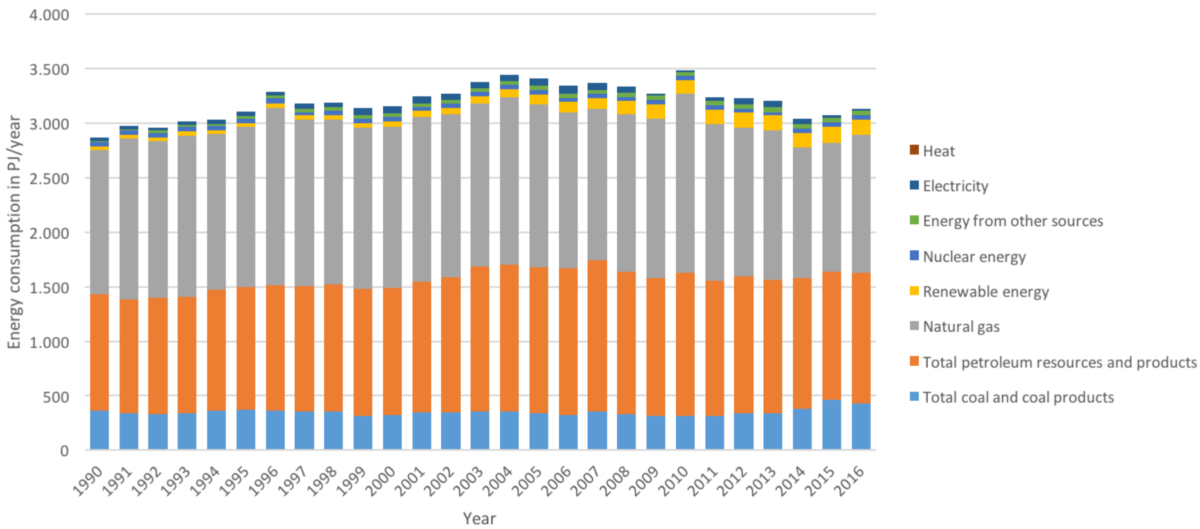
[101] Image can be found by using code: tsdcc100, data is published by the European Environment Agency (EEA) and collected by Eurostats.

Table 20: Energy usage per sector of two different data sources

Sector	Final energy use per sector (PJ) in 2013 (EEA, 2016)	Final energy use per sector (PJ) in 2013 (CBS *et al.*, 2014a; CBS, PBL, & Wageningen UR, 2014b)
Industry	608	Not given
Transport	607	Not given
Residential	478	451
Services	301	Not given
Agriculture and fishery	154	Not given
Others	4	Not given
Total final energy usage	2160	Not given
Gross Inland Consumption (primary energy consumption)	3361	3255
%residential of total final energy use	22%	
%residential of gross inland consumption	14%	14%

13.5 Appendix 5: Spatial impact of the energy demand within the Netherlands

"*In 2011, the Netherlands used 3.258 petajoules of energy*" (De Blois *et al.*, 2014: 30). One petajoules (PJ) is about 278 million kWh. The largest share of 42,2% was use by the industry (1375 PJ), the second largest share is used by traffic and transport (15,3%, 499PJ). Households are the third biggest energy consumer with a usage of 407 PJ (12,5%). Energy companies used a share of 11,6% or 377PJ of energy. The remaining 18,4% (598 PJ) was used by other energy consumers, like agriculture, horticulture, construction, trade, services and the government. (De Blois *et al.*, 2014) There are around 42 windmills with a power of 3MW needed to supply 1 PJ every year (Hocks *et al.*, 2016: 4). A 3MW wind turbine is the average size in 2007, with a height of more than 100 meters. A simple calculation makes that a little more than 17 thousands 3MW windmills can make all households zero energy and around 137 thousand windmills make the Netherlands energy neutral.



Graph 32: The total primary energy consumption in the Netherlands since 1990 (own illustration based on data of the CBS (2017b)).

13.5.1 Spatial diversification of the energy demand throughout the Netherlands

Over the past 25 years the energy consumption in the Netherlands looked rather stable (see Graph 32). The year 2004 seems to be a tipping point. Ever since the energy consumption is decreasing. However, this energy consumption is not evenly spread over the country. Middel *et al.* (2017) identified based on data of the European Environment Agency (EEA) how the CO_2-emissions of the big industries and energy suppliers are spread over the Netherlands (see Figure 67). In the top 10 of companies with the most CO_2-emissions are companies like Shell, ExxonMobil, Texaco/BP (all oil refineries) and others in harbour of Rotterdam, Tata Steel (former Hoogovens, steel company) in IJmuiden, YARA (fertilizer manufacturer) and DOW Chemical (petrochemical company) in Terneuzen and Chemelot (large industrial area) in the South of Limburg. Especially Tata Steel in IJmuiden and YARA in Terneuzen have extraordinary high energy usages. Oil refineries mostly exhaust CO_2, but do not necessary use the same amount of energy as those energy intensive companies in the chemical and metal industries. YARA and Tata Steel are used as example of the size of these companies.

First, the fertilizer producer YARA consumes a lot of energy during its production proces. An important resource for fertilizers is ammonia, which can be created by chemical reaction between hydrogen and nitrogen. In the traditional method hydrogen is obtained from natural gas. In this process high temperatures are required and many CO_2 is emitted. Kerkhoven and Terwel (2016) propose a method for YARA to become more sustainable. According to them YARA consumed about 2 billion cubic meters of natural gas in 2015, which is about the energy equivalent of 63PJ. This amount makes YARA by far the biggest consumer of natural gas in the Netherlands. However, hydrogen could also be produced by electrolysis based on renewable energy. Kerkhoven and Terwel (2016) sketch a vision where big surpluses of renewable energy cannot be used fully by other sectors, because of the volatile nature of the wind and solar. During these moments it can be expected that the costs per units of electricity are lower as the same amount of energy in natural gas[102]. In this case the fertilizer industry could replace usage of natural gas by renewable energy. This change would have a huge effect on their primary energy usage, CO_2-emissions and would make the industry much more competitive, because of the lower costs of energy. (Kerkhoven & Terwel, 2016: 39)

Secondly, Tata Steel also consumes a massive amount of energy during its production process of steel. There are different numbers available about their energy consumption. According to the same report of Kerkhoven and Terwel (2016: 35), Tata Steel used 87 PJ of energy to produce 6,57 Mton of steel at the IJmuiden production site in 2013, branch organisations VNMI and AVNeG (2011: 26) state in their roadmap for energy efficiency in the metal industry that Tata Steel uses around 70 PJ, Tigchelaar (2017: 5) of the Energy Research Center Netherlands (ECN) used Tata Steel as reference for Flevoland with a consumption of approximately 100 PJ, which is around three times the total consumption of the province. In spite of all previous sources, according to data data of the primary steel making activity in their own sustainability report[103], Tata Steel consumed about 136 PJ at the IJmuiden production site in 2015 (Tata Steel, 2016). Tata Steel believes that they are on the right track by saving 31% in the energy consumption to produce one tonne of steel at the IJmuiden site since 1989. However, while Tata Steel is improving the efficiency of their processes and operations incrementally, they argue for the thermodynamic limitations to the reduction of their CO_2-emissions on a large scale. New innovations are required to significantly drop their energy demand (Tata Steel, 2016: 31). According to the roadmap of VNMI and AVNeG (2011: 26) Tata Steel can save about 10 PJ in optimising their current operations.

The industrial companies YARA and Tata Steel consume together about 199 PJ[104], which is around 6% of the nationwide energy consumption and 49% of all the household consumption in the Netherlands. The two industrial sites thus consume the same amount of energy as approximately 3,7 million households[105]. The amount of energy they consume is so big, that it can hardly be produced by renewable sources on a regional scale. Especially Kerkhoven and Terwel (2016) state that YARA can use the overcapacity in the North Sea on windy days, because those surpluses are expected to be cheaper than the price of natural gas.

These amounts of regional consumption argue for the necessity of a nationwide energy policy supported by regional action plans to become energy neutral. If the coordination would be laid down purely with the regional governments, some regions with the major industries will be never able to achieve the objective of becoming energy neutral. Regions with a low energy pressure (e.g. Flevoland[106]) will have to compensate for the others (e.g. IJmuiden, Terneuzen and the harbour of Rotterdam).

[102] The price of natural gas is expected to increase, because of its depletion in the Netherlands. Surpluses of renewable energy are expected to have a low price, because in these times supply exceed the demand (which can cause blackouts). All can also be argued that YARA can bargain a great contract for the supply of high caloric Norwegian or Russian natural gas.

[103] The energy intensity per tonne crude steel was 19,60 GJ; the crude steel production in the IJmuiden production site was 6,922 million tonnes. Both numbers are from 2015 (Tata Steel, 2016: 33).

[104] Taking the total consumption numbers of Tata Steel itselves from Tata Steel (2016), which was 136 PJ in 2015.

[105] The Netherlands counted 7,7 million households in 2015 (CBS, 2016b).

[106] All energy users in Flevoland consumed in total 36 PJ in 2015 (Tigchelaar, 2017: 5).

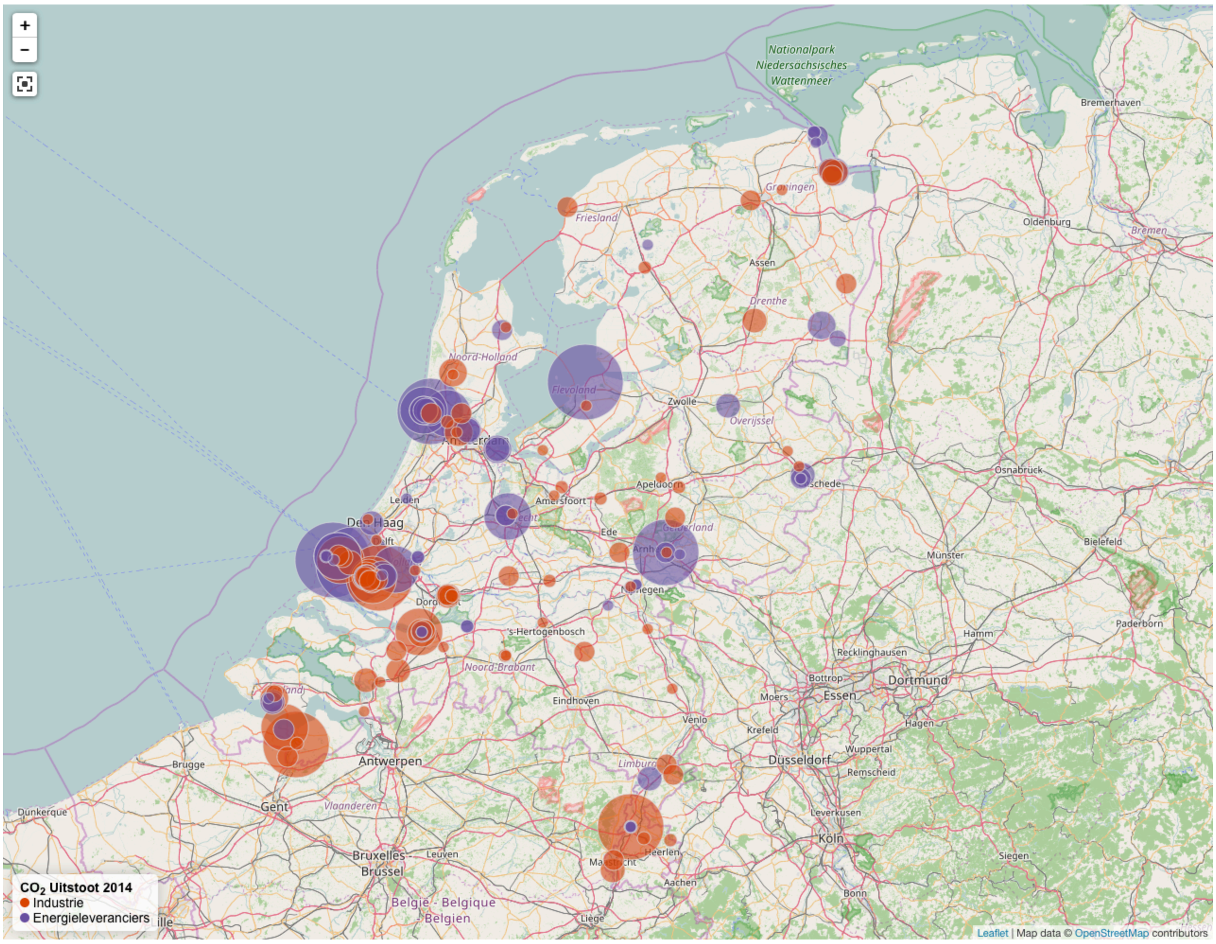


Figure 67: Largest CO_2-emissions in the Netherlands for industry and energy suppliers (Middel *et al.*, 2017).

13.5.2 Size and scale of a renewable energy supply

The energy transition from fossil fuels to renewables requires space. For instance, windmills are very visible in the landscape, while people hardly know where the power plants are located in the Netherlands. The energy supply of all windmills is even lower as a single power plant. De Blois *et al.* (2014) state that all Dutch windmills together supply 18 PJ of electricity yearly, which is even less power than the ‘Amercentrale’ power plant[107] can supply (21 PJ of electricity and 3,7 PJ of heat). The ‘Amercentrale’ is for a large part unsustainable, as the power plant is fuelled for 65% by coal and for 35% by biofuel in the form of wood chips.

Solar and wind energy are suitable renewables for the Netherlands. In terms of space usage is a wind turbine the least space consuming in comparison to solar roofs and solar farms (Figure 68). However, there are many restrictions for windmills, among others because of noise, the stroboscopic effect of the wings and a safety zone for the possibility of falling wings. For solar panels there are less restrictions, as the risk of accidents due to damage to the panels is limited and they are less visible from a distance. The major restrictions for solar panels are the protected cityscape and nature conservation areas.

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[107] The ‘Amercentrale’ power plant can be seen in Figure 67, as the single, little purple dot in the south-east of Rotterdam (in Geertruidenberg).

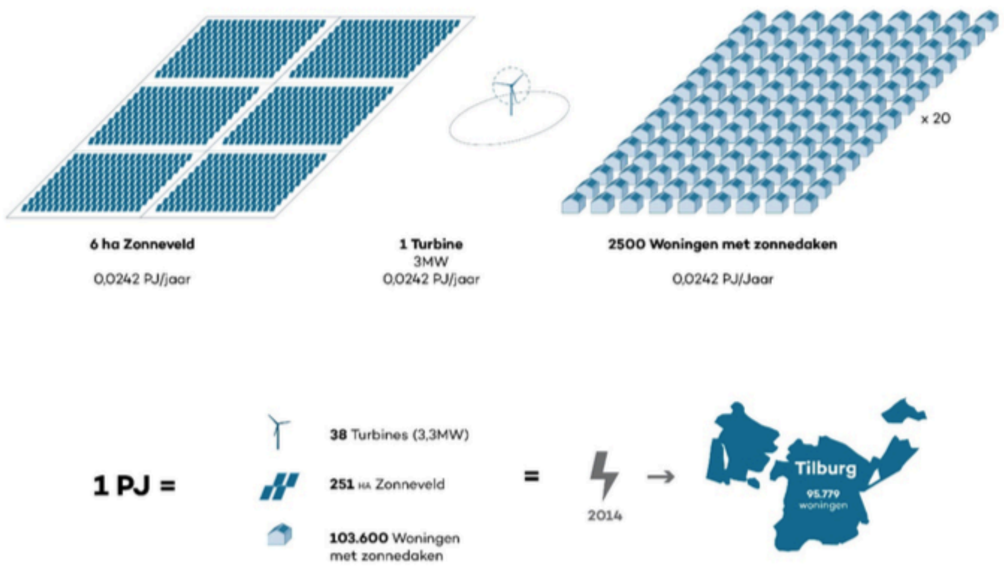


Figure 68: Size and scale of renewable energy technologies (Hocks *et al.*, 2016: 4)

Hocks *et al.* (2016) shows restrictions, techniques and the spatial impact of wind and solar energy. It also shows that the coastal areas in the Netherlands have a bigger potential for solar and wind energy, because of better conditions in terms of an increased wind speed and more solar power.

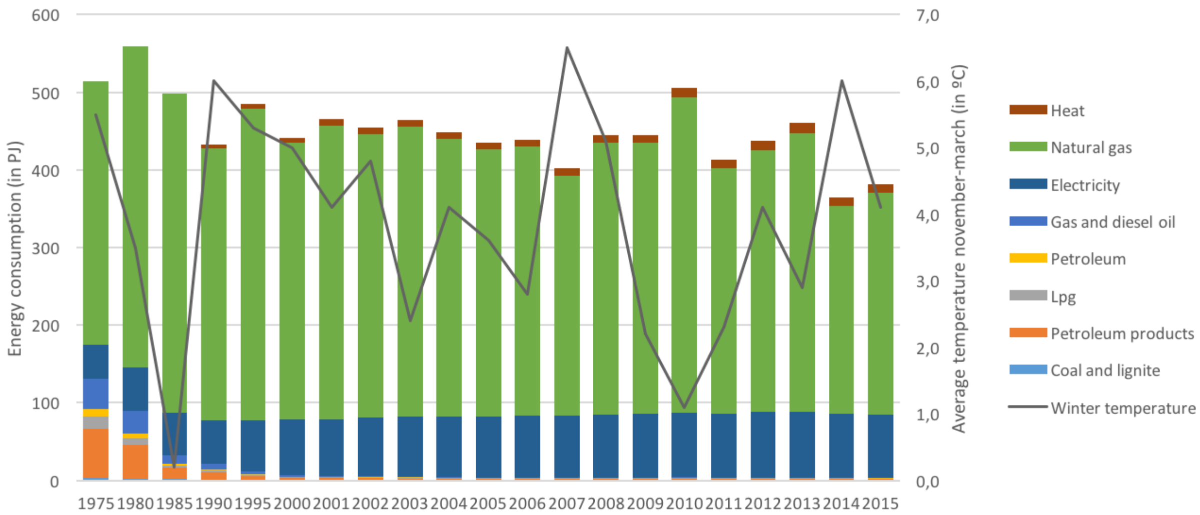
What is not mentioned in the above text on spatial impact, is that fossil fuels have a spatial impact at the mining places. Sijmons *et al.* (2014) made an analyses on the total spatial impact of energy sources. The size of the mines cause that the total spatial impact of fossil fuels is much larger, however, because those mines are not located in the Netherlands, inhabitants hardly notice their spatial impact.

POSAD and Machiel Bakx investigated the spatial impact of the energy agreement (Dutch: '*Het Energieakkoord*') and concluded that the ambition of a 100% renewable energy production and consumption is only possible for 80% of the energy demand in 2050 (Kuijers *et al.*, n.d.). The remaining part has to come from energy savings. By saving more, decision space is created to choose between energy resources (e.g. wind or solar). The team also states that a generic approach does not exist, but needs to be customized for every area, type of land uses and soil conditions. In the next paragraph the results of one of the studies of POSAD, the possibilities of Noord-Brabant, are shown.

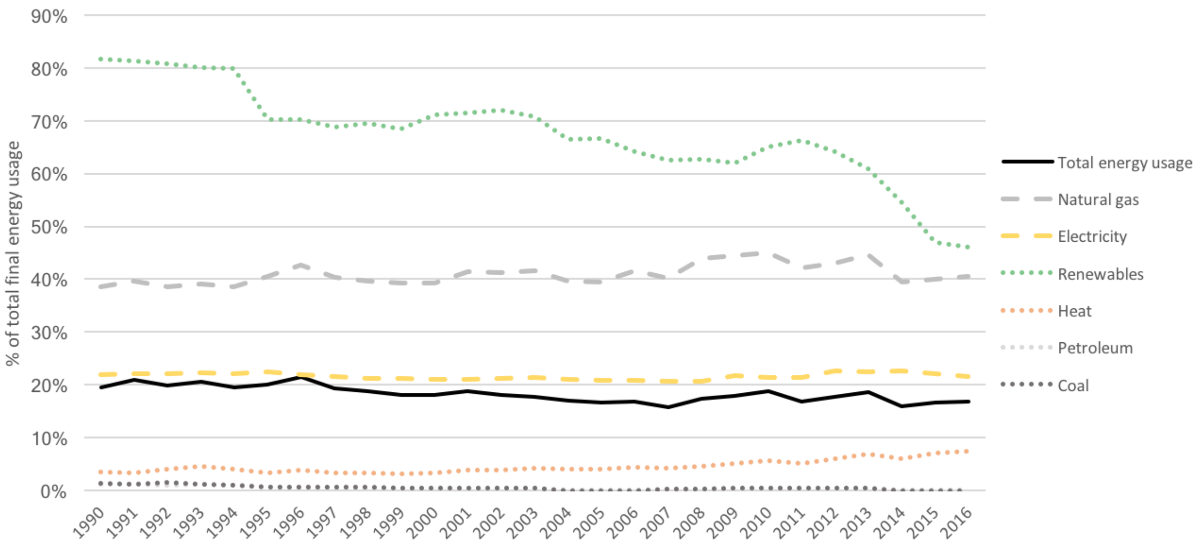
13.6 Appendix 6: Energy consumption of households throughout the years

The consumption pattern of households differentiates during the years, because most of its energy consumption is used for heating purposes and therefore related to the outdoor winter temperature (see Graph 33).

Last 25 years approximately a relatively stable 20% of the total final energy consumption was used by households (see Graph 34)[108]. Most of the direct energy usage is the consumption of natural gas (see Graph 33)[109]. The total usage of electricity looks rather stable over the last 15 years (see Graph 33). A little increase of the electricity usage can be seen till 2010 and since 2013 the total usage of electricity seems to be decreasing. However, the usage of natural gas is heavily fluctuating through the years, because of hot and cold winters. The extreme winter temperatures (both hot and cold) are clearly visible in Graph 33. Those numbers especially show the need for a new heating system of Dutch dwellings.



Graph 33: Energy consumption of households since 1975, period till 2000 is for every 5 years (own illustration based on data about energy usage of the CBS (2016a) and data about the winter temperature of the KMNI (2017a)



Graph 34: Household energy usage compared to the total final usage in the Netherlands since 1990 (own illustration based on data of CBS (2017a)).

108 Be aware of the fact that this graph uses the total final energy consumption and not the total primary energy supply.
109 The production of electricity also causes an indirect usage of natural gas, see CBS (2017a).

Both graphs show an increasing usage heat within households, which is related to the development of heating grids. The last graph shows a decline in the relative usage of renewables in households. The numbers of CBS (2017a) show that the renewables used in households were mainly based on biomass with a stable energy value of 10-13PJ. The increasing production of renewable electricity outside of the households is much bigger compared to the increasing usage of a renewable heat production, which cause a relative decline of renewable energy usage. The increasing renewable energy production is mainly caused by the huge new wind parks and the adding of biomass to the coal power plants. Both are accounted to the energy supply sector and not directly to the usage within households.

13.7 Appendix 7: Attended congresses, presentations and interviews

This Appendix gives a summary of the data sources from practice. Another strategy as expert interviews was used, namely attending new courses, congresses, presentations/lectures and many personal communications with professionals in the field (e.g. of SITE, Planmaat, VORM, OVG, Dura Vermeer, Merosch, Fakton and many more). This is a not exclusive list, but the most important once are mentioned below. Consecutively, the attended congresses, presentations and lectures and interviews hold are described.

13.7.1 Courses

The researcher followed several courses related to sustainable urban development after he started the graduation research. Input from these courses was used during the process. The relevant courses and tasks to this graduation research are summed below.

Some of this courses are also used the apply for the '*Technology in Sustainable Development*'-annotation of the TU Delft.

ENP37803 (WageningenUR) and ENP38303 (WageningenUR): Sustainable Design (Jan. – Mar. 2016)

- Literature on transition management, related to the energy transition
- Research on Sustainable building with interviews and two case studies:
    - Multifunk by ANA architecten and Lingotto, multifunctional and easy transformable building which needed innovative solutions for design and installations. Interview with Jannie Vinke of ANA Architecten about Multifunk on March 3, 2016 in Amsterdam
        - http://www.lingotto.nl/projecten/multifunk/
    - Renovation of the Alliander Headquarter in Duiven. First BREAAM Outstanding renovation including a big greenhouse to connect several offices and to prevent heat from being lost. Interview and guided tour with Peter Schoch & Eugenie Knaap of Liander about the renovation project of their headquarters on March 3, 2016 in Duiven
        - https://www.alliander.com/nl/media/nieuws/alliander-opent-circulaire-energiepositieve-herhuisvesting

ETE33806 (WageningenUR): Planning & Design of Urban Space (Mar. - May 2016)

- Lectures on the topic of passive solar design and adaptive design – Marc Spiller lecture
- Lectures on the topic of participatory planning – Gerrit-Jan Carstjens
- Excursions and interviews about eco-neighbourhoods, planning, design and co-creation.
    - Eva Lanxmeer, eco-neighbour with high degree of citizen power (development: 1998-now)
    - GWL neighbourhood, which is the Netherlands first eco-residential neighbourhood (development: 1994-1998)

ETE32806 (WageningenUR): Managing Urban Infrastructures (Mar. - May 2016)

- Lectures about the energy system in the Netherlands (Vreeburg, 2016).

YMS50307 (WageningenUR): Capita Selecta Advanced Metropolitan Solutions (Jun. - Aug. 2016)

- Contains the MOOC on Sustainable Urban Development
    - https://online-learning.tudelft.nl/courses/sustainable-urban-development-discover-advanced-metropolitan-solutions/
- Literature research on passive solar design and its application in the neighbourhood of Vauban, Germany.

AR3R058 (TU Delft, A&BE): Operational Research Methods (Sept. - Nov. 2016)

- Literature of Barendse *et al.* (2012)
- Development of an optimisation model about the energy efficiency of the thermal envelop of a single building

SPM9750 (TU Delft, TBM): Environmental Sustainability of the Built Environment (Sept. - Nov. 2016)

- Literature of Itard (2011), Rahola and Straub (2013) and more.
- Development of the calculation model for the energy demand of an (apartment) building.

13.7.2 Congresses

Two congresses were attended with the purpose of this research. Both focussed about the realization of energy efficiency new dwellings. One was focussed on housing associations (‘*How sustainable must new development be*’) and the other for real estate developers (‘*ZEN Platform Meeting*’).

<u>‘How sustainable must new development be’</u>

The congress ‘How sustainable must new development be’ was about the optimal sustainability ambition of new dwellings for housing associations. The congress was organized and hosted by Luijkx (2017a) on June 15, 2017.

Referred presentations:

- Jos Verlinden, part of the managing board of the building and energy department within the Ministry of Home Affairs, about the approach of the Ministry of Home Affairs towards sustainable residential development (Verlinden, 2017).
- Thijs , senior advisor at W/E-adviseurs (know for GPR-gebouw and GPR-stedenbouw), about measuring and presenting quantitative data on sustainable housing development (Kurstjens, 2017).

<u>ZEN Platform meeting</u>

The ZEN Platform meeting was about different topics related to the development of very energy efficient dwellings and many key players from practice were present. The congress was organised and hosted by Claudia Bouwens (writer of Bouwens (2015b); (Bouwens, 2017b); Bouwens and Bouwmeester (2017)) on June 20, 2017.

Spoken to:

- Bas van de Griendt (writer of Van de Griendt (2011, 2015, 2016, 2017); Van de Griendt and De Vries (2012, 2013); Van de Griendt and Schilt (2010); Van de Griendt and Van Cann (2012); Van de Griendt and Van Estrik (2010)).
- And reason for contact with Van Seumeren (2017) and Dijkshoorn (2017).

And presentation of Harm Valk (e.g. Haytink and Valk (2016, 2017); Valk (2017)):

- Harm Valk, Partner Nieman RI about the BENG legislation and new energy standards (Valk, 2017)

13.7.3 Presentations/ lecture series

Evening lectures ‘Designing with energy’ at the Amsterdam Academy of Architecture:

> *“There is mounting evidence that the assimilation, conversion, storage, and transport of renewable energy will give rise to the most pivotal land use changes of the twenty-first century. Landscape architects, architects, urban planner and other environmental designers play a critical role in this socio-technical transition that affects both the built and natural environment. This lecture series will cover fundamental design concepts, explorative design as well as best-practice that can inform design-inquiry towards a low carbon future. The notion of energy transition is explored from a spatial perspective, critically discussing policies, governance and the (potential) role of environmental designers.”*
>
> - *Sven Stremke, e-mail February 3, 2017*

Attended lectures ‘Designing with energy’ at the Amsterdam Academy of Architecture:

- Associate Prof. Dr. Sven Stremke about designing with energy (Stremke, 2017).
- Prof. Em. Ir. Dirk Sijmons about the energy transition (Sijmons, 2017).
- Prof. Dr. Andy van den Dobbelsteen about the energy transition of the built environment (Van den Dobbelsteen, 2017).
- Ir. Boris Hocks, partner of POSAD spatial strategies about the spatial implications of the energy transition (Hocks, 2017).

Attended lunch lectures ‘Meet the energy leaders’ from the Energy Initiative of the TU Delft:

- Peter Molengraaf, CEO Liander about future changes in the energy system and the role of grid operators (Molengraaf, 2017)
- Aart van Veller, CEO Vandebron about empowering the consumer and generation of renewable energy (Van Veller, 2017)

13.7.4 Interviews

Interviews are held with the following persons for the case studies:

- Sander van der Wolf, concept developer at VORM on 2017, July 03 (Van der Wolf, 2017)
- Han van Seumeren, real estate developer at AM on 2017, July 10 (Van Seumeren, 2017)
- Xavier Delnoij, real estate developer at Blauwhoed on 2017, July 11 (Delnoij, 2017)
- Marco Dijkshoorn, real estate developer at Van Omme & De Groot on 2017, July 19 (Dijkshoorn, 2017)

All recordings of the interviews can be requested at the author of this thesis.

In addition, the researcher had many ongoing conversations with one of his clients with whom he organized a congress for housing associations about movable dwellings in October 2016 and one congress about energy efficiency is still in the planning, his supervisors during its internship at SITE urban development as urban developer from November 2016 to April 2017 and during his student job at Planmaat mostly about value creation in energy efficient developments from May 2017 to present day.

- Thijs Luijkx, partner of Watkostdebouwvaneenhuurwoning, client and supervisor from to 07-2017 to 10-2016 (referred to as Luijkx (2016, 2017b))
    - Other sources: Luijkx (2017a))
- Wouter Spijkerman, urban developer at SITE urban development (former job), supervisor from 11-2016 to 04-2017 (referred to as Spijkerman (2017b))
    - Other sources: Spijkerman (2017a), Versteijlen *et al.* (2010)
- Patrick Nan, director/partner at Planmaat, supervisor from 05-2017 to moment of writing (referred to as Nan (2017))
    - Other sources: Nan *et al.* (2017), see Appendix 13.29)

13.8 Appendix 8: Interview scheme case study interviews

The interview is introduced by shortly stating the following aspects of the interview/research:

- Interview is part of the graduation project at TU Delft.
- Topic is about how the real estate developer can optimize his business case to realize an energy-neutral (new-build) residential neighbourhood.
- Motives are the stricter regulation on energy-efficient developments, climate change and resource depletion, the expected rising energy price and with that the monthly living costs for households and the changing process in urban area development
- The result is an optimization model that optimizes financial, organizational and physical aspects to provide advice in the initial stages of the project on the feasibility of energy ambitions and what the optimal matching business case would be for.
- Motive for interview is a qualitative case description about what the market is doing today in terms of energy efficiency.
- Structure of the interview:
    - Part 1: Context cases and decision moments in development process
    - Part 2: Organisational, financial and physical aspects of the business case
    - Part 3: Reflections on choices made

13.8.1 Part 1: Context cases and decision moments in development process

<u>Questions about the context of the case</u>

- Can you give a brief description of the project?
- What has been the role of energy in the project? / What was the ambition at the start and which one is achieved?
- What is the status of the project within the organization?
    - E.g. one-off, practice case, business-as-usual
- What was/is your function within the project?
- Why did you decide as a real estate developer to pursue a higher than required energy target?
    - Corporate social responsibility; profit-driven; goal municipality; obligation from the municipality; practice for the future; tender requirement

<u>Questions about the decision moments in the development process</u>

Here I want to examine what decisions have led to the final result. In the last part, I would like to evaluate whether or not afterwards other knowledge had led to other decisions and how these decisions could be made in the future.

- What have been the most important decision-making moments when it comes to energy in each development phase (e.g. initiative / feasibility, urban planning and planning, design, detailing)?
- At what level of scale had these decisions their effect?
    - Urban design and collective systems (e.g. heating grid, collective heat-and-cold storage and pump)
    - Architectural design
    - Construction engineering and individual systems
- How and by whom were these decisions taken (which party)?
- Based on what information?

With this information, I want to make an inventory about the most important decisions and which information is needed to have influence in those decisions.

13.8.2 Part 2: Organisational, financial and physical aspects of the business case

The following questions concern organizational, financial and spatial / technical solutions. Organizational questions are about whether there are new collaborations with new, non-traditional parties in urban area development, the degree of involvement of the end-user and the key issues for the topic of energy. Financing is about how the additional costs of energy measures are financed (e.g. by an ESCO, higher selling price or otherwise). Spatial/ technology questions deal with the physically applied solutions.

Questions about the organisational aspects related to the energy ambition

- How was the partnership with the municipality designed?
    - Land ready for construction purchased from the municipality as public land development
    - Collaboration through building rights, concession or a public-private-partnership
    - Private land development with a facilitating government
- Why?
- Which construction contract was used between the client (developer) and the contractor?
    - Design-Bid-Build
    - Design-and-Build
    - Design-Build-Maintain
    - More integrated variant
- Why?
- Are there non-traditional parties involved in the development that also affected the decisions? Traditional parties include the municipality, real estate developer, architects and other designs, advisors, contractors and suppliers.
- What was the role of advisors? Why?
    - E.g. setting the boundary conditions for the project.
- Which role did the end-user have? Why?

Concluding; Can you give a response to the following statements?

- In the optimal business case of a real estate developer to realize an energy neutral residential area ...
    - ... new non-traditional parties need to be involved (e.g. ESCo, grid operator, end-user).
    - ... the commitment of the architect and the consultant is changing.
        - E.g. the adviser is more early on involved in the project to set boundary conditions. This restrains the architect in its freedom.
    - ... have to work together in an integral way. This is concretized by a minimal level of integration of the contracts being design & build.

Questions about the financial solutions to pay for the energy ambition

Side note. The research is not focused on the market developments, but on how the additional investment in energy-saving and renewable energy is financed by the end-user.

- How are the additional investments in energy neutrality / BENG / NOM financed for the real estate developer? And to what extent or which combinations?
    - Higher selling price.
    - Measures to lower the selling price.
    - Financed by an additional investor.
- How are the additional investments made affordable to the buyer?
    - Higher purchase price (consumer pays relatively more, but this he gets back by saving on energy costs)
    - Higher purchase price with green loan
    - Equal purchase price as a similar property without energy savings with a third investor (ESCo)
    - Others; For example, in a heat sink, the network administrator invests
- How are the total-cost-of-ownership/ future exploitation taken into account?
- How is the end-user involved in the end-result?
    - Not; developed and sold on the market
    - Yes; additional work or possible energy packages

Concluding; Can you give a response to the following statements?

- In the optimal business case of a real estate developer to realize an energy neutral residential area ...
    - ... the focus on the demand side of the real estate finance.
    - ... can end-users make choices about the configuration/design of the dwelling.
    - ... is a part of the investment financed by third investors (e.g. ESCo's, green mortgages).

Questions about the physical solutions for realizing energy efficiency

- What solutions have been chosen to realize the energy ambition?
- How did you get to these solutions?

If time questions are asked about the following technical aspects:

- Which energy concepts have been taken into consideration? What is the argumentation behind the selection of the current energy concept?
- To which extent is the conceptualizing of the development (Dutch: '*conceptueel bouwen*') of importance?
- Is overheating during summer seen as problem? If yes, how are problems with overheating solved?
- What is the solution for the supply of hot tap water?

Concluding; Can you give a response to the following statements?

- In the optimal business case of a real estate developer to realize an energy neutral residential area ...
    - ... the focus is on energy efficient building installations (ventilation, heat recovery, PV-panels, etc.) instead of to the thermal envelop of the dwelling.
    - ... are solutions implemented on individual housing levels, because of the spread of financial risks.

<u>Questions about the integration of the three aspects in relation to energy efficiency</u>

- How are the decisions made between the above aspects?
- Is this the best solution for that aspect or a compromise in the decision-making process?
- Is the result more than the sum of its parts? Can you give your opinion?

13.8.3 Part 3: Reflections on choices made

Questions about the reflection on the business case.

<u>Questions about decision-making and optimisation</u>

- If you look back at the process, what decisions would you make differently in the future?
- What did you learn from this project?
- Which aspect is most important for the developer?
- How is this optimized?

<u>Questions about the decision support tool</u>

- How could a decision model on ENRND help to support next projects?
    - Which information should it offer? How presented?
    - For which development phase could it have the most added value?
    - For which decisions could it have the most added value?
- What were the biggest barriers to develop dwellings which this energy ambition?

13.8.4 Wrapping up

Have important aspects not been addressed yet?

The answers on the questions are used for the case study and for the decision support tool.

Thank you for your time and answers.

13.9 Appendix 9: Theoretical insight howto involve LP in (sustainable) multi-actor decision-making processes

LP can incorporate the viewpoint of multiple stakeholders into account by using negotiable constraints (Barendse *et al.*, 2012; Binnekamp *et al.*, 2006). The basic structure of a design problem in linear programming and its standard form for Excel and Whatsbest is explained in the coming paragraphs. The text is based on the explanation in Barendse *et al.* (2012: 9-13) about the application of linear programming with negotiable constraints (based on Hillier and Lieberman (2005)).

As described in the theoretical framework and research methodology, only the design variables, the constraints and the objectives are needed to evaluate the design space for the optimal solution (Barendse *et al.*, 2012). As the decision is about the design, the design variables are also called the decision variables. The objective function is used for finding the greatest extent possible of the (design-)decision variables. This can be executed by minimization and maximisation. Each decision variable can have a certain parameter, influencing its effect on the total result. The mathematical expression of this is shown in formula 6.1. *An example,* if the design has to be made about the number of houses, each housing type will represent a certain amount of profit. In formula 6.1 the decision variable x_n is in this case the amount of housing type x_n developed and parameter c_n represent the amount of profit made for each housing type x_n developed. The total amount of profit made (Z) is the amount of houses developed of each type (x_n) multiplied by the profit for each housing type (c_n).

The possibilities of the objective function are limited by certain constraints. Constraints can be either fixed (e.g. limits of physics or system constraints) or negotiable (e.g. maximum amount of dwellings). The sum of the decision variables multiplied by its parameters has to be lower (or higher, the example uses lower) as the given constraint. The calculation is shown by formula 6.2a-c. *An example*, the decision is still about the amount of house to developed (see previous example). However, the possibilities are limited by the budget of the developer. Each housing type of x_n has certain development costs, represented by the parameter a_{mn}. The total budget is constrained by b_m. The total development costs (calculated by the left part of formula 6.2a) has to be lower as the constraint b_m.

In addition to these constraints are the non-negatively constraints, because the decision variables cannot be negative (formula 6.3). The decision variables (x_n) are also called endogenous or uncontrolled variables and the parameters (a_{mn}, b_m, c_n) are also called exogenous or controlled variables. In the description of the model the endogenous and exogenous terms are used.

In mathematical terms linear programming thus searches for the minimum or maximum value of the objective function Z by:

$$min!\, or\, max!\, Z = c_1 * x_1 + c_1 * x_2 + c_3 * x_3 + c_4 * x_4 + \cdots + c_n * x_n \quad (5.1)$$

Subject to the following constraints:

$$a_{11} * x_1 + a_{12} * x_2 + a_{13} * x_3 + a_{14} * x_4 + \cdots + a_{1n} * x_n \leq b_1 \quad (5.2a)$$

$$a_{21} * x_1 + a_{22} * x_2 + a_{23} * x_3 + a_{24} * x_4 + \cdots + a_{2n} * x_n \leq b_2 \quad (5.2b)$$

$$a_{m1} * x_1 + a_{m2} * x_2 + a_{m3} * x_3 + a_{m4} * x_4 + \cdots + a_{mn} * x_n \leq b_m \quad (5.2c)$$

And (decision variables cannot be negative):

$$x_1 \geq 0, x_2 \geq 0, x_3 \geq 0, x_4 \geq 0, \dots, x_n \geq 0 \quad (5.3)$$

The concise formulation is (Barendse *et al.*, 2012: 10-11):

$$min!\, or\, max!\, Z = \sum_{j=1}^{n} c_j * x_j \quad (5.4a)$$

13

Subject to:

$$\sum_{j=1}^{n} a_{ij} * x_j \leq b_i \qquad \text{For } i = 1, 2, \ldots, \text{m.} \qquad (5.4b)$$

and

$$x_j \geq 0 \qquad \text{For } j = 1, 2, \ldots, \text{n.} \qquad (5.4c)$$

The standard form to add these formulas in Excel is shown in Figure 69.

	A	B	C	D	E	F	G	
1	Endogenous variables	var1	var2		var$n$			
2	Outcome	x_1	x_2	...	x_n			
3								
4	Objective Function	c_1	c_2	...	c_n		Z	Formula 6.1
5								
6	Constraint 1	a_{11}	a_{12}	...	a_{1n}	<=	b_1	Formula 6.2a-c
7	Constraint 2	a_{21}	a_{22}	...	a_{2n}	<=	b_2	
8		...	...		...		...	
9	Constraint m	a_{m1}	a_{m2}	...	a_{mn}	<=	b_m	

Figure 69: The standard form of LP-models (Barendse et al. (2012: 12) with slight additions)

The values of *Z* and *Bm* can be obtained with the SUMPRODUCT function in Excel. For instance, formula 6.5 applies formula 6.1 in Excel and gives the value of *Z* in cell G4. The add-on of Whatsbest in Excel can be used for getting the maximum value of the objective function (*Z*) by taken into account the different constraints. Whatsbest automatically searches through all different combinations of the endogenous variables and returns the maximum possible value of *Z*. Of no solutions are possible Whatsbest returns 'INFEASIBLE'.

$$Z = SUMPRODUCT(B2{:}\,E2;B4;E4) \qquad (5.5)$$

This is how the basic structure of LP-modelling works and how it the standard form can be applied in Excel, using Whatsbest. The possibilities of this system are taken into account when selecting a feasible alternative for the decision support tool.

The described formulas are applied in Figure 24, Figure 25 and Figure 26 to get the solution space and in the end, the optimal solution from a single-actor perspective. Figure 70 shows how the formulas of the constraints and the objective function relate to the solution space and optimal solution.

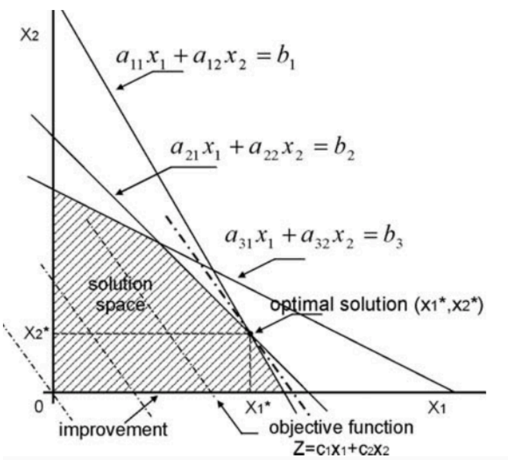


Figure 70: Manufacturing allocation problem (Binnekamp et al., 2006: 31).

13.10 Appendix 10: Components of the calculation of the three principles of BENG

Kruithof and Haytink (2015) give an explanation about the possible calculations of the three principles. A English summary is given below.

