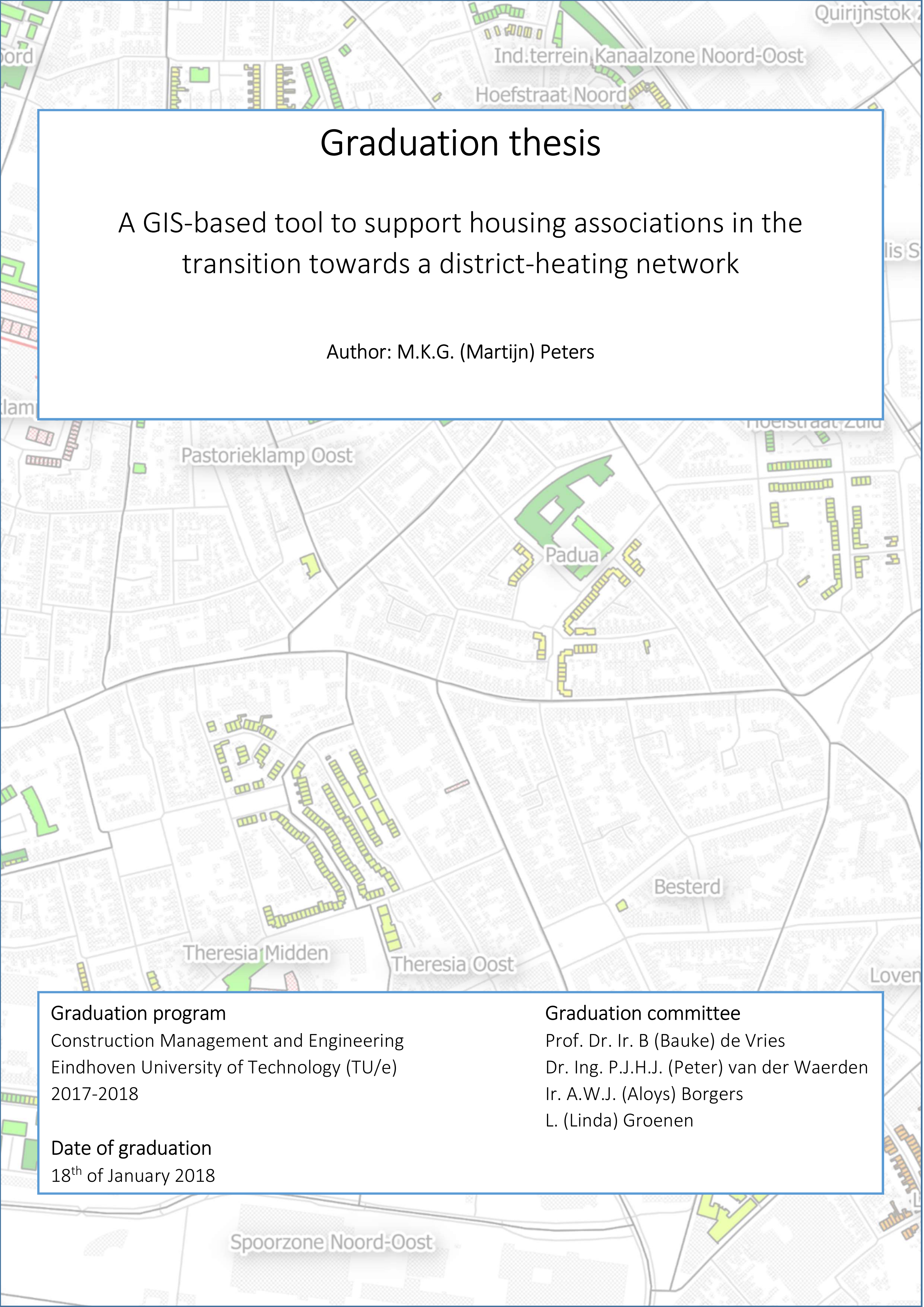

Graduation thesis

A GIS-based tool to support housing associations in the transition towards a district-heating network

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COLOPHON

Graduation thesis

A GIS-based tool to support consultancy towards housing associations for achieving a more sustainable dwelling stock

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QUOTE

''Sustainability is no longer about doing less harm. It's about doing more good.''

- Jochen Zeitz

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ACKNOWLEDGEMENTS

After seven months, I finished my master thesis as closure of my graduation at the Technical University of Eindhoven. The research is the conclusion of the master program Construction Management and Engineering (CME). I am proud to finally present my official thesis to you.