13.10.1 Principle 1: The maximum energy demand of building-related energy

The first principle is the maximum energy demand of a building. This demand is displayed in the amount of kWh needed for each square meter of usage area per year [kWh/m^{2}year]. The energy need for lighting has not been considered for housing, as the design of a home cannot be influenced. When determining the energy requirement of a building, the energy demand for heating and cooling (or summer comfort when there is no active cooling) is taken into account. When using an air conditioning unit, it may take part of the heat and / or cold needs. (Kruithof & Haytink, 2015) Figure 71 gives insight in the parameters used in the calculation.

This requirement is based on 'standard behaviour' of the residents and is therefore mainly related to the building shelf and is independent of residents' behaviour.

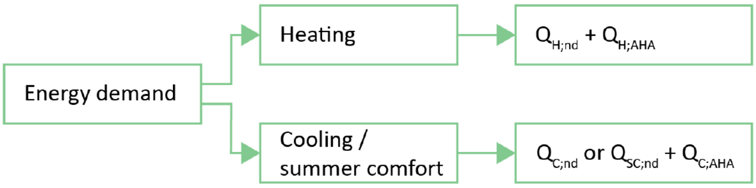


Figure 71: Energy requirements of a dwelling with the calculation parameters from NEN 7120 (own illustration based on Kruithof and Haytink (2015: 8)).

Kruithof and Haytink (2015: 9) show how the parameters for the determination of BENG1 are linked to the formulas in the NEN standard.

13.10.2 Principle 2: The maximum primary energy consumption

The second principle is about the maximum primary energy consumption of a building [in kWh / m^2.year]. This only takes into account the building-related energy consumption. The determination of the primary energy consumption is in the basis the same as the calculation of the primary energy usage in the standard NEN 7120 (Kruithof & Haytink, 2015). There are two important deviations, namely 1) lighting is not considered in BENG and 2) in case more electricity is generated than building-related electricity is used, then that surplus of electricity production is settled with a primary energy factor of 1 (Kruithof & Haytink, 2015). The different components of the calculation are shown in Figure 72.

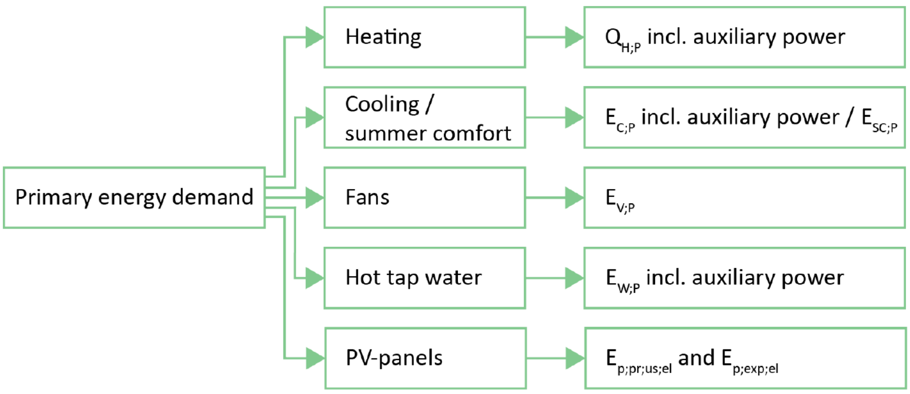


Figure 72: Primary energy usage of a dwelling with the calculation parameters from NEN 7120 (own illustration based on Kruithof and Haytink (2015: 11)).

Kruithof and Haytink (2015: 12) show how the parameters for the determination of BENG2 are linked to the formulas in the NEN standard.

13.10.3 Principle 3: The minimum percentage renewable energy

The third principle is about the minimum percentage of renewable energy (in % of the total primary energy demand), which has to be supplied on the location of the building. The different components of the calculation are shown in Figure 73.

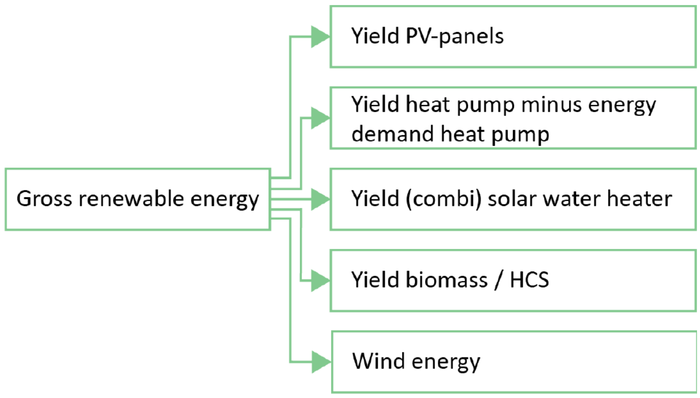


Figure 73: Possible aspects of renewable energy in BENG (own illustration based on Kruithof and Haytink (2015: 7)).

Kruithof and Haytink (2015: 16) show how the parameters for the determination of BENG3 are linked to the formulas in the NEN standard.

13.11 Appendix 11: Explanation of public-private partnerships and integrated contracts

This appendix gives an explanation of the common used types of public-private partnerships and integrated contracts.

13.11.1 Public private partnerships

The public-private partnership model has transformed into an umbrella term in which in a planning context a partnership between a governmental party and a private-sector organization is set up for a spatial development (Chao-Duivis *et al.*, 2010). Below, six different are discussed, which are shown in Figure 74. The explanations are based on J. C. De Jong (2016: 39-41), Heurkens (2012: 148-158) and Ten Have *et al.* (2011), which essentially give the same explanations. Figure 74 show all different models during the different process steps. Figure 75, Figure 76 and Figure 77 show the partnership steps in more detail by indicating what happens to the status of the land and the real estate.

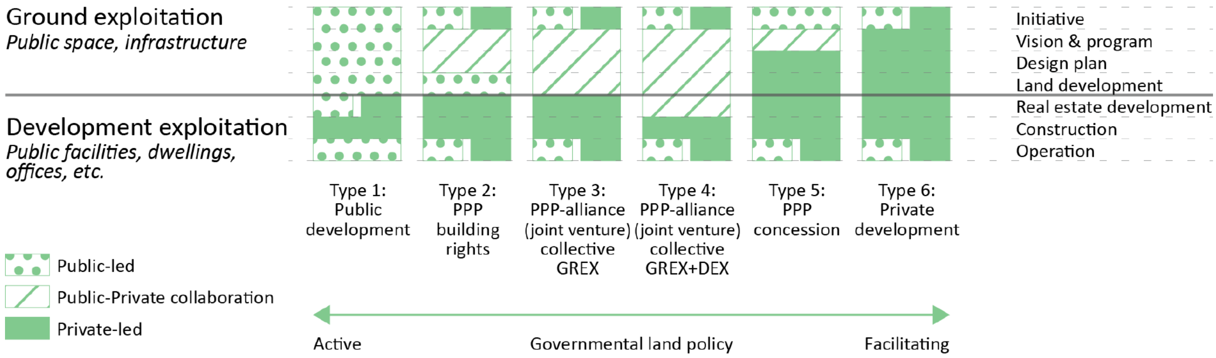


Figure 74: Models of public-private collaboration in the ground and real estate development combined with the roles of the public & private sector in each development stage within public-private-partnership models (own illustration based on J. C. De Jong (2016: 40)

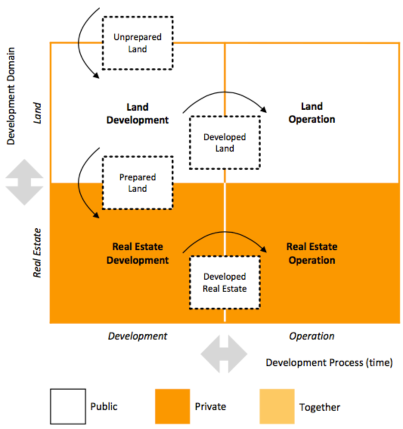


Figure 75: Public & private roles in building rights model (Heurkens, 2012: 151).

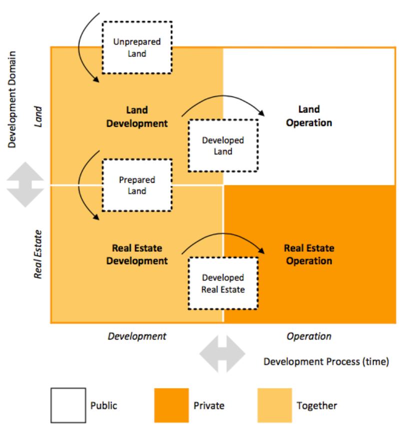


Figure 76: Public & private roles in joint venture model (Heurkens, 2012: 153).

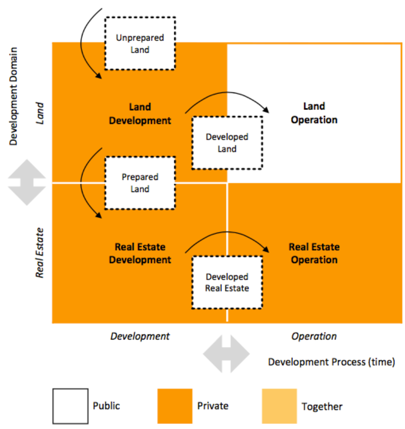


Figure 77: Public & private roles in concession model (Heurkens, 2012: 154).

Some additional notes about the figures of Heurkens (2012). Figure 75 shows the building right model, which is not the most active form of an active land policy, which is public realization. However, it shows the government in charge of the land development. Figure 77 shows the concession model, which is not the most facilitating form of an facilitating land policy. That would be private realization. In this case the government still initiates the development. However, the figure will not change in case of a private realization.

13.11.1.1 Type 1: Public development (traditional)

This is the traditional model. In this case the municipality owns or acquires the ground and is responsible for the site preparation works. When the site is ready for real estate construction, the municipality has the option to sell the ground to a private party or to develop the real estate itself in case of public works. If the municipality selected a private party (e.g. a real estate developer), they have to collaborate within the stipulated conditions of the municipality, like the land use plan or the image quality plan (Dutch: '*Beeldkwaliteitsplan*'). In this way, the municipality can exert maximum influence on the future land use by setting these conditions during the land allocation. The real estate developer does not share the risks or the profits of the ground exploitation. (J. C. De Jong, 2016)

13.11.1.2 Type 2: Coalition as public private partnership (Agreement or building rights)

The starting point of this model is that the private party owns the land and both this party and the municipality wants to develop the location. The municipality shall execute the site preparations after the private party transferred the ownership of the land to the municipality. One of the agreements for this transaction is that the private party gets building rights in return for his land. In most cases the municipality is paying less as the book value of the land. This financial deficit has to be compensated with the realization of real estate by the private party. (J. C. De Jong, 2016)

13.11.1.3 Type 3+4: Alliance/ joint venture as public private partnership (Collective ground exploitation or collective ground and real estate exploitation)

The starting point of this model is that both the public as the private party owns land. This land is transferred in a shared land operating company (Dutch: '*grondexploitatiemaatschappij*', GEM). This company is responsible for the site preparation and performs the control function on the development of the grounds in the name of the participating parties. Land allocation is mostly towards real estate developers who are participating in the land operating company. The risks of the ground exploitation are shared among the municipality and market parties in this model. The land operating company can be made responsible for the collective ground exploitation or for the collective ground and real estate exploitation. The participating parties should agree on this aspect on forehand. (J. C. De Jong, 2016)

13.11.1.4 Type 5: Concession as public private partnership

The concession model looks like the model of self-realisation, which is described below. The difference is the starting point. In this case the municipality defines the desired output on forehand by specifying an (urban planning) program of requirements and an image quality plan. These focus on the quality of the real estate and the public space. The realization of the program is outsourced therefore tendered by the municipality. After winning the tender, a private party or a consortium has committed themselves to realize the development in accordance with the defined output in the concession contract. This means that within the boundaries of the development framework the private party can steer, plan and phase the development at own insights. The grounds are also transferred to the market party, which implies that they are now responsible for the risks within the ground exploitation, but they can also make advantage of opportunities. In most cases of the concession model the ground exploitation is combined with the real estate exploitation, which creates an efficiency gain. After the municipality has set the boundary conditions and lead the procurement, their role changes to facilitating the execution and testing the service of the market party in terms of size, time and quality. (J. C. De Jong, 2016)

Ten Have *et al.* (2011) describe the model in the same way, but add the insight that the concession model has a relatively small burden on the municipal finances. However, a lot of investment is required from the market party that will execute the concession. They have to invest in the land acquisition, site preparation and real estate development and all costs that comes with it. The municipality only has their staff costs for the preparation of the concession and facilitation during execution.

13.11.1.5 Type 6: Private development (Self-realisation)

In this partnership model the municipality does not allocate the land. The private party is executing the role of land operator for his own account and risks by adapting the land use plan. This adaptation has to be executed in close collaboration with the municipality. The municipality shall influence the way the private sector is using is ownership of the land by agreeing upon an operating agreement, which specifies the conditions under which the site may be developed. In this model the municipality retains to it public function in the development process by taking responsibility for the review of the land use plan and the authorization of permits. In most cases the municipality takes over the ownership of the public space after development, often as part of the operating agreement. (J. C. De Jong, 2016)

13.11.2 Integrated contracts

The next section explains in more depth the differences between the procurement methods of Design-Bid-Build, Design Team, Design-and-Build, Design-Build-Maintain and Design-Build-Finance-Maintain.

First, the traditional procurement methods:

- Design-Bid-Build (DBB): the various contracted parties (design companies, construction companies and maintenance companies) are involved in the project one after the other and therefore involves several moments of tendering (Rahola & Straub, 2013). In this case there is a triangular relationship between client, designer and constructor (Chao-Duivis *et al.*, 2010). First, the client tenders the design work. The appointed design companies develop the technical specifications that will be used to tender a contractor for the construction works. Maintenance works are tendered thereafter when required. The DBB procurement method is also called the traditional method in Chao-Duivis *et al.* (2010). The client has to compensate the contractor in case there are mistakes in the design that cause the contractor to spend more time on the project (Chao-Duivis *et al.*, 2010).
- Design team model: A design team is a partnership between the client, designers and contractors for the purpose of producing a design (Chao-Duivis *et al.*, 2010). Once the design is complete the client enters into a contract with a contractor (or another contractor) for the execution of the works. The design team model therefore looks like the traditional (DBB) model in sense of tendering moments.

In an integrated contract, the design and execution (and possibility also the management, operation and finance) are tendered to a single actor or consortium of actors in relation to the client (Chao-Duivis *et al.*, 2010). The point of integrated contracts is that the client takes a seat back, plays a far smaller role and as result, the client attract far less liability (Chao-Duivis *et al.*, 2010).

- Design and Build (DB): the client tenders the design and construction works in a single contract (Rahola & Straub, 2013). The execution of the constract is in hands of a single entity, which could be a single company, with or without subcontractors, or a consortium that includes design and construction companies (Chao-Duivis *et al.*, 2010; Rahola & Straub, 2013).
- Design-Build-Maintain (DBM): the client tenders the design, construction works and maintenance works in a single contract (Rahola & Straub, 2013). Again, the contracted entity could be a single company, with or without subcontractors, or a consortium that includes design, construction and maintenance companies.
- Design-Build-Finance-Maintain (DBFM): Similar to the previous two procurement methods, however, in this case the investment of the construction is also done by the contracted single company or consortium and the client pays a periodically fee.

The integrated procucement methods are based on the desire to transfer risk to the private development parties, however, the transfer of risk from owner to contractor is accompanied by the transfer of control in the project decision-making (Rahola & Straub, 2013). In general, research agrees that DB offers shorter project durations by the involvement of the construction companies in the design decisions, higher price certainty, better communication between the actors involved and reduced construction time compared to DBB (Rahola & Straub, 2013). Therfore, clients perceive that DB delivers better value for money and causes fewer disputes (Rahola & Straub, 2013).

An advantages of DBB is that it is the traditional project delivery method and that all actors know their roles and what to expect from the process. In addition, DBB is well suited to tender for the lowest price and tendering for the lowest price entails less administrative burden, because the tender procedure saves time and responsibility for demonstrating that the selection process is transparent and objective (Costantino *et al.*, 2012). The main disadvantage of DBB is the lack of collaboration between the design, construction and maintenance companies and it is therefore harder to manage liabilities (Rahola & Straub, 2013). For example, the design company may choose a particular heating system, whilst the construction or maintenance company knows that it does not perform as it should.

DB and substantially DBM improve the price certainty of the project, and the majority of the risk of design failure is transferred to the contractor or the consortium, as a single entity is responsible for design and construction. Moreover, the majority of DB projects are completed within a shorter time frame than is the case with DBB projects, as there is a single tendering procedure and it is not necessary to have a definitive design before starting the works (Hale *et al.*, 2009; Pietroforte & Miller, 2002). The use of performance-based specifications can be implemented in both DB and DBM, because the single entity responsible for design and construction can offer its own solutions that fit with the specifications (Pless *et al.*, 2011). In case of DBM is it possible to use energy performance guarantees by means of Energy Performance Contracting[110]. Disadvantages are that is that presupposes a change in the role of the actors; as a consequence, extra effort and time is needed to adapt to the new situation (Chang *et al.*, 2010).

13

[110] More about energy performance contracting and ESCOs in chapter 6.5.4.3.

13.12 Appendix 12: The steps of a residual calculation in real estate finance

J. C. De Jong (2016: 34) uses a generic example to develop a better understanding of the phases through the residual calculation. These steps are described below.

Starting with the final products implies that the calculation starts by the user. The end-user needs housing (e.g. office space for his company or a dwelling to live). This floor space can be paid by from salary in a private situation or from revenues of business operation. A part of the income is thus used for housing. This expenditure can exist of the mortgage or financing costs in case the user wants to own the space or it can exist of rental costs in case the user rents the space. In the last situation the rent is paid to the owner of the building, which is often an investor or a housing association. In the other situation the user can buy the property directly from the real estate developer. The user wants to pay a market price for the rent or the building. The amount of money the user can pay is limited by the amount of salary or the revenues from its business operation.

The second step is the investor. He rents the place to the user. If the user owns the place, the calculation can skip this step. The investor makes among others costs for the operation and maintenance of the building, pays taxes, has overhead costs for his organisation and has financing costs for the portfolio he owns. The residual value he can pay to the real estate developer is the difference between these costs and the expected income from the rent. This is calculation in the real estate exploitation of the investor. The goal of the investor is to yield a return on the long-run.

The real estate developer is realizing the building for the owner-occupied market or the investment market. This is the third step in the calculation. The developer has to cover its development costs by the revenue of sales to the owner or investor. This development costs consist of construction costs, additional costs (e.g. costs for advisors, marketing and construction site costs), financing costs, taxes and others. However, the real estate developer needs a location for its development. The price this party can pay for the ground is the residual value of this part of the calculation, the development exploitation.

The real estate developer mostly buys prepared land from a municipality (in case of a public development or a building rights model), a shared land operating company (in case of a joint venture model) or from a private party, which could also be an internal transaction within the company (in case of the concession model or private realisation). This party is responsible for the site preparation before the development and after the real estate development this party often also constructs the public space, for which a reservation must be made. This costs and costs for consultants and financing, taxes and others, have to be covered from the revenue of the prepared land. The remaining part is the value of the ground. This calculation is the ground exploitation and the fourth step in the process.

This ground exploitation is the financial tool in developing integrated urban area developments, which is an integral feasibility study of a larger urban area development (J. C. De Jong, 2016). J. C. De Jong (2016) sees that many aspects are visible in the ground exploitation, like partnerships, interests, future demands, spatial restrictions and finance. First, the partnerships are visible as different parties own ground or have agreed upon restrictions in the urban design. The interests and ground positions are brought into the ground exploitation, independent of which plan comes out of the process. Second, next step in the process, the restrictions to the final result are visible, as the input of the different parties can be evenly redistributed among parties to create an integrated result, which is respecting the interests of all parties involved. This is the most important aspect of the ground exploitation. The most important characteristics of the ground exploitation are according to J. C. De Jong (2016: 38-39) that the ground exploitation is about a transformation of a larger (urban) area. The costs are based on the 2-dimensional interventions in this area, because buildings are excluded in this exploitation. However, the relation with buildings is clear in the restrictions set in the type of public space needed, the technical requirements of different types of buildings for the urban infrastructures and the value of the ground based on the type of real estate, which determine the potential revenues.

As last step the considerations are made if the development is feasible. This step is called the financing of the ground. Mostly the land is used for another purpose and it has a book value or a company value for the current owner. The previous calculation can show if the residual value of the ground outweighs the value for the current owner. The financial business case is feasible in case this applies. However, this consideration only counts from a financial-economic point of view. Roughly speaking is the residual value of the land is the market price minus all the development costs. This costs are also including transaction costs, interests, risks and profits, which were not mentioned previously.

The line of reasoning shows that the different exploitations are connected by a financial transaction between different parties, or, by exception, between departments within one party. The revenues of one phase are the (first) costs of the successive phase (J. C. De Jong, 2016). This relationship, the major costs and revenue streams in each phase and the five described steps are visualized in Figure 78.

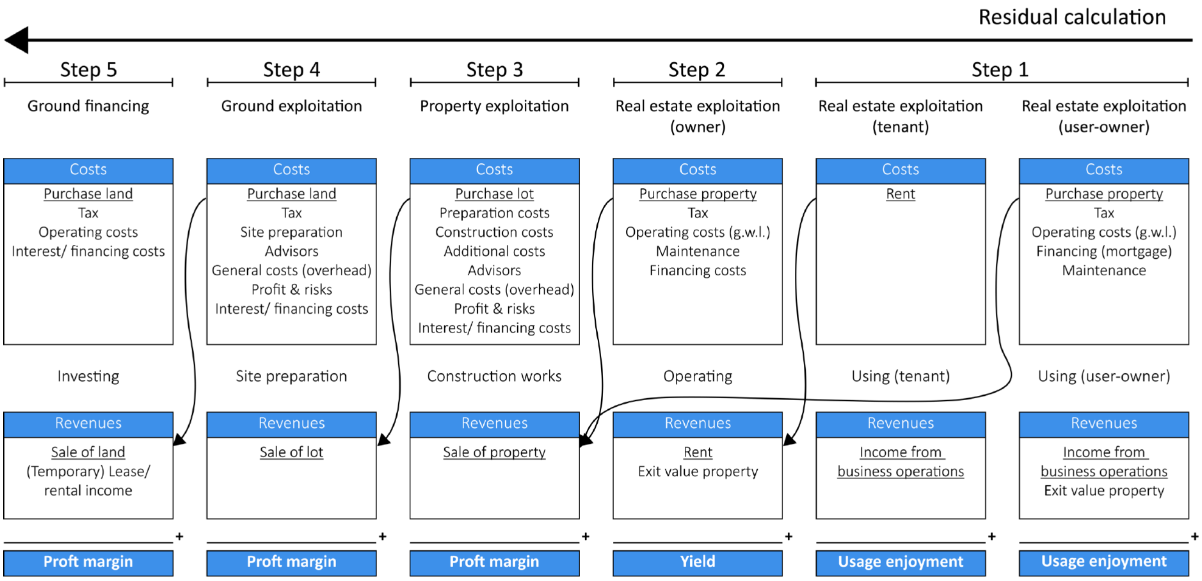


Figure 78: Basic scheme for calculating the residual value of land (own illustration based on images of J. C. De Jong (2016: 35-44)).

Not all of these steps are included in the development process. J. C. De Jong (2016) and Vlek *et al.* (2016) see the ground exploitation, development exploitation and the real estate exploitation as three distinguished exploitations with all a different calculation method. The calculation of the costs for the user and the ground financer or the speculator is excluded. The exploitations are calculating the expected effect on the cash flow and the balance.

13

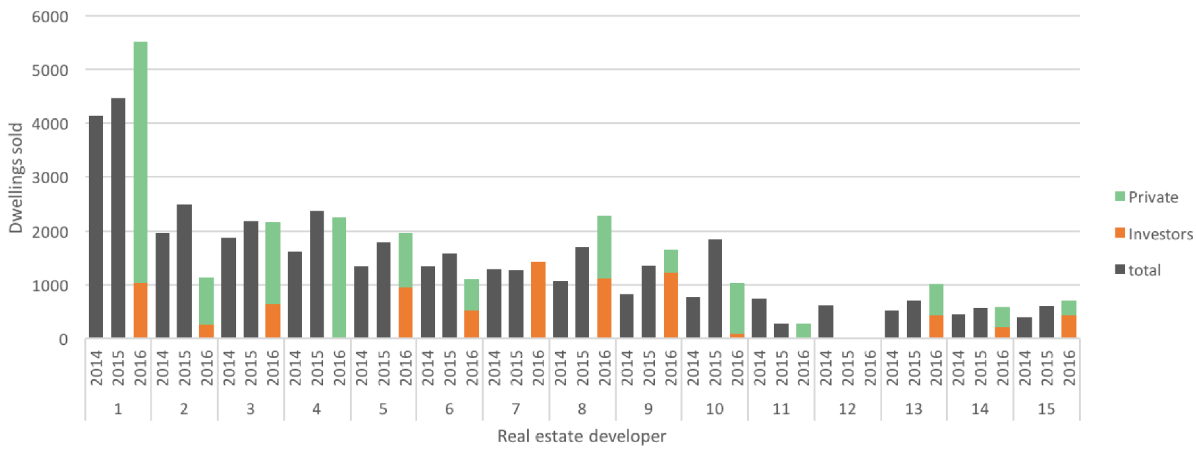
13.13 Appendix 13: Search strategies for sampling

Four search strategies are used in the selection of case studies: literature, google, websites of real estate developers and the ZEN project database.

Literature (e.g. Meijer, Dubbeling, and Marcelis (2010) and Fraker (2013)) gives a clear and formal description of the state of the art in sustainable neighbourhood design. However, these cases are often example projects to develop an eco-neighbourhood based on large subsidies (e.g. Bo01 and Hammerby Sjostad), stricter regulations (e.g. Vauban) or a new value perspective (e.g. EVA Lanxmeer). In addition, literature is often behind the actual practical developments, because the research is executed sometime after construction is finished. That is why the named cases are excluded from further study.

They often say Google knows everything. Search terms like ‘energy neutral neighbourhood development’ are used (and the Dutch translation). Results were huge and research intensive projects (3.000 dwellings and more) like RijswijkBuiten and Project Locatie Valkenburg. The last one is from the consortium ‘*Gebieden Energie Neutraal*’ (GEN). Both are partly interesting, because the role of the real estate developer in the decision-making processes is unclear (Mensink & Franzen, 2013: 15). Project Locatie Valkenburg is excluded from further research. The project does not fit the selection criteria, because the plans are still in the initiating and feasibility stage.

Thirdly, websites of real estate developers are scanned for their recent single-family projects. For this, first a pre-selection of real estate developers is made. The selected real estate developers have a stable output of at least 500 dwellings since the financial crisis (since 2015) and focuses on owner-occupied dwellings. This results into a selection within the top 15 dwelling developers within the Netherlands.



1	BPD	6	VORM	11	ABB Ontwikkeling
2	Van Wijnen	7	Foolen & Reijs Vastgoedgroep / Citypads	12	ASR Vastgoedontwikkeling
3	AM (BAM)	8	TBI (o.a. Synchroon, ERA Contour, Koopmans)	13	Klok Groep
4	VolkerWessels	9	Van Wanrooij Projectontwikkeling	14	Blauwhoed
5	Heijmans Vastgoed	10	Dura Vermeer Groep	15	Nijhuis

Graph 35: Annual sales per real estate developer (own illustration based on De Blauw (2016b) and De Blauw (2017b)).

The top 15 of dwelling developers in 2014 is shown in Graph 35. Borghese/COD and Certitudo are not in the list, because they are new in the list since 2015 and they focus on transformation and/or they sell turn-key to institutional investors (De Blauw, 2017b). Some real estate developers of this selection are still left out of consideration. Heijmans (#4) is excluded, because of their financial problems (De Blauw, 2017a). Assumed is that they will not reserve a budget for training projects. Foolen & Reijs Vastgoedgroep / Citypads (#7), Van Wanrooij Projectontwikkeling (#9) and Nijhuis (#15) are further excluded, because these are specialized developers focussing on the transformation of office buildings and/or rental dwellings (De Blauw, 2017b). Lastly, ABB Ontwikkeling (#11) and ASR Vastgoedontwikkeling (#12) are excluded, because of their drop in development output. This results into that the online project databases of BPD, Van Wijnen, AM, VolkerWessels, VORM, TBI (e.g. Synchroon, ERA Contour), Dura Vermeer, Klok Groep and Blauwhoed are scanned for interesting cases. Of these parties only Blauwhoed sells less as 1.000 dwellings annually, however, their CEO Phillip Smits expects to sell 900-1.000 dwellings in two years (De Blauw, 2016a).

The last search strategy is discussed in the report itselves, as it delivered the two most interesting case studies for this research.

The results of the four search strategies are shown in Table 21.

Table 21: Search strategies and results

Search Strategy	Results
Literature	None
Google	RijswijkBuiten, Rijswijk Project Locatie Valkenburg, Katwijk
Real estate developers' website project database	Nieuw Kortenoord, Wageningen Oase (Veemarkt), Utrecht Wonen 'op Smaak' (Hoge Weide), Utrecht Helsdingen, Vianen
ZEN project database	Prof. Schoemaker Plantage, Delft Het Verborgen Geheim, Rotterdam

No cases that fit the selection criteria were found on the websites of real estate developers Van Wijnen, VolkerWessels and Klok Groep. Dura Vermeer is involved in RijswijkBuiten. That is why those real estate developers are not included in results of the third search strategy.

The cases of the pre-selection are shortly introduced in the coming paragraphs.

First, RijswijkBuiten. The ambition for the neighbourhood RijswijkBuiten is an energy neutral, all-electric neighbourhood of 3,500 dwellings, which is still under construction. The first developed buildings were energy neutral (EPC=0) and in the next step they increased the ambition to become completely energy-neutral, also called zero-on-the-meter (Schilt, 2013; Van Rijswijk, 2014). The ESCO Klimaatgarant pays the additional costs of energy neutrality and gets a reimbursement of the future residents during the in-use phase. The ESCO is needed to prevent increasing v.o.n. prices, which would otherwise be the result of the high energy ambition (Schilt, 2013; Van Rijswijk, 2014) and at that time further buyers were not convinced to pay extra for this (interview Dick Boelen[111] in Mensink and Franzen (2011: 19)). Besides the ESco, the municipality applied a new development approach: 'The building rights model – new style' (Ten Have *et al.*, 2011). With this approach the municipality granted a selected real estate developer a building right of 250 dwellings for advise on marketing, sustainability techniques and costs and financial planning early in the process. Involved real estate developers in RijswijkBuiten are DuraVermeer as development partner of the municipality (Schilt, 2013; Ten Have *et al.*, 2011; Van Rijswijk, 2014) and VolkerWessels & AM (RvO, 2017b, 2017c, 2017d). The case is also used to gather knowledge about energy neutral neighbourhood development by the Praktijkleerstoel Gebiedsontwikkeling TU Delft and Deloitte Real Estate Advisory. This knowledge is published in Mensink and Franzen (2011, 2013).

The next four cases are found by the websites of real estate developers. The second possible case is thereby of the largest dwelling developer in the Netherlands (De Blauw, 2016b, 2017b): BPD. Their best option is Nieuw Kortenoord in Wageningen. This is an all-electric neighbourhood in which energy efficiency among residents is encouraged, a discount on PV-panels is given over a certain period of time, all dwellings are future-proof through preparation for PV-panels and different sale options are given to the future inhabitants about the amount of PV-panels (Holle, 2017; Van de Griendt, 2015). Future-proof dwellings are, according to Willem van den Berg[112] in Hentenaar (2017) dwellings in which provisions are made that allow for later adjustments without too much crushing or chopping. The dwellings in Nieuw Kortenoord have a disconnected cable to the roof to connect to PV-panels. All dwellings in Nieuw Kortenoord have an energy-efficient heating system that uses ground energy. This system is a heat and cold storage in the soil, which requires low-temperature floor heating (Holle, 2017; Van de Griendt, 2015). This is standard in every dwelling. The combination provides low heating costs for its residents

[111] Director at Dura Vermeer
[112] Product developer at Heijmans

(Van de Griendt, 2015). In addition, many homes generate their own green electricity using solar panels. In this neighbourhood is no gas present.

For this neighbourhood the usage of the option theory was investigated (Van Cann, 2011; Van de Griendt & Van Cann, 2012). The option theory concerns about the added value of investing at later in time. Conclusion of this research was that it is advisable to develop dwellings that are not more energy-efficient than required by national building regulations, but also (and perhaps more importantly) not excludes options to improve the energy efficiency of the dwelling in the future.

Home buyers have a pronounced opinion about the added value of an increased energy performance. Van de Griendt and Van Estrik (2010) did research and concluded that energy efficiency and energy costs of a home are currently hardly a factor in the decision factors for home buyers in the Netherlands. More importantly, the price, size and especially the environment of the property are important. In addition, the researches state that buyers are only willing to pay for additional energy-saving measures if there is a financial benefit. Side note, the research is already seven years old. Since that time the dwelling market boomed.

As third option is the Veemarkt in Utrecht. A total of approximately 630 homes are being realized at this former cattle market location. Veemarkt becomes a mixed urban residential area with rental housing, social housing and owner-occupied dwellings (VJ, 2014). The municipality of Utrecht applied the MEAT-tendering procedure to force a higher energy ambition in the bids of the real estate developers (Gemeente Utrecht, 2016, 2017a) and has commissioned extensive research into the possible energy concepts (Mooij, 2011, 2012). This case came to the attention, because real estate developer VORM used conceptual, standardized dwellings with the possibility for future residence to influence the design and the ESCO Klimaatgarant for the PV-panels (Klimaatgarant Solar, 2015). An EPC of 0,2 was realized with those PV-panels.

The fourth possibility was 'Wonen op Smaak' phase 3 of real estate developer Synchroon[113] at the other side of Utrecht (Hoge Weide, Leidsche Rijn). From the start of the project a heating grid connection was planned. However, Van den Boogaard (2016) revealed to the board of the major and alderman that the CO_2-emissions of the district heating were bigger as expected and that was why the environmental efficiency had to be lowered from 177% to 110%. This drop had a huge effect on the EPC-levels and related energy labels of the developed dwellings. Van den Boogaard (2016) continues that formally all dwellings comply with the building degree, however, if the real environmental efficiency was used in the calculations, more CO_2-saving measures were taken by project developers, which would result into more energy-efficient dwellings. Although, the environmental efficiency has no effect on the actual energy usage of the dwellings and thus the energy costs for the residents remain the same (Van den Boogaard, 2016). Synchroon had to invest in more energy saving measures, because Eneco did not reach the promised environmental efficiency. A power struggle followed and in the end Synchroon was not obligated to connect their dwellings to the heating grid. Instead, they applied their all-electric E-house concept (Synchroon, 2015) to realize an EPC=0 (TBI, 2017). They applied an air source heat pump and collaborated with Radix & Veerman and Eneco (Synchroon, 2016; TBI, 2017). Although, it can be disputed if it really was a collaboration with Eneco. Synchroon (2017) states some arguments why this concept is better as the dwelling connected to the heating grid. First, the techniques have a proof-of-concept as already 250,000 heat pumps and 4,500,000 PV-panels are applied in the Netherlands. In addition, home buyers get a guarantee on their systems which will be monitored in the early years. Second, the all-electric concepts have low-temperature floor heating, good insulation values and airtightness. This creates a comfortable temperature during the whole year. Third, the energy costs are noticeable lower than in a new dwelling with district heating. The energy costs can be tens of euros lower a month, compared with a somewhat older dwelling. Fourth, the all-electric dwellings are not connected to district heating or natural gas. Future inhabitants have the freedom of choice between the available electricity suppliers and are not dependent on a fixed heat supplier.

Real estate developer Blauwhoed offered the fifth possible case by the project Helsdingen in Vianen. Since a few years, Blauwhoed applies a new strategy. According to their CEO Phillip Smits in De Blauw (2016a) Blauwhoed now gains 90% of their work by acquiring one-on-one and only 10% with tenders. In addition, they are only interested in tenders that also involve the quality (added value) of the development process and not only the highest bid. This added value was applied through co-design, co-creation and co-decision-making during the development process of Helsdingen, which makes it possible for current and future residents to share and discuss

[113] Synchroon is part of the TBI concern.

ideas on the desired future of Helsingen (Blauwhoed, 2016b). The development manager of Blauwhoed Xavier Delnoij states in Blauwhoed (2015) that the huge variety of dwelling types as the result of the first co-creation session and online responses from all participants. He continues that during the second co-creation workshop Blauwhoed discussed the housing types with the participants and thereby they got a clear picture on the interests of the current and future residents. As final results, Helsdingen gets a variety in dwelling types and energy ambitions. All dwellings have at least the required EPC of 0,4, two dwelling types are energy neutral (EPC=0) and the semi-detached dwellings are even zero-on-the-meter (EPC=-0,4) (Blauwhoed, 2016b). Blauwhoed also had an interesting project in Weesp (Leeuwenveld 2-4, a collaboration with real estate developer Van Wijnen (Blauwhoed, 2016a)), however, the involvement of future inhabitants and its effects on energy efficiency was less clear.

The last two cases are found by the ZEN-database. The sixth suitable case is Het Verborgen Geheim of real estate developer Van Omme & De Groot Projectontwikkelaars en Bouwers (VO&DG). VO&DG realizes 170 single-family and owner-occupied zero-on-the-meter dwellings at Heijplaat Rotterdam (RvO, 2017f). They collaborated with the ESCO Klimaatgarant (RvO, 2017f). The development is part of the urban renewal of Heijplaat. From the beginning of the renewal housing association Woonbron was in the lead of the demolition and development, however, after new tighter governmental regulations for housing associations Woonbron ceased to be able to fulfil the role of land development company and the municipality of Rotterdam took over their ground positions after Woonbron had guaranteed to compensate for possible risks and losses (Gemeente Rotterdam *et al.*, 2015). In the tender description was stated that Woonbron and the Municipality of Rotterdam jointly search for a creative market party who wants to take on the development. The assignment contains the development, sale and construction of approximately 170 dwellings within the recent completed and irrevocable land use plan (VKZ, 2015).

The seventh possible case is the Professor Schoemaker Plantage in Delft. Real estate developer AM is going to realise around 600-800 dwellings in total (AM, 2017). All dwellings in this development have to become zero-on-the-meter (RvO, 2017g). The development was difficult to start. In the beginning of the millennium the municipality of Delft wanted the area to transform to a mixed use area and collaborated with TNO and Cheops Development BV (Gemeente Delft, 2005). This urban area development did not started apart from the large-scale renovation and expansion of an single office building of TNO (Gemeente Delft, 2005, 2015). In the meantime, real estate developer AM became involved and wanted to transform the whole area into a residential neighbourhood. This was made possible by the adjustment of the land-use plan in 2015 (Gemeente Delft, 2015). The real estate developer saw a market opportunity of ZOM-dwellings in the proximity of the campus of the TU Delft (Van Seumeren, 2017). They expected rational decision-making based on the lowest TCO from the home buyers and an increased purchasing power because of the higher incomes of the home buyers.

13.14 Appendix 14: Price list of the dwellings in phase 2-3 of the project 'Het Verborgen Geheim'

Table 22 shows the price list of the dwellings in phase 2 and 3 of the project 'Het Verborgen 'Geheim'. Some dwellings were already sold and no selling prices were available on the project website. These numbers are estimated based on similar dwellings within the project.

Table 22: Price list of the dwellings in phase 2-3 of the project 'Het Verborgen Geheim' (Ooms, 2017). #: Dwelling number; P: Phase; CAT: Dwelling category; #R: Number of rooms; UFA: Usable Floor Area; SFD: Single-family dwelling; *: Price based on similar object

#	P	TYPE	CAT.	#R	UFA M^2	LOT M^2	PRICE	ADDITIONAL INFO	PRICE IN €/M^2 UFA	GROUND BID	GROUND QUOTE
517	2	Baak	Quay	6	160	174	€ 320.000	*	€ 2.000	€ 21.450	6,70%
518	2	Baak	Quay	6	160	134	€ 309.000		€ 1.931	€ 21.450	6,94%
519	2	Baak	Quay	6	160	134	€ 306.000	*	€ 1.913	€ 21.450	7,01%
520	2	Baak	Quay	6	160	134	€ 305.000		€ 1.906	€ 21.450	7,03%
521	2	Baak	Quay	6	160	134	€ 304.000		€ 1.900	€ 21.450	7,06%
522	2	Baak	Quay	6	160	134	€ 303.000		€ 1.894	€ 21.450	7,08%
523	2	Baak	Quay	6	160	134	€ 302.000		€ 1.888	€ 21.450	7,10%
524	2	Baak	Quay	6	160	174	€ 320.000		€ 2.000	€ 21.450	6,70%
525	2	Kiel	SFD	5	121	199	€ 242.500		€ 2.004	€ 21.450	8,85%
526	2	Kiel	SFD	5	121	140	€ 229.500		€ 1.897	€ 21.450	9,35%
527	2	Kiel	SFD	5	121	140	€ 229.500		€ 1.897	€ 21.450	9,35%
528	2	Kiel	SFD	5	121	140	€ 229.500		€ 1.897	€ 21.450	9,35%
529	2	Kiel	SFD	5	121	140	€ 229.500		€ 1.897	€ 21.450	9,35%
530	2	Kiel	SFD	5	121	140	€ 229.500		€ 1.897	€ 21.450	9,35%
531	2	Kiel	SFD	5	121	140	€ 229.500		€ 1.897	€ 21.450	9,35%
532	2	Kiel	SFD	5	121	195	€ 242.500		€ 2.004	€ 21.450	8,85%
533	2	Mast	SFD	5	121	258	€ 249.500		€ 2.062	€ 21.450	8,60%
534	2	Mast	SFD	5	114	150	€ 220.000	*	€ 1.930	€ 21.450	9,75%
535	2	Mast	SFD	5	121	159	€ 235.000	*	€ 1.942	€ 21.450	9,13%
536	2	Mast	SFD	5	121	159	€ 237.500		€ 1.963	€ 21.450	9,03%
537	2	Mast	SFD	5	114	136	€ 215.000		€ 1.886	€ 21.450	9,98%
538	2	Mast	SFD	5	114	136	€ 216.500		€ 1.899	€ 21.450	9,91%
539	2	Mast	SFD	5	114	136	€ 215.000	*	€ 1.886	€ 21.450	9,98%
540	2	Mast	SFD	5	121	234	€ 242.500	*	€ 2.004	€ 21.450	8,85%
501	3	Kiel	SFD	5	121	181	€ 255.500		€ 2.112	€ 21.450	8,40%
502	3	Kiel	SFD	5	121	140	€ 242.500		€ 2.004	€ 21.450	8,85%
503	3	Kiel	SFD	5	121	140	€ 242.500		€ 2.004	€ 21.450	8,85%
504	3	Kiel	SFD	5	121	140	€ 242.500		€ 2.004	€ 21.450	8,85%
505	3	Kiel	SFD	5	121	140	€ 242.500		€ 2.004	€ 21.450	8,85%
506	3	Kiel	SFD	5	121	140	€ 242.500		€ 2.004	€ 21.450	8,85%
507	3	Kiel	SFD	5	121	140	€ 242.500		€ 2.004	€ 21.450	8,85%
508	3	Kiel	SFD	5	121	181	€ 255.500		€ 2.112	€ 21.450	8,40%
509	3	Baak	Quay	6	160	174	€ 342.500		€ 2.141	€ 21.450	6,26%
510	3	Baak	Quay	6	160	134	€ 325.000		€ 2.031	€ 21.450	6,60%
511	3	Baak	Quay	6	160	134	€ 325.000		€ 2.031	€ 21.450	6,60%
512	3	Baak	Quay	6	160	134	€ 325.000		€ 2.031	€ 21.450	6,60%
513	3	Baak	Quay	6	160	134	€ 325.000		€ 2.031	€ 21.450	6,60%
514	3	Baak	Quay	6	160	134	€ 325.000		€ 2.031	€ 21.450	6,60%
515	3	Baak	Quay	6	160	134	€ 325.000		€ 2.031	€ 21.450	6,60%
516	3	Baak	Quay	6	160	174	€ 342.500		€ 2.141	€ 21.450	6,26%
541	3	Mast	SFD	5	121	234	€ 257.500		€ 2.128	€ 21.450	8,33%
542	3	Mast	SFD	5	114	136	€ 229.500		€ 2.013	€ 21.450	9,35%
543	3	Mast	SFD	5	114	136	€ 229.500		€ 2.013	€ 21.450	9,35%
544	3	Mast	SFD	5	121	144	€ 245.500		€ 2.029	€ 21.450	8,74%
545	3	Mast	SFD	5	121	144	€ 245.500		€ 2.029	€ 21.450	8,74%
546	3	Mast	SFD	5	114	136	€ 229.500		€ 2.013	€ 21.450	9,35%
547	3	Mast	SFD	5	114	136	€ 229.500		€ 2.013	€ 21.450	9,35%
548	3	Mast	SFD	5	121	234	€ 255.500		€ 2.112	€ 21.450	8,40%

13.15 Appendix 15: Context of 'Het Verborgen Geheim'

The development process has encountered quite a few difficulties. This part elaborations on the context of the process. First, the most important decision moments with the role of energy is explained. It makes clear which partly had the decision power and on which information they based their decisions. Second, the surrounding projects are discussed.

13.15.1 Dynamics of the decision-making process

In September 1990, the city council decided to maintain the historical district with its recognizable, garden village environment and to demolish the post-war dwellings, because of the poor building and living quality (Gemeente Rotterdam, 2013). The owner Woonbron will be leading the process and replaces the demolished dwellings by new dwellings. This concerns 288 dwellings. In total 296 dwellings will be replaced by two apartment blocks containing social rental dwellings and in between 170-205 single-family dwellings in 'het Nieuwe Dorp' (the new village), see Table 23 for the program (Gemeente Rotterdam, 2013). This meets the wishes of the residents association to maintain the number of houses (Vereniging Wijkbewoners Heijplaat, 2014).

Table 23: Program in 'Het nieuwe dorp' (based on Gemeente Rotterdam (2013)

Number of dwellings to be demolished		Number of new dwellings	
Owned by Woonbron	288	**Heijse Blick**	32
Owned by individuals	8	**Wijde Blick**	58
		Nieuwe Dorp (based on zoning plan)	170-205
Total	296	**Total**	260-295

In 2011 the first 46 dwellings are demolished and in 2013 the remaining part (Top010, 2015). Woonbron accelerated the demolition to prevent degradation in the neighbourhood (Top010, 2015).

In June 2013, the municipality of Rotterdam and Woonbron signed an anterior agreement 'Het Nieuwe Dorp', after previously signed Cooperation Agreements (Dutch: '*Samenwerkingsovereenkomst*', SOK) about the area development of Heijplaat in 2011 and 2012 (F. De Jong, 2015: 7). Several parties collaborates in these SOKs, namely Woonbron, the municipality of Rotterdam, the harbour of Rotterdam, the residents association, Eneco, Stedin and the RDM Campus (Gemeente Rotterdam, 2015: 425). Agreements within the sock were the amount of dwellings, the ambiance of the village after the development, the higher level of facilities and sustainable development of this isolated location.

In October 2013, the new land-use plan was established by the municipality of Rotterdam (Gemeente Rotterdam, 2013). The land-use plan contains a strategic master plan with freedom for the developers. For the whole garden village of Heijplaat a procedure is deployed to designate it as a protected cityscape. The new development is not part of this protected cityscape, but has to take this into account. This paragraph of the amenities committee (Dutch: '*welstandsparagraaf*') is one of the substructures in the new land-use plan. The land-use plan assumes a development of Woonbron. An anterior agreement between the municipality and Woonbron assures that the municipality can collect the costs for the public space from Woonbron.

In December 2013, Woonbron ceased to be able to fulfil the role of land development company for 'Het Nieuwe Dorp', due to the new, tighter governmental regulations for housing associations (F. De Jong, 2015; Gemeente Rotterdam *et al.*, 2015; Raets & Aboutaleb, 2015). At that time, Woonbron prepared already most of the land for development (Gemeente Rotterdam, 2013).

Since that time the municipality of Rotterdam and Woonbron discussed an alternative strategy for the development of 'Het Nieuwe Dorp'. At stake was the content of the SOK and anterior agreement. The municipality did want Woonbron to transfer their agreed duties to another third party. At the end of 2014, the city council discussed the strategy to take over the control of the development and selected together with Woonbron a third party to execute the development of the dwellings. In the city council meeting of November 2014, there was a huge discussion before they all agreed, as can be read in the minutes in Gemeente Rotterdam (2015: 425-427) and in F. De Jong (2015: 7). The city council prioritized the liveable future of Heijplaat and their interests. Some political parties wanted a new SOK with signatures of the resident association. This would give them a formal vote in the development. However, the alderman Schneider did not agree to this. He expected that this would cause delays in the process, because it would give the residents association an opportunity to negotiate new terms. For that reason, he does not want collaborations to be 'contractualised'. Alderman Schneider did agree to keep complying to the agreed terms in the previous SOKs. That implies that the level of facilities on Heijplaat, the increased sustainability level and the ambiance of the dwellings will keep as planned. At the end of the city council meeting they decided to take-over the control the development under some strict conditions (Raets & Aboutaleb, 2015: 2):

- The tender has to be completed with a positive result regarding a signed development agreement with a market party.
- That market party has to bid at least the ground price of € 19.419 per dwelling and has to buy at least a fixed amount of lots per year.
- The made costs by Woonbron has to be counted as loss by Woonbron
- The municipality gets the ground from Woonbron without costs
- Woonbron pays the municipality for the unprofitable projects in the ground exploitation.

At the start of 2015, the municipality of Rotterdam and Woonbron organized a tender for the selection of a creative market party who wants to take on the development of 'Het Nieuwe Dorp' on Heijplaat (VKZ, 2015). This market party has to develop, sale and construct approximately 170 single-family dwellings (VKZ, 2015). The tender gives the extra information that the municipality is owner of all the land and the land-use plan has been completed and became irrevocable.

At June 1, 2015, the municipality of Rotterdam, housing association Woonbron and real estate developer Van Omme & De Groot signed the development agreement 'Heijplaat Nieuwe Dorp'. The real estate developer has drawn up a plan that complies with the spatial ambition and preconditions, made a bid of € 21.450 per plot, which is higher than the minimum land price of € 19.419 from this project and agreed to realizes the dwellings with a speed of 25 units each year (Gemeente Rotterdam *et al.*, 2015; Raets & Aboutaleb, 2015: 2). The municipality will develop the public space. At the same time, the agreement was signed between the municipality and Woonbron. With this agreement, the municipality takes over the urban area development of Woonbron. The ownership of the ground is transferred free of charge to the municipality (Gemeente Rotterdam *et al.*, 2015; Raets & Aboutaleb, 2015). With the consent of these partners, the agreements from the SOK relating to the development will be transferred by Woonbron to the municipality. The municipality monitors that the market party performs its real estate operation in accordance with the agreements of the SOK (for example, adaptive construction and energy neutral development). The steps taken for the development also implement the motion of Van der Lee *et al.* (2014) about the facilitation of sustainable new constructions in Het Nieuwe Dorp (filed in the city council on 2014, November 14). Therefore, the board proposed to dismiss this motion (Raets & Aboutaleb, 2015).

The decision timeline is shown in Figure 45. The timeline also shows some moments that are not included in the decision-making process as described above. They are not directly related, but do indirectly effect the results. These events are discussed in the next paragraph.

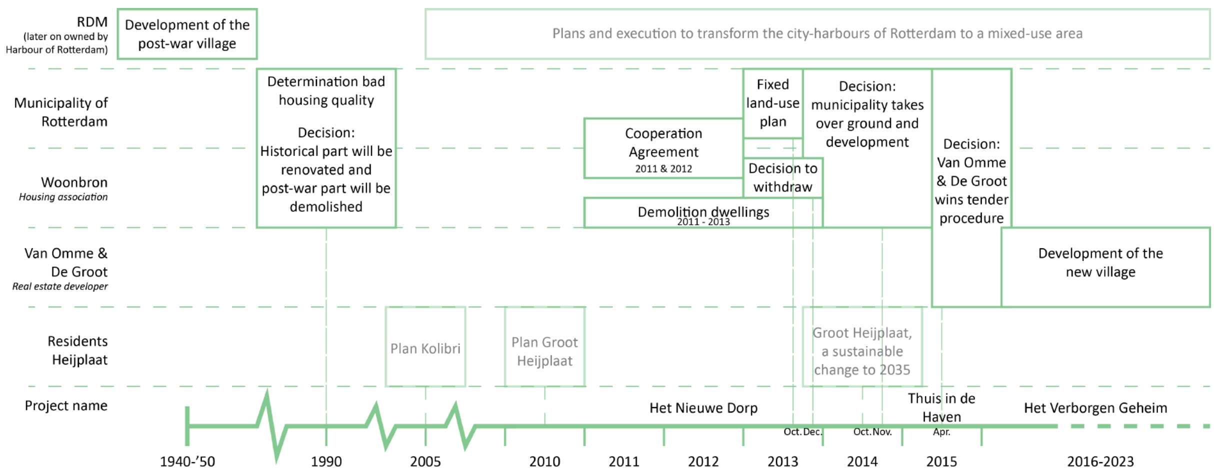


Figure 79: Decision timeline and involved stakeholders (own illustration based on Gemeente Rotterdam (2013, 2017); Gemeente Rotterdam *et al.* (2015), Stadshavens Rotterdam (2009), Vereniging Wijkbewoners Heijplaat (2014), Top010 (2015) and Ooms (2017)).

13.15.2 Surrounding projects and other relevant events

The current residents of Heijplaat and the development within the harbour of Rotterdam also effected the result. First the position of the current residents is discussed and secondly the development within the harbour of Rotterdam.

The current residents of Heijplaat wants a liveable and sustainable Village. Since the demolition of nearly 300 dwellings, the population of the village dropped and many facilities became infeasible. Previously, the RDM subsidised many activities in the village, due to its origin connection. However, the RDM is now bankrupt and without an increase in population, the level of facilities, will decrease (Vereniging Wijkbewoners Heijplaat, 2014: 7). The current residents are united in the '*Verenging Wijkbewoners Heijplaat*' (VWH), which can be translated as the Association Residents Heijplaat. The VWH made three area visions: 'Plan Kolibri' in 2005, 'Plan Groot Heijplaat' in 2010 and 'Groot Heijplaat, een duurzame verandering naar 2035' (Groot Heijplaat, a sustainable change to 2035) in 2014 (Vereniging Wijkbewoners Heijplaat, 2014: 3).

These plans seem to have contributed indirectly to the final development. First, improving the energy efficiency was one of the goals in the second area vision in 2010. After this vision, Heijplaat was appointed as a pilot area for sustainable development. Heijplaat offered great opportunities to realize a sustainable living and working area, due to its isolated location and outstanding possibilities in the area (Vereniging Wijkbewoners Heijplaat, 2014: 7). And second, at urge of the residents the post-war village was accelerated demolished between 2011 and 2013. This demolition was being postponed, which let to years of impoverishment and vacancies in this part of the neighbourhood (Vereniging Wijkbewoners Heijplaat, 2014: 17). For these two reasons, it seems that residents have enforced a sustainable, energy-neutral and accelerated development by making plans and presenting them to councillors. However, from the plans (especially Vereniging Wijkbewoners Heijplaat (2014)) can be read that they feel out of control.

The development is located in the middle of a big urban area development, namely the harbour of Rotterdam is developing a new future for its city ports (Dutch: '*Stadshavens*'). After completion of the 'Tweede Maasvlakte', part of the port activities is going to withdraw from the city ports. This creates room for new destinations on and along the water. Stadshavens Rotterdam (2009) describes the desired future for one of those city ports. From west to east, a development is envisioned to gradually shift the logistical port activities into knowledge-intensive business, training, living and work environment for pioneers and luxury living. Every city port retains its own identity and together they will form the economic hub between the port and the city. This transformation of the city ports will be realized by the Municipality of Rotterdam and the Port of Rotterdam. Together they created an ambition program with two main goals: 1) to strengthen the port and city's economic structure and 2) to create attractive and high-quality living and working environments. The program is given concrete implementation in four area plans: The Rijnhaven-Maashaven, Merwehavens-Vierhavens, Waalhaven-Eemhaven and the RDM area (Stadshavens Rotterdam, 2009). Het Verborgen Geheim is located next to the RDM areas. The village of Heijplaat are the blue areas in the middle of the purple ones in Figure 80 and 'Het Verborgen Geheim' is the part with the dwelling icons. Heijplaat is one of the little spots in the harbour of Rotterdam that is not owned by the Port of Rotterdam N.V. and therefore the area is not governed by the decision-making power of this market party.

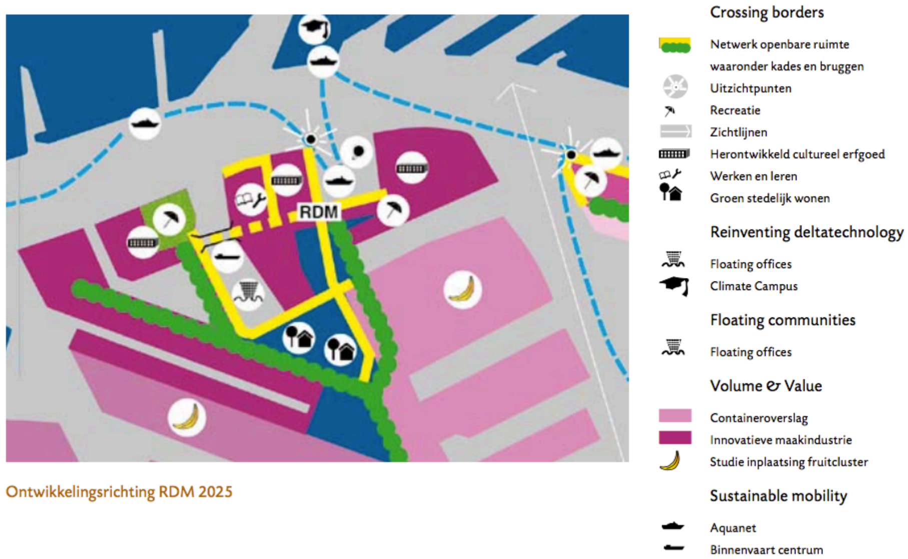


Figure 80: Desired development of the RDM harbours in a strategic map. The blue parts are the locations that are not owned by the port of Rotterdam (Stadshavens Rotterdam, 2009).

13.16 Appendix 16: Conceptual design alternatives leading to a preliminary design

Several alternatives are explored for the development of the LP-model. In the explorations questions were asked like what is the model going to optimise exactly and why is that useful? How can this be executed by linear programming? The alternatives are shortly introduced and the part concludes with the selected alternative.

The first alternative was to model the urban design and building characteristics to optimise the passive solar gain. The philosophy behind was that passive solar gain is freely available to heat dwellings if the urban design and dwellings are properly designed. A model can find the optimal balance between the cost advantage of not having to invest in expensive energy efficiency measures and the missed opportunity costs of the urban space that passive solar design requires, as it is possible that because of the low winter sun less high or less dwellings can be developed. A literature study about the optimization of urban form to reduce energy demand in the Dutch climate in which the application of passive solar design in the neighbourhood of Vauban, Germany was evaluated, shows among other things that the electricity gain by solar panels at the roof is more than it would gain as heat from the sun (Fraker, 2013; Stevanović, 2013; van Esch, Looman, & De Bruin-Hordijk, 2012; Zirnhelt & Richman, 2015). Design details raise importance to prevent overheating during hot summer days and capture the weaker winter sun for heating. The energy balance calculation of Itard (2011) shows similar conclusions by stating that the main aspects in energy efficiency are the level of insulation, ventilation, infiltration, solar gain and internal heat generation. Huge, passive house standards for the insulation values of walls, roof and floor are needed to make it possible to heat dwellings by solar and internal heat gains. These huge investments in insulation, airtightness and ventilation are higher as a heating system. This alternative is not selected for multiple reasons. First, the costs-effectiveness of passive solar gain is questionable. Second, passive solar design contains complex and nonlinear relationships. For instance, the height, width and depth of dwellings and the angle of the sun throughout the year needs to be included in the urban design. A combination of the drawing tool SketchUp and Excel was examined, but appeared infeasible for the graduation. Those variables are nonlinear connected and require approximation tricks in order to be added to the model. Thirdly, the urban design is not the core focus of the first feasibility study. This contains the dwelling mix in the urban programme and the investment costs. Those needs optimisation.

The second alternative was to use the official calculation method of NEN 7120+C2 (2012). This would offer the opportunity to make a precise optimisation of the energy efficiency of a dwelling. When the measurements are related to the costs, the most cost-effective solution can be found for different types of dwellings. However, this alternative appeared too complicated, because of its nonlinear relations between many variables and the almost impossible task to divine the costs per measure. Thereby, the calculation method is going to be replaced around 2018 (Bouwens, 2017a; Valk, 2017). The model would thus calculate the most costs-effective implementation of the BENG requirements with a method that would not be used for that in the future.

The third alternative had to overcome this complexity and have the possibility to be modelled by linear programming. These complexity was also experienced by Milan *et al.* (2012), whose objective was to develop a simplified linear, ready-to-use model for the optimization of a 100% renewable energy supply system for a residential building in the design phase in terms of the overall costs. Their approach facilitated the implementation of on-site renewable energy technologies, like PV-panels, solar thermal collectors and a ground source heat pump, with hourly energy consumption and production rates of the installed systems. The third alternative would upscale this approach to optimises the urban dwelling mix and the generic energy measurements, including possibilities of a heating and a combined heat and power facility. This alternative can meet the requirements of a profit optimisation of the dwelling mix. In the conceptual design this alternative for the LP-model was structured by the real estate developer dilemma as described by Barendse *et al.* (2012: 13-22) and an optimal 100% renewable energy supply system on a neighbourhood scale by combining the method of Milan *et al.* (2012) for the hourly precision and the supply by solar collectors and PV-panels, the method of Merkel *et al.* (2015) for added an decentral CHP-system and the calculation of the optimal capacity of this system and the method of Mehleri *et al.* (2012) for the optimal design of the piping of this decentral heating system including the locations of the CHP-facilities and backup boilers. All sources use (mixed-integer) linear programming as method. However, the formulas used in the method of Milan *et al.* (2012) have already more variables than Whatsbest can offer. This alternative is not possible to develop by the available means.

13.17 Appendix 17: Description of the result of the unstructured interviews with experts

The second method of feedback by experts is executed by unstructured interviews. In these interviews individual experts give their ideas on the possibilities for application in practise. The experts were all supervisors during the development process of the model (see Appendix 13.7). The experts all have different background knowledge and a different profession within the field of urban development. The unstructured interviews were feedback sessions held apart from the supervision sessions.

The applied method is comparable to the 'unstructured interview'. This is approach is different as the 'semi-structured interview', because on forehand only a range of topics is prepared and not an interview schedule (Bryman, 2012). This approach looks similar to a conversation. The unstructured interview method offers the possibility to adjust the emphasis of the interview as result of interesting topics that emerge during the interview (Bryman, 2012: 470). The specific focus of the interview about the added value of the model therefore rapidly shifted to the specific knowledge of the three different supervisors. For these sessions no questions were prepared on forehand, only the idea and model were presented. In some cases, the model was nothing more than a sketch of the conceptual design, because the feedback is acquired throughout the research process. However, the presented feedback is still valid. The results of the sessions is in chronological order described and referred to as personal communication - e.g. Spijkerman (2017b), Luijkx (2016, 2017b) and Nan (2017).

13.17.1 Complexity of decision-making processes by Wouter Spijkerman

The next part summarizes the feedback of Wouter Spijkerman (2017b) about the complexity of decision-making processes in urban area development. It starts with an introduction about Wouter Spijkerman and the company SITE urban development, followed by the main points of feedback on the model. The model was in its conceptual phase at the moment of feedback.

Wouter Spijkerman was working as urban developer at SITE urban development during the internship of the researcher. Spijkerman is conceptual driven, highly skilled in complex multi-actor decision-making processes within the field of urban area development and his special focus of expertise is in business ecologies. SITE urban development works on complex urban tasks with various parties and interests. SITE combines sharp strategic insight into conceptual thinking and connects design, finance and market development in the development of a clear vision and turns them into feasible concepts and development strategies.

Spijkerman (2017b) had many points on advise on the possible scope of the model. The relevant points about the added value of the decision support tool are explained, namely scale level of decision-making and type of energy sources included, the context of the location, the design approach, collaboration with other stakeholders and the multi-layered approach of urban area development.

The complexity of decision-making increases with the scale level involved, which is explained by Figure 81. The left part of the image is about one building and is mainly about the optimisation of the EPC-level. The increased scale level provides more options on renewable energy and energy reduction systems. A way to cope with this is to work with a database with possible systems, for instance energy from solar, wind and water power, heat exchange between buildings and hot-and-cold-storage. In the case of one building only a few actors have influence and often one stakeholder has the real decision power. In the case of an energy system on a neighbourhood or city scale with exchanges of different type of energies, the amount of stakeholders increase dramatically with both direct and indirect stakeholders and all involved stakeholders have a bit of decision power. They interact with each other and operate as a system within a system. The solution needs to be more than just a good design to get the stakeholders to agree with the plan of approach. This often involves a type of solution that has to provide a win-win situation, but this is difficult to attain in a multi-stakeholder environment since interests often conflict with one another.

There is also a scale level in between, namely the scale of the block, street or small neighbourhood. Still multiple parties can decide what happens in this scale level, but it is more clear how to decide on what. One way to cope with this decision-making is to start with mapping the various stakeholders by their decision power and work from there. In that way the people with the real decision power can be disentangled from the rest, which makes it easier to make decisions.

Spijkerman (2017b) recommends to not solely depend on computer models and to use them as guidance and as a means to provide insight in the various possibilities. The proposed model in the graduation could be used to provide insight in a dual concern model (Edelman, 2007). This model identifies strategic styles in the search for innovative problem solving that can be found in both the distributive and integrative elements of negotiations (Edelman, 2007: 60). A computer model is a means, not the goal and should be wisely used as such. When properly done a computer model can provide insight and get conflicts or discussions in a different mode, moving from an emotional state into a concensus driven and mutual gains solution.

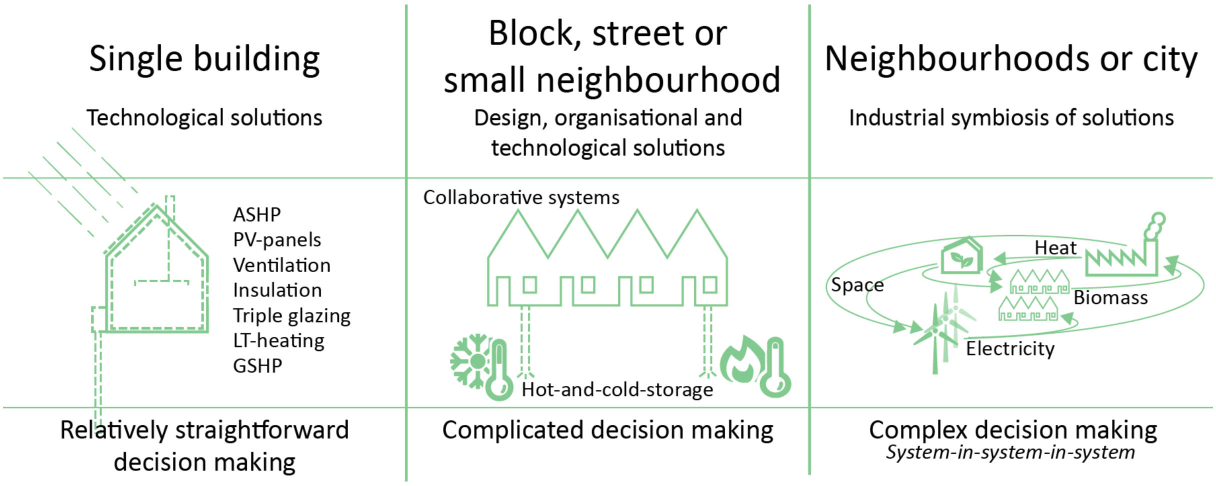


Figure 81: Complexity of decision-making processes for different scale levels (own illustration based on Spijkerman (2017b))

As an graduated urbanist Spijkerman (2017b) often refers to take the context into account. This context is about the physical location and the design possibilities, the demand (of the market, different interests and policies) and the means (possible investments and realism). This approach is also the core of SITE urban development. An urban development projects needs to balance those three components. A computational approach lacks design and vision which can be incorporated with a design approach. The approach of SITE often applies a sequence of four steps: Analysis > Vision > Concept > Development framework. A shared vision, concept and/or development framework can be realized by involving other stakeholders into the processes of development. This shared plan is not solely about one aspect, but needs to give a holistic image of the desired future situation, also referred to the multi-layered approach of urban area development. This last aspect is not included in the model, that only focusses on one aspect, energy. Therefore, it neglects the interaction of this aspect with other important layers.

For the purpose of this research the complex decision-making environment of larger scale developments is not taken into account. extent. Insights of Spijkerman (2017b) are considered in the design of the model to ensure it has added value. The model takes into account the various interest of the involved parties by quantifying those to constraints. The database with the long list of energetic possibilities is captured by the focus of one single concept and housing type, namely the all-electric, single-family dwellings.

The context is taken into account by the summarizing market value, area sizes and amount of developable land into numbers. This is not exactly in line with the meaning of context from Spijkerman (2017b), which is more about the qualitative story of the site. The usage of the model does not mean that this has to be neglected. The focus of the model is on the first step of the development, the feasibility stage. This step starts with an analysis (called ‘exploration’ in this thesis) of the solution space. The model checks for the energetic ‘layer’ of the urban development project, whether the desired energy ambitions can be realized. The model has to return a feasible solution for this single layer within the whole development. This can be done by changing constraints or lowering the ambitions. When a feasible solution is returned, the model represents the values of the design attributes. This can be either the values for the optimal design alternative or the boundary conditions by returning the values of the given constraints. The last option keeps possibilities for optimisation open for other layers/aspects within the project. The returned values can be used for the urban design. This process of exploration can be complementary to other design analysis and the approach of SITE, which is based on aligning interests and coming up with mutual gains solutions.

The vision and concept can be created besides the quantitative feasibility study of the model. The results of the model can be added to the development framework, as boundary conditions to keep the development realistic and feasible. On the other site, the expert focus group saw an opportunity to use the model in a later stage of development. When a vision, concept and development framework are ready, the model can answer the question which dwellings can be developed best to create the optimal energetic and financial solution within the interests of all parties. This is also how the model was used in the quantitative case study analysis. The model thus focuses on complicated, but not complex, decision-making processes in urban area development and can be used additional to qualitative tools in which visions, concepts and development frameworks and strategies are created.

13.17.2 Environmental Performance Coefficient by Thijs Luijkx

The next part summarizes the feedback of Thijs Luijkx (2016, 2017b) about the current questions in the field, which results into the usage of the Environmental Performance Coefficient. First an introduction about Thijs Luijkx and his company Watkostdebouwvaneenhuurwoning is given, followed by the main points of feedback on the model. The model was in its preliminary design phase at the moment of feedback.

Thijs Luijkx is educated in Spatial Planning in WageningenUR, but gradually more specialized into housing associations and their operation. Thijs Luijkx executes applied research and is founder and owner of Watkostdebouwvaneenhuurwoning. Watkostdebouwvaneenhuurwoning is a benchmark with more than 460 projects about the new development of social rented dwellings. The benchmark is used to substantiate the value-added (e.g. higher quality, lower costs and/or other benefits) of these projects within decision-making processes of housing associations. This information is used by property managers, asset managers, portfolio managers, policy makers, controllers, directors and commissioners in supporting investment and investment scenarios. In addition, the benchmark is used to monitor trends in new housing development and to search for reference projects. Thijs Luijkx also organises congresses for the users of his benchmark.

The combination of energy and materials was the main point of advice during the talks between the researcher and Luijkx (2016, 2017b). Many housing associations already know what sort of the possibilities are to realize a higher energy ambition. Most of the present housing associations during the congress did not knew about the MPG (Luijkx, 2017c). The model has an added value when it shows new insights in the possibilities when combining both energy legislation with the MPG.

This point of advice was considered, but decided not to be incorporated into the model. It is too complex to take this one in account. The financial business case of re-using materials is mostly unknown, according to recent graduation research about the circular economy. That research showed that the sustainable approach of 'cradle to cradle' (McDonough & Braungart, 2002) and other circular solutions are still in a stage of exploration in academic research, as showed in latest graduation research of Stigter (2016) and Kazemi (2016). The last one named that there is indeed an urgency for developing new strategies for implementing circular economy in the construction industry and that it offers big potentials, but an on-going discussion about the shift in responsibilities still exists. The most recent thesis of Djoegan and Van den Reek (2016) even conclude with the assumption that a circular economy can only be implemented successfully if resource prices increase, or if labour costs decrease for suppliers. Based on these three theses can be stated that the private sector is not ready to implement this new approach of cradle to cradle and circular economy in their business plans without market stimulus. That is why the MPG is not incorporated. However, it is a point that has to be taken into account by future research. The model proposes to use many installation technologies that require a lot energy to be developed, for instance the example about PV-panels earlier. It is unknown within this research how the proposed energy concepts of the model score on the MPG-requirement.

13.17.3 Residual value of land by Patrick Nan

The next part summarizes the feedback of Patrick Nan (2017) about appreciation of the financial results of the LP-model. First an introduction about Patrick Nan and his company Planmaat is given, followed by his additional points of feedback on the model. Most points of feedback are already handled within the expert focus group of Nan *et al.* (2017). For sense of brevity only new insights are added. The model was in its detailed design phase at the moment of feedback.

Patrick Nan is graduated at the TU Delft in Building Informatics and specialized in decision science. In 2004 Patrick Nan and Ellen Mettes founded Planmaat with the aim of further specialization in the content-driven guidance of open design processes in urban and spatial planning. Planmaat is an independent financial consultancy firm in the field of (urban) area development[114].

Nan (2017) is highly skilled in the application of the LP-modelling technique and sees the added value in how it is applied in the model. The results of the model take into account the interests of various stakeholders by the added constraints. It can be used in the exploration of the decision space. The interests of the various stakeholders can be added to a different objective function and with various runs the different feasible solutions can be mapped. For instance, if profit is fixed, the best ground price can be identified for the municipality or if those are fixed, the best energetic possibilities can be explored. In all explorations, the interest of the stakeholders has to be fixed by constraints, otherwise the results will look feasible, but there will still be parties that are unsatisfied.

Nan (2017) notified one point of attention. The results of the model are presented as extra profit, but in fact is it the profit rate combined with the extra residual value of the land. If the land value is fixed, for instance in a tender, the real estate developer can still decide to increase the ground bid, or the increase the quality of the plan.

[114] More information about Planmaat in Chapter 9.3, Appendix 13.7.4 and Appendix 13.29.

13.18 Appendix 18: Detailed design of the decision support tool

This Appendix describes the mathematical structure of the final detailed design of the model and the formally set inputs for the linear programming model. The mathematical structure is based on endogenous (fixed input) variables and exogenous (output) variables. First, the real estate developers' dilemma is introduced with the objective function on profit and the endogenous dwelling types. Second, the energy installations are introduced with the possibilities for the thermal and renewable energy installations. The amount of installed installations are endogenous variables. Third, the constraints for BENG are introduced based on the size of energy dwelling type and the energy installations applied in each type. Fourth, the calculation of the total investment is added as endogenous variable. Fifth, the total investment must be financed in some way and this is made possible by the endogenous variables about finance: two for mortgage types, one for the ESCO and one for the financing by the real estate developer. This one is connect to the amount of profit made, as will be explained in that section. Seventh, the dwelling type, installations and financing methods used relate to the TCO. This part introduces energy costs, maintenance costs and costs related to the additional investment and financing method. Lastly, multiple possible objective functions from other stakeholders' perspective are given. In the end a model is created which maximizes the amount of profit made by the real estate developer, but constraint by all previous mentioned aspects.

13.18.1 Real estate developers' dilemma: the dwelling mix and profit

The underlining structure of the whole LP-model has the objective function to find the optimal mix of single-family dwellings the real estate developer must develop to get the maximum profit. This structure is based on the real estate developer dilemma as described by Barendse *et al.* (2012: 13-22). Twelve dwelling types are created as the endogenous variables. Those types are based on four unique architypes in single-family dwellings, namely corner dwellings in terraced dwellings, mid-terraced dwellings, semi-detached dwellings and detached dwellings (see Figure 82). The critical reader will see six different types in the figure, however, the corner dwellings of terraced dwellings and semi-detached dwellings can be mirrored and therefore those dwellings are not unique. The four architypes differ in the market value per m^2 UFA and in the lot size per dwelling.

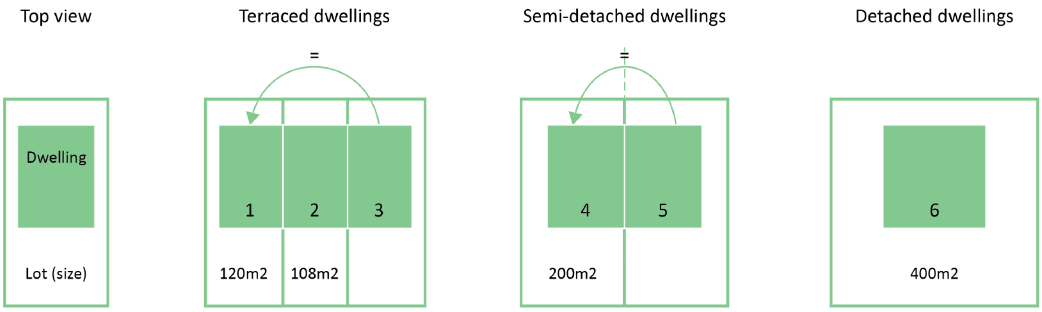


Figure 82: Four unique architypes of single-family dwellings are included in the optimisation.
All differ in the market value per m^2 UFA and the lot sizes per dwelling (own illustration).

Each of the four architypes has three sub-types, which differ in the amount of UFA (and thus in the related total market value and construction costs). In total 12 types of dwellings can be selected in the optimisation (see Figure 83).

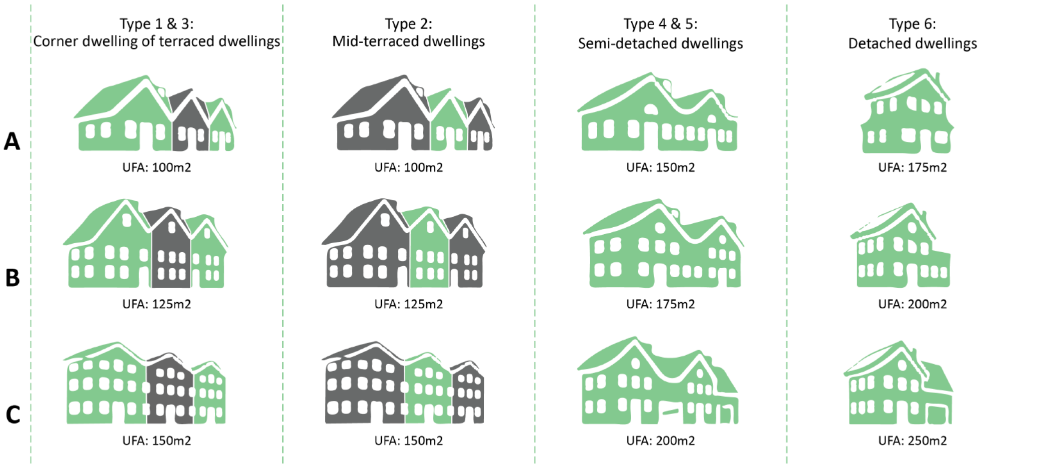


Figure 83: Three sub-types for each architype gives 12 dwelling types in total.
Sub-types differ in the amount of UFA (own illustration).

These twelve possible dwelling types are the decision variables in the LP-model. The objective function is to maximise the amount of profit made:

$$max!\, P_{tot} = \sum_{i=1}^{n} (P_i * D_i) \qquad \text{For } n = 12 \qquad (6.6)$$

In which:

- P_{tot} is the total amount of profit made (exogenous)
- D_i is the amount of dwellings of type *i* (endogenous)
- P_i is the amount of profit for dwelling type D_i (exogenous)

However, the objective function is subjective to several constraints. First, the amount of available land for dwelling development cannot be exceeded:

$$\sum_{i=1}^{n} (A_{lot;i} * D_i) \leq A_{lot;tot} \qquad \text{For } n = 12 \qquad (6.7)$$

In which:

- $A_{lot;tot}$ is the total amount of available land for dwelling development (exogenous).
- $A_{lot;i}$ is the surface of the lot of dwelling type D_i (exogenous).

Second, the total amount of dwellings developed must fit the bandwidth of the density requirements:

$$\sum_{i=1}^{n} D_i \geq D_{tot;min} \qquad \text{For } n = 12 \qquad (6.8a)$$

$$\sum_{i=1}^{n} D_i \leq D_{tot;max} \qquad \text{For } n = 12 \qquad (6.8b)$$

In which:

- $D_{tot;min}$ is the minimum amount of dwellings required (based on density requirement, exogenous).
- $D_{tot;max}$ is the maximum amount of dwellings required (based on density requirement, exogenous)

Third, the individual dwelling types must fit the bandwidth set for each architype. Each architype contains three different subtypes. Therefore, the summation must not include all dwelling types for each architype, but D_{1-3} for architype 1, D_{4-6} for architype 2, etc.:

$$\sum_{i=1}^{i+2} D_i \geq D_{tot;min;i-i} \qquad \text{For } i = 1, 4, 7 \text{ and } 10 \qquad (6.9a)$$

$$\sum_{i=1}^{i+2} D_i \leq D_{tot;max;i-i} \qquad \text{For } i = 1, 4, 7 \text{ and } 10 \qquad (6.9b)$$

In which:
- $D_{tot;min;i-i}$ is the minimum amount of D_i - D_i required (based on density requirement, exogenous).
- $D_{tot;max;i-i}$ is the maximum amount D_i - D_i required (based on density requirement, exogenous)

Fourth, because dwelling type D_{1-3} and D_{7-9} represent corner dwellings (of the terraced dwelling and the semi-detached dwelling) a system constraint is added to ensure that they get an even number:

$$0{,}5 * D_i - D_j = 0 \qquad \text{For } i = 1, 2, 3, 7, 8 \text{ and } 9 \qquad (6.10)$$

In which:
- D_j is the amount of single corner dwellings developed (endogenous, integer).

And fifth, a terraced dwelling without at least one mid-terraced dwelling is a semi-detached one. Therefore, D_4 must at least get half the number of D_1, D_5 at least half of D_2 and D_6 at least half of D_3:

$$0{,}5 * D_i - D_i \leq 0 \qquad (6.11)$$

For i = 1 (left D_i) & 4 (right D_i),
for i = 2 (left D_i) & 5 (right D_i) and
for i = 3 (left D_i) & 6 (right D_i).

The objective function and the constraints are created within the basic structure of a LP-model. The result is shown in Figure 84. This shows the twelve possible dwelling types as endogenous variables in column C-N and also the mathematical functions are clearly recognisable:
- Formula 6.6 (objective function) in row 6
- Formula 6.7 (maximum amount of available development space) in row 11
- Formula 6.8a and 6.8b (minimum and maximum total amount of dwellings allowed) in row 12 resp. 13
- Formula 6.9a and 6.9b (minimum and maximum total amount of dwellings allowed per architype) in row 16 resp. 17 for the first architype, in row 18 resp. 19 for the second architype, in row 20-21 for the third architype and in row 22-23 for the fourth architype.
- Formula 6.10 (ensuring an even number of corner dwellings) in row 26-29 (for the terraced dwellings) and 32-34 (for the semi-detached dwellings)
- Formula 6.11 (ensuring at least one mid-terraced dwellings in every row of terraced dwellings) in row 26-29.

This LP-model is used as the basic structure for the final LP-model with the objective function to optimize the dwelling program and the related energy installations, which maximize the profit for the real estate developer.

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
1				Dw;1,3			Dw;2			Dw;4,5			Dw;6		Dw;1=3, Dw;4=5									
2			a	b	c	a	b	c	a	b	c	a	b	c	1=3a	1=3b	1=3c	4=5a	4=5b	4=5c				
3	**Endogenous variables**		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0				
4																								
5	**Objective functions**																					Outcome		
6	Max Ptot		I 9.600,00	I 12.000,00	I 14.400,00	I 7.000,00	I 8.750,00	I 10.500,00	I 18.900,00	I 22.050,00	I 25.200,00	I 28.000,00	I 32.000,00	I 40.000,00								I -	MAX!	
7																								
8	**Negotiable (design) constraints**																					Outcome	<=>	Constraint
9																								
10	*Urban design*																							
11	Alot;tot		120	120	120	108	108	108	200	200	200	400	400	400								-	<=	9000
12	MIN Dw;tot		1	1	1	1	1	1	1	1	1	1	1	1								-	Not >=	60
13	MAX Dw;tot		1	1	1	1	1	1	1	1	1	1	1	1								-	<=	120
14																								
15	*Program*																							
16	MIN Dw;1,3		1	1	1																	-	Not >=	5
17	MAX Dw;1,3		1	1	1																	-	<=	30
18	MIN Dw;2					1	1	1														-	Not >=	5
19	MAX Dw;2					1	1	1														-	<=	30
20	MIN Dw;4,5								1	1	1											-	Not >=	5
21	MAX Dw;4,5								1	1	1											-	<=	30
22	MIN Dw;6											1	1	1								-	Not >=	5
23	MAX Dw;6											1	1	1								-	<=	30
24																								
25	**System constraints (non-negotiable)**																							
26	Dw;1=3a		0,5												-1							-	=	0
27	Dw;1=3b			0,5												-1						-	=	0
28	Dw;1=3c				0,5												-1					-	=	0
29	Dw;1,3a < 0,5 Dw;2a		0,5			-1																-	=<=	0
30	Dw;1,3b < 0,5 Dw;2b			0,5			-1															-	=<=	0
31	Dw;1,3c < 0,5 Dw;2c				0,5			-1														-	=<=	0
32	Dw;4=5a								0,5									-1				-	=	0
33	Dw;4=5b									0,5									-1			-	=	0
34	Dw;4=5c										0,5									-1		-	=	0

13

Figure 84: Basic structure of the LP-model (own illustration).

The profit per dwelling in the described basic structure is calculated separately from the optimisation process and added as exogenous variable in the objective function (formula 6.6). The calculation of the profit is based on the example of the development exploitation in J. C. De Jong (2016: 165-174). From this example, two linear formulas are drafted:

$$MV = SP * (1 + VAT\%) \quad (6.12a)$$

$$SP = GC + CC + AC + P \quad (6.12b)$$

In which,
- MV is the market value per dwelling (v.o.n.-price, including VAT)
- VAT% is the value added taxes
- SP is the selling price (excluding VAT)
- GC are the ground costs
- CC are the construction costs
- AC are the additional costs
- P is the residual value representing profit, but can also be used to increase the ground price.

Both formulas can be combined to:

$$P = \frac{MV}{1 + VAT\%} - GC - CC - AC \quad (6.12c)$$

This simplified formula needs to be expanded with the following issues:
- The ground costs are calculated by the ground quote, as a % of the total market value
- The construction costs are calculated by multiplying the construction costs per m^2 and the UFA
- The additional costs are calculated as % of the total construction costs.