During the process of my education at the Technical University of Eindhoven, I started within the field of the Built Environment during my Bachelor, continued with the Certificate Technology Entrepreneurship and Management and now in the final phase of my Master (CME). Before getting into the content of my thesis, I would like to use this opportunity to thank those involved. First of all, I would like to thank my graduation committee for the support last months and the academic guidance and constructive feedback throughout the research. Peter van der Waerden, Aloys Borgers and Bauke de Vries shared their academic knowledge with me during the graduation process and I am very thankful of that.

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I have learned a lot during the last seven months of graduation. I will take this experience with me for my further career. I hope the contribution of this report to the world of GIS is as great as this graduation project was for Atriensis and for me.

M.K.G. (Martijn) Peters

Eindhoven, January 2018

SUMMARY

The governance of the Netherlands has set an agreement for 2050 to maintain an energy neutral built environment (Energieakkoord). The energy performance of the built environment should be improved step by step. The government will also expire the legal obligation for constructing gas pips in the new built neighbourhoods. All these measurements have the same goal, namely reaching an energy neutral housing stock. Housing associations need to make decisions on how they want to reach this neutral housing. They have as core business activity realizing, maintaining and renting their dwellings. Housing associations need to make decisions on how they want to reach this neutral housing, by themselves or by bringing in a consultant.

Decision making is based on numerous data concerning the problem and requires a careful selection of the right approach. Housing associations do not use spatial information to determine a strategy for their dwellings to meet the agreements which are stated by the government. The lack of spatial data within the work activities of housing associations is a problem. Information visualization is widely used to convey information and assist communication. Visualizing spatial information can support the collaboration between the housing association and other stakeholders, for example the government and utility companies. Spatial relationships between dwelling, subterranean infrastructure and renewable energy resources are not accessible.

More than 21% of all the energy consumption in the European Union is consumed by the residential sector. Energy improvements must be made to the existing dwelling stock to fulfil the greater energy efficiency. Housing associations have a key role in achieving a more sustainable environment, despite their vulnerable target group. This can be achieved by implementing renewable energy resources in the dwellings. Wind, solar, geothermal energy and surplus heat are the four most likely renewable energy resources in the Netherlands. Those four renewable energy resources should fulfil the energy demand for a big part. Implementing renewable energy resources into the current energy systems means a shift from centralized to decentralized energy systems.

This energy transition is complex with a lot of different interests at the stakeholders. The housing associations need to find balance between investing in sustainability versus taking care of their vulnerable tenants. The utility companies need to maintain the subterranean infrastructure. The shift towards more renewable energy resources causes another approach for them. The interest of the government is to ensure the quality of life of all the inhabitants in their range, tenants of the housing associations are also part of that. They also set legislations and should guide the stakeholders through the process. District heating networks are not yet regulating, taking initiative in regulating those district heating networks could accelerate the transition. The consultancy companies use their knowledge about achieving a more sustainable dwelling stock, but their focus is still commercial.

Geographical Information System (GIS) is commonly used in urban and regional scale planning. Integrating energy and environmental models in urban planning tools is recommended for the development of sustainable regions. GIS-models facilitate decision-making in the field of energy transition. The spatial analyses function a GIS has, distinguished the system from other information systems. Those analyses use the spatial attributes to connect data of various sources based on their geographical component. A GIS can illuminate the underlying trends in geographic data and make additional information available. QuantumGIS (QGIS) is an open source GIS software package with the highest score compared to other open sources packages.

QGIS can be used to combine data of the stakeholders involved within the energy transition. Buffer and overlay analysis can search for spatial relationships between two or more data layers. In case of this research, a GIS-based tool is developed focused on the likelihood of dwellings to be attached to a district heating network in the future. The approach is based on a multi-criteria analysis, which means 12 criteria are determined with assigned weights. Each dwelling scores a value at a criterion, based on spatial and non-spatial analysis executed within QGIS. Based on those scores, there can be concluded whether it is likely for a dwelling to be attached to a district heating network in the future or not. The two renewable energy sources which can deliver heat to a district heating network are geothermal energy and surplus heat.

The outcomes of this GIS-based tool can be used in the decision-making process towards a more sustainable built environment. Data layers about energy, building characteristics, infrastructure of district heating networks and scale are combined within the GIS-based tool. Housing associations, governments and utility companies should provide and share data to successfully use this GIS-based tool. It enhances the collaboration between the stakeholders to achieve a more sustainable dwelling stock with a district heating network together.