Resulting in the formula to calculate the profit made per dwelling D_i:

$$P_i = \frac{MV_i * UFA_i}{1 + VAT\%} - (MV_i * UFA_i * GQ\%) - CC_i * UFA_i * (1 + AC\%) \quad (6.12d)$$

In which:
- P_i is the amount of profit made for dwelling type D_i (same as the one in formula 6.6)
- MV_i is the market value per m^2 UFA for dwelling type D_i
- UFA_i is the amount of usable floor area for dwelling type D_i
- GQ% is the ground quote
- CC_i are construction costs per m^2 UFA for dwelling type D_i
- AC% are the additional costs as % of the total construction costs

In all cases:
- Market values are based on data available on Funda (2017). See Appendix 0 for calculation per case.
- Ground quote of at around 30% (Nederlandse Grondmaatschappij, 2009), or indicated otherwise by the desk research.
- Construction costs figures are based on the Bouwkostenkompas (Vonk, de Wilde, & Groot, 2016).
- Additional costs of 25,55% (see Appendix 13.21.2 for calculation); exclusive profit.

By taking into account real data and calculations and not a generic number for profit per dwelling type, a more realistic result can be obtained from the optimisation model.

13.18.2 Energy measurements: thermal and electrical supply installations

Part of the optimisation is to solve the energy problem. For each dwelling an installation is selected to supply the thermal energy demand. The all-electric concept offers electric boilers and heat pumps as solutions. This selection is described in the first part. Secondly, installations for the renewable electricity supply are selected. PV panels and wind are offered as possibilities. Third, the household energy usage is calculated. This is needed to calculate to total energy consumption of the dwelling for the energy bill in the TCO and the needed renewable supply methods to get towards zero-on-the-meter or even energy positive.

13.18.2.1 Thermal energy demand: Domestic heat pumps and electro boilers

The thermal energy demand per m^2 UFA is an exogenous variable. Only the supply gets optimised. Each dwelling type has two packages of energy saving measures. One that complies to the BENG1-requirement of 25 kWh thermal energy/m^2/annum and one that does not comply to the BENG1-requirement. This is chosen for the sake of simplicity, however, more levels can be added. The calculation of the needed energy saving measurements per dwelling type is described in Appendix 13.7.

The supply of the thermal energy demand in the all-electric concept can be done by electric boilers, air source heat pumps (AHSP) and ground source heat pumps (GSHP). The operation of those systems is described in the theoretical framework. Heating by infrared is left out of consideration, because these systems are still under development for domestic application and little is known about their correct application. In total 36 unique dwellings can be developed by the real estate developer (see Figure 85).

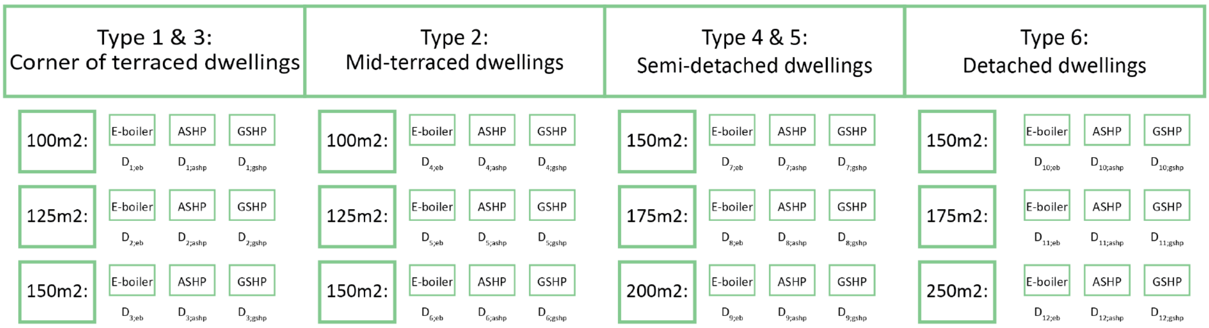


Figure 85: 36 endogenous dwelling types are created by offering three thermal energy supply installations per dwelling type (own illustration).

The three thermal energy supply installations have different efficiencies. The efficiency of a heat pump is expressed by its Coefficient of Performance (COP), which is defined as the ratio of produced heat by the electrical input to the compressor (Itard, 2011). The COP is higher than 1, because a heat pump uses free heat from the environment (Itard, 2011). The efficiencies used are (see Appendix 13.23.1 for argumentation):

- 0,75 for the electric boiler
- 2,6 for the air source heat pump
- 3,9 for the ground source heat pump

The Appendix also shows a wide variety in possible efficiencies/COPs. The effect of this numbers on the outcome need to be checked by a sensitivity analysis, because this number highly effects the total amount of electricity consumed over its lifetime and thus the TCO.

The electricity consumption in kWh to supply the annual heat demand is calculated by:

$$E_{c;j;i} = E_t * UFA_i / \eta_j \qquad (6.13)$$

In which:

- $E_{c;j;i}$ is the electricity consumption of dwelling type D_i provided with thermal energy supplier *j*
- *j* is 1 for the electric boiler, 2 for the ashp and 3 for the gshp
- E_t thermal energy demand (BENG1); set the same for every dwelling type
- UFA_i usable floor area of dwelling type D1
- η_j is the efficiency of thermal energy supplier *j*

All stated variables are exogenous, thus the electricity consumed per dwelling type D_i with thermal energy supplier *j* is fixed. No constraint for this formula is added, but the formula is needed to calculate if the BENG-requirements are met, the total amount of electricity consumed and the total costs of electricity.

All dwellings need to have a heating installation. Therefore, the total number of dwelling type D_i can be calculated by:

$$D_i = D_{i;eb} + D_{i;ashp} + D_{i;gshp} \tag{6.14a}$$

In which:

- $D_{i;eb}$ are the number of developed dwellings with an electric boiler for dwelling type D_i
- $D_{i;ashp}$ are the number of developed dwellings with an air source heat pump for dwelling type D_i
- $D_{i;gshp}$ are the number of developed dwellings with an ground source heat pump for dwelling type D_i

This formula is added as constraint:

$$D_{i;eb} + D_{i;ashp} + D_{i;gshp} - D_i = 0 \tag{6.14b}$$

D_i is connected to the objective function for profit, the density constraints and the system constrains as described in the previous part.

13.18.2.2 Energy demand of the ventilation system

The primary energy usage of the ventilation system is calculated based on the method described in Itard (2011: 131). The method starts by determining the power needed for the ventilation system, the co-called ventilator law (Itard, 2011).

$$P_{elec;vent} = \frac{V * \Delta p}{\eta_v} \tag{6.15a}$$

In which:

- $P_{elec;vent}$ is the electrical power needed by the ventilator system of one building
- V is the volume flow rate of ventilation air in m^3/s
- Δp is the total pressure drop through valves, ducts and the ventilator in Pa
- η_v is the efficiency of the ventilation system

The volume flow rate of ventilation air (*V*) is dependent on the amount of residents in the dwelling (*aor*) and a fixed amount per resident, which is calculated by formula 14.2. The fixed amount per residents is approximately 25 m^3/s (Itard, 2011). The total pressure drop can be set on 200 for small buildings for a quick estimation (Itard, 2011: 131). And the efficiency of the ventilation system is mostly in the range of 0,5-0,75 (Itard, 2011: 131). For simplicity the average value of 0,625 is used.

The energy usage needs to be calculated by the kWh and formula 6.15a calculates the power output in W (J/s). That is why the result is divided by 3.600.000 (3600 W = 1 Wh and 1000 Wh = 1 kWh). The amount of kWh used is determined by the amount of full load hours that the system operated. For simplicity, 50% of the amount of hours in a year (4380 hours) is used. This implies that 50% of the time are all the residents at home. This results in the following transformation of formula 6.15a:

$$E_{vent;i} = \left(\frac{V_{aor} * aor_i * \Delta p}{\eta_v}\right) * \frac{1}{3600000} * FLH \tag{6.15b}$$

In which:

- E_{vent} is the yearly energy usage of the ventilation system for dwelling type D_i
- aor_i is the amount of residents in dwelling type D_i (calculated by formula 6.15c)
- V_{aor} is the fixed ventilation requirement per resident
- *FLH* is the amount of full load hours the ventilation system operates

The amount of residents per dwelling type D_i is calculated as part of the formula in NEN 7120+C2 (2012: 255). This part is distracted from the whole formula and written as follows:

$$aor_i = 1{,}28 * N_{W;zi} + 0{,}01 * A_{g;zi} \qquad (6.15c)$$

In which:
- aor_i is the amount of residents in dwelling type D_i
- $N_{W;zi}$ is the number of housing units per calculation zone;
- $A_{g;zi}$ is the UFA of the considered calculation zone, in m^2.

This formula determines the number of residents in a dwelling or an apartment building based on national averages for the number of residents per property, taking into account the distribution of housing dimensions (NEN 7120+C2, 2012).

The result of formula 6.15b is added to the energy usage of the heating system per dwelling type D_i. In this way the amount is used in the calculation of the total costs of energy and the primary energy usage for BENG.

$$E_{c;tot;j;i} = E_{c;j;i} + E_{vent;i} \qquad (6.15d)$$

In which:
- $E_{c;tot;j;i}$ is the total energy consumption for supplying the thermal energy demand and other building related energy sources as the ventilation system.

13.18.2.3 Renewable energy supply
The supply of renewable electricity is possible by windmills and PV-panels.

The model calculates per dwelling type D_i the optimal amount of PV-panels based on three different types. The used PV-panels, their efficiencies, their Wp-output and degradation rate can be found in Appendix 13.23.2 together with the used conversion factor to convert the amount of Wp to kWh generated.

The amount of renewable energy generated by PV-panel *k* (in kWh) on dwelling type D_i without degradation is calculated by:

$$E_{r;pv;h=0;k;i} = WP_{pv;k} * E_{fpv} * PV_{k;i} \qquad (6.16a)$$

In which:
- $E_{r;pv;h=0;k;i}$ is the amount of renewable energy generated annually by PV-panel *k* for dwelling type D_i without degradation
- $WP_{pv;k}$ is the generation capacity in Wp for PV-panel *k*
- E_{fpv} is the energy conversion factor for PV-panels (Wp to kWh) in the Netherlands
- $PV_{k;i}$ is the amount of PV-panels *k* on dwelling type D_i

However, the amount of generated electricity declines over the years, caused by the degradation rate. An exponential decrease is described by:

$$H_o * g^t = H_t \qquad (6.16b)$$

In which:
- H_0 is the amount of *H* at *t*=0
- g is the growth factor
- t is the time (operational period)
- H_t is the amount of H at t=t

In this case:

- H_0 are yield generated from the amount of electricity produced by the PV-panels at the moment of installation (t=0, outcome of formula 6.15a).
- g^t can be added to calculation 6.15a to calculated the yield of H_t

The antiderivative calculations (Dutch: '*integraalberekeningen*') are to calculate totals, such as the total area under a graph. The antiderivative of formula 6.16c thus calculates the total amount of electricity generated by the PV-panels during the operational period of *t*=0 to *t*=*t*.

$$H_o * \int_0^t g^t \, dt = h_o * \left(\frac{g^t}{\ln(g)} - \frac{g^o}{\ln(g)} \right) \quad (6.16c)$$

In this formula the endogenous variable is part of H_0. That is why the antiderivative can be calculated as an input factor, an exogenous variable, based on the growth factor, which is 1-the degradation rate and the operational period *t*. The calculation of this factor is shown in formula 6.xc

$$E_{f;d} = \left(\frac{(1 - g_{dr})^t}{\ln(1 - g_{dr})} - \frac{(1 - g_{dr})^o}{\ln(1 - g_{dr})} \right) \quad (6.16d)$$

In which:

- $E_{f;d}$ is the energy factor for the calculation of the total generated electricity over the operational period by taking into account degradation
- g_{dr} is the degradation rate
- t is the time (operational period)

In addition, there is a yearly price increase of electricity (*pie*). Assumed is that the prices increases once a year (e.g. when a new contract is signed, or like the yearly rent increase). The exogenous variable which is used in the calculation of the amount of money saved by the PV-panels is calculated by the summation of the yearly antiderivatives multiplied by the price increase of that year (see formula 6.16e).

$$E_{f;d+c} = \sum_{t=1}^{n} \left(\left(\frac{(1 - g_{dr})^t}{\ln(1 - g_{dr})} - \frac{(1 - g_{dr})^{t-1}}{\ln(1 - g_{dr})} \right) * (1 + pie)^t \right) \quad \text{For } n = t \quad (6.16e)$$

In which:

- $E_{f;d+c}$ is the energy factor for the calculation of the money saved based on the degradation of the PV-panel through the year and an annual price increase
- pie is the price increase of electricity

The maximum amount of solar panels on dwelling type D_i is constrained by the available roof surface, calculated by:

$$\sum_{k=1}^{n} A_{pv;k} * PV_{k;i} \leq A_{roof;Di} * D_i \quad \text{For } n = 3 \quad (6.17a)$$

In which:

- $A_{pv;k}$ is the surface of one PV-panel *k* (exogenous)
- $A_{roof;di}$ is the roof surface in m^2 for dwelling type D_i (exogenous)
- PV_k is the amount of PV-panel *k* on dwelling type D_i (endogenous, same as formula 6.16a)
- D_i is the amount of dwelling type *i* (i=1-12, endogenous, same as formula 6.6)

This constrained is added in the model as:

$$\sum_{k=1}^{n} A_{pv;k} * PV_{k;i} - A_{roof;Di} * D_i \leq 0 \qquad \text{For } n = 3 \qquad (6.17b)$$

The amount of renewable energy generated by wind (in kWh) is calculated by:

$$E_{r;w;i} = FLH_w * W_{c;i} \qquad (6.17c)$$

In which:
- $E_{r;w;i}$ is the amount of renewable energy generated by wind for dwelling type D_i
- FLH_w is the amount of full load hours for wind mills (exogenous)
- $W_{c;i}$ is the capacity installed for dwelling type D_i in kW

The maximum amount of wind power is constrained by the amount of windmills allowed and the maximum capacity per windmill, calculated by:

$$\sum_{i=1}^{n} W_{c;i} \leq W_{c;max} * W_{max} \qquad \text{For } n = 12 \qquad (6.18)$$

In which:
- $\Sigma W_{c;i}$ is the capacity installed for all dwelling types in kW
- $W_{c;max}$ is the capacity per windmill (exogenous)
- W_{max} is the maximum amount of windmills allowed (exogenous)

This constrained is added in the model as written.

Formula 6.15d, 6.16a and 6.17c are not directly added to the model as constraint, but are used in other calculations. These are described in coming parts.

13.18.2.4 Household energy demand

The household energy demand is needed in the calculation of the total energy costs and the TCO. This determines if the zero-on-the-meter ambition is cheaper or not over the operational time.

The calculation of the energy demand for household appliances is provided in NEN 7120+C2 (2012: 74) by the following formula:

$$\mathrm{E}_{nEPus;el} = \sum_{usi} e_{nEPUs;e;usi} * A_{g;usi} * 365 * 24 * 0{,}0036 \qquad (6.19a)$$

In which:
- $E_{nEPus;el}$ is the total annual electricity demand for the functions not included in the total energy performance calculation, in MJ;
- $e_{nEPus;el;usi}$ is the specific electricity consumption of the appliance '*usi*' for equipment in the building that is not included in the total energy performance calculation, whereby process equipment for physical production processes should be disregarded, in W/m^2;
- $A_{g;usi}$ is the usable floor area of function '*usi*' in the building, in m^2.
- If 0,0036 is changed to 0,001 the output unit is kWh.

The value of $e_{nEPus;el;usi}$ is fixed at 3,2 W/m^2 (NEN 7120+C2, 2012: 75), which makes the total yearly energy demand of household appliances only dependent on the usable floor area.

$$\mathrm{E}_{c;hh;i} = A_i * E_{fhh} * 365 * 24 * 0{,}001 \qquad (6.19b)$$

In which:
- $E_{c;hh;i}$ is the energy consumption for household appliances for dwelling type D_i
- A_i is the UFA in m^2 of dwelling type D_i

- E_{fhh} is the energy factor to for households' energy consumption in W/m^2
- And instead of 0,0036 is 0,001 used to calculated $E_{c;hh;i}$ in kWh instead of MJ.

This formula is not added to the model as constraint, but used to support other functions (e.g. zero-on-the-meter and energy costs).

13.18.2.5 Check zero-on-the-meter[115]

The dwellings are zero-on-the-meter (ZOM) when on a yearly basis the renewable electricity supply is higher as the amount of electricity consumed by the heating installations and the household appliances. ZOM is important for two things. First, these dwellings can get a higher mortgage at the bank (see 13.24.1) and second, the renewable energy they generate above this level is worth less, because of the balancing agreement (see the theoretical framework).

The calculation goes into two steps:

1. It is checked whether the dwellings of type D_i are ZOM. If they are ZOM a binary variable gets the value 1. If they are not ZOM this variable gets the value 0.
2. The amount of ZOM-dwellings of dwelling type D_i is calculated and added to a new endogenous variable ZOM_i.

The model needs three new endogenous variables per dwelling type D_i to make this possible:

- B_ZOM_i is the binary variable to check whether dwelling D_i reaches ZOM (1=yes, 0=no)
- ZOM_i is the amount of ZOM-dwellings for dwelling type D_i
- NO_ZOM_i is the amount of none ZOM-dwellings for dwelling type D_i

And exogenous variable *big_w* is added to represent an infinite number. However, the model gets slower when an infinite number would be added. This number has to be bigger as any other number, for instance the maximum amount of energy consumed within a dwelling type. The number is added as 100.000.000 (max 1.000 dwellings * 10.000 kWh/dwellings * 10 buffer).

The following constraints are added to the model. The first constraints check whether the dwellings are ZOM. If the amount of renewable electricity supply is higher as the amount of electricity consumed by the heating installations and the household appliances, the binary variable gets the value 1:

$$\sum_{k=1}^{n} E_{r;pv;h=0;k;i} * (g_{dr})^{t_g} + E_{r;w;i} - \sum_{j=1}^{m} E_{c;tot;j;i} - \mathrm{E}_{c;hh;i} \leq big_w * B\_ZOM_i \quad \text{For } n = 3 \text{ and for } m = 3 \qquad (6.20a)$$

In which:

- $E_{r;pv;h=0;k;i}$ is the amount of renewable energy generated annually by PV-panel *k* for dwelling type D_i without degradation
- g_{dr} is the degradation rate
- t_g is about the time, in this case the guarantee period of zero-on-the-meter performance

Rewritten and added to the model as:

$$\sum_{k=1}^{n} E_{r;pv;k;i} + E_{r;w;i} - \sum_{j=1}^{m} E_{c;tot;j;i} - \mathrm{E}_{c;hh;i} - big_w * B\_ZOM_i \leq 0 \quad \text{For } n = 3 \text{ and for } m = 3 \qquad (6.20b)$$

And if the amount of renewable electricity supply is not higher as the amount of electricity consumed by the heating installations and the household appliances, the binary variable gets the value 0. The following formula is needed to make that happen:

[115] This calculation in particular would not be possible without the help of Rein de Graaf.

$$-\sum_{k=1}^{n} E_{r;pv;k;i} - E_{r;w;i} + \sum_{j=1}^{m} E_{c;tot;j;i} + \mathrm{E}_{c;hh;i} \leq big_w * (1 - B\_ZOM_i)$$ For *n* = 3 and for *m* = 3 (6.21a)

Rewritten:

$$-\sum_{k=1}^{n} E_{r;pv;k;i} - E_{r;w;i} + \sum_{j=1}^{m} E_{c;tot;j;i} + \mathrm{E}_{c;hh;i} \leq big_w - big_w * B\_ZOM_i$$ For *n* = 3 and for *m* = 3 (6.21b)

Rewritten and added to the model as:

$$-\sum_{k=1}^{n} E_{r;pv;k;i} - E_{r;w;i} + \sum_{j=1}^{m} E_{c;tot;j;i} + \mathrm{E}_{c;hh;i} + big_w * B\_ZOM_i \leq big_w$$ For *n* = 3 and for *m* = 3 (6.21c)

In which:
- $E_{r;pv;k}$ is the amount of renewable energy generated by PV-panel *k* (formula 6.15)
- $E_{r;w}$ is the amount of renewable energy generated by wind (formula 6.17)
- $E_{c;i;j}$ is the electricity consumption of dwelling type D_i provided with thermal energy supplier *j* (formula 6.13)
- $E_{c;hh;i}$ is the energy consumption for household appliances for dwelling type D_i (formula 6.19b)

Second, the endogenous variables of ZOM_i and NO_ZOM_i are introduced. The total amount of dwelling type D_i is the same as the amount of ZOM-dwelling and none ZOM-dwellings:

$$D_i = ZOM_i + NO\_ZOM_i \quad (6.22a)$$

Added as constraint as:

$$D_i - ZOM_i - NO\_ZOM_i = 0 \quad (6.22b)$$

Only one of the endogenous variables ZOM_i and NO_ZOM_i gets a value uneven to zero. The formula to ensure this for ZOM_i is

$$ZOM_i \leq big_w * B\_ZOM_i \quad (6.23a)$$

Rewritten and added to the model as:

$$ZOM_i - big_w * B\_ZOM_i \leq 0 \quad (6.23a)$$

And the formula to ensure this for NO_ZOM_i is:

$$NO\_ZOM_i \leq big_w * (1 - B\_ZOM_i) \quad (6.24a)$$

Rewritten and added to the model as (according to the same intermediate step as in formula 6.21b):

$$NO\_ZOM_i + big_w * B\_ZOM_i \leq big_w \quad (6.24b)$$

No_ZOM_i is only used to make the calculation of ZOM_i possible.

In case the renewable energy supply is exactly the same as the electricity consumption B_ZOM_i can get both the value 1 and 0. If this is the case the dwelling is exactly ZOM and therefore B_ZOM_i must get the value of 1. In order to ensure that B_ZOM_i gets 1, B_ZOM_i must be included in the objective function and be maximized by a very small value, e.g. MAX! $1/big_w * B\_ZOM_i$. It must be noticed that this contradicts to the requirement of linear programming that all variables in the objective function should have the same dimension. However, the

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contribution to the final result is so low that it would not be visible (max 12 dwelling types * 1/100.000.000 =0,000.000.12).

13.18.2.6 Energy balance

At the start of the previous part was told that the renewable energy dwellings generate above the ZOM-level is worth less, because of the balancing agreement. That is why the exact energy balance has to be calculated. In case the dwelling is not ZOM, electricity is taken from the grid annually, which make the balance negative. In case the dwelling is ZOM and renewable energy is supplied to the grid on an annual basis, the balance is positive. Hereby the non-negativity constraints of endogenous variables should be taken into account. Therefore, two endogenous variables are introduced. Each representing one of the situations:

- $E_{pp;i}$, which is the positive production of renewable energy supplied to the grid in kWh annually for dwelling type D_i
- $E_{np;i}$, which is the negative production of energy; the amount of electricity taken from the grid in kWh annually for dwelling type D_i

The breaking point is reached when the dwelling is ZOM and starts being energy positive.

The following formula calculates the energy balance, in which only one of the two endogenous variables on the rights side of the equality sign can get a value:

$$\sum_{k=1}^{n} E_{r;pv;k;i} + E_{r;w;i} - \sum_{j=1}^{m} E_{c;tot;j;i} - \mathrm{E}_{c;hh;i} = E_{pp;i} - E_{np;i} \qquad \text{For } n = 3 \text{ and for } m = 3 \qquad (6.25a)$$

Rewritten and added to the model as:

$$\sum_{k=1}^{n} E_{r;pv;k;i} + E_{r;w;i} - \sum_{j=1}^{m} E_{c;tot;j;i} - \mathrm{E}_{c;hh;i} - E_{pp;i} + E_{np;i} = 0 \qquad \text{For } n = 3 \text{ and for } m = 3 \qquad (6.25b)$$

To ensure that only one of the two endogenous variables get a value, the following constraints are added to the model. Both make use of the binary ZOM_i variable, because in case the dwelling is ZOM (and B_ZOM_i=1) then there will be a positive production. The other way around, if the dwelling is not ZOM (and B_ZOM_i=0), then there will be a negative production.

If B_ZOM_i=1, then $E_{pp} > 0$:

$$E_{pp;i} \leq big_w * B\_ZOM_i \qquad (6.26a)$$

Rewritten and added to the model as:

$$E_{pp;i} - big_w * B\_ZOM_i \leq 0 \qquad (6.26b)$$

If B_ZOM_i=0, then Enp > 0:

$$E_{np;i} \leq big_w * (1 - B\_ZOM_i) \qquad (6.27a)$$

Rewritten and added to the model as:

$$E_{np;i} + big_w * B\_ZOM_i \leq big_w \qquad (6.27b)$$

The calculation of the energy costs and the TCO needs E_{pp}. E_{np} is not needed for the costs calculation, because then it will be included twice, as the energy usage is already included in the consumption variable. E_{np} is only needed to make the calculation of E_{pp} possible.

13.18.3 Comply with BENG-legislation

The previous described formulas are constrained by the BENG-legislation. This legislation requires the amount of primary energy usage to be lower as a certain amount (in BENG2) and the renewable energy supply higher as a certain percentage of the total primary energy consumption (in BENG3). The next paragraphs describe the formulas and related constraints to make this possible in the LP-model.

13.18.3.1 BENG2: primary energy demand

The calculation method of BENG2 is described by Kruithof and Haytink (2015: 10-14). They use many formulas of NEN 7120+C2 (2012) to calculate and sum the amount of electricity used for heating, cooling, fans, hot water and any auxiliary electricity need to generate those. The amount of electricity generated on site is deducted from this total. The formulas are applied on an annual basis. For simplicity, the used formulas in Kruithof and Haytink (2015: 10-14) and EN 7120+C2 (2012) are summarized accordingly:

$$(E_c - E_s) * P_{fc} - E_{exp} * P_{fe} = E_{pr} \qquad (6.28)$$

Constraint by:

$$E_c \geq E_s \qquad (6.29)$$

In which;

- E_c is the amount of electricity consumed annually (in kWh)
- E_s is the amount of renewable electrical supply annually (in kWh)
- E_{exp} is the amount of renewable electrical supply annually which is exported to the grid or used by household appliances (in kWh)
- P_{fc} is the primary energy factor for self-consumed electricity
- P_{exp} is the primary energy factor for exported electricity
- E_{pr} is the amount of primary energy (in kWh)

Those constraints are added to the model in several steps. First, the supplied renewable energy must be split into the amount of supplied energy for consumption on site (E_s) and the amount of exported energy (E_{exp}):

$$\sum_{k=1}^{n} E_{r;pv;k;i} + E_{r;w;i} = E_s + E_{exp} \qquad \text{For } n = 3 \qquad (6.30a)$$

Rewritten and added to the model as:

$$\sum_{k=1}^{n} E_{r;pv;k;i} + E_{r;w;i} - E_s - E_{exp} = 0 \qquad \text{For } n = 3 \qquad (6.30b)$$

Second, the constraint of formula 6.28 is added to ensure that the amount of supplied energy for consumption on site (E_s) does not exceed the amount of consumed energy on site (E_c).

$$\sum_{j=1}^{m} E_{c;j;i} \geq E_s \qquad \text{For } m = 3 \qquad (6.31a)$$

Rewritten and added to the model as:

$$\sum_{j=1}^{m} E_{c;j;i} - E_s \geq 0 \qquad \text{For } m = 3 \qquad (6.31b)$$

Third, the amount of primary energy is calculated. The amount of primary energy can also be negative in case the total amount of renewable energy supplied (E_s+E_{exp}) is higher as the consumed energy (E_c), thus when:

$$E_s * P_{fc} + E_{exp} * P_{fe} > E_c * P_{fc} \quad (6.32)$$

Therefore, two endogenous variables must be used to make the calculation possible:

- E_{prp}, in case the primary energy is positive
- E_{prn-}, in case the primary energy is negative

$$E_c * P_{fc} - E_s * P_{fc} - E_{exp} * P_{fe} = E_{prp} - E_{prn} \quad (6.33a)$$

Rewritten and added to the model as:

$$E_c * P_{fc} - E_s * P_{fc} - E_{exp} * P_{fe} - E_{prp} + E_{prn} = 0 \quad (6.33b)$$

The primary energy factor for self-consumed electricity is 2,56, the primary energy factor for exported electricity is 2,0 (Kruithof & Haytink, 2015: 12) and the BENG2-required is such that the amount of primary energy used must be lower as 25 kWh/m^2 UFA/annually (Bouwens & Bouwmeester, 2017: 4-5). This can be written as the following constraint:

$$E_{pr} \leq BENG2 * UFA \quad (6.34a)$$

In the model the endogenous variable of the primary energy represent the total amount of primary energy consumed in all the dwellings of that type. Therefore, the part on the right of the equality sign must be multiplied with the number of dwellings of that type, which is the endogenous variable D_i.

$$E_{pr} \leq D_i * BENG2 * UFA \quad (6.34b)$$

Rewritten and added to the model as:

$$E_{prp} - E_{prn} - D_i * BENG2 * UFA \leq 0 \quad (6.34c)$$

This last constraint ensures that the BENG2-requirement is met.

13.18.3.2 BENG3

BENG3 is calculated by Kruithof and Haytink (2015: 15):

$$\%E_r = \frac{E_r}{E_{pr} + E_r} \quad (6.35)$$

In which:

- E_r is the amount of renewable energy as primary energy equivalents (in kWh). This is the sum of E_s and E_{exp} (see BENG2; formula 6.29-6.30 for the calculation).
- E_{pr} is the amount of primary energy (in kWh) as calculated by BENG2 (see formula 6.32).
- %R is the % of renewable energy in the energy mix as required in the legislation.

Because *%R* is an input variable, formula 6.34 can be rewritten to a formula suited to LP-modelling. Step 1:

$$E_r = \%E_r * E_{pr} + \%E_r * E_r \quad (6.36a)$$

Step 2:

$$\%E_r * E_{pr} = E_r - \%E_r * E_r = (1 - \%E_r) * E_r \quad (6.36b)$$

Final step:

$$E_{pr} = \frac{(1 - \%E_r)}{\%E_r} * E_r \quad (6.36c)$$

The legislation requires a minimum level of E_r in related to E_{pr}. For that reason, the equality sign of formula 6.35c can be changed:

$$\frac{(1-\%E_r)}{\%E_r} * E_r \geq E_{pr} \quad (6.36d)$$

E_r needs to be calculated, before this formula can be added to the LP-model:

$$E_s * P_{fc} - E_{exp} * P_{fe} = E_r \quad (6.37a)$$

Rewritten and added to the model as:

$$E_s * P_{fc} - E_{exp} * P_{fe} - E_r = 0 \quad (6.37b)$$

In the LP-model the next constrained is added to ensure that the % of renewable energy is at least at the required input of BENG3 (based on formula 6.35d):

$$\frac{(1-\%E_r)}{\%E_r} * E_r - E_{prp} + E_{prn} \geq 0 \quad (6.38)$$

In the proposed legislation of BENG, BENG3 is fixed on 50% (Bouwens & Bouwmeester, 2017: 4-5).

13.18.4 Extra investment in energy measures

The extra investment in energy measures is calculated by the amount of PV-panels, the amount of kW of windmill power installed and the cost per dwelling type for each heating installation. The costs for the energy saving measures are pre-calculated for every dwelling type D_i and added to the costs for the heating installations (exogenous variable: $C_{di;...}$). See Appendix 13.7 for the method how these measures are calculated.

$$I_i = \sum_{k=1}^{n} (C_{pv;k} * PV_k) + C_{wind} * W_{c;i} + C_{di;eb} * D_{i;eb} + C_{di;ashp} * D_{i;ashp} + C_{di;gshp} * D_{i;gshp} \quad \text{For } n = 3 \quad (6.39a)$$

In which:

- I_i is the (total) investment in energy installations for dwelling type *i*
- $C_{PV;k}$ are the investment costs of a PV-panel of type *k*
- PV_k is the amount of PV-panels *k* (formula 6.15)
- C_{wind} are the investment costs per kW of windmill power installed
- $W_{c;i}$ is the capacity of windmill power installed for dwelling type D_i in kW (formula 6.17)
- $C_{di;eb}$ are the costs for energy saving and heat installations for dwelling type D_i with an electric boiler
- $D_{i;eb}$ are the number of developed dwellings with an electric boiler for dwelling type D_i (formula 6.14a)
- $C_{di;ashp}$ are the costs for energy saving and heat installations for dwelling type D_i with an ashp
- $D_{i;ashp}$ are the number of developed dwellings with an air source heat pump for dwelling type D_i (formula 6.14a)
- $D_{i;gshp}$ are the number of developed dwellings with an ground source heat pump for dwelling type D_i (formula 6.14a)
- $C_{di;gshp}$ are the costs for energy saving and heat installations for dwelling type D_i with an gshp

Rewritten and added to the model as:

$$-\sum_{k=1}^{n}(C_{pv;k} * PV_k) - C_{wind} * W_{c;i} - C_{di;eb} * D_{i;eb} - C_{di;ashp} * D_{i;ashp} - C_{di;gshp} * D_{i;gshp} + I_i = 0 \quad \text{For } n = 3 \qquad (6.39b)$$

The variable $C_{di;...}$ can appear in two different values. If the thermal energy demand meets the BENG1-requirement of 25 kWh/m^2/year, more investment is needed in energy saving measures and therefore the costs per dwelling are higher. In case the requirement is not met, less energy saving measures are needed and the cost per dwelling are lower. This calculation can also be seen in Appendix 13.7.

13.18.5 Financing the extra investment

The calculated extra investment of the previous part has to be financed in some way. Three possibilities are offered by the model to finance the extra investment:

4. By an increased mortgage of a bank;
5. By third financing of an energy service company;
6. By the real estate developer (deducted from the amount of profit).

All options effect the total cost of ownership. The interest rate has to be paid in the first two options and the investment is lower in the last one, which is reducing the selling price of the dwelling.

A fourth option of direct financing by own equity of the individual buyer was explored. However, in that case the selling price and the related market value would increase. At this moment in time, the market value is not directly related with the required additional investment in energy saving measurements, because the energy concept will not be bought by a majority of buyers when this spending complies with other living requirements (J. W. J. De Vries, 2010). In addition, this option is not affordable for everyone. The extra market value is assumed the same as the extra mortgage, because this additional borrowing space is in line with energy cost savings (Blok, 2014a, 2015a, 2016; Dijsselbloem, 2013) and the living expenses remain within the existing reference building with energy label C (J. W. J. De Vries, 2010). In case buyers select this fourth option, the price is still market conform and only the total cost of ownership would be lower as they do not pay the interest rate. That is why this fourth option can be seen as comparable to the mortgage option for the viewpoint of the real estate developer.

The cheapest way for consumers to finance the extra investment is to invest in more mortgage (J. W. J. De Vries, 2010). That is why other consumer financing options are not considered.

The investment is thus spread over three options. Therefore, the calculation is the following:

$$I_i = F_{m;beng;i} + F_{m;zom;i} + F_{esco;i} + F_{red;i} \qquad (6.40a)$$

In which (all endogenous variables):

- I_i is the (total) investment in energy installations for dwelling type *i* (formula 6.39)
- $F_{m;beng;i}$ is the amount financed by the BENG-mortgage for dwelling type D_i
- $F_{m;ZOM;i}$ is the amount financed by the ZOM-mortgage for dwelling type D_i
- $F_{esco;i}$ is the amount financed by the ESCO for dwelling type D_i
- $F_{red;i}$ is the amount financed by the real estate developer for dwelling type D_i

Rewritten and added to the model as:

$$I_i - F_{m;beng;i} - F_{m;zom;i} - F_{esco;i} - F_{red;i} = 0 \qquad (6.40b)$$

The amounts that can be financed by the mortgage and the ESCO are constraint and the real estate developer has to finance the remaining part. The constraints are explained next.

Firstly, the constraints related to the mortgage. Since a few years it is possible to borrow an additional amount for the financing of a zero-on-the-meter dwelling and for a dwelling with an energy label of at least A++. In this part the calculation for the maximal extra borrowing capacity is given. More information, the amounts of extra borrowing capacity and fluctuations over the past few years are given in Appendix 13.24.1.

The amount of money financed by the BENG-mortgage must be smaller as the borrowing capacity. The borrowing capacity counts for all developed dwellings of type D_i. This is summarized in the next constraint:

$$F_{m;beng;i} \leq B_{c;beng} * D_i \tag{6.41a}$$

In which:

- $F_{m;beng;i}$ is the amount financed by the BENG-mortgage for dwelling type D_i
- $B_{c;beng}$ is the extra borrowing capacity for BENG
- D_i is the amount of dwellings of type *i* (formula 6.6)

Rewritten and added to the model as:

$$B_{c;beng} * D_i - F_{m;beng;i} \geq 0 \tag{6.41b}$$

ZOM-dwellings add extra borrowing capacity on top of the amount of the extra borrowing capacity for BENG. This amount has to be deducted from the extra capacity ZOM offers. This is summarized in the next constraint:

$$F_{m;zom;i} \leq (B_{c;zotm} - B_{c;beng}) * ZOM_i \tag{6.42a}$$

In which:

- $F_{m;ZOM;i}$ is the amount financed by the ZOM-mortgage for dwelling type D_i
- $B_{c;ZOM}$ is the extra borrowing capacity for ZOM
- ZOM_i is the amount of ZOM-dwellings for dwelling type D_i

Rewritten and added to the model as:

$$\left(B_{c;zom} - B_{c;beng}\right) * ZotM_i - F_{m;zom;i} \geq 0 \tag{6.42b}$$

The second group of constraints are added for the energy service company. The cases learned us that the ESCO does not want to invest in all energy saving measurements and only invest in PV-panels and all-electric concepts based on ground source heat pumps (see lessons learned in chapter 7.4). The rapid upswing of the usage of air source heat pumps in Graph 9 is promising for innovation and improvement of those systems. The possibility is created to manually select the options in the LP-model in which the ESCO wants to invest, because the ESCOs readiness can change in the future.

First the maximal possible amount for the financing by the ESCO is calculated by the model:

$$B_{esco;i} = \sum_{k=1}^{n} (F_{esco;pv} * C_{pv;k} * PV_{k;i}) + F_{esco;wind} * C_{wind} * W_{c;i} + F_{esco;eb} * C_{di;eb} * D_{i;eb} + F_{esco;ashp} * C_{di;ashp} * D_{i;ashp} + F_{esco;gshp} * C_{di;gshp} * D_{i;gshp} \quad \text{For } n = 3 \tag{6.43a}$$

In which:

- $B_{esco;i}$ is the maximum budget the ESCO is willing to finance for dwelling type D_i (endogenous)
- $F_{esco;y}$ is an exogenous binary variable to determine if installation *y* is financed by the ESCO (1=yes, 0=no)
  - If *y* is pv; it is about the financing of PV-panels.
  - If *y* is wind; it is about the financing of PV-panels.
  - If *y* is eb; it is about the financing of PV-panels.

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- If y is ashp; it is about the financing of PV-panels.
- If y is gshp; it is about the financing of PV-panels.

Rewritten and added to the model as:

$$\sum_{k=1}^{n}(F_{esco;pv} * C_{pv;k} * PV_{k;i}) + F_{esco;wind} * C_{wind} * W_{c;i} + F_{esco;eb} * C_{di;eb} * D_{i;eb} + F_{esco;ashp} * C_{di;ashp} * D_{i;ashp} + F_{esco;gshp} * C_{di;gshp} * D_{i;gshp} - F_{esco;i} = 0 \quad \text{For } n = 3 \quad (6.43b)$$

The amount of the investment financed by the ESCO for dwelling type D_i is constraint by its maximum budget for dwelling type D_i:

$$F_{esco;i} \leq B_{max;esco;i} \quad (6.44a)$$

In which:
- $F_{esco;i}$ is the amount financed by the ESCO for dwelling type D_i

Rewritten and added to the model as:

$$B_{max;esco;i} - F_{esco;i} \geq 0 \quad (6.44b)$$

13.18.6 Total costs of ownership (TCO)

The future owners do not only have an interest in choosing the optimal solution in terms of investment costs, but also in the costs of energy and maintenance during the lifecycle of the project. These are the so called total cost of ownership (TCO) and are an important input indicator for the decision-making process of the future owners (Dijkmans & Klerks, 2013).

In the proposed LP-model the TCO of ownership takes into account the investment costs, financing costs, maintenance costs and the energy costs and is calculated according to the following formula.

$$TCO_i = \sum_{k=1}^{n}\left(\left(C_{en;pv;k} + C_{mo;pv;k} + C_{pv;k}\right) * PV_{k;i}\right) + \left(C_{en;wind} + C_{mo;wind} + C_{wind}\right) * W_{c;i} + \left(C_{en;eb} + C_{di;mo;eb} + C_{di;eb}\right) * D_{i;eb} + \left(C_{en;ashp} + C_{di;mo;ashp} + C_{di;ashp}\right) * D_{i;ashp} + \left(C_{en;gshp} + C_{di;mo;gshp} + C_{di;gshp}\right) * D_{i;gshp} + C_{en;hh} * D_i + R_{m;i} * F_{m;beng;i} + R_{m;i} * F_{m;zom;i} + R_{esco} * F_{esco;i} - E_{fc} * C_{en} * E_{pp;i} - F_{red;i} \quad \text{For } n = 3 \quad (6.45a)$$

In which (new variables are explained in the last part of this sub-chapter):
- TCO_i are the total costs of ownership for all dwellings of dwelling type D_i
- $C_{en;pv;k}$ are the costs of energy for PV-panel of type k
- $C_{mo;pv;k}$ are the maintenance and operational costs for PV-panel of type k
- $C_{pv;k}$ are the investment costs for PV-panel of type k
- $PV_{k;i}$ is the amount of PV-panels k for dwelling type D_i (formula 6.15)
- $C_{en;wind}$ are the costs of energy for windmill power per kW installed
- $C_{mo;wind}$ are the maintenance and operational costs for windmill power per kW installed
- C_{wind} are the investment costs for windmill power per kW installed
- $W_{c;i}$ is the capacity of windmill power installed for dwelling type D_i in kW (formula 6.17)
- $C_{en;eb}$ are the costs of energy a dwelling with an electric boiler

- $C_{di;mo;eb}$ are the costs for maintenance and operation of the energy saving and heat installations for dwelling type D_i with an electric boiler
- $C_{di;eb}$ are the investment costs for energy saving and heat installations for dwelling type D_i with an electric boiler
- $D_{i;eb}$ are the number of developed dwellings with an electric boiler for dwelling type D_i (formula 6.14a)
- $C_{en;ashp}$ are the costs of energy a dwelling with an ashp
- $C_{di;mo;ashp}$ are the costs for maintenance and operation of the energy saving and heat installations for dwelling type D_i with an ashp
- $C_{di;ashp}$ are the investment costs for energy saving and heat installations for dwelling type D_i with an ashp
- $D_{i;ashp}$ are the number of developed dwellings with an air source heat pump for dwelling type D_i (formula 6.14a)
- $C_{en;gshp}$ are the costs of energy a dwelling with an gshp
- $C_{di;mo;gshp}$ are the costs for maintenance and operation of the energy saving and heat installations for dwelling type D_i with an gshp
- $C_{di;gshp}$ are the investment costs for energy saving and heat installations for dwelling type D_i with an gshp
- $D_{i;gshp}$ are the number of developed dwellings with an ground source heat pump for dwelling type D_i (formula 6.14a)
- Cen;hh are the costs of energy for household appliances
- D_i is the amount of dwellings of type *i* (formula 6.6)
- $R_{m;i}$ is the cumulative interest rate payment factor for mortgages of dwelling type *i*
- $F_{m;beng;i}$ is the amount financed by the BENG-mortgage for dwelling type D_i (formula 6.40)
- $F_{m;ZOM;i}$ is the amount financed by the ZOM-mortgage for dwelling type D_i (formula 6.40)
- R_{esco} is the cumulative interest rate payment factor for ESCo's
- $F_{esco;i}$ is the amount financed by the ESCO for dwelling type D_i (formula 6.40)
- E_{fc} is the energy cost factor
- C_{en} is the costs of energy per kWh
- $E_{pp;I}$ is the positive production of renewable energy supplied to the grid in kWh annually for dwelling type D_i (formula 6.25)
- $F_{red;i}$ is the amount financed by the real estate developer for dwelling type D_i (formula 6.40)

Rewritten and added to the model as:

$$-\sum_{k=1}^{n}\left(\left(C_{en;pv;k}+C_{mo;pv;k}+C_{pv;k}\right)*PV_{k;i}\right)-\left(C_{en;wind}+C_{mo;wind}+C_{wind}\right)*W_{c;i}-\left(C_{en;eb}+C_{di;mo;eb}+C_{di;eb}\right)*D_{i;eb}-\left(C_{en;ashp}+C_{di;mo;ashp}+C_{di;ashp}\right)*D_{i;ashp}-\left(C_{en;gshp}+C_{di;mo;gshp}+C_{di;gshp}\right)*D_{i;gshp}-C_{en;hh}*D_i-R_{m;i}*F_{m;beng;i}-R_{m;i}*F_{m;zom;i}-R_{esco}*F_{esco;i}+E_{fc}*C_{en}*E_{pp;i}+F_{red;i}+TCO_i=0 \quad \text{For } n=3 \qquad (6.45b)$$

The TCO for dwelling type Di cannot be higher as the TCO for a dwelling of the same dwelling type and size, but with an average energy label. That is why the next constraint is added:

$$TCO_i \leq D_i * TCO_{max;i} \qquad (6.46a)$$

In which:
- TCO_i are the total costs of ownership for all dwellings of dwelling type D_i (formula 6.45)
- $TCO_{max;i}$ are the maximum allowed TCO for each dwelling of dwelling type D_i

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Rewritten and added to the model as:

$$D_i * TCO_{max;i} - TCO_i \geq 0 \tag{6.46b}$$

Formula 6.45 uses many new undescribed exogenous variables for the calculation of energy costs, maintenance costs and financing costs. Those are described in the next paragraphs.

13.18.6.1 Energy costs

The calculation of the energy costs for PV-panels of type *k* resembles the calculation in formula 6.15:

$$C_{en;pv;k} = WP_{pv;k} * E_{fpv} * E_{f;d+c} * C_{en} \tag{6.47}$$

In which:

- $C_{en;pv;k}$ are the costs of energy for PV-panel of type *k*
- $WP_{pv;k}$ is the generation capacity in Wp for PV-panel *k*
- E_{fpv} is the energy conversion factor for PV-panels (Wp to kWh) in the Netherlands
- $E_{f;d+c}$ is the energy factor for the calculation of the money saved based on the degradation of the PV-panel through the year and an annual price increase
- C_{en} is the costs of energy per kWh

The energy costs factor is used to get the cumulative energy costs over the whole operational period. The annual energy costs cannot be just multiplied by the number of years of the operational period, because of the increasing energy costs. For the calculation of the sum of an exponential function the calculation of a geometric sequence can be applied. This is a sequence of numbers "*where each term after the first is found by multiplying the previous one by a fixed, non-zero number called the common ratio*" (Wikipedia, 2017b). The sum of a geometric series can be calculated by Sydsæter *et al.* (2016):

$$S_n = a * \frac{k^n - 1}{k - 1} \tag{6.48a}$$

In which:

- Sn is the sum of the geometric series (for *n* =1, 2, 3, 4, …, *n*)
- n is the amount of terms
- a is the initial value
- k is the common ratio

The initial value is kept out of the formula, because it is calculated by the other variables. The factor is determined for the correct summation of costs (including price increases) over the operational period:

$$E_{fc} = \frac{pie^d - 1}{pie - 1} \tag{6.48b}$$

In which:

- E_{fc} is the energy cost factor
- pie is the price increase of electricity (in %/year)
- d is the duration in time (operational period)

The calculation of the energy costs for windmill power resembles the calculation in formula 6.17:

$$C_{en;wind} = FLH_w * E_{fc} * C_{en} \tag{6.49}$$

In which:

- $C_{en;wind}$ are the costs of energy for windmill power per kW installed
- FLH_w is the amount of full load hours for wind mills (exogenous)
- E_{fc} is the energy cost factor

- C_{en} is the costs of energy per kWh

13.18.6.2 Maintenance and operational costs

The maintenance and operational costs are calculated as percentage of the investment costs and multiplied by a same type of factor as described earlier to get the total maintenance and operational costs over the total operational period. The calculation is the same for all installations. An example for the PV-panels is given. The formula for the calculation of the total maintenance and operation costs of the operational period is for a PV-panel of type *k* is:

$$C_{mo;pv;k} = C_{pv;k} * M\%_{pv;k} * M_{fc} \tag{6.50}$$

In which:

- $C_{mo;pv;k}$ are the maintenance and operational costs for a PV-panel of type *k* over the operational period
- $C_{PV;k}$ are the investment costs of a PV-panel of type *k*
- $M\%_{pv;k}$ are the yearly maintenance and operation costs for PV-panel *k* as % of the investment costs per PV-panel of type *k*
- M_{fc} is the maintenance and operational cost factor (calculated the same as the energy cost factor in formula 6.48)

13.18.6.3 Financing costs

The financing costs consist of the costs for the mortgage (in interest payments) and the costs for the ESCO (in monthly fees). These are explained sequentially.

The financing of the mortgage is done by interest payments. In the TCO the total amount of interest paid is relevant. This is referred to as the '*cumulative interest payment*'. Two types of mortgage are used in the model, namely the linear and annuity mortgage. Both mortgage have their own way of dealing with the rent calculation. More information about these mortgage types and their selection can be found in Appendix 13.24.3.

In a linear mortgage the buyer pays the same amount of repayment per period. The interest comes on top of this with a certain percentage of the remaining outstanding amount. The amount of interest paid per amount thus decrease by the repayment per period multiplied by the rent. This is an arithmetic sequence. Wikipedia (2017a) defines it as: "*a sequence of numbers such that the difference between the consecutive terms is constant.*" The cumulative interest payments are the sum of this arithmetic series minus the borrowed amount. The sum of a arithmetic series can be calculated by Sydsæter *et al.* (2016):

$$S_n = \frac{1}{2} * n * (a + b) \tag{6.51a}$$

In which:

- Sn is the sum of the arithmetic series (for *n* = 1, 2, 3, 4, …, *n*)
- n is the amount of terms
- a is the value of the initial term
- b is the value of the last term

The terms relate to the interest payment of a linear mortgage at period *p*, which can be calculated by the outstanding amount multiplied by the interest rate:

$$interest\ payment\ at\ p = \left(F_m - \frac{F_m}{d} * (p - 1)\right) * r \tag{6.51b}$$

In which:

- F_m is the financed amount by the mortgage
- d is the duration in time (operational period)
- p is the period in time

- r is the interest rate

The formula for the cumulative interest payment over total duration of the mortgage is the combination of 6.51a and 6.51b:

$$CIP = \frac{1}{2} * d * \left(\left(\left(F_m - \frac{F_m}{d} * (p_1 - 1) \right) * r \right) + \left(\left(F_m - \frac{F_m}{d} * (p_d - 1) \right) * r \right) \right) \quad (6.51c)$$

In which:

- CIP is the cumulative interest payment
- F_m is the financed amount by the mortgage
- d is the duration in time (operational period)
- p_1 is the first term
- p_d is the last term of the operational period
- r is the interest rate

Rewritten, because F_m is an endogenous variable and must be left out to get the cumulative interest rate payment factor for linear mortgages and thereby taken into account in that p_1=1 (the payment starts right away) and p_d=d (the last term is the end of the duration). For brevity reason that formula is not shown, but this one can be obtained by dividing the next formula by F_m.

$$CIP = F_m * R_{m;linear} = \frac{1}{2} * d * r * F_m * \left(2 - \frac{(d-1)}{d} \right) \quad (6.51d)$$

In which

- $R_{m;linear}$ is the cumulative interest rate payment factor for linear mortgages

Next, the calculation of the cumulative interest payment of the annuity mortgage. In an annuity mortgage the buyer pays the same amount every period. The formula for the calculation of the recurring amount (the annuity) is as follows (same explanation of variables as in formula 6.51b):

$$Annuity = \frac{F_m * r}{1 - (1 + r)^{-d}} \quad (6.52a)$$

The interest is part of this amount and its share decreases when the remaining outstanding amount is slinking. The cumulative interest paid is the total amount paid (annuity multiplied by the duration) minus the borrowed amount:

$$CIP = d * \frac{F_m * r}{1 - (1 + r)^{-d}} - F_m \quad (6.52b)$$

This formula has to be rewritten, because F_m must be left out to get the cumulative interest rate payment factor for linear mortgages (dividing by F_m gives $R_{m;annuity}$ in the next formula):

$$CIP = F_m * R_{m;annuity} = F_m * \left(\frac{d * r}{1 - (1 + r)^{-d}} - 1 \right) \quad (6.52c)$$

Finally, the cumulative interest payment for each dwelling type D_i is calculated by the ratios and factors of the both mortgages types per dwelling type (ratios can be found in Appendix 13.24.3):

$$R_{m;i} = R_{m;linear;i} * R_{m;linear} + R_{m;annuity;i} * R_{m;annuity} \quad (6.53)$$

In which

- $R_{m;i}$ is the cumulative interest rate payment factor for mortgages of dwelling type *i*

- $R_{m;linear;i}$ is the ratio in which linear mortgages are applied for dwelling type *i*
- $R_{m;linear}$ is the cumulative interest rate payment factor for linear mortgages
- $R_{m;annuity;i}$ is the ratio in which annuity mortgages are applied for dwelling type *i*
- $R_{m;annuity}$ is the cumulative interest rate payment factor for annuity mortgages

The ESCO can be seen as a subscription or a fixed connection fee in which users pay fixed monthly fees. That is why the calculation is based on the annuity mortgage. The interest payment can be seen as the profit rate of the ESCo. The calculation for the cumulative payment towards the ESCO is based on formula 6.52c:

$$R_{esco} = \frac{d * r}{1 - (1 + r)^{-d}} - 1 \qquad (6.54)$$

In which:

- R_{esco} is the cumulative interest rate payment factor for ESCo's

13.18.7 Objectives functions from other stakeholders' perspective

The LP-model can also be used to view the design problem from another stakeholders' perspective, such as the future owner of the dwelling, the environmental agency, the bank or the ESCo. The variety of the dwellings cannot be optimized. The model lacks therefore the viewpoint of the municipality as objective function. However, all viewpoints are also taken into account as constraints.

The future buyer wants to have the minimum total costs of ownership:

$$max!\, TCO_{tot} = \sum_{i=1}^{n} (-TCO_i) \qquad \text{For } n = 12 \qquad (6.55)$$

In which:

- TCO_{tot} are the total costs of ownership for all dwellings together.
- TCO_i are the total costs of ownership for all dwellings of dwelling type D_i

The environmental agency wants the maximal renewable energy production:

$$max!\, E_{p;tot} = \sum_{i=1}^{n} (E_{pp;i} - E_{np;i}) \qquad \text{For } n = 12 \qquad (6.56)$$

In which:

- $E_{p;tot}$ is the total energy production of renewable energy supplied into the grid in kWh annually
- $E_{pp;i}$, which is the positive production of renewable energy supplied to the grid in kWh annually for dwelling type D_i
- $E_{np;i}$, which is the negative production of energy; the amount of electricity taken from the grid in kWh annually for dwelling type D_i

The bank wants the maximal mortgage (rent is exogenous and cannot be optimized):

$$max!\, F_{m;tot} = \sum_{i=1}^{n} (F_{m;beng;i} + F_{m;zotm;i}) \qquad \text{For } n = 12 \qquad (6.57)$$

In which:

- $F_{m;tot}$ is the total amount financed by mortgages
- $F_{m;beng;i}$ is the amount financed by the BENG-mortgage for dwelling type D_i (formula 6.40)
- $F_{m;ZOM;i}$ is the amount financed by the ZOM-mortgage for dwelling type D_i (formula 6.40)

The ESCO wants the maximal financing (rent is exogenous and cannot be optimized):

$$max!\,F_{esco;tot} = \sum_{i=1}^{n}(F_{esco;i}) \qquad \text{For } n = 12 \qquad (6.58)$$

In which:

- $F_{esco;tot}$ is the total amount financed by the ESCo
- $F_{esco;i}$ is the amount financed by the ESCO for dwelling type D_i (formula 6.40)

13.19 Appendix 19: Assumptions and simplifications in the energy and cost calculations

Several assumptions and simplifications are made for the energy and cost calculations in the LP-model. Some assumptions are adopted from or based on J. W. J. De Vries (2010: Bijlage VII).

Assumptions and simplifications:

- The weather is the same throughout the Netherlands. In reality it is cooler at the sea during the summer and hotter during the winter. The average temperature in the Southern provinces is higher in comparison to the Northern provinces.
- The amount of full load hours of wind is the same throughout the Netherlands. In reality, the amount of full load hours of wind increases near the sea/the Western provinces.
- The amount of solar power is the same throughout the Netherlands. In reality the Southwestern provinces (Zeeland and Zuid-Holland) are gaining the most solar power.
- The average values of the outdoor temperature, full load hours of wind and solar power is the same for every year, based on a standard climate year. The outdoor temperature and solar gain is translated to an hourly average and used in the demand calculation model. The full load hours and solar power factor is used on a yearly basis.
- All dwellings are oriented southwards. This increases the amount of solar during the heating season and the electricity gain by PV-panels. In reality all dwellings are orientated differently and the amount of solar gain is less. The costs of energy are therefore seen from a conservative starting point. This compensated by using a low conversation factor for the electricity gain in kWh by the PV-panels (see Appendix 13.23.2).
- Only one price level is used for energy. In reality the price level difference by a day and night tariff and per energy provider. The average price of energy throughout the Netherlands is used.
- Only one price percentage is used for the additional costs. Those are normally smaller for bigger projects. All projects have a size of at least 100 dwellings. Therefore, this effect was neglected. Although, the percentage can be changed within the input-variables

13.20 Appendix 20: Calculation of the energy demand (BENG1)

The needed measurements to meet the BENG1-requirements are calculated in a second model. The model applies the energy balance method of Itard (2011) in Excel with hourly precision. The formulas are also discussion in the theoretical framework.

Solutions for transmission, ventilation and infiltration losses are that transmission can be minimized by applying triple glazing and extra insulation in wall, roof and floors, ventilation can be minimized by heat recovery in the ventilation system and infiltration losses can be minimized by increasing the level of airtightness (the $Q_{v;10}$-factor). Those energy saving measurements are checked in the model if they are needed to get towards the required maximum thermal heating demand of 25 kWh/m^2 annually. The results are checked by proposed energy saving measures for realizing BENG in Bouwens and Bouwmeester (2017).

The energy balance method of Itard (2011) was extra checked on the internal heat gain, if it matches the formal calculation method. This method is discussed below. The reason behind this was that the model of Itard (2011) quickly gives high values. Thereby the new requirement minimum insulation values of homes is used as described in the second part.

13.20.1 Match of the internal heat gain to formal NEN-calculation

The NEN 7120+C2 (2012) has differences with the calculation method of Itard (2011). Although the definition is quite the same, both talk about the heat supplied within the building by users (sensible metabolic heat) and equipment such as lighting, household appliances, office equipment, etc., other than energy deliberately released for heating, cooling or hot water preparation (text based on definition of the NEN 7120+C2 (2012: 26)). The difference is in the calculation method. Itard (2011) uses a hourly calculation as explained in the theoretical framework. The NEN 7120+C2 (2012: 122) determines the amount of heat from the internal heat production in the considered calculation zone by formula 6.1 (formula 10.2a in the standard).

$$\Phi_{\text{int;zi}} = 230 * N_{W;zi} + 1{,}8 * A_{g;zi} \qquad (14.1)$$

In which;

- $\Phi_{int;zi}$ is the sum of heat flows of the internal heat gains in the considered computing zone zi, in W;
- $N_{W;zi}$ is the number of housing units per calculation zone;
- $A_{g;zi}$ is the usable floor area of the considered calculation zone, in m^2.

When the result is multiplied with the length of the period considered (in seconds) the amount of J used is calculated. Dividing this by 3,600 gives us the amount in kWh.

13.20.2 Match of the hot tap water demand to formal NEN-calculation

The NEN 7120+C2 (2012) determines the net heat demand for hot tap water on the basis of a fixed requirement per inhabitant in MJ per year, with the number of residents dependent on the usable floor area. The calculation method of Itard (2011) has an easier calculation that is not dependented on, among other things, pipe lengths. In the calculation model for this graduation thesis the fixed requirements of the NEN 7120+C2 (2012) for the hot tap water demand and amount of residents per dwelling are used within the calculation method of Itard (2011).

According to NEN 7120+C2 (2012: 256) the specific use of hot tap water in quantities of 60 ° C litres of water for hot tap water is 40.29 litres per day per person and the amount of residents per dwelling is calculated as part of the formula for the net heat demand for hot tap water (NEN 7120+C2, 2012: 255). This part is distracted from the whole formula and written as follows:

$$Amount\ of\ residents = 1{,}28 * N_{W;zi} + 0{,}01 * A_{g;zi} \qquad (14.2)$$

In which:

- $N_{W;zi}$ is the number of housing units per calculation zone;
- $A_{g;zi}$ is the usable floor area of the considered calculation zone, in m^2.

This formula determines the number of residents in a dwelling or an apartment building based on national averages for the number of residents per property, taking into account the distribution of housing dimensions (NEN 7120+C2, 2012).

The total daily hot tap water demand in m^3 is consequently the amount of persons multiplied by the usage of 40.29 litres per day per person. Since the usage of heat recovery systems in the shower are more frequently applied, these must also be included in the formula. The energy recovery efficiency in the field was measured around the 57% of the total energy usages for the hot tap water demand (Deng, Mol, & Van der Hoek, 2016: 7)

$$Hot\ tap\ water\ demand = \left(1{,}28 * N_{W;zi} + 0{,}01 * A_{g;zi}\right) * \frac{40{,}29}{1000} * (1 - HR_s) \quad (14.3)$$

In which:

- HR_s is the heat recovery efficiency of the shower

13.20.3 Minimum input values for the thermal envelope

Since the start of 2015, the regulations got tighter for the thermal envelop of a building. Before 2015 the insolation value (R_c-value) needed to be at least 3,5 m^2K/W for the whole thermal envelop. The new requirements are separated per construction type (Blok, 2014b: 2):

- Floor: R_c-value of at least 3,5 m^2K/W
- Façade: R_c-value of at least 4,5 m^2K/W
- Roof: R_c-value of at least 6,0 m^2K/W

This separation reflects the wish of market parties that more attention should be paid to the building's thermal envelop (Nieman RI, 2014).

The stated values are used as minimal values in the model.

13.20.4 Results

The results of the energy saving measures are shown in Table 24 for dwellings which meet the BENG1-requirement and in Table 25 for the dwellings which does not meet the BENG1-requirement, but are quite energy efficient as the thermal demand is max 40 kWh/m^2 annually. Output checked with the energy measures taken for several similar dwelling concepts in Bouwens and Bouwmeester (2017) and taken the different possibilities into account, fit these results the concept described as more measurements are needed for detached dwellings.

Table 24: Thermal demand < 25kWh/m^2/annual (BENG1)

Dwelling type	Corner of terraced houses	MID-terraced houses	Semi-detached	Detached
A	100 m^2	100 m^2	125 m^2	175 m^2
ELECTRIC BOILER	Balance ventilation $Q_{v;10}$=0,2 Triple glazing	Balance ventilation $Q_{v;10}$=0,2 Triple glazing	Balance ventilation $Q_{v;10}$=0,2 Triple glazing	Balance ventilation $Q_{v;10}$=0,2 Triple glazing Extra insulation
B	125 m^2	125 m^2	150 m^2	200 m^2
AIR SOURCE HEAT PUMP	Balance ventilation $Q_{v;10}$=0,2 Triple glazing	Balance ventilation $Q_{v;10}$=0,2 Triple glazing	Balance ventilation $Q_{v;10}$=0,2 Triple glazing	Balance ventilation $Q_{v;10}$=0,2 Triple glazing Extra insulation
C	150 m^2	150 m^2	200 m^2	250 m^2
GROUND SOURCE HEAT PUMP	Balance ventilation $Q_{v;10}$=0,2 Triple glazing	Balance ventilation $Q_{v;10}$=0,2 Triple glazing	Balance ventilation $Q_{v;10}$=0,2 Triple glazing	Balance ventilation $Q_{v;10}$=0,2 Triple glazing Extra insulation

Table 25: Thermal demand > 25kWh/m^2/annual

Dwelling type	Corner of terraced houses	mid-terraced houses	Semi-detached	Detached
A	100 m^2	100 m^2	125 m^2	175 m^2
ELECTRIC BOILER	Balance ventilation $Q_{v;10}$=0,2	Balance ventilation $Q_{v;10}$=0,2	Balance ventilation $Q_{v;10}$=0,2	Balance ventilation $Q_{v;10}$=0,2 Triple glazing
B	125 m^2	125 m^2	150 m^2	200 m^2
AIR SOURCE HEAT PUMP	Balance ventilation $Q_{v;10}$=0,2	Balance ventilation $Q_{v;10}$=0,2	Balance ventilation $Q_{v;10}$=0,2	Balance ventilation $Q_{v;10}$=0,2 Triple glazing
C	150 m^2	150 m^2	200 m^2	250 m^2
GROUND SOURCE HEAT PUMP	Balance ventilation $Q_{v;10}$=0,2	Balance ventilation $Q_{v;10}$=0,2	Balance ventilation $Q_{v;10}$=0,2	Balance ventilation $Q_{v;10}$=0,2 Triple glazing

13.21 Appendix 21: Construction and additional costs

This appendix shows the used construction costs and additional costs.

13.21.1 Construction costs

The construction cost of Table 26 are used, which are based on Vonk *et al.* (2016). Except if stated differently.

Table 26: Construction costs used.

Typology	Price in €/m^2 UFA	Form factor (UFA/GFA)	Page of Vonk *et al.* (2016).
Terraced	€814 - €1009	0,77	Page 44; page 48
Semi-detached	€1248 - €1308	0,70	Page 38-39
Detached (manor house)	€1400	0,71	Page 26

13.21.2 Additional costs

For the additional costs 25,55% is used in all cases. This percentage does not contain profit and risk, because that is the output of the model and not the input. This number is based on the following table from Vonk *et al.* (2016: 247).

Table 27: Additional costs in % of the construction costs (Vonk *et al.*, 2016: 247).

Type	Low	High	Used
Advisory fees			
Architect	3,0	4,8	
Urban designer	0,3	0,6	
Interior designer	0,0	0,2	
Constructor	0,5	1,0	
Installation advisor	0,5	1,5	
Building Physics / Sustainability Advisor	0,3	1,1	
Project management	1,5	2,1	
Costs management	0,5	0,8	
Construction supervision	1,0	2,0	
Other advisors	0,5	1,5	
Total advisory fees	8,1	15,6	11,85
Levies, connection costs and insurance			
Fees and connection costs	2,5	5,0	3,75
Insurance as client	0,5	1,0	0,75
Starting costs			
Advertising costs	0,2	0,5	0,35
Brokerage and agency fees	0,5	1,2	0,85
Notary fees	0,8	1,6	1,2
Financing costs and reference date shift			
Financing costs	1,5	4,5	3,0
Reference date shift	0,0	1,1	0,55
Project development costs			
General costs	1,5	5,0	3,25
Profit and risk	2,0	10,0	0,0
Total			**25,55**

13.22 Appendix 22: Market values in Delft and Rotterdam-Heijplaat

The key figures of the market prices calculated for the model are based on real-life situations. First the calculation and sampling method is explained, after which the numbers used in the model are given for both cases.

13.22.1 Sampling and method of analysis

The market prices are based on data of Funda (2017). Funda is the most used website in the Netherlands where owner-occupied houses are offered. Funda presents almost all houses which are for sell at that moment. That is why is it a valid source to use for gathering data. For each case a sample is made based on several selection criteria. First, the dwellings need to be in a similar location as the case study (e.g. city, distance from city centre, public transport or highway) and second, for these locations only houses developed after 2010, single-family dwellings and houses with an energy label A or higher are selected. This group of dwellings is the sample.

In this sample data is collected for each unit about the typology, year of construction, energy label, selling price, type of selling price, the usable floor area and its unique address. The typology can be a corner-terraced dwelling, row-terraced dwelling, semi-detached dwelling and detached dwelling.

The type of selling price can be costs buyer (Dutch: '*kosten koper*', abbreviated as k.k.) and the cost payable by vendor (Dutch: '*vrij op naam*', abbreviated as v.o.n.). The costs buyer are only the costs for the dwelling and excluding the costs a buyer must make to realize a transaction, such as transfer tax, brokerage and advisory fees (Vlek *et al.*, 2016: 204). A selling price is cost buyer (k.k.) if no additional costs are included in the price. The cost payable by vendor includes these several additional costs (e.g. transfer tax or VAT, notary and brokerage costs). In the case the selling price was given in k.k. an 4% additional costs were added to get the v.o.n.-price and make the selling prices comparable. This 4% is based on S. H. C. Van den Berg *et al.* (2016: 50-54). Both v.o.n. and k.k. needs a 2-3% of additional costs, for example for closing a mortgage at the bank (taxation costs, closing commission and notarial fees for the mortgage deed). This brings the addition costs for k.k. at 6%, which is a more commonly known key figure.

After the data gathering some steps were executed to get the selling price per square meter for each dwelling category. These steps are based from the approach of the regression analyses in Binnekamp *et al.* (2006). First, the sampled houses are divided into the four categories of the dwelling types. Secondly the selling price was plot in relation to the number of square meters' usable floor area and third, relationship was calculated between both variables. Lastly, the error term R^2 was calculated to define the strength of the relationship. R^2 has to get a value between 0 and 1 and indicates the relative fit of the regression analysis to the data. In which R2=0 means no fit at all and r2=1 means a perfect fit (Binnekamp *et al.*, 2006: 267). Assumed is a relationship crossing (0,0). Projects are deleted from the sample when projects have a very strong disruptive effect on the relationship and contain multiple dwellings. In that case it is assumed that another variable has a strong influence on the price and not it size. After this selection the steps are retaken.

This approach of the regression analysis gives a more precise calculation than dividing the selling price by the number of square meters' usable floor area and calculating the average selling price per square meter.

13.22.2 Data gathering Rotterdam-Heijplaat

On the data of research (21-09-2017) the search for owner-occupied houses in Rotterdam and max 5km around offered 12.080 results. When the selection criteria where applied 2.245 dwellings remain of which 97 dwellings are for sale on similar locations. These locations are based on the proximity to the location on the south banks of Rotterdam and the distance of the city centre (shown as blue 'flags' in Figure 86).

13

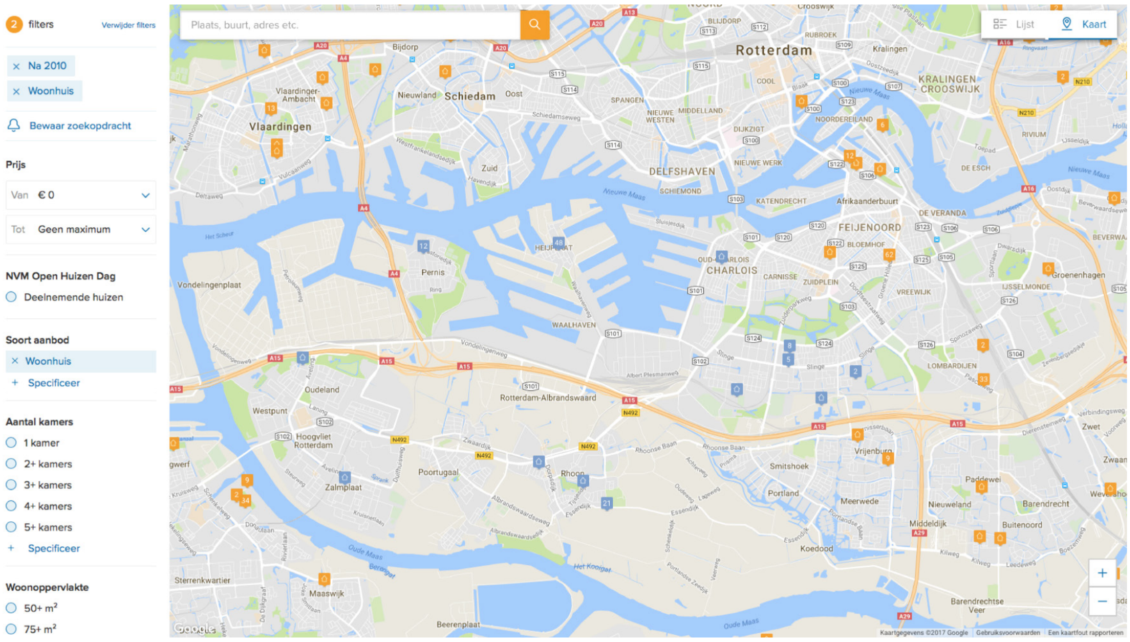

Figure 86: The blue labels indicate the houses located near a similar location as the case study 'Het Verborgen Geheim' (screenshot of Funda.nl).

13.22.3 Results and conclusion Rotterdam Heijplaat

After the steps have been completed, the following graph is the result from the sample (see Figure 87).

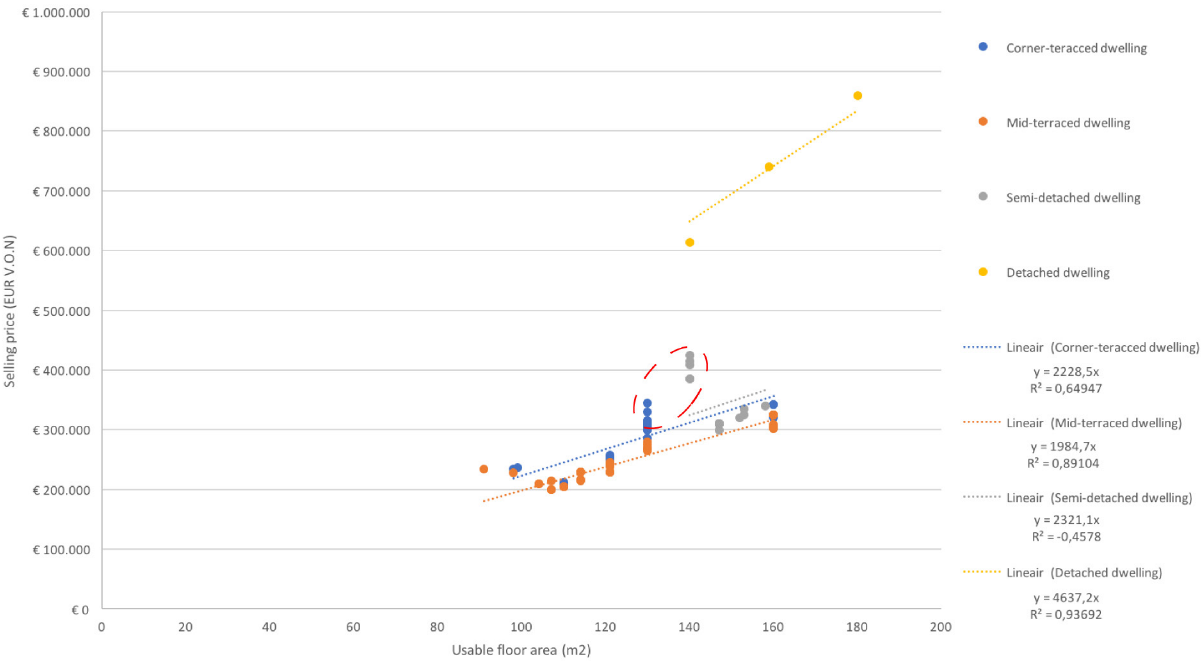

Figure 87: Selling prices of four different dwelling types at locations similar to Rotterdam-Heijplaat. The whole sample is included in this graph (own illustration based on data of Funda (2017).

Three things stand out in this graph: the absence of a relationship for the semi-detached dwellings (R^2=-0,46), the weak relationship for corner-terraced dwellings (R^2=0,65) and the little amount of detached dwellings. These results are further investigated. It appeared that one project on the edge of the village in Rhoon and one semi-detached dwelling on the city edge in the south of Charlios heavily effects the two relationships. Projects on the edge of the city are therefore excluded from the sample. These are the projects in the red dotted circle of Figure 87. This variable thus influences the market value of the dwellings. For the last one, there are only three detached dwellings for sale in this area. One of these villas dropped in selling price from €625.000 to €590.000 after being for sale for more than 6 months. The other two are located in Rhoon. For that reason, it can be assumed that

Rhoon is a different housing market and in Rotterdam-Heijplaat and surroundings there is no market for (expensive) detached dwellings.

The new sample is without the dwellings on the city edge (mainly project Rhoon) and the three detached dwellings. This search area is shown in Figure 88.

Figure 88: Redefined search area, which excludes detached dwellings and dwellings on the edge of the city, located with a view on the rural area (own illustration based on Funda (2017)).

Based on this new sample and the previous descripted method the following can be concluded for the location of the case study (see Figure 89 and Table 29): The average selling price for a corner-terraced dwelling is 2.100 euro/m^2, of a mid-terraced dwelling 1.969 euro/m^2 and 2.115 euro/m^2 for a semi-detached dwelling. No number can be given for a detached dwelling, as there is no realistic market for it. This also indicates that the market space for semi-detached dwellings is not that much better as those for corner-terraced dwellings.

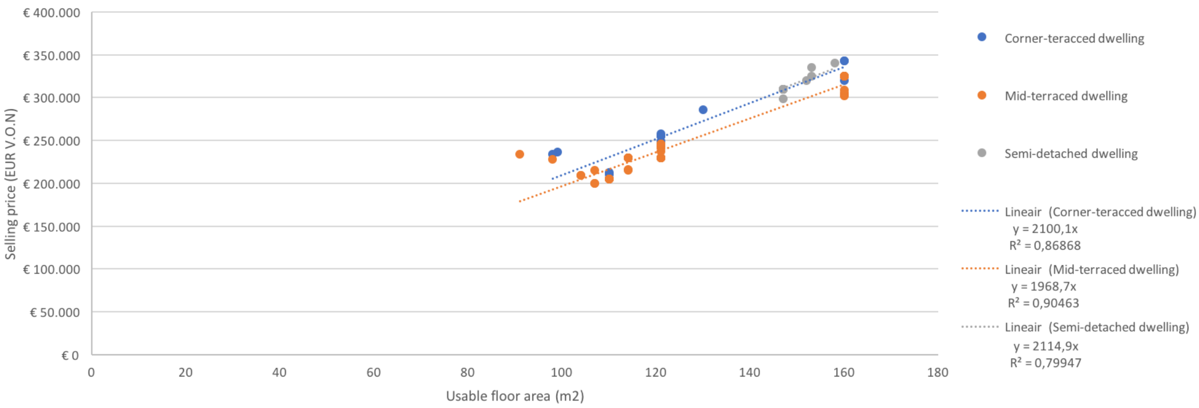

Figure 89: Selling prices of four different dwelling types at locations similar to Rotterdam-Heijplaat. This graph shows the new sample (own illustration based on data of Funda (2017).

Table 28: Results market study for single-family dwellings in Rotterdam-Heijplaat at similar locations of the case.

Housing type	#dwellings used	Relationship VON price in €/m^2	R^2
Corner terraced-dwelling	15	€ 2.100	0,869
Mid-terraced dwelling	45	€ 1.969	0,905
Semi-detached dwelling	12	€ 2.115	0,799
Detached dwelling	0	n/a	n/a
Total	**72**		

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In this case both all dwellings types have a relatively good relationship (R^2>~0,80).

There is one point of discussion, which is the assumed the relationship through point (0,0). In case this relationship was not assumed, there was hardly an effect for the terraced dwellings. R^2 would be 0,874 for the corner-terraced dwellings and 0,906 for the mid-terraced dwellings. For the semi-detached dwellings, R^2 would be 0,877, which is an effect of 0,078. This can be caused by two things. First, the little amount of dwellings available in the sample, however, this is also the cause for the corner-terraced dwellings, which were hardly influenced. Second, the units of research almost all have quite the same size. All semi-detached dwelling sizes in the sample are between 147 m^2 and 158 m^2. Other factors must have a bigger influence on the price as these few square meters.

13.22.4 Data gathering Delft

On the data of research (26-08-2017) the search for owner-occupied houses in Delft and max 5km around offered 3.799 results. When the selection criteria where applied 902 dwellings remain of which 274 dwellings are for sale on similar locations. These locations are based on the proximity to a highway and the distance of the city centre (shown as blue 'flags' in Figure 90).

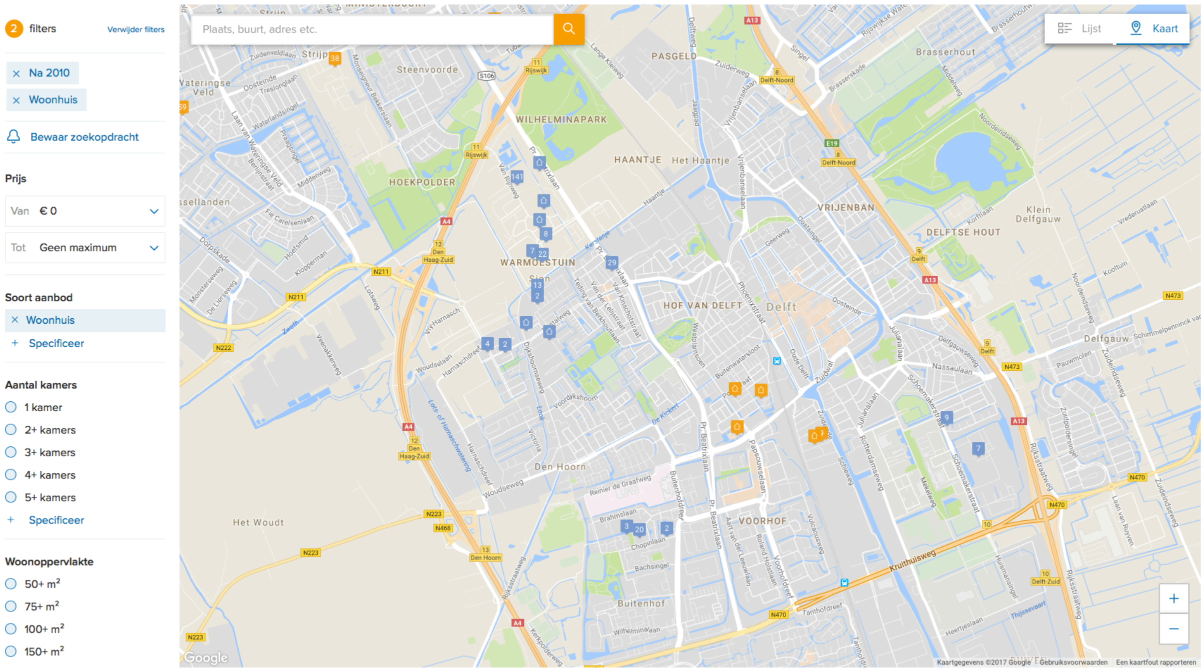

Figure 90: The blue labels indicate the houses located near a similar location as the case study 'Prof. Schoemaker Plantage' (screenshot of Funda.nl).

13.22.5 Results and conclusion Delft

After the steps have been completed, the following graph is the result from the sample (see Figure 91).

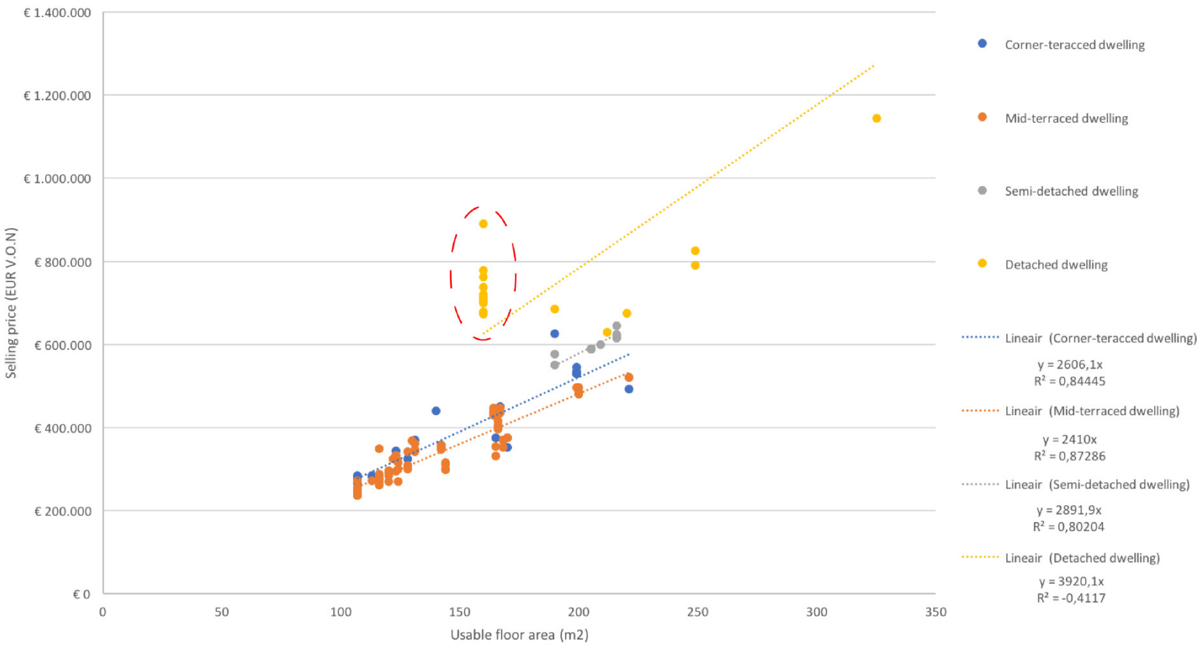

Figure 91: Selling prices houses in Delft at similar locations of the case (own illustration, data of Funda.nl)

One aspect stands out from this graph, there is no relationship at all between the detached dwellings (R^2=-0,41). This error margin can be explained by one project, which offers a special type of villas (project Laan van Bentvelsen of ZuiverWonen). All villas have the same usable floor area, but different prices. Those units are indicated in Figure 91 by the red dotted circle. This causes a disturbing effect within the small sample.

This project is excluded in the new sample. This brings the total sample to 117 selected dwellings. All dwellings are developed after 2013 and some still needs to be developed (latest finished in 2019). The individual selling prices are plot in the graph of Figure 93 and more conclusions are shown in Table 29.