The GIS-based tool is enrolled for the municipality of Tilburg as a case study to verify whether it can support the housing associations with the transition towards a district heating network. The GIS-based tool is developed from the consultancy point of view, so housing associations can keep track on their daily practice. The power of the GIS-based tool is to store data of different stakeholders, modify this data with multiple spatial and non-spatial analyses and present new data in form of suitability maps. Witch additional information projected. The additional information in case of the enrolment in Tilburg was a calculated score between 0 and 10 for each dwelling of a housing association to measure the likelihood whether a dwelling could be attached to a district heating network in the future.

The highest score of a building was 6.8 out of 10.0. This score is sufficient, but not very high. This can be causes by the well-thought-out assumptions which have been made to the ranges of each criterion to be able to assign a score. Despite the interviews with experts, those assumptions are still rough approximations. Still, the outcomes of the GIS-based tool give additional information which can be used by different stakeholders to achieve a more sustainable dwelling stock.

SAMENVATTING

De Nederlandse overheid heeft een akkoord bereikt om een energie neutrale gebouwde omgeving te hebben in 2050, vastgelegd in het Energieakkoord. De energieprestatie van de gebouwde omgeving moet hierdoor stap voor stap verveteren. De overheid wil ook de verplichting schrappen om gasleidingen aan te leggen naar nieuwe wijken. Al deze maatregelen hebben hetzelfde doel, namelijk het bereiken van een energie neutrale woningvoorraad. Woningbouwcorporaties moeten hiervoor beslissingen maken over hoe ze dit willen bereiken. Ze hebben normaal gezien als kerntaak het realiseren en onderhouden van woningen en huurders. Ze staan nu voor de keuze of ze zelf de beslissingen richting 2050 willen gaan maken of een adviesbureau in te schakelen.

Besluitvorming is gebaseerd om een enorme hoeveelheid aan data gerelateerd aan het uiteindelijke doel, en vergt een voorzichtige selectie om tot de juiste aanpak te komen. Woningbouwcorporaties gebruiken geen ruimtelijke data om hun strategie te bepalen om aan het akkoord voor 2050 te kunnen voldoen. Het gebrek aan ruimtelijke data is dan ook een probleem. Het visualiseren van informatie wordt wereldwijd gebruikt om data over te brengen en te assisteren bij communicatie. Visualiseren van ruimtelijke informatie kan de samenwerking tussen woningbouwcorporaties en andere belanghebbende, bijvoorbeeld de overheid en energiebedrijven, ondersteunen. Ruimtelijke relaties tussen woningen, ondergrondse infrastructuur en hernieuwbare energiebronnen zijn zonder niet toegankelijk.

Meer dan 31% van de totale energieconsumptie in de Europese Unie wordt gebruikte door de woonsector. Energie verbeteringen moeten dan ook doorgevoerd worden aan de bestaande woningvoorraad om aan een hogere energie efficiëntie te kunnen voldoen. Woningbouwcorporaties hebben ondank hun kwetsbare doelgroep wel een belangrijke rol in het behalve van een duurzamere woonomgeving, mede door hun omvang. Deze duurzame woonomgeving kan worden verkregen door het toepassen van hernieuwbare energiebronnen voor woningen. De vier voornaamste hernieuwbare energiebronnen in Nederland zijn zonne-, wind-, geothermische energie en restwarmte. Deze vier hernieuwbare energiebronnen zouden voor een groot gedeelte in de energiebehoefte moeten gaan voorzien. Het inbrengen van deze bronnen betekent wel een verschuiving van centrale energy systemen naar decentrale energy systemen.

Deze energietransitie is complex en er zijn veel verschillende belanghebbende bij betrokken. De woningbouwcorporatie moet een evenwicht vinden tussen het investeren in duurzaamheid en de zorg op zich nemen voor hun kwetsbare doelgroep. De energiebedrijven moeten de ondergrondse infrastructuur onderhouden en klaar maken voor deze transitie. De overheid wil een zo’n hoog mogelijke leef kwaliteit voor alle bewoners, dus ook die van sociale huurwoningen. Echter, warmtenetten zijn nog niet gereguleerd door de overheid. Het initiatief nemen om dit te doen zou de energietransitie wel kunnen versnellen. Een adviesbureau gebruikt zijn/haar kennis om tot een duurzamere

woningvoorraad te komen. Echter ligt de focus bij deze bedrijven ook bij de commerciële doelen.

Een Geografische Informatie Systeem (GIS) wordt voornamelijk gebruikt bij stedelijke en regionale planningen. Het integreren van energie en omgevingsmodellen in stedelijke planningen is aanbevolen voor de ontwikkeling van duurzame gebieden. GIS-modellen faciliteren de besluitvorming binnen de energietransitie. Met de ruimtelijke analyses die een GIS heeft onderscheidt dit systeem zich van andere informatiesystemen. Deze analyses maken gebruik van ruimtelijke attributen om data van verschillende bronnen te kunnen koppelen op hun geografische component. Een GIS kan de onderliggende trends in geografische gegevens verhelderen en toegevoegde informatie beschikbaar maken. QuantumGIS (QGIS) is een open source GIS-software pakket wat het beste presteert vergeleken met andere open source GIS pakketten.

QGIS kan gebruikt worden om de gegevens van de belanghebbende binnen de energietransitie te combineren. Een buffer- en overlay-analyse kan ruimtelijke verbanden zoeken tussen twee of meerdere data lagen. Voor dit onderzoek is daarom ook een op GIS gebaseerde tool ontwikkelt, gericht op de waarschijnlijkheid dat een woning in de toekomst aangesloten kan worden op een warmtenet. Deze aanpak is gebaseerd op een multi-criteria analyse met 12 gedefinieerde criteria met bijbehorende gewichten. Elke woningen scoort voor ieder criteria een waarde, berekend met ruimtelijke en niet ruimtelijke analyses binnen QGIS. Gebaseerd om de som van deze scores kan er geconcludeerd worden hoe waarschijnlijk het is dat een woning in de toekomst op een warmtenet aangesloten kan worden of niet. De twee genoemde hernieuwbare energiebronnen die warmte aan een warmtenet kunnen leveren zijn geothermische energie en restwarmte.

De uitkomsten van deze GIS-tool kunnen gebruik worden in de besluitvorming richting een duurzamere gebouwde omgeving. Datalagen over energie, gebouweigenschappen, infrastructuur van warmtenetten en schaalgrootte kunnen gecombineerd worden binnen deze GIS-tool. Woningbouwcorporaties, overheden en energiebedrijven kunnen data aanleveren en delen om de tool succesvol te kunnen gebruiken. Het moedigt de samenwerking tussen de belanghebbende aan om samen tot een duurzamere woningvoorraad te komen, aangesloten op een warmtenet.

De GIS-tool is in de gemeente Tilburg uitgerold om te verifiëren of het inderdaad woningbouwcorporaties kan ondersteunen tijdens de transitie naar een warmtenet. De tool is vanuit het oogpunt van een adviesbureau ontwikkeld, zodat de woningbouwcorporatie zich met hun dagelijkse taken bezig kan houden. De kracht van deze tool is het opslaan, verwerken en presenteren van ruimtelijke en niet ruimtelijke data om vervolgens de geschiktheid van woningen gericht op een warmtenet te laten zien met een score tussen de 0 en 10.

De hoogste score die gehaald is, is een 6,8. Dit is wel voldoende, maar niet erg hoog te noemen. Dit kan komen doordat de weldoordachte aannames alsnog berusten op grove benadering. Ondanks dat, de GIS-tool geeft nieuwe informatie wat gebruikt kan worden door verschillende belanghebbe om tot een duurzamere woning voorraad te komen.

ABSTRACT

The governance of the Netherlands has set an agreement for 2050 to maintain an energy neutral built environment. The energy performance of the built environment should be improved step by step. Housing associations need to make decisions on how they want to reach this neutral housing. They do not use spatial information to determine a strategy for their dwellings. Visualizing spatial information can support the collaboration between the housing association and other stakeholders, for example the government and utility companies. Geographical Information System (GIS) is commonly used in urban and regional scale planning. GIS-models facilitate decision-making in the field of energy transition. A GIS can illuminate the underlying trends in geographic data and make additional information available. A GIS-based tool is developed, focused on the likelihood of dwellings to be attached to a district heating network in the future. The two renewable energy sources which can deliver heat to a district heating network are geothermal energy and surplus heat. The outcomes of this GIS-based tool can be used in the decision-making process towards a more sustainable built environment. The GIS-based tool is developed from the consultancy point of view. A final suitability score for a DH-network for all the housing associations' dwellings in Tilburg is calculated. The highest score of a building was 6.8 out of 10.0. This score is sufficient, but not very high. This can be caused by the rough approximations which are made for the ranges of the criteria.

KEYWORDS: GIS, district heating network, housing associations, consultancy, sustainability.

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1 INTRODUCTION

POTENTIAL OF SPATIAL INFORMATION WITHIN THE BUILT ENVIRONMENT

There will be a huge challenge for the built environment in the upcoming 30 years. The government of the Netherlands has set an agreement for 2050 to maintain an energy neutral built environment. The energy performance of the existing buildings should be improved step by step to reach this goal. The housing associations' dwellings represent 30% of the total housing stock in the Netherlands in 2016 (CBS, 2017). This report focuses on the approach for housing associations to meet this agreement and how spatial information can be part of this approach.