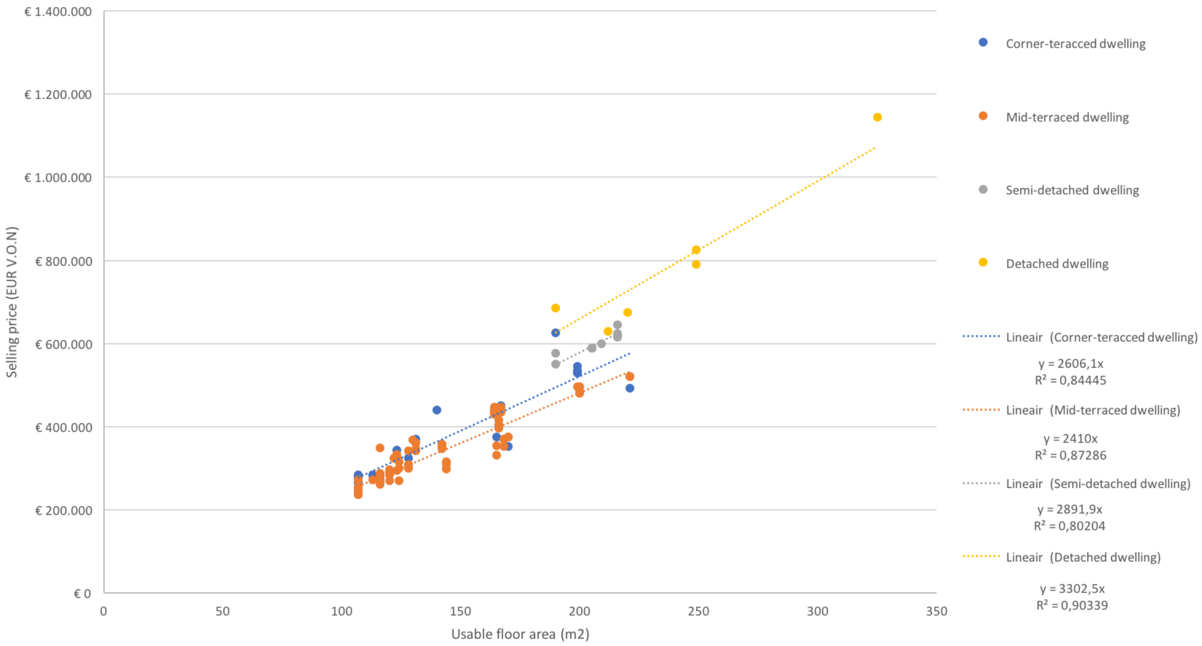

Figure 92: Selling prices of four different dwelling types at locations similar to the case in Delft. This graph shows the new sample (own illustration based on data of Funda (2017).

Based on this new sample and the previous descripted method the following can be concluded for the location of the case study: The average selling price for a corner-terraced dwelling is 2.606 euro/m^2, of a mid-terraced dwelling 2.405 euro/m^2, 2.892 euro/m^2 for a semi-detached dwelling and 3.303 euro/m^2 for a detached dwelling.

Table 29: Results market study for single-family dwellings in Delft at similar locations of the case.

Housing type	#dwellings used	Relationship VON price in €/m^2	R^2
Corner terraced-dwelling	24	€ 2.606	0,844
Mid-terraced dwelling	75	€ 2.410	0,873
Semi-detached dwelling	13	€ 2.892	0,802
Detached dwelling	6	€ 3.303	0,903
Total	**118**		

In this case both all dwellings types have a relatively good relationship (R^2>0,80).

There is one point of discussion, which is the assumed the relationship through point (0,0). In case this relationship was not assumed, there was hardly an effect for the terraced dwellings. R^2 would be 0,846 for the corner-terraced dwellings and the same R^2 of 0,873 for the mid-terraced dwellings. For the semi-detached dwellings, R^2 would be 0,831, which is an effect of 0,029 and R^2 would be 0,922 for the detached dwellings, which is an effect of 0,021. This effect for both dwelling types can be caused by the little amount of dwellings available for the sample.

13.22.6 Comparison of both cases

Both cases are compared in the next section.

Table 30: Amount of dwellings used

Housing type	Case Rotterdam-Heijplaat	Case Delft
Corner terraced-dwelling	15	24
Mid-terraced dwelling	45	74
Semi-detached dwelling	12	13
Detached dwelling	0	6
Total	**72**	**117**

In addition to the totals of Table 30 it must be reported that in the case of Rotterdam-Heijplaat 42 dwellings of the total amount of dwellings are from the case itself, which is 58%. In Delft this amount contains only 16 dwellings, which is only 14%. Based on Table 30 and the previous addition can be stated that the competition is bigger in Delft. For the Prof. Schoemaker Plantage is RijswijkBuiten their main competitor with 58 dwellings for sale at the moment of sampling. Besides that, some dwelling types only have a small sample.

Table 31: Relationship VON price in €/m^2

Housing type	Case Rotterdam-Heijplaat	Case Delft
Corner terraced-dwelling	€ 2.100	€ 2.606 (+24%)
Mid-terraced dwelling	€ 1.969	€ 2.405 (+22%)
Semi-detached dwelling	€ 2.115	€ 2.892 (+37%)
Detached dwelling	n/a	€ 3.303

Table 31 shows is that for all dwelling types the market value per m^2 is bigger in Delft. This counts especially for the semi-detached and detached dwellings.

Table 32: The strength of the relationship as indicated by R^2

Housing type	Case Rotterdam-Heijplaat	Case Delft
Corner terraced-dwelling	0,869	0,844
Mid-terraced dwelling	0,905	0,880
Semi-detached dwelling	0,799	0,802
Detached dwelling	n/a	0,903

All relationships are relatively good (R^2> ~0,80) for all cases.

13.23 Appendix 23: Efficiencies/ COPs and costs of energy installations

In this appendix data for the efficiencies and COP of the energy installations is given and reasons are explained why those data points are selected. The Appendix starts with the thermal energy installations, followed by the PV-panels and ends with the wind mills.

13.23.1 Efficiencies, COP and costs of thermal energy suppliers/ installations

Introduction

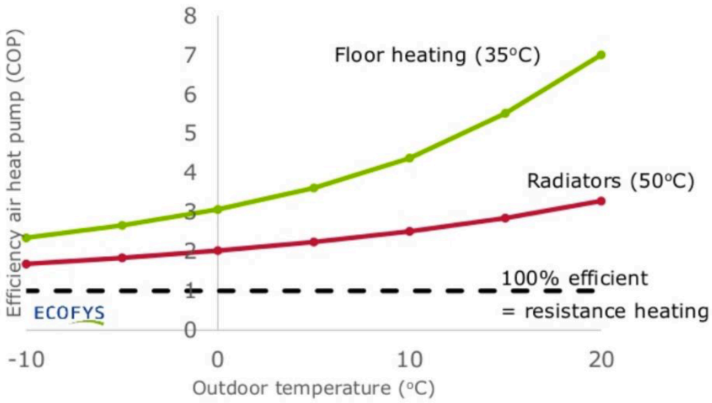

Figure 93: Varying efficiency of ASHP depending on ambient air temperature and supply temperature (Ecofys (2016) in Thies (2017: 10))

Table 33: Efficiency and COP of electric boilers, air source heat pumps and ground source heat pumps. Sources are in alphabetical order and the number represents the position of the source in the list (Furuno *et al.*, 2016: 173; Miara *et al.*, 2011: 27;31; NEN 7120+C2, 2012: 193-194;291; Thies, 2017: 10;24).

Appliances	η/COP[1]	η/COP[2]	η/COP[3]	η/COP[4]	Used η/COP
Electra boiler	n/a	n/a	0,75	n/a	0,75
Air source heat pump	2,2-4,5 (average 3,4)	2,3-3,4 (average 2,9)	1,9-3,2	2,6	2,6
Ground source heat pump	4,0-5,7 (average 4,9)	3,1-5,1 (average 3,9)	3,0-5,1	3,8	3,9

But, the research of Furuno *et al.* (2016) was in applied in cold regions, which has an increasing effect on the COP. The COP of heat pumps varies depending on the heat source and the design between 2 and 5 (Itard, 2011).

In general, the COPs for different heating technological are difficult to estimate, because they are highly depended on ambient air and water output temperatures (Thies, 2017). For instance, in case there is a very cold period during winter, the COPs level will be lower.

Table 34: Investment costs, maintenance costs and subsidies for the different thermal installations (data based on course SPM, Mooij (2011, 2012), Mars and Teunizen (2012) and onlines stores[116]).

Appliances	Investment costs	Maintenance (annually)
Electra boiler	€400,-	5% of investment costs
Air source heat pump	€ 12.100,-	2,5% of investment costs
Ground source heat pump (5kW)	€ 12.800,-	2,5% of investment costs
Ground source heat pump (8kW)	€ 14.900,-	2,5% of investment costs
Subsidy ASHP	€ 1.100,-	
Subsidy GSHP	€ 2.500,-	

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[116] For instance, www.electraboiler.nl and www.warmtepomp-info.nl/boiler were used to determine the price of an electra boiler.

13.23.2 Capacities, costs and efficiencies of PV panels

The used PV-panels are based on the options of Zonatlas by Schwerhoff *et al.* (2017). This is an independent platform with the goal to support local authorities and individuals in the local energy transition and therefore it collaborates with municipalities to ensure that all residents have independent and very accurate information about the potential of their roofs for solar energy and related costs (Schwerhoff *et al.*, 2017). Data therefore is assumed non-commercial and reliable. The used PV-panels are shown in Table 35. In the model the user has to select three possibilities, otherwise the model would get too extended.

Table 35: Used PV-panes in the model (Schwerhoff *et al.*, 2017)2.

Type	Wp/panel	m^2/panel	Wp/m^2	EUR/kWp
Solar panel – type 1	200	1,58*0,808 = 1,28	156,7	1300
Solar panel – type 2	250	1,65*0,99 = 1,63	153,0	1380
Solar panel – type 3	255	1,65*0,99 = 1,63	156,1	1411
Solar panel – type 4	250	1,65*0,99 = 1,63	153,0	1400
Solar panel – type 5	270	1,65*0,99 = 1,63	165,3	1500
Solar panel – type 6	300	1,65*0,99 = 1,63	183.7	1600

Wp is the unit indicating the capacity of the PV-panels. 1 Wp is the production of 1W under the standard test conditions. These include among others an incoming solar power of 1000 W/m^2, a temperature of 25 °C and a direction of the incoming solar beams perpendicular to the PV-panel.

The efficiency of the solar panel in test conditions can be extracted from the column mentioning the Wp/m^2, because 1000W/m^2 is the incoming solar power and only a part is transformed to electric power. The efficiencies of the solar panels are thus in between the 15,3% and 18,4%. According to Weber (2016) and Teo *et al.* (2012), traditional solar panels achieve an efficiency of 15% to 20% to convert the solar irradiation into electricity, while the rest is wasted as heat. The numbers above fit the standardized solar panels. However, those numbers can increase in the future. Green *et al.* (2017) publishes every six months a list of the highest confirmed efficiencies for a range of photovoltaic cell and its module technologies. An efficiency of 46% was stated in his last listings. These solar panels were constructed of completely different materials as the current standardized solar panels. For those standardized solar panels based on crystalline silicon, a maximum efficiency was stated of around 26%. This confirms that the numbers used are realistic.

The capacity of the solar panels in Wp needs conversion to kWh in order to be useful. Wp represents the yield in the most ideal (test) conditions. The actual output of a solar panel can be calculated using the conversion factor for the Netherlands, which is based on the number of hours of sunshine and light intensity. However, different sources state different conversion factors (see Table 36). Because orientation and angle are mostly neglected in the model, the lowest factor is selected. Orientation and angle are not completely neglected, because solar panels cannot be added to north-facing roofs and all roofs have an angle of around 25-40°.

Table 36: Sources state multiple possible conversion factors for Wp-to-kWh in the Netherlands (31-08-2017).

Wp-to-kWh-factor	Source
0,9	https://solar-box.nl/uitleg/onderdelen-en-begrippen-zonnepanelen/abc-begrippenlijst/
0,87	http://www.regge-stroom.nl/zonnestroom/begrippenlijst/
0,85-1	https://nl.wikipedia.org/wiki/Wattpiek
Average: 0,876	http://users.skynet.be/betberge/pvdiary/pvcalc.htm
0,85	https://www.tentensolar.nl/semi-overheid/dossiers/item/zonnepanelen-van-wp-naar-kwh.html
0,85	Used in the model if no other data is presented

According to Masters in Solar (2017) this standard conversion factor for the output of the PV-panels is different throughout the Netherlands. They state that in the east of the country, a conversion factor of 0,85 usually applies. In Central Netherlands it is 0,9 and in the coastal areas 0,95-1. This is because the coastal areas get on average more sun than the inland. This is summarized in Figure 94.

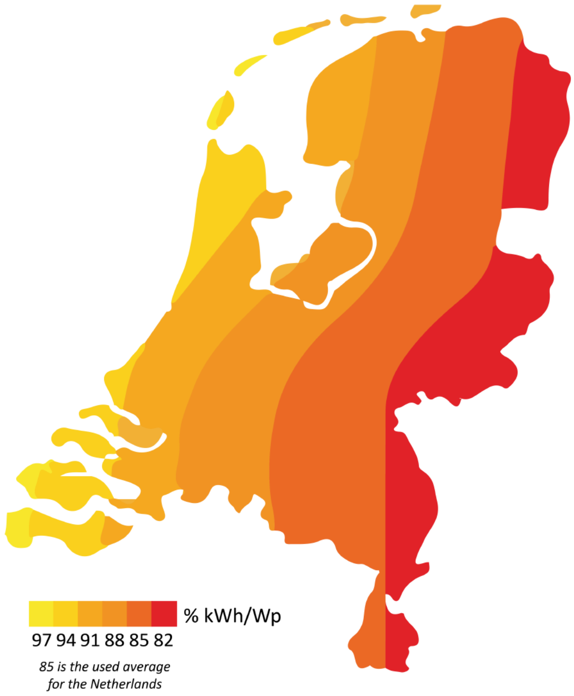


Figure 94: Conversion factors Wp -> kWh (own illustration based on Masters in Solar (2017)).

Also the orientation and the inclination of dwellings has effect on the efficiency of the PV-panels, see Figure 95.

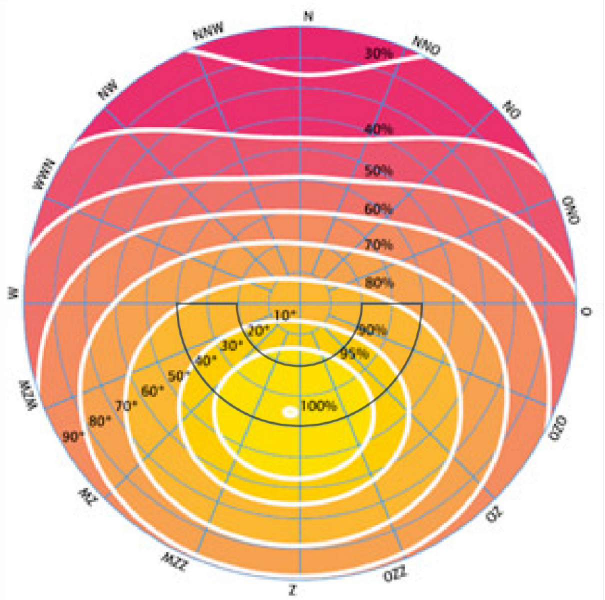


Figure 95: Effect of orientation and inclination on efficiency PV-panel. The half of a circle represent the possible orientations and inclinations of the dwellings within the model (adapted illustration of Masters in Solar (2017)).

The above described Wp are not a stable state. During the operational phase the system efficiencies decreases and maintenance has to be executed. Degradation and maintenance levels are based on crystalline silicon PV systems, because they are the most often used PV systems on a rooftop. First the degradation levels, these PV systems were assumed to have an approximate degradation rate of 0.5% per year over the project lifetime in Jordan *et al.* (2010), Jordan and Kurtz (2013: 12), Jordan *et al.* (2016: 978) and Limmanee *et al.* (2016). This value is measured as median value on individual modules and entire systems (Jordan & Kurtz, 2013: 12). The case study analysis of Kirmani and Kalimullah (2017: 212) indicates that the stated degradation rate is even a maximum level. They expect a "rate of change" of −0.5% per year or fewer after at least 8 years of operation. In practise however, higher degradation rates are used as guarantee level. Common is a guarantee of 80% of the power output after 20 or 25 years (Van der Wilt, 2017). MetdeZon (2017), one of the largest solar energy suppliers in the Netherlands, guarantees a power output of 90% after 12 years and 80% after 25 years. This is a degradation rate of 0,8% in the worst case-scenario. Based on the above information a degradation rate of 0,5% is used during the whole operational period.

Second, the costs of maintenance; According to European Commission (2005: 48) and Koner, Dutta, and Chopra (2000) the annual operating and maintenance costs for PV installations is approximately 1% of the investment cost. The costs increases with the inflation rate (Tantisattayakula & Kanchanapiyab, 2017).

13.23.3 Capacities, costs and efficiencies of wind mills

The capacities, costs and efficiencies of wind mills are based on the description of Clerix (2015). Some statements to support the data presented in Table 37.

- The price of the wind turbine itself - the mast, the blades and the built-in technology - is usually not so much variation. The average cost of recent wind turbines on which the Vlaams Energieagentschap (translated as the Flemish Energy Agency) has data is 1070 euros per kilowatt.
- The construction costs of a wind turbine are on average 77% of the total investment. In addition, the project developer has costs for project management (6% of the total costs), connection costs (5% of the total costs), related jobs (8% of the total costs) and additional costs (4% of the total costs). What exactly is included in these costs can be read in the source.
- Flexibel annual operational costs are maintenance costs, injection costs for the energy into the grid, exploitation costs, insurance costs, legal costs, environmental studies (e.g. real noise impact), etc.. According to the Vlaams Energieagentschap these are on average 43 euro per kilowatt.
- Fixed annual operation costs are the location lease. This right is usually between 20,000 and 25,000 euro. In the LP-model this amount is divided by the maximum allowed capacity for a wind turbine and added to the yearly operational costs. The underlining assumption is that only wind mills of the maximum allowed capacity (according to the constraints of, for instance, the municipality or the residents). This is done to create simplicity in the LP-model, otherwise binary calculations had to be added. This also coincides with the LP-model based on households that take a particular interest in the windmill and do not buy a whole windmill per household.
- For the amount of electricity generated on a yearly basis the '*equivalent full load hours*' is used, which is the number of hours on a yearly basis that the wind turbine generates electricity to the maximum power of that windmill. The Vlaams Energieagentschap calculates 2130 full load hours per wind turbine.

The average capacity of wind on land is based on Wind op land (2016) and Bosch and Van Rijn (2017). The former state that the current generation of wind turbines has a power of at least 2MW (Wind op land, 2016) and data of the latter showed that the new windmills on land have an average power output of about 3MW (range 2,3-4,2MW, excluding the 0,80MW ones) and has a size of 125m-175m (Bosch & Van Rijn, 2017). Therefore 3MW is selected as the wind mill capacity.

Table 37: Key figures used in the LP-model for wind energy
(based on Bosch and Van Rijn (2017); Clerix (2015); Wind op land (2016)).

Category	Key figure used
Construction costs	€ 1070/kW
% construction costs of total investment	77%
Annual operational costs	€ 43/kW annually
Location lease	€ 22.500 annually
Full load hours	2130
Constraint: Max kW per windmill	3000 kW

How much money a wind turbine owner gets for the power he injects into the power grid depends on the contract he concludes with the energy buyer. This data is explained and given in the Appendix on costs and revenues of energy usage and supply (Appendix 13.25).

13.24 Appendix 24: Mortgage and interest rates

The additional borrowing capacity and interest rates are explained in this appendix and recent numbers are given. Those numbers are applied in the LP-model.

13.24.1 Additional borrowing capacity based on energy label dwelling

From the start of 2014, consumers with an income from € 29,000 may additionally borrow an amount of up to € 13,500 for the financing of zero-on-the-meter dwelling and € 8.000 for a dwelling with an energy label of at least A++, which relate to an EPC of 0,6 (Dijsselbloem, 2013).

Since that time the extra borrowing capacity is increased to € 27.000 for ZOM-dwellings (Blok, 2015a). The qualification for this exemption is made more difficult, because the income limit is increased to € 32.000 (Blok, 2015a) and he construction company has to guarantee the energy performance for at least 10 year to qualify (Bouwmeester, 2015). Also the extra borrowing capacity for A++-dwellings is increased with €1.000,- (Blok, 2014a, 2015a, 2016). Table 38 shows the steps the capacity increased.

Table 38: Additional borrowing capacity is possible for energy efficient dwellings and increased during time (Blok, 2014a, 2015a, 2016; Dijsselbloem, 2013).

	2014	2015	2016	2017	2018
ZOM	€ 13.500,-	€ 25.000,-	€ 27.000,-	€ 27.000,-	Unknown
A++	€ 8.000,-	€ 9.000,-	€ 9.000,-	€ 9.000,-	Unknown
A/B	€ 0,-	€ 0,-	€ 0,-	€ 0,-	Possible € 3.000,-

13.24.2 Interest rates of mortgages

In 2017 interest rates are very low and the expectation is that these will increase (Van Oirschot, 2017). Partly because of that are interest rates increasing when they are fixed for multiple years (see Table 39). The described interest rates are applied in the LP-model.

Table 39: Best interest rates for mortgages in 2017 (Van Oirschot, 2017).

Interest rate	Duration
1,50%	Variable
1,68%	Fixed for 10 years
2,30%	Fixed for 20 years
2,55%	Fixed for 30 years

In order to allow five-year intervals, the relationship between the interest rates is examined. The graph of Figure 96 shows that three types of trend lines have all an R^2 higher as 0,95. For simplicity the formula for the linear trend line is used. Based on this relationship, the interest rates for 25 and 35 years are calculated and added to the possibilities in Table 40.

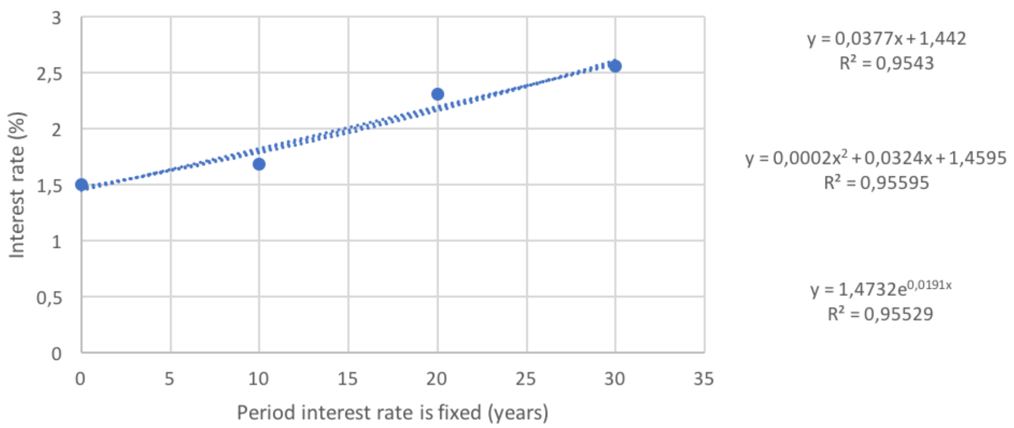


Figure 96: Interest rates for different timeframes of fixed interest rate periods (own illustration based on Van Oirschot (2017)).

Table 40: Interest rates for mortgages used in the LP-model (based on Van Oirschot (2017) and Figure 96.

Interest rate	Duration
1,50%	Variable
1,68%	Fixed for 10 years
2,30%	Fixed for 20 years
2,38%	Fixed for 25 years
2,55%	Fixed for 30 years
2,76%	Fixed for 35 years

13.24.3 Different mortgage types

Two different types of mortgages are used in the LP-model: the annuity mortgage and the linear mortgage. A. De Vos (2016) explains them shortly from the buyers perspective. The buyer with the annuity mortgage pays the same gross amount for the entire period monthly, but because that the deductible interest rate is getting lower and the repayment component increases, net monthly expenses increase. In the second option with the linear mortgage, the repayment fraction is exactly the same for each month. Because there is little repaid in the beginning, there is still a lot of interest on top. As a result, the monthly expenses are relatively high at the start, but they also fall rapidly. After around 15 years the linear mortgage get cheaper as the annuity mortgage. The linear mortgage is the cheapest over the entire period of the mortgage (A. De Vos, 2016).

The redemption free mortgage is excluded, because this option is not eligible for mortgage interest deduction since the start of 2013 (A. De Vos, 2016; I. Van den Berg, 2017) and almost no one closes them today (I. Van den Berg, 2017).

For the LP-model the cumulative rent has to be known to determine the TCO. The cumulative rent is dependent on the type of mortgage, its rent and its duration. Interest rates for both mortgage forms are the same and only 5% of Dutch home buyers opt for the linear option (A. De Vos, 2016). Assumed is that buyers with less purchasing power apply for the annuity mortgage and buy cheaper dwellings. With that assumption an increased percentage of buyers of the semi-detached and detached dwellings apply for a linear mortgage. For both dwelling types is 12,5% respectively 25% taken. Together with the ratio between the numbers of dwellings could the remaining percentages to get 5% of linear mortgages in total, be appointed to the corner dwellings by applying goal seek in Excel. The result is shown in Table 41.

Table 41: Educational guess about the division of mortgage types over the different dwelling types (based on A. De Vos (2016), I. Van den Berg (2017) and AgentschapNL (2012a, 2012b, 2012c, 2012d)).

	Corner of terraced dwelling	Mid-terraced dwelling	Semi-detached dwelling	Detached dwelling	% of mortgages
Annuity mortgage	98,81%	99,0%	87,50%	75,0%	95,0%
Linear mortgage	1,19%	1,0%	12,50%	25,0%	5,0%
% of newly built dwellings	13,5%	36,5%	13,0%	5,0%	n/a
% of included dwellings	19,85%	53,68%	19,12%	7,35%	n/a

A calculation shows that in the most extreme case with an interest rate of 2,76%, a duration of 35 years and a borrowed amount of € 27.000, the differed total interest payment between the dwelling types is only around 540 euro. This is about € 15,- a year. For that reason the numbers of Table 41 are applied in the LP-model as fixed.

13.25 Appendix 25: Costs and revenues of energy usage and supply

The data within this appendix is used for the calculation of the TCO in the LP-model.

13.25.1 Current costs of energy

The current costs of energy are calculated based on data gathered by NIBUD (2017).

First, natural gas. Natural gas is only used in the reference situation to determine the maximum amount of TCO for an average dwelling. The amount of natural gas used is mainly dependent on the type of dwelling (NIBUD, 2017). That is why a separation in costs is made between the dwelling types. First, the connection costs are deducted from the annual costs for natural gas per dwelling type (based on data of (NIBUD, 2017)). Second, the remain costs per dwelling type are divided by the average UFA per dwelling type in the Netherlands (based on data of (AgentschapNL, 2012a, 2012b, 2012c, 2012d)). This brings the average costs for natural gas per m^2 UFA per dwelling type. An estimation of the costs for natural gas per dwelling type is obtained by multiplying this amount by the UFA of the used dwelling type and then added by the connection costs. The data used for this calculation is shown in Table 42.

Table 42: Natural gas usage of the reference case (AgentschapNL, 2012a, 2012b, 2012c, 2012d; NIBUD, 2017).

Dwelling type	Annual costs for natural gas	Average UFA (m^2) per dwelling type in the Netherlands
Corner-terraced dwelling	€ 1.200,-	127
Mid-terraced dwelling	€ 1.032,-	125
Semi-detached dwelling	€ 1.380,-	142
Detached dwelling	€ 1.740,-	164
Connection fee	€ 222,24	

Second, electricity. The amount of electricity used is mainly dependent on the number of people in the household (NIBUD, 2017). As the household size can be different within the same dwelling type, the average consumption of all households is taken as input (Essent, 2017; NIBUD, 2017):

- Costs: € 0,1948 per kWh
- Connection fee: € 23,50 a month
- Total costs: € 480,00 annually
- Tax return: € 373,33 annually
- Return fee for electricity € 0,07 per kWh (more electricity produced as consumed in that year)

The tax return is assumed to change by the inflation rate.

The changes in energy costs (natural gas and/or electricity) depend on the energy scenario chosen. These scenarios are explained in the next section.

13.25.2 Energy scenarios

Several energy scenarios are developed based on data of household energy costs (published by the RvO (2017e), see Appendix 13.5). First the topic is introduced with scenarios developed by J. W. J. De Vries (2010: 16). Second, new scenarios are developed, because those scenarios appeared too high.

In the scenarios of J. W. J. De Vries (2010) is the electricity costs index lower than that for natural gas. Although he states that the relationship between the rise in electricity prices and the rise in natural gas prices cannot be determined for the future. However, he continues, the overall view is that the (bare) electricity price will increase less in comparison to the (bare) natural gas price. This expectation is based on the fact that electricity can be generated not only with natural gas but also with coal, nuclear energy and renewable energy. These multiple options beat down the price increase of electricity. J. W. J. De Vries (2010: 16) calculated that the costs of natural gas almost doubled in the period between 2000 and 2010, which was on average about 6,7%. Table 43 shows his expectations at that time.

Table 43: Scenarios for the increasing energy costs (J. W. J. De Vries, 2010: 16).

	Low scenario	Base scenario	High scenario
Natural gas price (incl. tax)	2%	6%	8%
Electricity price (incl. tax)	2%	4%	5%
Fixed energy-related costs such as maintenance and fixed connection costs	2%	2%	2%

Little has come true of these predictions. One year after the start of the financial crisis energy prices of both electricity and natural gas started to decrease. This can be seen in Figure 97 (electricity) and Figure 98 (natural gas). The energy prices in the figures include the bare energy price of electricity (per kWh) or natural gas (per m3), the regulating energy tax (Dutch: 'Regulerende Energie Belasting (REB)') / energy tax as RET/ET and the renewable energy surtax (Dutch: 'opslag duurzame energie') as RES. Those numbers are shown stacked in the image to see the fluctuations of the total price of one unit of energy (kWh or m3).

The price of one kWh is in 2016 lower as the low-scenario of J. W. J. De Vries (2010), even with 2001 as reference year instead of 2009. For that reason, new scenarios are developed for the future price of electricity. The price developments are not predictable. But taken into account the current situation with an over-abundance of coal in the world market and the USA who are installing shale gas facilities, it is possible that the prices of electricity are going to decrease even further. The base scenario is based on the average price increase over the last 16 years, which is 0,5%. The other scenarios are shown in Figure 97 and Table 44.

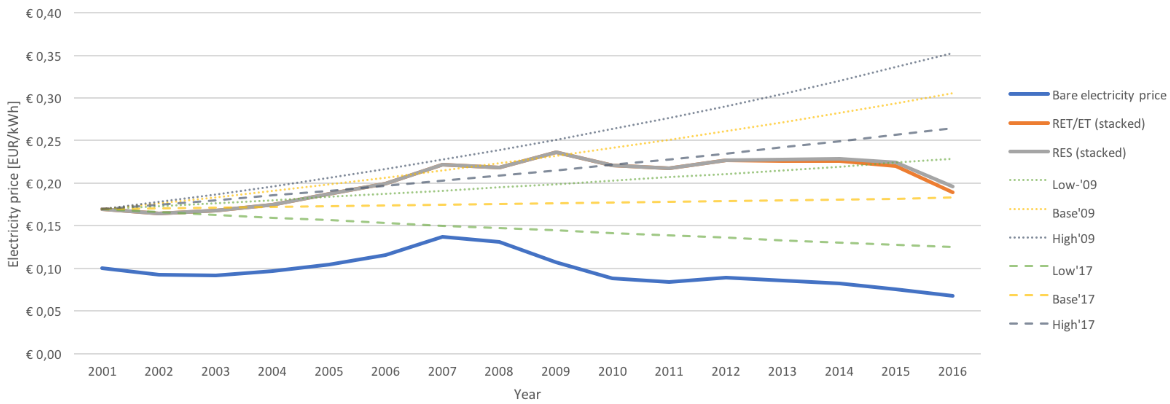


Figure 97: Variable costs of electricity for households in the Netherlands from 2001-2016 (own illustration based on data of RvO (2017e) in Appendix 13.5 and scenarios'09 of J. W. J. De Vries (2010: 16).

The development of natural gas goes by ups and downs since the 2008 crisis. Currently the bare price of natural gas is decreasing and this is compensated by an increase in taxes (see Figure 98). On average the price of natural gas increased by 3,0% since 2001. This is taken as base scenario. An extra scenario (high+, 7,0%) is included, because the price of natural gas did not drop below the base scenario in the last 16 years and this scenario almost perfectly follows the price developments in the period 2001-2008. When taken into account that such a huge crisis only happens every generation (Florida, 2011) and that the natural gas reserves in the Netherlands are empty in a few decennia (Van Rossum & Swertz, 2011), these price developments can happen again and for a longer time period. It has to be noticed that high caloric gas is imported from Russia and Norway for electricity generation and this cannot be used without modifications in households (CBS *et al.*, 2016). That is why the price of natural gas will increase for households and it has no big effect on the electricity prices. The other scenarios are shown in Figure 98 and Table 44.

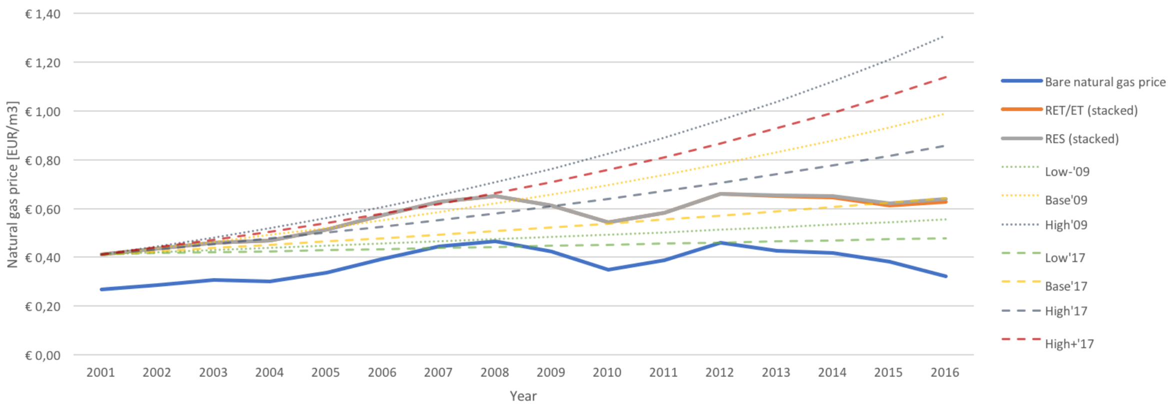


Figure 98: Variable costs of natural gas for households in the Netherlands from 2001-2016 (own illustration based on data of RvO (2017e) in Appendix 13.5 and scenarios'09 of J. W. J. De Vries (2010: 16).

Table 44: Used scenarios in the optimisation (based on Figure 97 and Figure 98).

	Low	Base	High	High+
Natural gas price (incl. tax)	1,0%	3,0%	5,0%	7,0%
Electricity price (incl. tax)	-2,0%	0,5%	3,0%	n/a
Fixed energy-related costs such as maintenance and fixed connection costs	Inflation	Inflation	Inflation	Inflation

13.25.3 Costs of the ESCo

Stroomversnelling opts for a yield of 5,25% for ZOM-dwellings, however, it appeared difficult to realize (De Wit *et al.*, 2016: 13). This sounds as a reasonable yield. That is why 5,0% is used at interest rate/ yield for the ESCO in the LP-model.

This approach is selected over the approach of Klimaatgarant whose monthly costs are just a bit lower as the reference case (Van den Bogerd, 2016). In this calculation method, the calculation of the reference scenario is of key importance. This scenario is calculated in the first part of this appendix and is made on very generic key figures. For that reason, the first method with a fixed yield percentage is considered more reliable for this research.

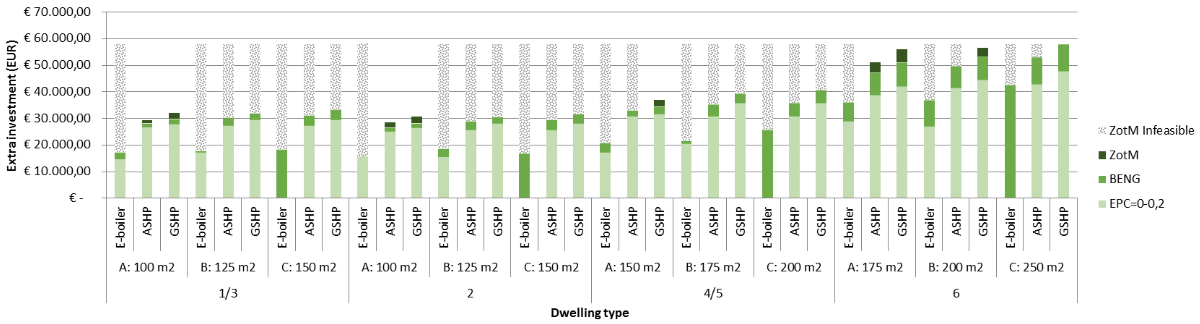
The maintenance is included in the TCO as costs for the residents. It is assumed that these costs are deducted from the monthly contribution. In that way, those costs are still indirectly paid by the future owner.

13.26 Appendix 26: Assessment and validation report of the decision support tool

The model is continuously analysed and tested during its development and with this feedback the model is continuously redefined and optimized model. This leaded to the final, detailed and described design. This final result of the model is applied to real life situations. The results of the assessment are shortly addressed in general. The model is assessed the following topics:

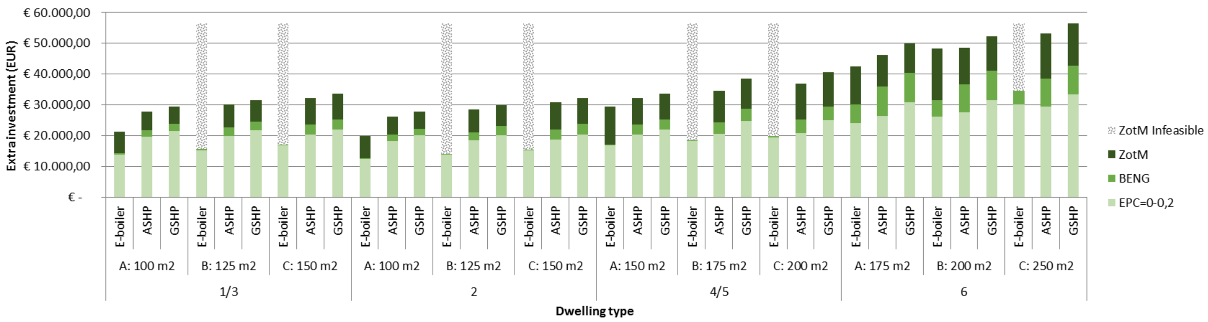
- Correct operation of the objective function
- Correct energy demand calculation (of BENG1) with a model, which used prior the designed model
- Construction costs in relation to profit rate
- Construction costs of BENG and ZOM
- Energy outputs

All cases are related to common knowledge and/or reference cases. The headlines for the comparison of the construction costs of BENG and ZOM and the energy outputs to the reference case are shown.



Graph 36: Extra investment for realizing energy ambitions as output of the LP-model. The output is optimised on maximum profit. Roof design was normal and only one side was used. TCO are included (own illustration).

Graph 36 shows that many of the dwelling types cannot be realized with a zero-on-the-meter energy ambition. Solutions were to implement the newest type of solar panels (350Wp) and to increase the roof size (as if the other side of roof was used). In next improvement, this side can be added with a lower efficiency compared to the first side. Graph 37 shows the improvement with additional roof surface. Only dwellings with a UFA>125m^2 and with an e-boiler as heating device were not feasible.



Graph 37: Extra investment for realizing energy ambitions as output of the LP-model. The output is optimised on minimum costs. Roof surface was enlarged and TCO was not included (own illustration).

The terraced dwelling can be realized within a range of €20.000 to €30.000, the semi-detached dwellings have a range of €30.000 to €40.000 and the detached dwellings a range of €40.000 to €55.000. These are high prices compared to the case of a detached dwelling: € 31.863,- to realise BENG in Bouwens and Bouwmeester (2017: 19) and according to Beek (2015) the additional costs for a new dwelling are about € 15.000 to realize a zero-on-the-meter standard.

The reason for these high prices is that all energy saving and supplying installations are taking into account. However, the current building degree requires an EPC=0,4 and in order to realize this level also energy saving and/or supplying installations are required. It is hard to determine from which level additional costs are required. Kuijpers - van Gaalen (2014) calculated different solutions to realize an EPC=0,4 (see Table 45). In all concepts are PV-panels included. In that case would not all PV-panels have to be taken into account to realize BENG or

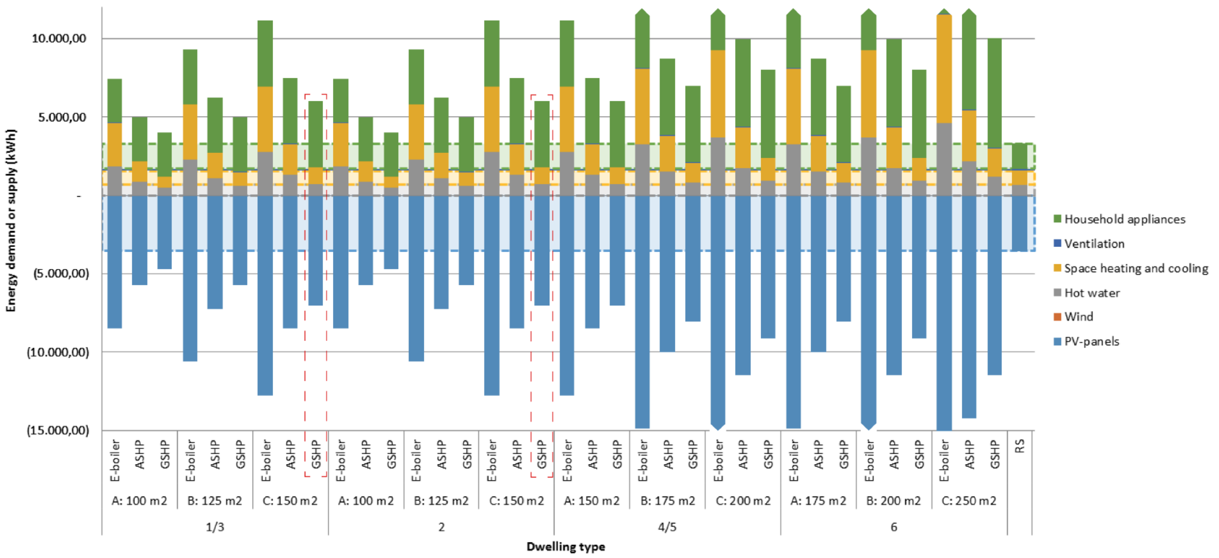
ZOM. A difficulty is that the EPC requirements can be obtained without PV-panels. For the three SFD, the use of high-quality insulation (R_c-values>7 m^2K/W), triple glazing and optimal orientation provides a solid foundation for the EPC-requirement to be achieved. The picture is completed with the installation techniques, such as a HR107 boiler, balanced ventilation with CO_2-control and heat recovery, shower heat recovery and solar thermal water heater.

Table 45: Amount of m^2 PV-panels needed to realize an EPC of 0,4 (Kuijpers - van Gaalen, 2014).

Concept	Terraced dwelling	Semi-detached dwelling	Detached dwelling
Ground source heat pump (incl. cooling) **Balance ventilation with CO_2-monitoring and heat recovery (type D – ventilation)** **No shower heat recovery or solar thermal boiler**	4,5 m^2 PV	6 m^2 PV	6 m^2 PV
Hybrid heat pump on ventilation air **Mechanical exhaust (type C – ventilation)** **Shower het recovery** **No solar thermal boiler**	5 m^2 PV	6 m^2 PV	7 m^2 PV

An exact reference image for costs is hard to get. The two price-levels from the sources indicate that the costs of a detached dwelling are twice the costs of a terraced dwelling. That is according to our prices. The price levels are checked within the appendices on price levels. For the reason that all the extra energy installations can be financed by the mortgage and most of them can be financed by the ESCo, no additional measures are taken to decrease the presented costs levels.

Graph 38 shows the energy usage of all dwelling types. The reference dwelling is the average energy usage of series of five terraced, ZOM-dwellings located in RijswijkBuiten and installed with a ground source heat pump (Sijpheer *et al.*, 2015). The size of the dwelling is around 150 m^2 UFA (Kadaster, 2013), this is a bit higher as our terraced dwelling type C. In the figure a minimal building-related energy usage can be seen, but it appeared that in the used reference case the COP of both hot water (3,8) and space heating (7,0) was higher as used in our case (Staats, 2016: 12). When adopting this exogenous variable, the energy usage was the same bit too low. The building-related energy output of the model looks valid, considering the little margins of the reference dwellings. However, the household-related energy usage has a huge difference. This low energy usage by household appliances in our reference case has it reasons. According to Sijpheer *et al.* (2015: 7) are the residents stimulated by making vouchers available for the purchase of LED-lighting and other A+++ appliances to buy these energy efficient appliances during this pilot project. These types of measurements also translate into a real measured low household electricity consumption. Our model uses the official requirement for the household-related energy usage of NEN 7120+C2 (2012).