This Chapter introduces the motivation for the research topic and the developments on this topic in practice. First, Section 1.1 describes a brief introduction, Section 1.2 describes the problem definition and the main research question. The Sub-questions, together with the objectives are described in Section 1.3. The process model of this research topic is set out in Section 1.4, followed by the research relevance in Section 1.5. Finally, a brief overview of the whole research structure is shown in the reading guide of Section 1.6.

1.1 INTRODUCTION

Sustainability is a broad discipline and can be defined as everything that we need for our survival and depends on our natural environment. Environmental awareness is important to create and maintain the conditions under which humans and nature can exist in balance (Environmental Protection Agency, 2017). The built environment is facing the need for sustainable development, because it has a broad spectrum of impacts on our lives, health and climate change. The categories of a sustainable built environment can be divided into eight aspects, namely; urban connectivity, site, materials, indoor environment, energy, water, cultural and economic value and management and operations (Horr, 2017). Focused on the energy aspect, new developments in legislation ask for a more sustainable built environment to improve the balance between humans and nature. Because of the extent of all the aspects within the built environment, the focus of this report is at the housing associations in the Netherlands. The residential sector is separated into three segments, namely private ownership, commercial rent sector and the housing associations. The housing associations' dwellings represent 30% of the total housing stock in the Netherlands in 2016, in total 2.252.640 dwellings (CBS, 2017). The core businesses of housing associations are developing, renting and managing affordable housing. To maintain the quality of the dwellings on the same level, they have invested in housing management and energy transition. A total of € 4.5 billion is already invested in housing improving management and have included € 126 million on energy topics (Aedes, 2014). Housing associations are more into improving the current housing stock instead of demolishing (Land & Wissink, 2013).

The government of the Netherlands has set an agreement for 2050 to maintain an energy neutral built environment. This agreement is called the Energy Agreement (in Dutch Energieakkoord). The energy performance of the built environment should be improved step by step. The Energy Agenda (in Dutch Energieagenda) is the follow-up of the Energy Agreement. Within this agenda, it is stated that the government will expire the legal obligation for creating gas connections to new built houses in 2018. There will be no longer an obligation for constructing gas pipes in the new built neighbourhoods (Musch, 2016). This will also have an impact on the housing associations.

Within these new agreements, it is stated that the energy-index of the social dwelling stock should have an average energy label B in 2020 and energy label A in 2030 (Nikdel, 2017). All the housing associations together should invest € 3.5 billion yearly in 2017, 2018, 2019 and 2020 (Autoriteit woningcorporaties, 2016). Part of these investments are a better insulation of the dwellings and another part will be investing in decentralized energy production. Examples of these decentralized energy productions are solar-energy, wind-energy, geothermal energy and surplus heat. All these measurements have the same goal, namely reaching a climate neutral housing stock in 2050 (Wijngaart, Folkert, & Middelkoop, 2014). Housing associations need to make decisions on how they want to reach this neutral housing by themselves or by bringing in a consultant. Decision making is based on numerous data concerning the problem and requires a careful selection of the right conceptual framework. Sustainable development can be achieved by the implementation of action plans. About 80%

of data used to support spatial planning is location specific. Putting Geographic Information System (GIS) at the core of the planning and strategies is necessary (Odum, Adeoye, Oluwaseun & Idoko, 2016). GIS is populated by data and is powered by mathematical analysis. The data which is necessary as input for mathematical analyses can be gained out of different (non-) spatial sources. Different layers with each specific data can be implemented into one (realistic) model. The main use of GIS is to conduct spatial analyses, develop predictive models, cartography and make visualisations about spatial data. Spatial analyses can generate more knowledge and information than data or maps can. (Schuurman, 2004).

1.2 Problem definition

A housing association has as core business activity realizing, maintaining and renting dwellings. Important is the affordability for vulnerable tenants, also known as 'social housing'. The business activities of housing associations are non-profit and under the control of the government (Huurwoningen.nl, 2017). They are also obligated to make policies towards an energy neutral future.

The housing association branch is explored during the proposal for this report. Conversations with a consultancy company act as base for the statement that housing associations do not use spatial information to determine which strategy is preferred to achieve a more sustainable dwelling stock. The data they used to store information about their dwellings, installations and their tenants is mostly non-spatial information, for example Excel-spreadsheets or other non-spatial databases. They employ consultancy companies to determine their strategy for the future. The consultancy company works with the non-spatial information of the housing associations and admits the lack of spatial data. This lack is a problem, because spatial relationships between dwellings, subterranean infrastructure and renewable energy resources are not accessible now. Also, the efficiency of the energy transition can be improved by using spatial information (Esri, 2016). Relevant data for this topic is divided over several stakeholders, namely housing associations, utility companies and the government. Combining these data can bring new insights to light.

The lack of spatial data within the work activities of housing associations is a problem. Information visualization is widely used to convey information from data and assist communication. There is an enormous need for efficient visualization design for users from diverse fields to use the power of data (Mei, Ma, Wei & Chen, 2017). This need for efficient visualization is not yet recognized by housing associations. Visualization can be defined as the use of computer-supported, interactive visual representations of data to amplify cognition. Visualizations can help people understand data better (Feteke, Wijk, Stasko & North, 2008). Visualizing spatial data can assist communication and support the collaboration between the housing association and stakeholders as utility companies and the government.

Looking at these findings during the exploration in practice, the problem statement for this research is formulated as follows;

> Housing associations do not use spatial information to determine a strategy for their dwellings to meet the agreements which are stated by the government. They employ consultancy companies to determine a strategy, based on non-spatial information. Spatial relationships between dwellings, subterranean infrastructure and renewable energy resources are not accessible because of the lack of spatial information.

The problem statement will be approached from a consultancy point of view, because of their daily practice on the topic of more sustainable dwellings. Housing associations can maintain their focus on their core business activities. The following main research question has been formulated;

> How can spatial information support consultancy towards housing associations for achieving a more sustainable dwelling stock?

1.3 Research objectives and questions

The objective is to develop a GIS-based tool which can support the consultancy towards housing associations for achieving a more sustainable dwelling stock. The GIS-based tool should include diverse types of (non-) spatial data so spatial analyses can be executed. The results of these analyses could support the consultancy towards housing associations.

The answer on the main research question is subdivided into five parts. The first part consists of analysing the interests of involved stakeholders. Achieving a more sustainable dwelling stock is a complex question with multiple involved stakeholders. Each stakeholder has its own interest within this question. For example, the utility company have other interests compared to the housing associations. The second part consists of analysing the involvement of a consultancy company in this question. The third part consists of analysing all diverse types of data involved and how a GIS-based tool should be defined to support achieving a more sustainable dwelling stock. The fourth part consists of how to combine various kinds of data into a GIS-based tool to run spatial analyses and obtain the desired results. The fifth part consists of verifying whether this GIS-based tool does support the consultancy towards housing associations and how it can affect the consultancy process. The following sub-questions are formulated according to the five defined parts.

1. What are the interests of the involved stakeholders? Section 3.2.4
2. What are the phases of a consultancy process towards a housing association? Section 3.2.5
3. Which (non-) spatial data is involved in the GIS-based tool? Section 4.4.2
4. How to combine (non-) spatial data in the GIS-based tool? Section 5.2.2
5. How to use the GIS-based tool in the consultancy process? Section 6.1.2

The sub- questions mentioned above will be answered in this report. The relevant section per question is listed along each question.

The GIS-based tool should act as a well underpinned grip on the process of determining a strategy for the housing associations. Different spatial analyses bring new opportunities to light regarding more efficient use of the available data. The final product of this research is a GIS-based tool which can produce a map of a certain area which shows the potential of a dwelling on a specific topic within sustainability.

The academic aspect in this research focuses on the design of a GIS-based tool which can have an added value in the decision-making process of a consultancy company. The GIS-based tool will be validated through a case study. The main objective of this research is to define the GIS-based tool in an ideal situation and unroll it in practice to verify whether it can have an added value. A better support towards housing associations can be outcomes after validating the tool. This will help the consultancy by the decision-making process to achieve a more sustainable dwelling stock which is obliged by the earlier mentioned Energy Agreements.

1.4 Process model

Figure 1 shows the five parts to answer the main question after the literature review is conducted. Each phase has its own aim. Phase one and two are exploration phases, phase three and four are phases in which the spatial information comes about and the fifth phase reflects on the findings during the research.

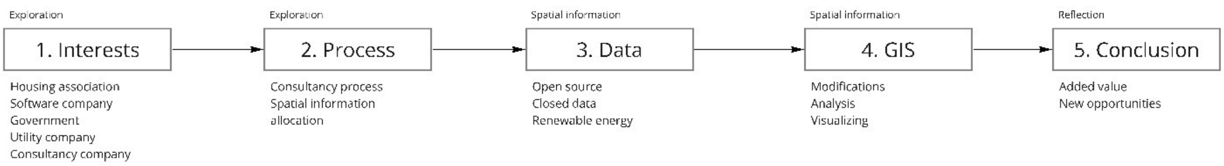


Figure 1. Overview of the five phases

The first part of the research will explore the core businesses of the involved stakeholders. Interviews with employees of different companies give a good overview of the current situation regarding the core businesses. Whether there is an awareness of spatial data and its potential will be verified. This phase contains a more qualitative interview method with an academic structure so the outcomes can be analysed and implemented in the GIS-based tool. Aspects like renewable energy, (non-) spatial data and GIS will be part of those interviews.