Graph 38: Energy usage profile of different dwelling types in first year (including energy demand of 37 $kWh/m^2/a$) (own illustration).

13

13.26.1 Assessment of the objective functions

If negotiable constraints are disregarded.

- Max profit -> biggest dwellings; cheap installations
- Min TCO -> near zero or even zero.
- Max energy -> GSHP & max PV panels
- Max Mortgage -> ZOM-dwellings; maximum is reached easily in other objectives
- Max ESCo; biggest dwellings with max PV-panels and gshp

Conclusion: works as expected

As stated before, only one of these objective function can be selected within a single run. The other objective functions can be applied as constraint. For instance, the amount of profit is constrained by a certain minimum amount, while the electricity production is maximised.

13.26.2 Assessment of demand calculation model

Another assessment was de validation of the demand calculation model. This model determines which energy saving installations are needed for each dwelling type $D_{i.}$ See Appendix 13.20 for the calculation method and the results of which energy saving installations are used for each dwelling type D_i.

Several iterations of input variables are applied on a case of a mid-terraced dwelling described in Bouwens and Bouwmeester (2017: 10). These researchers determined the needed energy installations to comply with the new BENG-regulations for newly built dwellings and provide date about the energy installations used and the results on BENG. This is also the case for the calculation model that needs verification.

The base scenario was to get a dwelling with a thermal energy demand of 30,1 kWh/m^2/a by correct calculations. In the first run of the base scenario of Bouwens and Bouwmeester (2017: 10) the thermal demand was about 43 kWh/m^2/a. The applied reference year of 1963 was outdated and new hourly data on the hourly temperatures was implemented based on the average hourly temperature in the Bilt in the period 2010-2016 (KMNI, 2017b). The ’63-year had 12.870 heating degree hours less as the new reference data. That means that the new reference scenario is on average 1,5 degree warmer each hour. This had a huge effect on the thermal energy demand and it dropped to 30,8 kWh/m^2/a in the second run.

For the third run the input of the incident solar radiation of the reference year ’63 was compared to the monthly averages given by the NEN 7120+C2 (2012: 319). Huge differences appeared (see Table 46). That is why the data of NEN 7120+C2 (2012: 319) was used to calculated hourly data in such a way that they are equal to the monthly averages of the standard. The effect on the result was not that much, as the thermal energy demand dropped to 29,9 kWh/m^2/a.

Table 46: Comparison of the used reference year with the data of NEN 7120+C2 (2012: 319)

	n/a	0° N	45° NE	90° E	135° SE	180° S	225° SW	270° W	315° NW
Average model input	93,7	33,8	34,9	43,9	57,2	72,7	79,1	67,2	46,0
Average NEN-input	115,4	40,0	51,0	73,8	93,1	98,4	91,7	73,0	51,2
Difference	21,7	6,2	16,1	29,9	35,9	25,7	12,6	5,7	5,2

The last input data that was verified was the hot tap water demand and a new calculation method was added to the model based on the usable floor area and calculations of NEN 7120+C2 (2012). The method is described in Appendix 13.20.2. When a shower heat recovery was added to the reference dwelling, all outputs of the thermal energy demand calculation model are quite similar to the verified calculations in Bouwens and Bouwmeester (2017: 10).

All inputs are checked, only educated guesses about the sizes of the dwelling (5,4x10 floorplan for terraced dwellings and 7x10 for detached dwelling; both a storey height of 2,8 meters), windows-to-wall-ratio of 30% and north-south oriented. Based on picture and UFA.

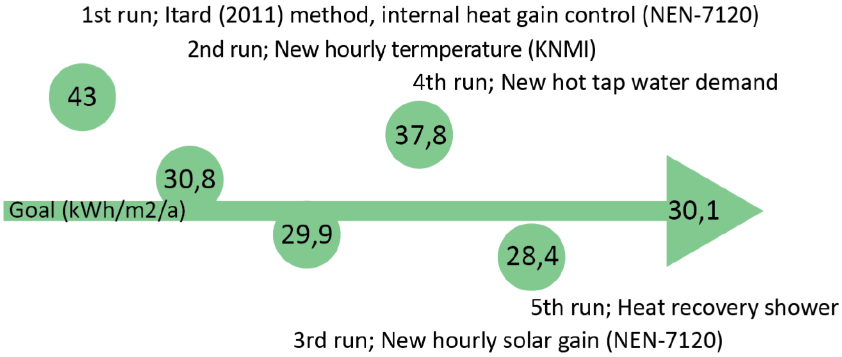


Figure 99: Iterative steps of going back and forth in the optimisation of the demand calculation model (own illustration).

Table 47: Verification of BENG1 for a mid-terraced dwelling of 111 m2 UFA in Bouwens and Bouwmeester (2017: 10)

	Input	Output	
	Energy concept specifications	Verified calculations	Demand model
1	Rc floor 5,0 Rc wall 5,3 Rc roof 6,6 HR++ glazing Ventilation type C (natural in/mechanical out) Qv;10 = 0,3	30,1 kWh/m2	37,8 kWh/m2 With shower hr: 28,4 kWh/m2
2	HR++ -> triple glazing; Sun protection	23,8 kWh/m2 Added costs: € 9.300,- = €84,-/m2 (pertaining to EPC=0,4)	32,1 kWh/m2 With shower hr: 22,6 kWh/m2
3	Ventilation type D (balance ventilation with hr)	24,9 kWh/m2 Added costs: € 10.800,- = €97,-/m2 (pertaining to EPC=0,4)	33,1 kWh/m2 With shower hr: 23,7 kWh/m2

Table 48: Verification of BENG1 for a mid-terraced dwelling of 110m2 UFA in Bouwens and Bouwmeester (2017: 14)

	Input	Output	
	Energy concept specifications	Verified calculations	Demand model
1	Rc floor 3,5 Rc wall 5,2 Rc roof 6,0 HR++ glazing Ventilation type C (natural in/mechanical out) Qv;10 = 0,4 Shower hr	35,2 kWh/m2	33,2 kWh/m2
2	Ventilation type D with hr and CO_2-monoriting	24,1 kWh/m2 Added costs: € 12.076,- = €110,-/m2 (pertaining to EPC=0,4)	28,2 kWh/m2
3	Increased insulation: Rc floor 5,0 Rc wall 5,2 Rc roof 8,0 Triple glazing Qv;10 = 0,3	24,8 kWh/m2 Added costs: € 10.413,- = €95,-/m2 (pertaining to EPC=0,4)	23,6 kWh/m2

CO_2-monoriting added; 25 m2 ventilation flow rate per person per hour -> half only changes the thermal demand by 0,2 kWh/m2. By far not the required level.

Table 49: Verification of BENG1 for a detached dwelling of 190 m2 UFA in Bouwens and Bouwmeester (2017: 19)

	Input	Output	
	Energy concept specifications	Verified calculations	Demand model
1	Rc floor 4,0 Rc wall 5,2 Rc roof 6,5 Triple glazing Ventilation type D with hr Qv;10 = 0,4	48,5 kWh/m2	38 kWh/m2
2	Ventilation type D with hr and CO_2-monoriting Rc floor 6,0 Rc wall 9,0 Rc roof 10,0 Qv;10=0,15	24,9 kWh/m2 Added costs: € 31.863,- = €168,-/m2 (pertaining to EPC=0,4)	25,5 kWh/m2

Conclusion

- The model is slightly positive in the results, but in the energy concepts always within the 1,5 kWh/m2 range (assumed that the first case has a shower heat recovery).
- CO_2-monitoring has a bigger effect as calculated in the model.

This calculation does not concern about the exact numbers, but is needed to provide a reliable indication of which installations are required to achieve the BENG1-requirement per dwelling type D_i. This data is used in the financial calculation. The value of BENG1 is an independent decision variable in the model. The calculated values are therefore reliable enough.

13.26.3 Assessment of construction costs in relation to profit rate

Results:

- Increased ground quote to 32% for the used market values in the case of AM (Delft).
- This is possible due to the high market values (see Appendix 13.22.5).
- Semi-detached dwelling to cheaper version; otherwise no profit: € 1050 euro/m2 UFA

13.26.4 Assessment of energy outputs

RijswijkBuiten, ground source heat pump monitoring of five ZOM-dwellings by Sijpheer *et al.* (2015). This case is used to assess the energy outputs.

Table 50: Average energy consumption of five terraced ZOM-dwellings in RijswijkBuiten (data based on graph in Sijpheer *et al.* (2015: 7)).

	Project plan	Monitoring
PV-panels (supply)	3.300	3.554
Cooling	203	203
Heating	457	711
Domestic and ventilation	2.031	1.726
Hot water	609	660
Total heat pump (cooling, heating, hot water)	1.269	1.574

However, the low energy usages by household appliances has it reasons as the example in Sijpheer *et al.* (2015: 7) shows. In this case, the residents are stimulated to buy energy efficient appliances during this pilot project by making vouchers available for the purchase of LED-lighting and other A+++ appliances. These types of measures also translate into an actually measured low household electricity consumption.

The case is also researched by Staats (2016). His data about the energy concept of the dwelling is stated in Table 51.

Table 51: Energy concept for the ZOM-dwellings in RijswijkBuiten (Staats, 2016: 8).

Appliances	Demand (+) & Supply (-) [kWh/a]
Ground source heat pump (1,1 kW)	1.200
Ventilation	125
LED-lighting	125
Household usage (A+++ appliances, standby-killer, etc.)	2.000
PV-panels (3,9 kWp)	-3.500

3900 kWp of PV-power on each roof (Staats, 2016: 8). That is about 16 PV-panels with 243 Wp. The average PV-panel used in the LP-model has an output of 250 Wp.

Also Staats (2016: 13) mentions the low electricity usages for household appliances. The average for five dwellings is even 1426 kWh in the first year (see Table 52), however, also huge differences can be seen.

Table 52: Energy usage of the five ZOM-dwellings during the first year (Staats, 2016: 13).

	Building-related energy usage	Household-related energy usage	Total energy usage	Generated by PV-panels	Balance
Dwelling 1	1600	1357	2957	3737	-780
Dwelling 2	1503	1693	3196	3947	-751
Dwelling 3	1112	978	2090	3784	-1694
Dwelling 4	1420	1219	2639	3630	-991
Dwelling 5	2002	1885	3887	3763	124
Average	**1527**	**1426**	**2954**	**3772**	**-818**

There are slight differences in data of Table 50 and Table 51, while they monitored the same case. For that reason, the reference scenario is based on the monitored data.

According to the BAG-viewer of Kadaster (2013), these ZOM-dwellings are 140 m^2.

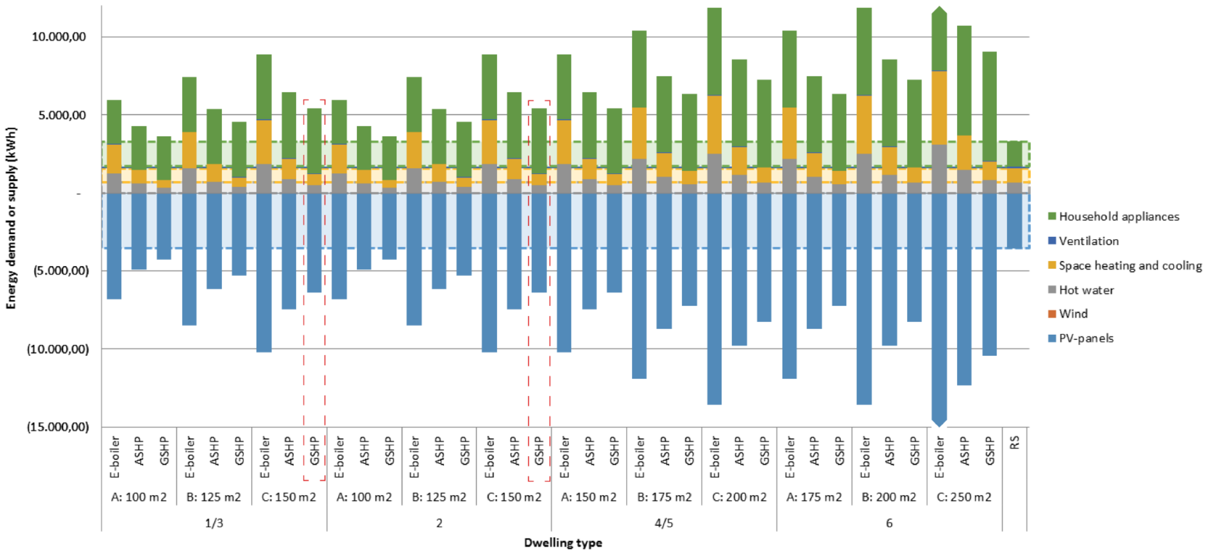


Figure 100: Energy usage profile of different dwelling types in first year (including energy demand of 25 kWh/m2/a, conform BENG) (own illustration).

Household energy usage to large; building-related too low.
GSHP

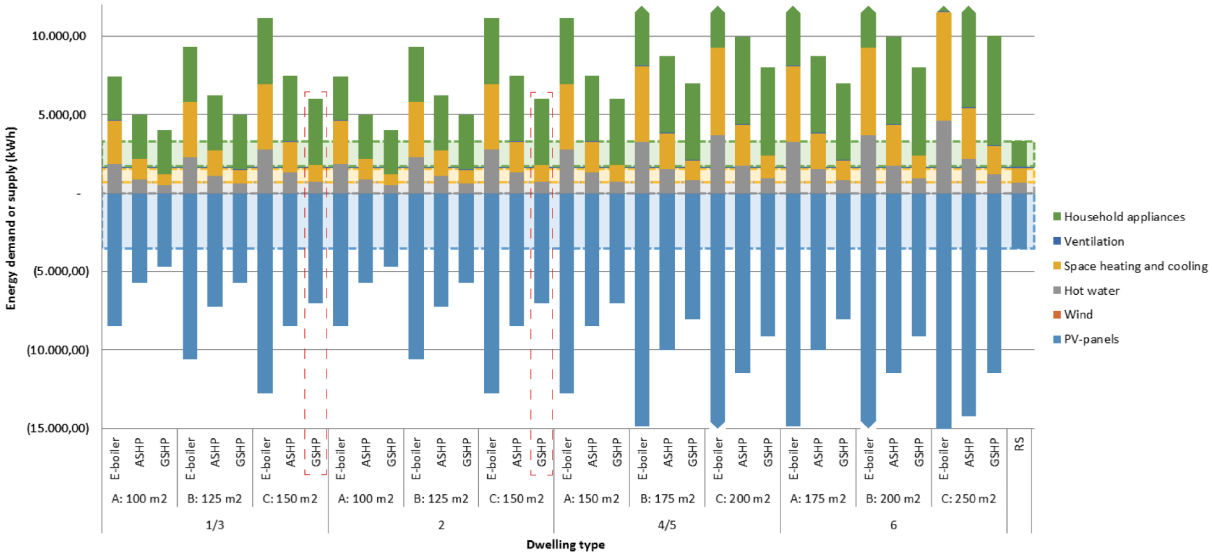


Figure 101: Energy usage profile of different dwelling types in first year (including energy demand of 37 kWh/m2/a) (own illustration).

COP hot water of 3,8 and space heating of 7, as based on Staats (2016: 12))
Based on energy demand of 37 kWh/m2/a. Especially the inefficiency of the electric boiler is visible.

Building related accordingly. The larger dwellings fit, although a bit too high. These dwellings are 10 m2 bigger as the reference dwellings.

Findings by Klimaatgarant as presented in Staats (2016: 12)

- Average COP space heating 7 (in theory COP of 6)
- Average COP tap water 3.8 (in theory COP of 3.2)

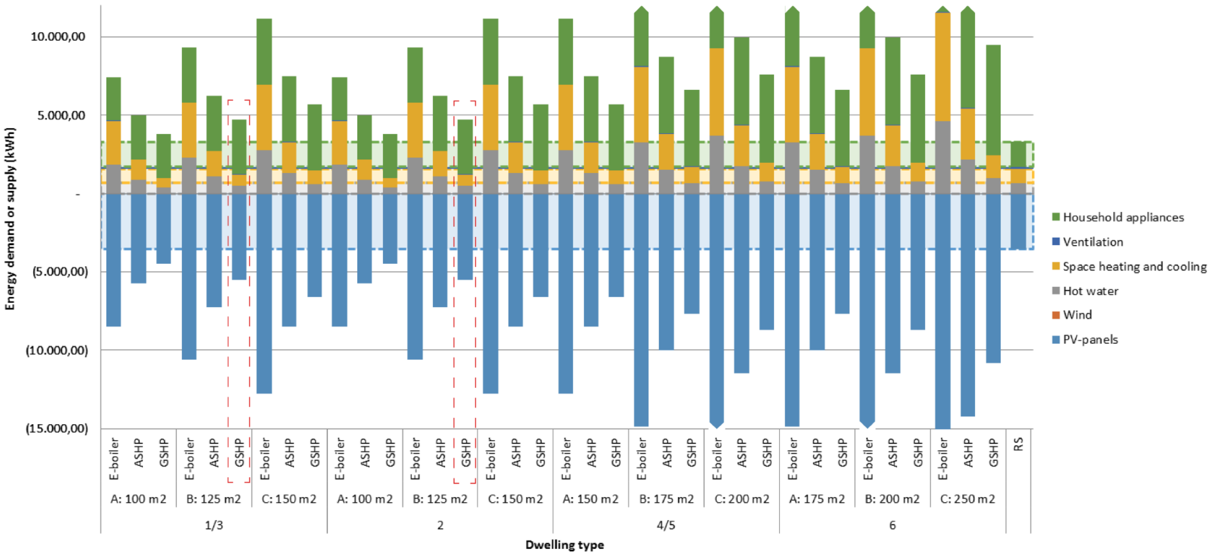


Figure 102: Energy usage profile of different dwelling types in first year (including energy demand of 37 kWh/m2/a and COP hot water of 3,8 and space heating of 7, as based on Staats (2016: 12)) (own illustration).

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Even better fit for the larger dwellings.
Good fit for the bigger dwellings of around 150m2.

The amount of energy used for space heating of a ZOM-dwelling is about 10 kWh/m2/a according to Beek (2015).

Ventilation adapted from 200Pa -> 800Pa (large buildings according to Itard (2011), otherwise hardly any energy usage for ventilations.

Conclusion, adjusted some inputs (ventilation, balance between hot water and space heating, from 80% space heating to 60% space heating; heat pumps less efficient). COP's are questionable. Household energy demand can be motivated, but now based on the official calculation of NEN 7120+C2 (2012).

13.27 Appendix 27: Area size of case studies

This Appendix gives the area sizes of the case studies and which amount can be developed. The area size is based on a drawing made with Google SketchUp from the land use plan.

In Rotterdam-Heijplaat the white plots with the numbers in the left part of Figure 103 can be developed by the real estate developer.

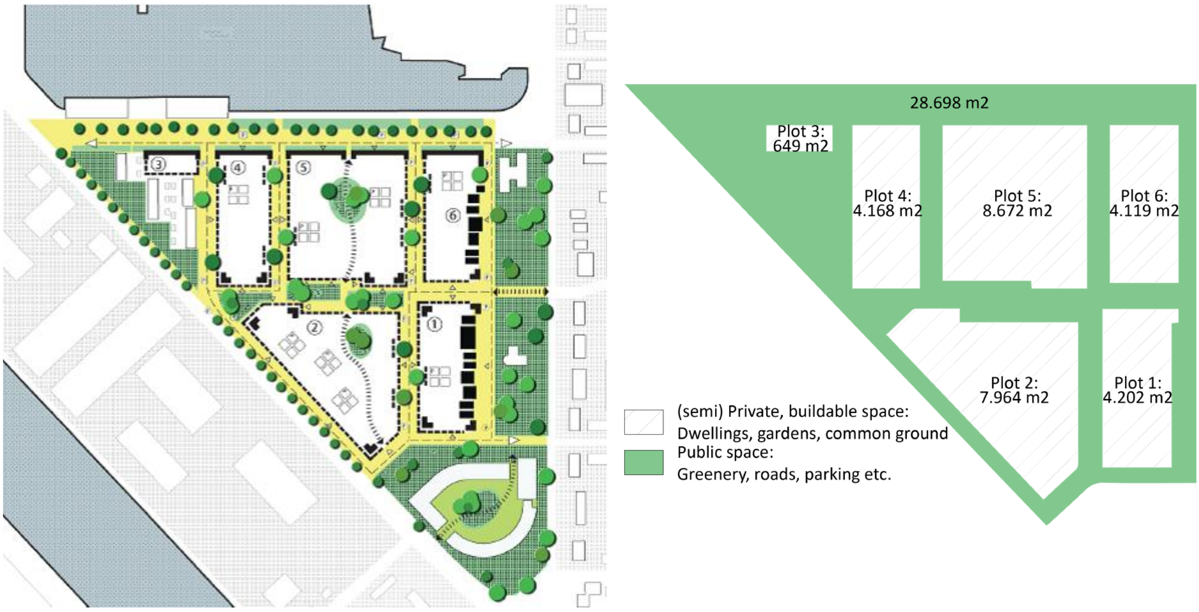

Figure 103: The land-use plan converted to area sizes of the development space (left part: Gemeente Rotterdam (2013); right part: own illustration based on left part).

The total area consists of 58.472,5 m2. Of this amount can 29.774,6 m2 be developed (51%). That means that the remaining part (28.697,9 m2) is for public space, roads, greenery, etc. Within the buildable area there are several plots:

- Plot 1: 4.202 m2
- Plot 2: 7.964 m2 (-25%)
- Plot 3: 649 m2
- Plot 4: 4.168 m2
- Plot 5: 8.672 m2 (-25%)
- Plot 6: 4.119 m2

From Plot 2 and plot 5 25% must be excluded due to the green path and community garden inside the plot. This number is an estimation based on the text in the land-use plan.

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13.28 Appendix 28: Case results 'Het Verborgen Geheim'

This Appendix shows the dashboard of the runs in Figure 62.

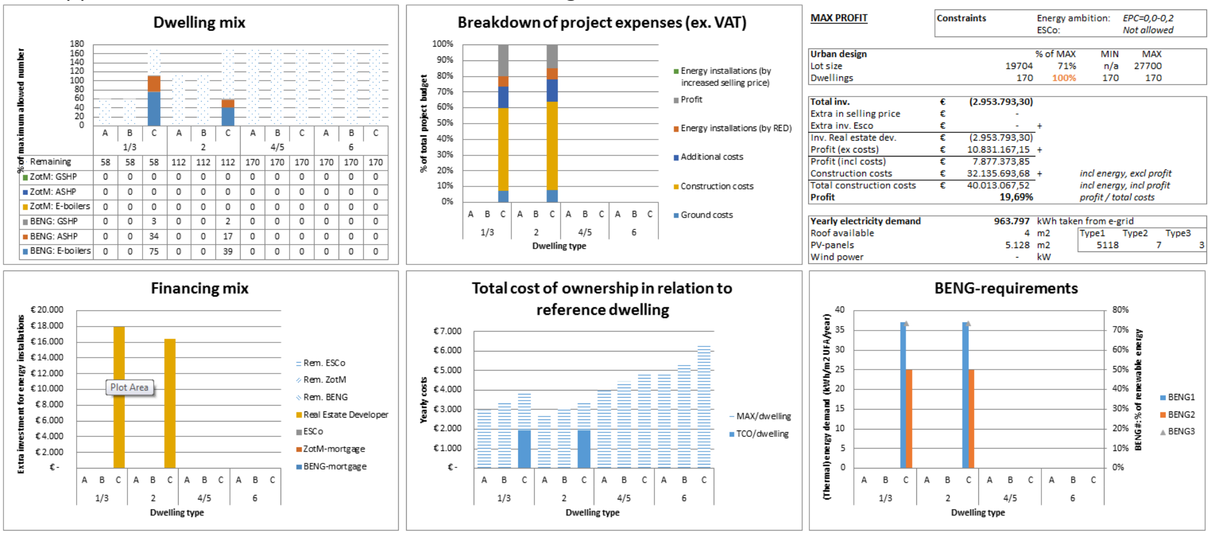

Figure 104: Run 3; EPC (as legislation), EPC= 0,0-0,2 (as energy ambition) and no usage of the ESCO (own illustration).

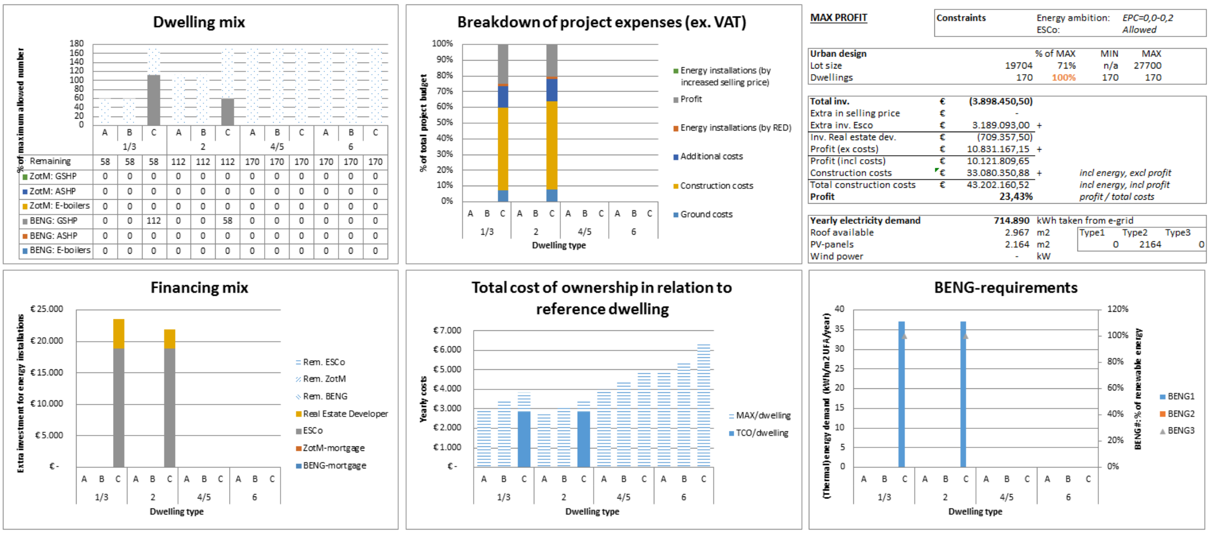

Figure 105: Run 4; EPC (as legislation), EPC= 0,0-0,2 (as energy ambition) and possible usage of the ESCO (own illustration).

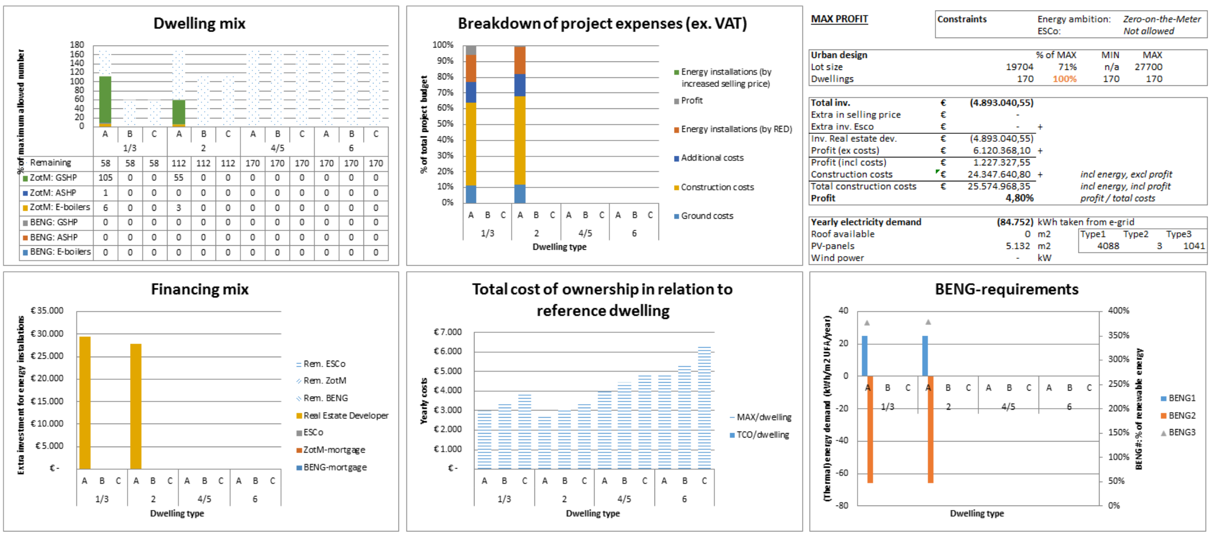

Figure 106: Run 5; BENG (as legislation), Zero-on-the-Meter (as energy ambition) and no usage of the ESCO (own illustration).

Figure 107: Run 6; BENG (as legislation), Zero-on-the-Meter (as energy ambition) and possible usage of the ESCO (own illustration).

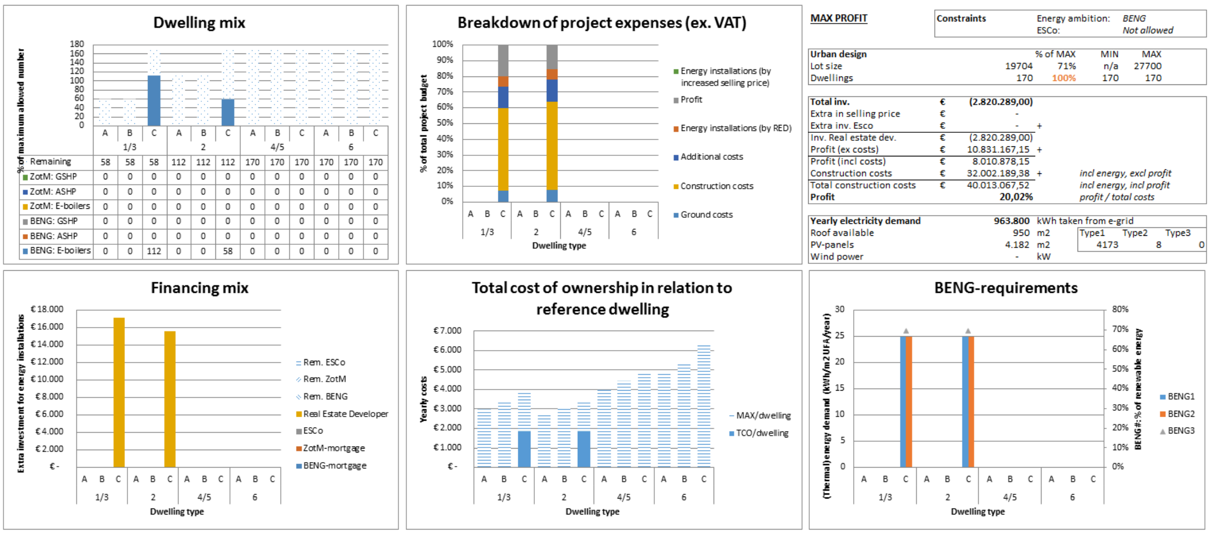

Figure 108: Run 7; BENG (as legislation), EPC= 0,0-0,2 (as energy ambition) and no usage of the ESCO (own illustration).

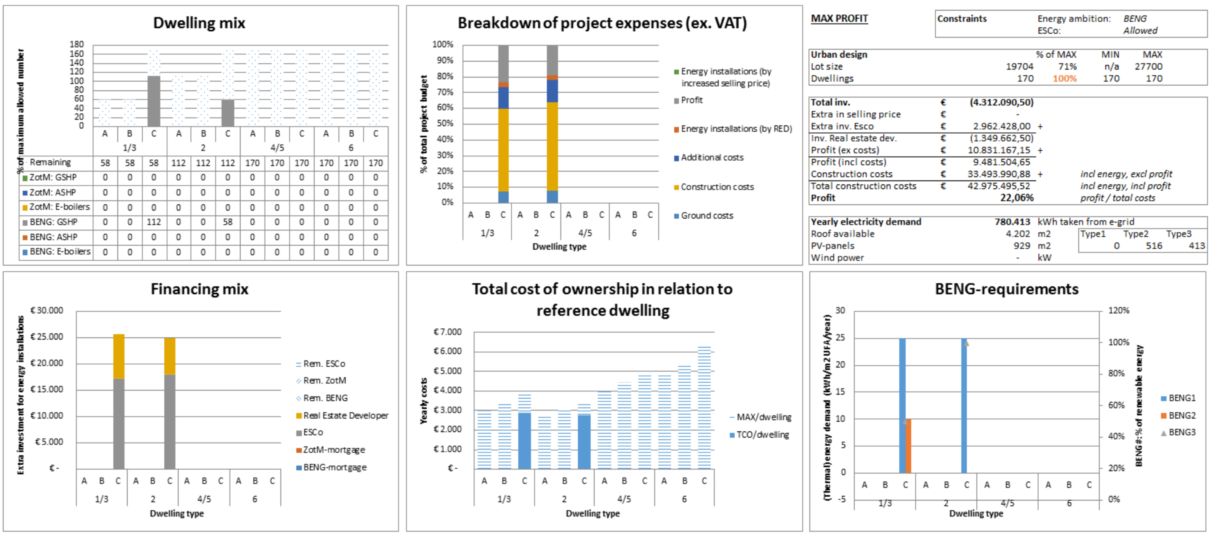

Figure 109: Run 8: BENG (as legislation), EPC= 0,0-0,2 (as energy ambition) and possible usage of the ESCO (own illustration).

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13.29 Appendix 29: Results sensitivity analysis 'Het Verborgen Geheim'

In the next pages the results of a quarter of the 268 runs are shown. These runs are for the Zero-on-the-Meter energy ambition and within the EPC-legislation. The runs for the involvement of other legislation of other energy ambitions are included in the other graphs.

The sensitivity analysis uses the abbreviations of BENG for both the legislation and the energy ambition. For sake of clarity ZED was added. ZED is the Zero Energy Dwelling. This is about the energy ambition (EPC=0,0-0,2). BENG is in legislation about the legislation used.

The sensitivitiy analysis involves six different aspects, namely:

1. Position of the ridge[117], normally 0,5 (halfway)
2. Maximum possible kWp of a PV-panel, normally 0,3 kWp
3. COP of the GSHP, normally 3,8
4. COP of the ASHP, normally 2,6
5. Higher selling price by mortgage possible (yes/no)
6. Involvement of ESCO possible (yes/no)

The graph on the next pages has at the bottom several rows with numbers. These numbers indicate the same aspects (from top to bottom, however the top one is the number of the run; 1-67).

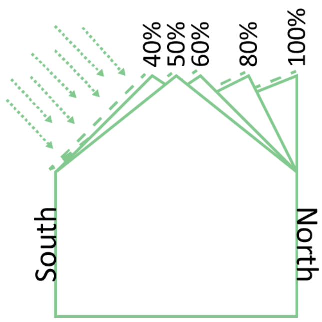
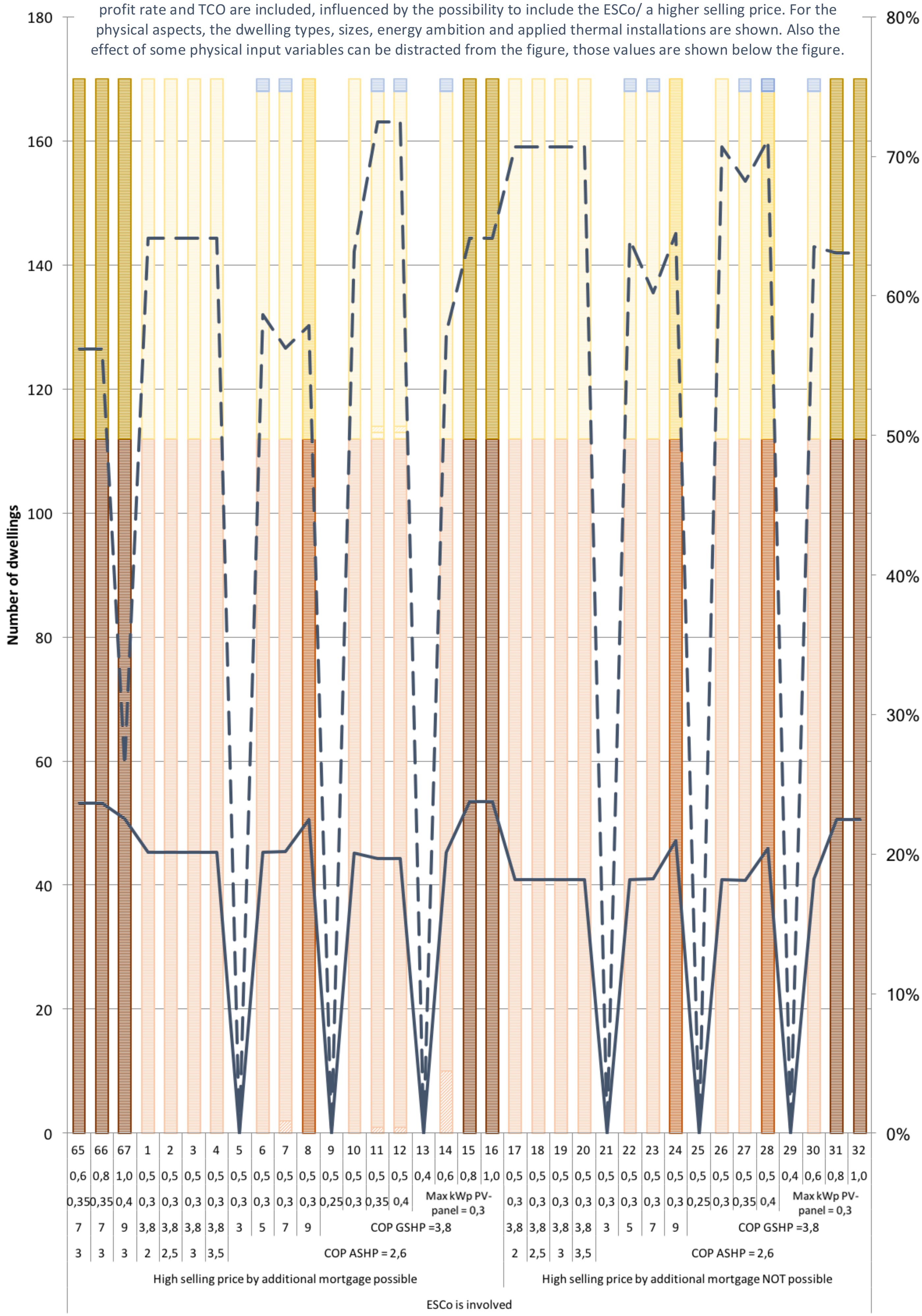


Figure 110: Position of the ridge explained (own illustration).

[117] See Figure 110 for explanation. The graphs on the next page shows ridge in numbers (0,4) instead of percentages (40%).

Graph 6 (continues on next page, legend on previous page): All information about financial and physical aspects are shown in this graph for the ZOM energy ambition and within the EPC-legislation. For the financial aspects the profit rate and TCO are included, influenced by the possibility to include the ESCo/ a higher selling price. For the physical aspects, the dwelling types, sizes, energy ambition and applied thermal installations are shown. Also the effect of some physical input variables can be distracted from the figure, those values are shown below the figure.



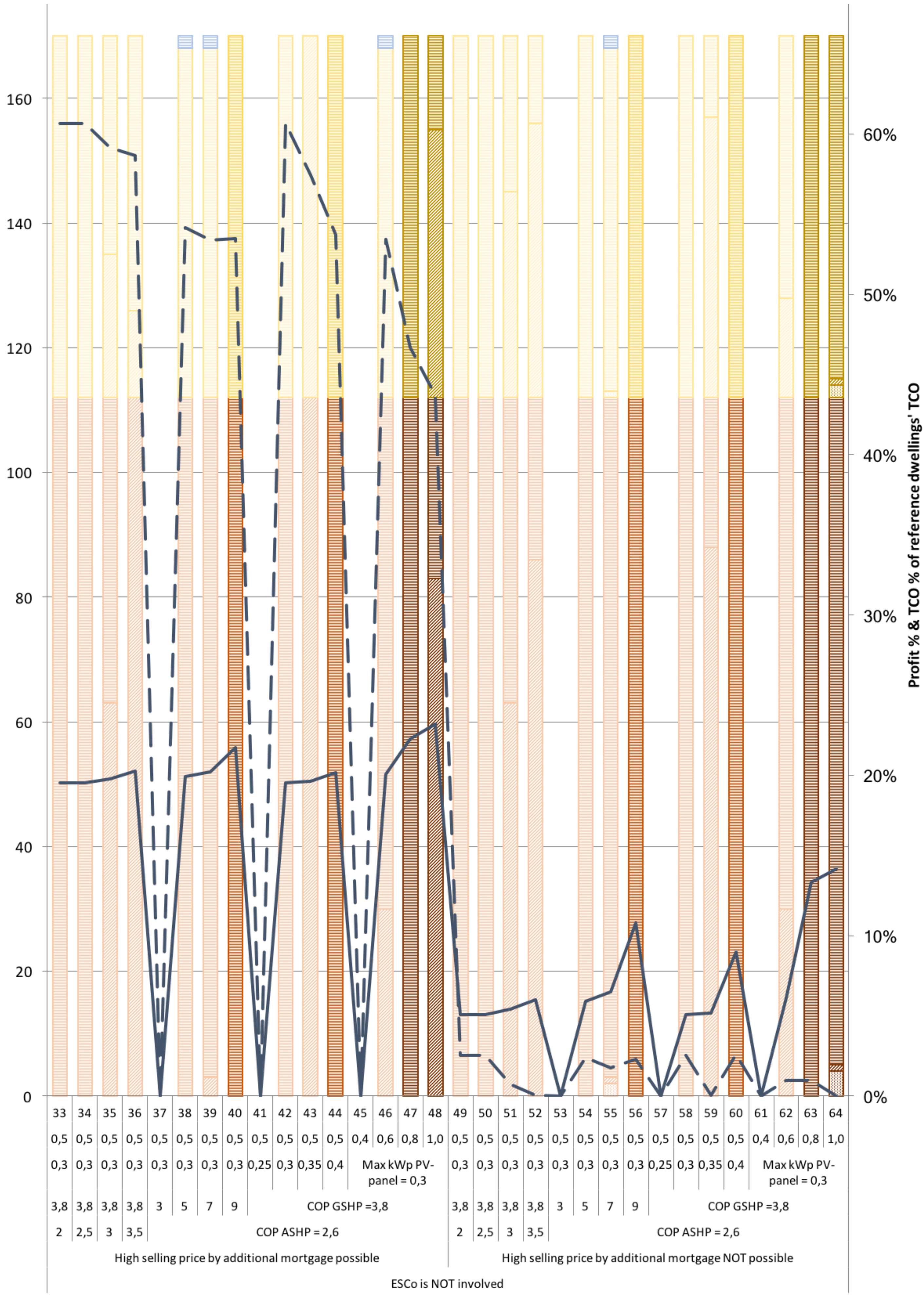
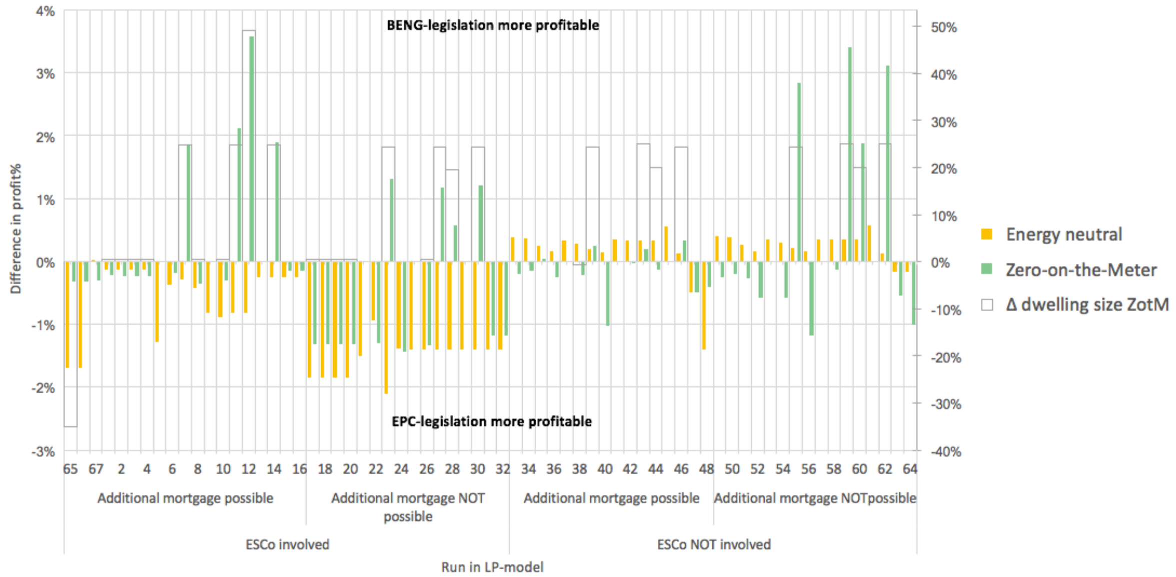

160
140
120
100
80
60
40
20
0
60%
50%
40%
30%
20%
10%
0%
Profit % & TCO % of reference dwellings' TCO
33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64
0,5 0,5 0,5 0,5 0,5 0,5 0,5 0,5 0,5 0,5 0,5 0,5 0,4 0,6 0,8 1,0 0,5 0,5 0,5 0,5 0,5 0,5 0,5 0,5 0,5 0,5 0,5 0,5 0,4 0,6 0,8 1,0
0,3 0,3 0,3 0,3 0,3 0,3 0,3 0,3 0,25 0,3 0,35 0,4 0,3 0,3 0,3 0,3 0,3 0,3 0,3 0,3 0,25 0,3 0,35 0,4
Max kWp PV-panel = 0,3
3,8 3,8 3,8 3,8 3 5 7 9 3,8 3,8 3,8 3,8 3 5 7 9
COP GSHP =3,8
2 2,5 3 3,5 2 2,5 3 3,5
COP ASHP = 2,6
High selling price by additional mortgage possible
High selling price by additional mortgage NOT possible
ESCo is NOT involved

Figure 111: Legend of Graph 39 (own illustration).
Dwelling type 1-6: Brown for the corner-terraced dwellings, yellow for the mid-terraced dwellings, blue for the semi-detached dwellings and green for the detached dwellings.
Dwelling size A-C: Light coloured for the small sized, normal coloured for the middle sizes and dark coloured for the large sized dwellings. All refer to the pure colour. Grey and white is reflected in the energy ambition.
Energy ambition: White background for the ZOM-energy ambition and grey background for the ZED-energy ambition
Thermal energy installation: Dotted are the e-boilers, diagonally striped the ASHP and horizontal striped the GSHP.