The second part of the research focuses on the consultancy process towards the housing associations. An interview with a consultancy company should provide an insight of the phases a consultancy towards housing associations consists. A view on the relations between different stakeholders, scale of projects and the steps that should be made during decision making processes are important. This part contains also a qualitative interview method with an academic structure.

The third part of the research focuses on data collection. Determining which data is necessary for developing a GIS-based tool is implemented in the literature review in Chapter 2 and in the findings in practice in Chapter 3. Atriensis (consultancy company which contributes to this research) managed multiple projects which can be used to determine the scale of this research. This part focuses on quantitative data collection in collaboration with different stakeholders, because they probably own already useful data.

The fourth part of the research will be developing a realistic GIS-based tool with the available data of the third part. Within this development, diverse types of data are converted into usable data for the GIS-based tool. Research to which analyses out of all the functionalities GIS software offers, is also implemented of this part. Buffer analyses and overlay analyses within the GIS-based tool are part of producing additional information / informative maps. These maps show spatial relationships between the different data. Aggregating these multiple maps into one final map is an important part of this phase.

The fifth and last part of this research validates whether the GIS-based tool can support the consultancy process towards housing associations. An earlier formed advice of Atriensis towards a housing association act as input for a content analyses. This content analysis is going to be conducted in this phase on an academic manner (SkillsYouNeed, 2017). The GIS-based tool will be implemented into a study case to show the usability. Recommendations for further research and limitations following up the conclusions of this study case and are also implemented in this part. Appendix A shows a more detailed overview of the whole research structure.

1.5 Research relevance

The need for sharing (non-) spatial data is important. Others can use already available data and vice versa and it also helps to reduce duplicated data storage. Sharing data with other parties or companies helps with data interoperability. By publishing data, others can see how the data is defined. Collecting the same or similar types of data improves the overlay possibilities, so much more data can be put together (Plunkett, 2015).

If decisions are made relying on data instead of pure intuition, chances of succeeding are 79% higher (Tiwari, 2013).

In case of the built environment, it is important to know what the geographic opportunities are compared with to data available about energy. Being aware of the geographical opportunities on district-scale can improve the decision-making process or at least support it. Decisions made based on data can improve the energy transition efficiency. These new opportunities have scientifically and societally contributions.

Societal contribution

As Tiwari already mentioned, chances of succeeding are 79% higher in case of decisions made relying on data (Tiwari, 2013). Because of this, the chance on failures can be reduces in an early stage. Preventing failures means also prevent wasting resources which is good for society. In case of this research, a more sustainable dwelling stock and a more optimal use of renewable energy sources contributes to a more efficient utilization of the resources the Earth offers. The utilization of damaging fossil fuels will be reduced, greenhouse effect will be reduced and a more sustainable environment will be created for this generation and more important for the subsequent generations.

Scientific contribution

Looking at the scientifically contribution of this research, combining energy transition of housing associations with spatial information has not previously been carried out. The complex situation of achieving energy neutrality in 2050, as already mentioned in the Energy Agreement, is approached by a qualitative research method with the help of combining spatial information. The approach on how to achieve a GIS-based tool in which the spatial information is combined is contributing to scientific publications and can act as basis for further research.

1.6 Reading guide

This research provides an approach on how to setup a GIS-based tool for a consultancy company to improve the housing associations' dwellings. Figure 2 shows the reading guide of this research. The various aspects of the approach for a GIS-based tool are set out in each chapter of this research, together with the involved components.

Chapter 2 consist of a literature review. A clear overview of existing publications of multiple journals, previous outcomes of researches and relevant topics which have already been covered are part of this chapter. The three main topics are energy demand (Section 2.2), renewable energy resources (Section 2.3) and the consultancy process (Section 2.4). Research gaps of the literature review are formulated in Section 2.5.

Chapter 3 is focuses on the current state of the earlier mentioned topics in practice. To get to know the current state, three main approaches are formulated, namely conducting interviews (Section 3.2). The result those interviews are summed in Section 3.2.4 and act as basis of the stated practical study gaps mentioned in Section 3.3.