13.29.1.1 Legislation

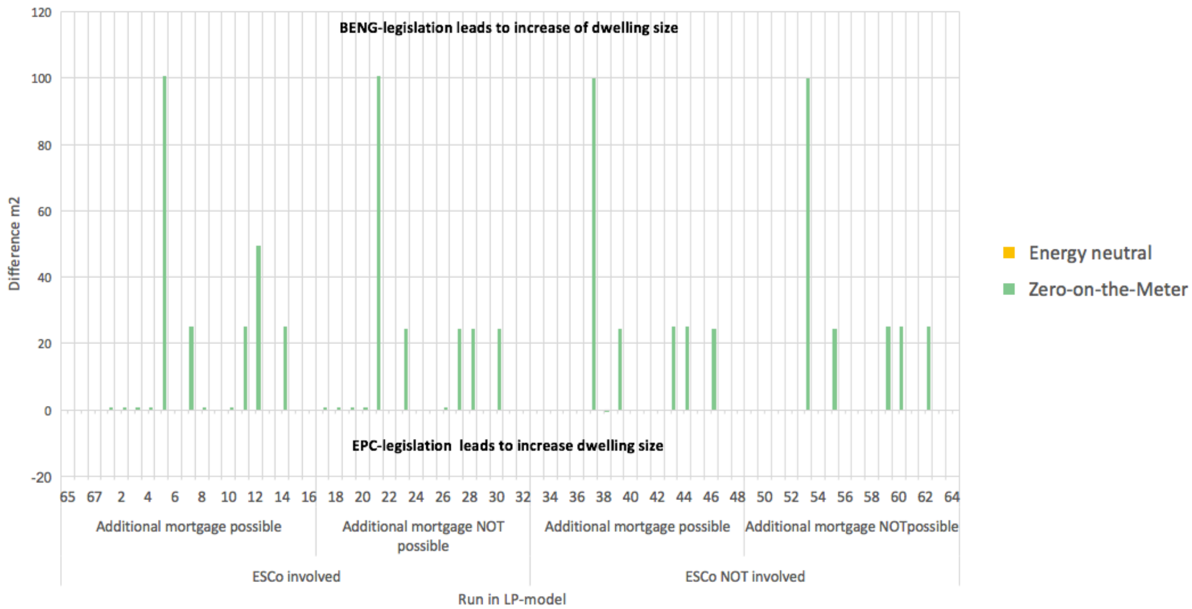
The first aspect is the one of legislation. The presumption in the first output runs was that the BENG-legislation caused lower profit rates, because of an increase in costs. This presumption is tested and more new insights are presented.



Graph 40: Difference in profit% between BENG and EPC-legislation for the two energy ambitions. The right axis shows the increase of dwelling size, referring to the open bars (own illustration).

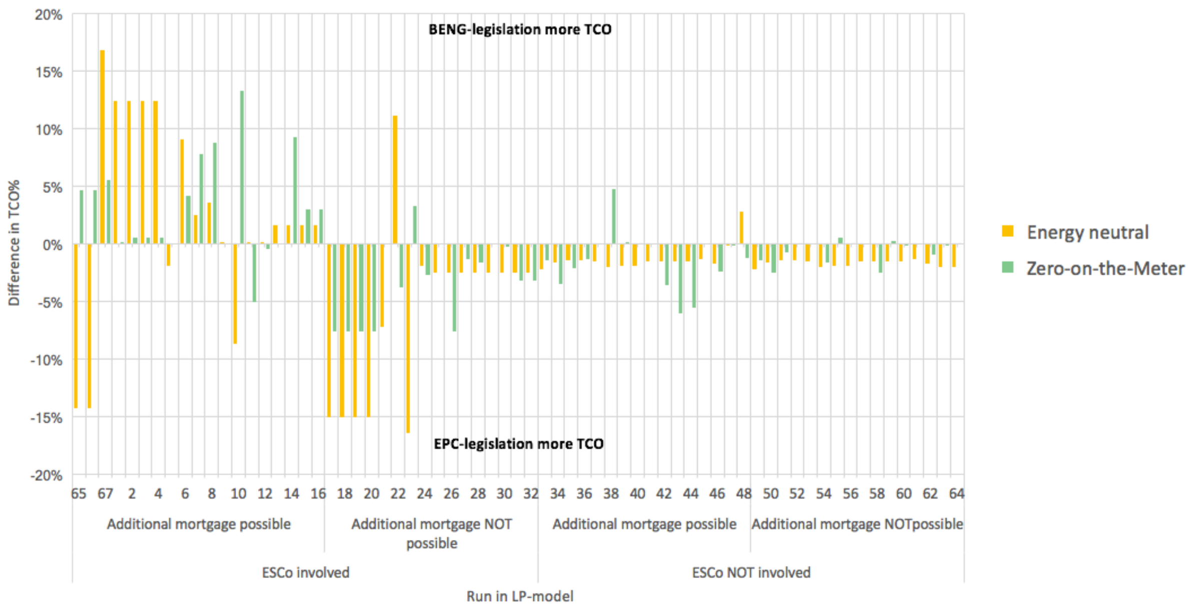
Graph 40 shows that for the 256 involved runs BENG is not always more expensive. The method of financing the energy installations and the energy ambition has influence. For instance, the energy ambition of ZOM offered the lower energy demand of BENG the opportunity to develop bigger dwellings in some runs, which results into an increase of profit. The graph also shows that in case of an energy ambition with energy neutral ZED-dwellings and a financing method with the ESCO, the EPC-legislation is always more profitable. This is caused by the used installations. More PV-panels are required in case of the EPC-legislation and those are paid by the ESCO. More energy saving installations and investment in the thermal envelop are required in case of the BENG-legislation and those are paid by the real estate developer. That is why the EPC-legislation is more profitable in those runs. In runs without the ESCO the EPC-legislation is slightly more expensive. Therefore, it depends on the energy ambition, physical measurements taken and the method of financing which type of legislation is more expensive.

Another insight appeared from the sensitivity analyses. BENG-legislation can lead to an increase of the dwelling size in case of a ZOM-energy ambition within these 256 runs. Graph 41 shows that the ZED-ambition does not have an effect on the dwelling size. The graph is slightly exaggerated for four points of measurement. The four lines till 100m are that large, because the EPC-legislation was infeasible. The effect is caused by the reduction of the thermal energy demand to 25 kWh/m2/a. This ensures that only little solar panels are needed, which leaves space to add more PV-panels needed to get a bigger dwelling ZOM. Also, the investment in the thermal energy installation has huge fixed costs and only little variable costs by the installation increase. Therefore, it is relatively cheaper to develop bigger dwellings. The profit rate will be higher for those.



Graph 41: Difference in dwelling size between BENG and EPC-legislation for the two energy ambitions. For the four lines to 100m2 had the model run based on the EPC-calculation an infeasible result (own illustration).

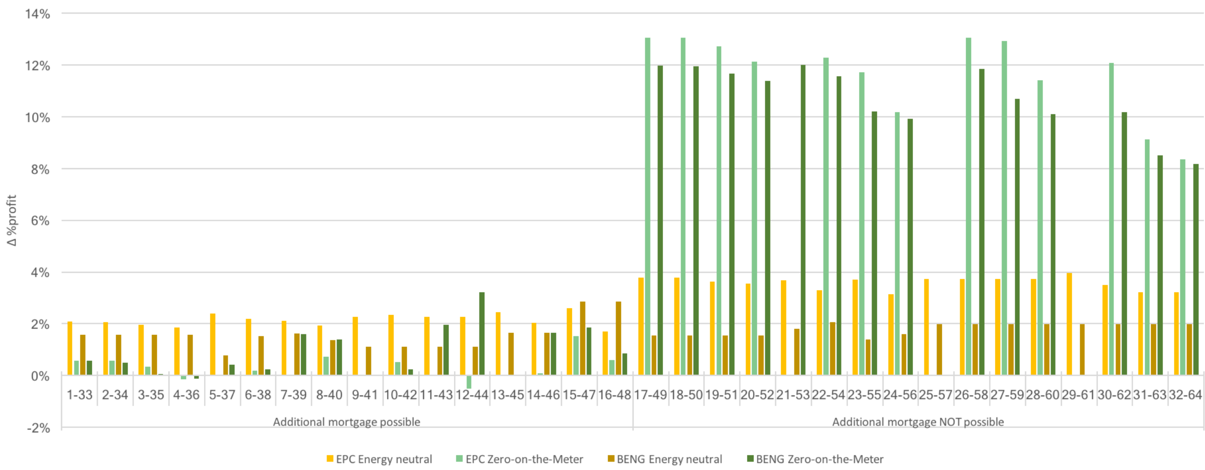
The effects of legislation on the TCO are unclear (see Graph 42). The TCO does change, however, the effect does not seem to be related to the legislation, but to the method of financing.



Graph 42: Difference in TCO between BENG and EPC-legislation for the two energy ambitions (own illustration).

13.29.1.2 Organisation

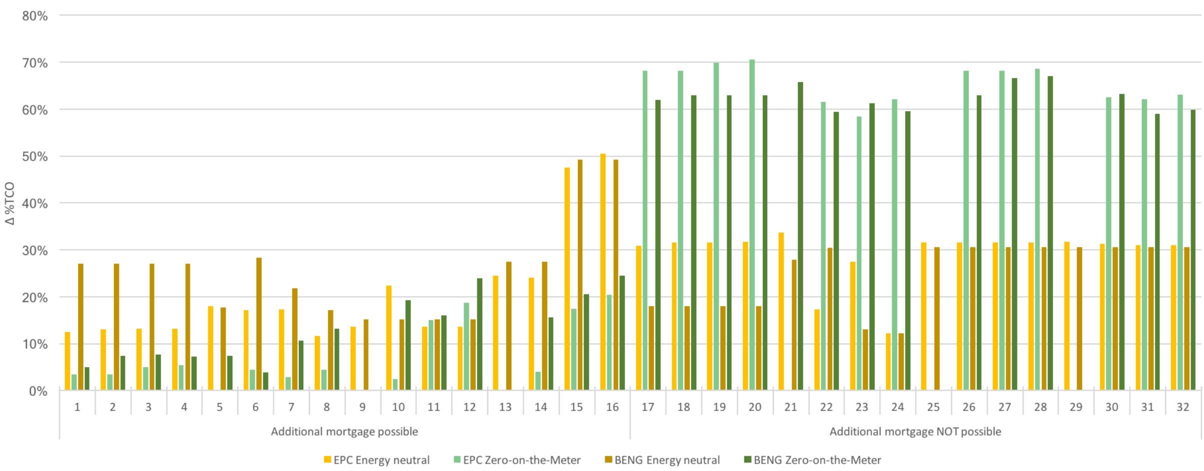
The second aspect of organisation is about the ESCO involvement. As explained before, the organisational aspect involves much more, but only the ESCO involvement is quantified in the model. The same three aspects of profit rate, TCO and dwelling size are discussed.



Graph 43: Comparison of profit rate between runs with ESCO and without ESCO involvement (own illustration).

Graph 43 shows the difference in profit rates for similar runs. Only the variable about the involvement of the ESCO was different for the compared runs. The graph shows that the involvement of an ESCO has in most cases a positive effect on the profit rate. The only scenario in which its effect was only little was in case of the presence of the additional mortgage space and a ZOM-energy ambition. The involvement of the ESCO only had a negative effect in tree comparisons. This effect had a maximal difference of less than 0,5%. For the ZED-energy ambition the effect on the profit rate was around 2% in the scenario with the additional mortgage space. The effect of the ESCO is clearest in case of the ZOM-energy ambition without the availability of the addition mortgage space, because in that case the profit rate has a huge difference between involvement of the ESCO or not (between 8,2pp - 13,1pp[118]).

The usage is an ESCO is more expensive to the home buyer, shown by the increasing TCO. All runs shows an increase of the TCO when the ESCO is involved (see Graph 44). Though, even with the involvement of an ESCO are the TCO lower as the reference dwelling. That is known because only feasible runs are presented.



Graph 44: Comparison of TCO between runs with ESCO and without ESCO involvement (own illustration).

Earlier was shown that within the ZOM-energy ambition differences in optimal dwelling sizes occur. In the comparison between the usage of an ESCO appeared that in one run it was more optimal to develop a smaller type of dwellings. This was the run in which a new type of solar types where used (400 Wp per PV-panel, see Graph 45).

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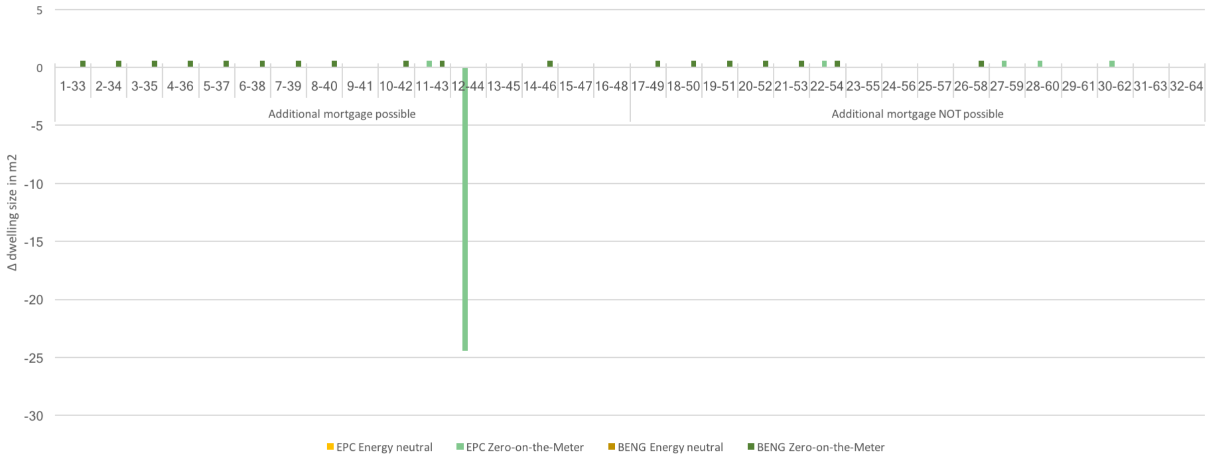
[118] pp is the abbreviation of procentage point.

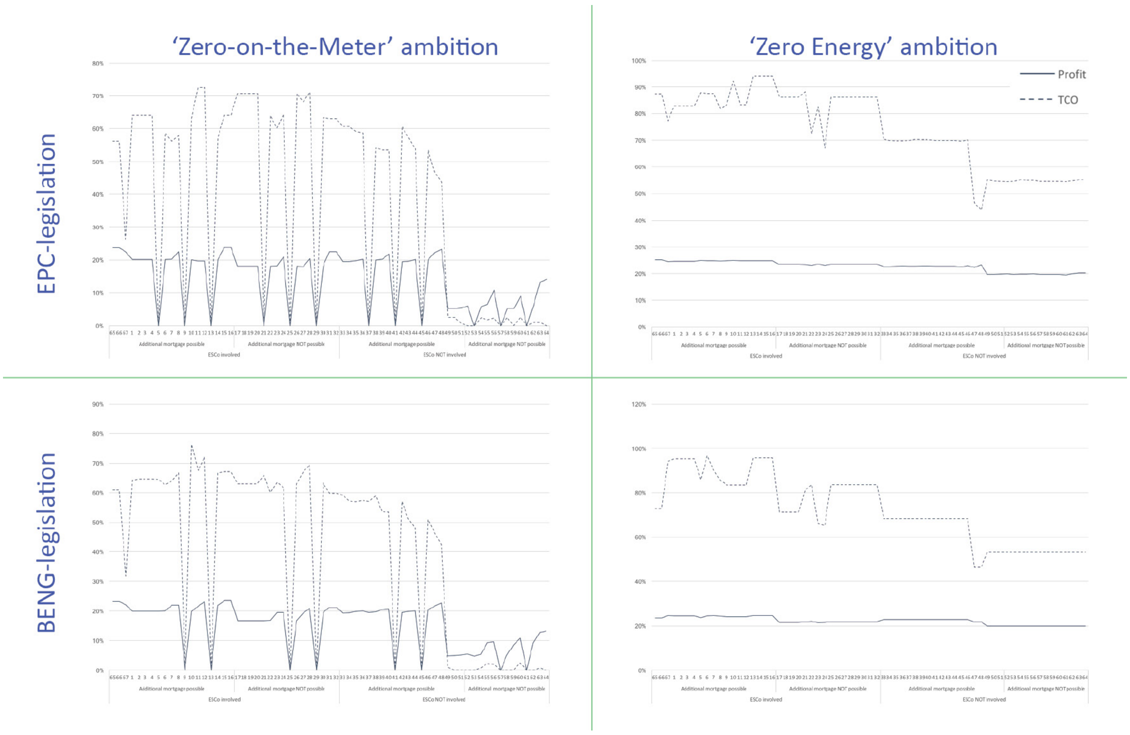


Graph 45: Comparison of dwelling size between runs with ESCO and without ESCO involvement (own illustration).

Concluding, the involvement of an ESCO has in most runs a positive effect on the profit rate. Only if both financing solutions are used and the energy ambition is ZOM, the effect of using the ESCO or not will not be big. In all cases the involvement of an ESCO has a negative effect on the TCO.

13.29.1.3 Finance

The third aspect is the one of finance. In the next paragraphs the effect of the additional mortgage space is discussed and a comparison of both financing types is presented. The effect of the ESCO is already discussed. First, a general overview of the effect of the energy ambition and legislation on the profit rate and TCO is shown.



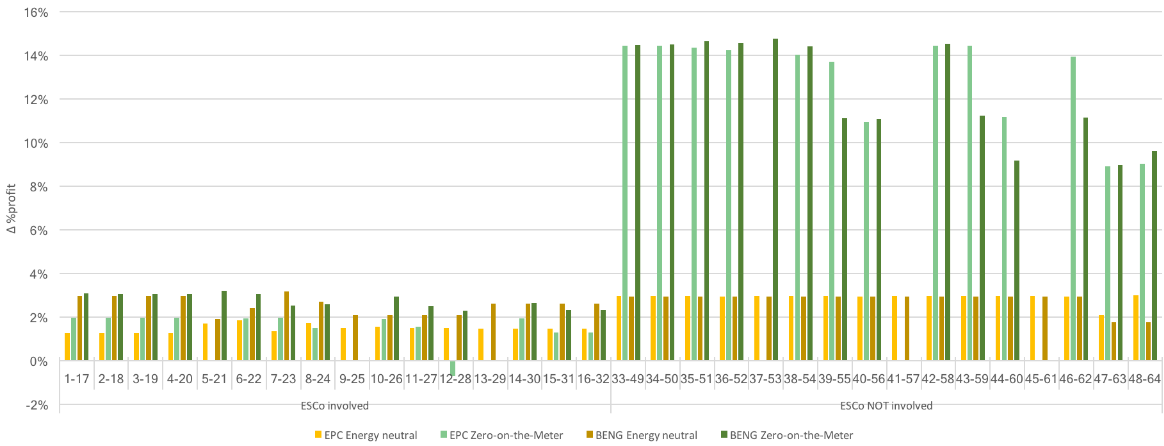
Graph 46: Effect of the different input variables on the amount of TCO and profit (own illustration).

A comparison of the effects of legislation and energy ambition is shown in Graph 46. Some insights became visible:

- The profit rate is relatively stable within the ZED-energy ambition. Most profit is made in case both financing options are the lowest profit is made in case no additional financing options are used.
- The TCO vary in between 45-95% within the ZED-energy ambition. If both financing options are used, the dwelling often has almost the same extra living costs for energy purposes as the reference

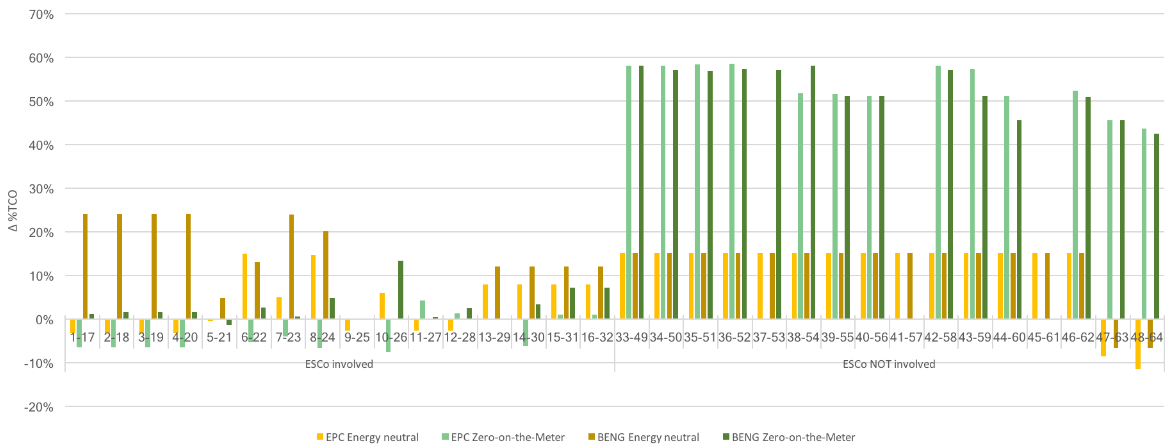
dwelling. If no financing options are used, the TCOs are the lowest. Except for one, the increase in type of PV-panel reflected by the maximum amount of kWp possible.

- The ZOM-energy ambition is more effected by the method of financing and the input variables about physical solutions. The infeasible runs within this ambition also present larger fluctuations.
- The ZOM-energy ambition is hardly financial feasible in case no extra financing options are used and has really low TCO. Only nine runs (out of 32) had a profit rate above 7%. These are the runs in which the newest 400Wp PV-panels or a change of the position of the ridge to 80-100% was applied.



Graph 47: Comparison of profit rates between runs with and without the possibility of additional mortgage space by increasing the selling price of the dwelling (own illustration).

Except for one comparison have all comparisons a higher profit price in case the additional mortgage space is possible (see Graph 47). Also for the mortgage counts that in case of the ZOM-energy ambition all runs without the involvement of the ESCO lead to an increasing profit price (+8,9pp-14,6pp). These increases are even higher for the mortgage possibility as for the ESCO. That comparison is later described. In the runs for the ZED-energy ambition and without the ESCO-involvement, the increase of profit rate is almost the same for all runs. That is likely because the additional borrowing capacity is limited to €9.000 (see Appendix 13.24.1).



Graph 48: Comparison of profit rates between runs with and without the possibility of additional mortgage space by increasing the selling price of the dwelling (own illustration).

In general, the TCO increases in case the additional mortgage space is possible. This increase is bigger in case the ESCO is not involved. The exceptions in which the TCO decreases are mostly in the runs with the comparisons for the ZOM-energy ambition and the combination with both financing options available. This was the case for 9-13[119] comparisons.

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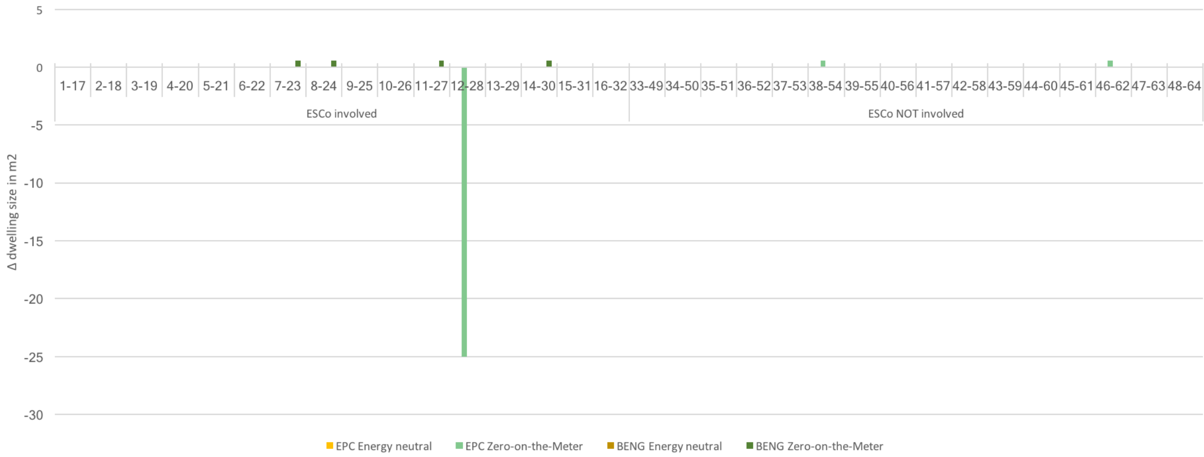
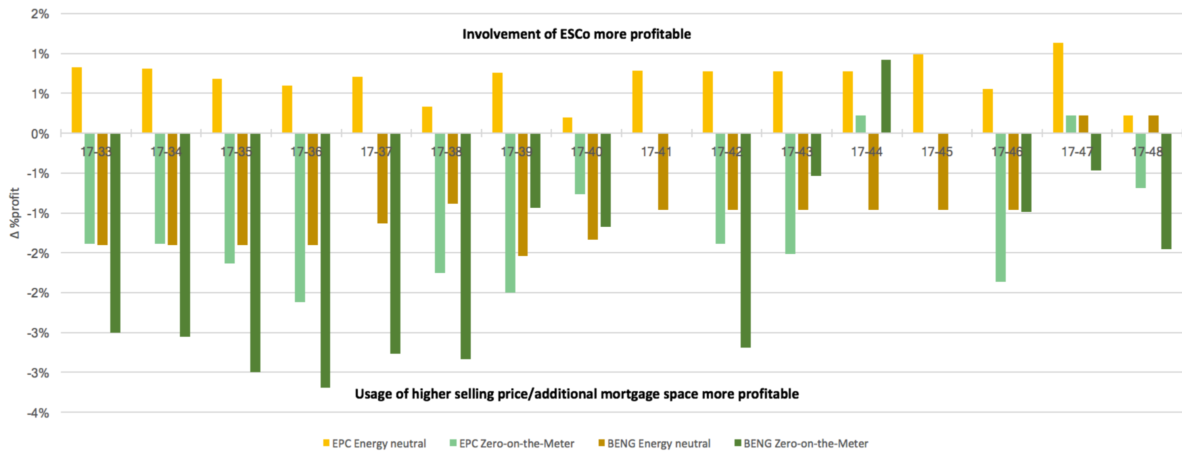
[119] Number is not 16, because 3 comparisons had to deal with an infeasible run.



Graph 49: Comparison of dwelling sizes between runs with and without the possibility of additional mortgage space by increasing the selling price of the dwelling (own illustration).

The absence of the additional mortgage possibility leaded one time to a larger dwelling (see Graph 49).

The comparison of the ESCO involvement and the mortgage possibility leads to interesting insights (see Graph 50). For most comparisons the additional mortgage possibility is more profitable. The ESCO is more profitable for all comparisons within the ZED-energy ambition and the EPC-legislation. The differences are mostly bigger in case of the ZOM-energy ambition. This is even more valid in case of the BENG-legislation. This difference can be explained that in that case the investment is higher, but the ESCO does not pays for this differences and the additional mortgage space does finance all solutions.



Graph 50: Comparison of profit rate between the usage of an ESCO and the usage of addition mortgage space by an higher selling price (own illustration).

The TCO are in most comparisons higher in case the ESCO is involved (see Graph 51). This is the case for all the comparisons with an ZOM-energy ambition.

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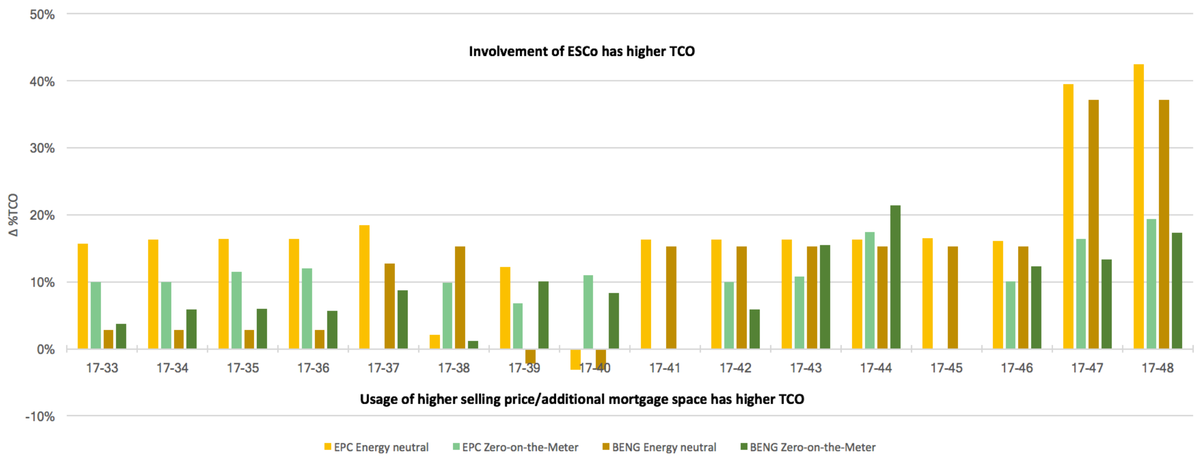
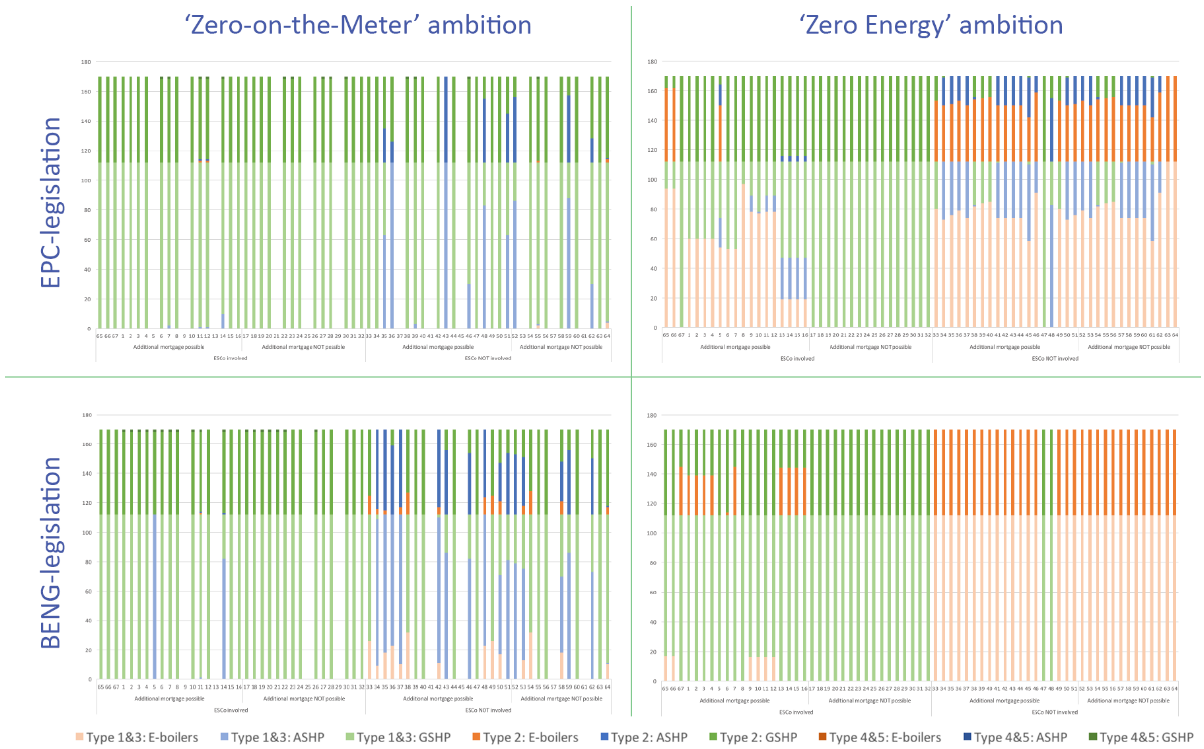


Graph 51: Comparison of TCO between the usage of an ESCO and the usage of addition mortgage space by an higher selling price (own illustration).

Concluding, increasing the selling price with the amount of additional borrowing capacity for a mortgage of an energy efficient dwelling is profitable in all but one comparison. The profit rate increased most (+8,9pp - 14,6pp) in case of the ZOM-energy ambition and without the involvement of the ESCO. However, this last one would lead to an increase of the selling price by €29.000 (see Appendix 13.24.1). In most comparisons the higher selling price leaded to increased TCO. The financing method with the increasing selling price also leads to an increased profit rate in most comparisons to the involvement of the ESCO (38 out of 59) and it also leads to a lower TCO in most comparisons (56 out of 59).

13.29.1.4 Physical

This paragraph discusses on the thermal supply installations selected by the model (output variables) and the effect of some physical input variables (COP efficiency of the ASHP and the GSHP, max kWp possible per PV-panel and the position of the ridge). First, a general overview of the effect of the energy ambition and legislation on the thermal energy supply installations selected is shown. And second, insights based on Graph 6 are presented.



Graph 52: Thermal energy supply installations selected within dwelling types (own illustration).

The financing options and the legislation has effect on the optimal thermal supply installation (see change in colours in Graph 52). More detailed, the GSHP is selected in all runs with only the financing possibility of the ESCO involved. In the other financing option mix does the legislation of BENG lead to a decrease of amount of GSHP selected. In addition, BENG-legislation leads to an increase of the electric boilers. This goes up to a 100% selection of e-boilers in case of the ZED-energy ambition and the absence both financing options. The e-boiler is the cheapest solution to meet the energy ambition. The feasibility of this option is limited by the amount of roof surface available to cover the electric demand.

Insights on the effect of the input variables is gathered from the different runs in Graph 6. *First,* the effect of the COP of the ASHP. In all 8 runs with an ESCO the GSHP was selected and therefore the changing COP of the ASHP had no effect on the profit rate. The profit rate is slightly increased (+1pp) without the ESCO involvement and the TCO decreased a bit (-2,5pp max). *Second*, the effect of the GSHP. The runs are infeasible for COP=3. If the run was feasible, an increase of the COP of the GSHP leads to an increased profit rate. This was even up to 5pp in case no additional financing option was selected, for the other 3 comparisons this was around 2,5pp of extra profit. COP=9 results into one size bigger dwellings, which increases profit, but increases also the TCO, because larger dwellings use more energy and need more installations to get ZOM. *Third,* the effect of the max Wp per PV-panel. In all runs the 250Wp PV-panel lead to an infeasible result. The rest of the results has different effects. In three of the four comparisons the best PV-panels (400Wp) leads to bigger dwellings and therefore increased profit rates. The profit slightly drops (-0,5pp) in the comparison with both financing options involved. In the same comparison the TCO increased with big numbers (+9,5pp), in case the PV-panels are paid by the extra mortgage the TCO drop by around 7pp. In the other two comparisons the TCO fluctuates with 2,5pp, first down and with the bigger dwellings up. *Fourth*, the effect of the roof surface influenced by the position of the ridge. In all cases at with the ridge positioned at 40% (less roof space) the result is infeasible. In the case with the ridge almost located at the northern part of the dwelling (at 80% and 100%), the roof offered enough space to create the biggest size dwellings. This ensured a rapid increase of profit level (3-4pp with additional financing measures and even 8pp without additional financing measures). The big increase was caused that four dwellings were installed with an e-boiler and heat exchange was possible within the block. In case of the ESCO the TCO increased 7pp with the mortgage and the TCO was stable without mortgage. In the case with the mortgage and without the ESCO, the TCO dropped rapidly (-10pp).

13.30 Appendix 30: Description of expert focus group at Planmaat

The expert focus group is referred to as Nan *et al.* (2017).

13.30.1 Introduction

The strategic application of the created model was the topic of discussion at an expert focus group at Planmaat on 2017, September 5th. During the session various opportunities and limitations were discussed.

Why Planmaat? Planmaat is an independent financial consultancy firm in the field of (urban) area development. Planmaat advises many different stakeholders by making the complex financial aspects of spatial planning projects understandable. In that way, they aim to involve multiple parties in the decision-making, accelerate the decision-making and optimise the quality of plans. Their approach can be best described by open, transparent and fair. It is the practical application of the open design approach of Binnekamp *et al.* (2006). With this background Planmaat is very suitable for reflecting upon the application of the decision support tool.

First, a description of the method applied is given, followed by the results of the session. The results are presented as a summary.

13.30.2 Method

An open dialogue is hold around the main question:
What is the added value of the decision support tool in decision-making processes for the realization of an energy neutral residential neighbourhood or one with a higher energy ambition?

Before the dialogue the researcher first explained the model to a part of the audience. This made it possible for the researcher to be the observer during the discussion. The researcher only intervened in case explanation of ambiguities was needed.

The session was started by an introduction of the thesis topic and a description about the functioning of the model. This was followed by an open discussion between the participants.

13.30.3 Results

Four topics were identified during the discussion: Single-actor or multi-actor application of the tool, the value of the tool for different types of stakeholders, application of the tool during different decision moments and other decision support tools. These are addressed in succession.

Single-actor or multi-actor application

- The model is very transparent on profit and development costs. It is therefore not very likely that it will be used often in multi-actor decision-making processes as the central decision support tool.
- The model gives clear and fast insight in the different possibilities. It can be used for exploration of the solution space by different kind of actors.

Value for types of different stakeholders

- Real estate developers often use predesigned (conceptual) dwellings. Most of the design and installation technology has already been fixed on forehand. This model will not be very useful for them in decision-making. However, those conceptual dwellings are developed incrementally. The model can be used to assess those dwellings. That would be on a building scale. More sophisticated detailed decision-design support tools could be more useful.
- Traditionally real estate developers design all their dwellings from the ground for every project. The model would be useful for those developers. Which installations do I need in my dwellings for the most profit? Which program of dwellings is best in this development?
- Municipalities have to define ground prices and energy ambitions for public-led developments. However, they found it difficult to set the price level for a high energy-ambition. The model can help municipalities to define the optimum between ground price and energy ambition, without having the risks of setting a too high or too low price.

Application during different decision moments

- The model can assist the municipality in defining the minimum energy ambition or ground price in the program of requirements, before a project is tendered to the market.
- The model can assist the real estate developer and/or municipality in the composition of the dwelling programme before the urban design is created.
- The model can assist the real estate developer in exploring the possibilities within the decision about the final installation technology and dwelling size used even after the dwelling program (typology – e.g. terraced dwellings, semi-detached dwellings and detached dwellings, and not the usable floor area).

Other decision support tools

- GPR Stedenbouw is often used for quantification of sustainability ambitions (e.g. energy, comfort and health, future value). This tool has a wider approach and is commonly recognized.

During the session new knowledge was shared about the upcoming energy legislation and extra borrowing capacity for highly energy efficient dwellings. The model thus also teaches experts about new possibilities and changing legislation. This was not mentioned within the discussion, but an observation.

13.31 Appendix 31: Limitations of the model

There are some limitations identified for the model:

- A simplification of the official calculation method of NEN 7120+C2 (2012) is used. This method is based on scientific research in Itard (2011). This was needed in order to get the formulas linear. This is also discussed with my mentor and the reasoning is described in chapter 6. For this reason, the BENG-results are not real outputs as they still contain an error margin. The model still gives useful results for its purpose, namely a fast exploration of the possibilities and the main playing field of the design-decision variables in the first exploring phase of urban area development.
- The LP-model calculates the income generated from the sale of energy supplied by the PV-panels as there is no degradation of the PV-panels during the operational period. For that reason, the TCO are a little bit too high. This is approximately €1,07 per PV-panel annually[120].
- The values however must be checked by official energy and financial calculations.
- The assumptions made must be checked for the location, as the soil has an effect on the application of ground source heat pumps and the location in the Netherlands effects the efficiency of the PV-panels.
- The model needs a feedback loop to check whether every single dwelling is also feasible or additional possibilities to share heat and electricity. Now it is somewhere in the middle, the best of both worlds, based on the next limitations:
    - The model assumes heat exchange between the dwellings of the same type. It is a point of discussion if this is realistic.
    - The orientation of PV-panels of the PV-panels is not directly included. The LP-model uses a conversion factor in which an average value for the effect of orientation can be included.
- The BENG1-input incorporates two levels: An annual thermal energy demand of 25 kWh/m^2 and 37 kWh/m^2. These levels are based on the case studies and the legislation. The 37 kWh/m^2 was assumed the price optimal level. The 25 kWh/m^2 is the required level.

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[120] Based on a 300Wp PV-panel, a solar factor (Wp->kWh) of 0,85, an operational period of 25 years, a degradation rate of 0,5% annually and a feed-in tariff of 7ct/kWh.

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