The main objective of Chapter 4 is to set out the GIS-based tool (Section 4.4) in an ideal situation. The base for this framework is set out based on the research- and practice gaps mentioned earlier. Section 4.2 sets out the chosen focus out of all the topics mentioned in earlier and Section 4.3 chapters gives the approach towards this GIS-based tool.

Chapter 5 contains the case study where the developed GIS-based tool is enrolled (Section 5.2) and verified (Section 5.3) whether it has an added value to the consultancy process or not. The framework which is already given before act as basis for this enrolment. The main objective for this research, namely the framework for the GIS-based tool, will produce a final map which can be used in the consultancy process of this case study.

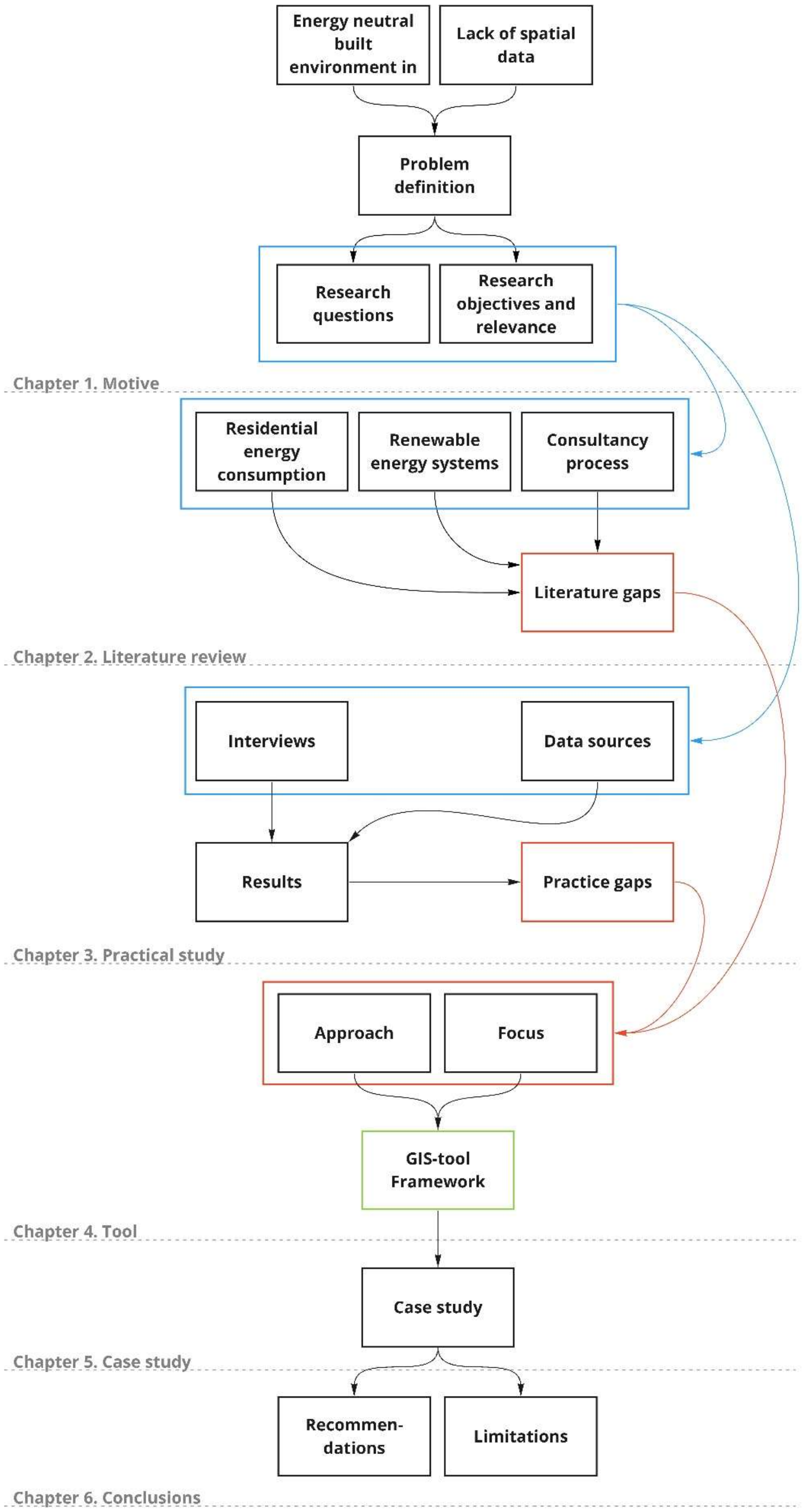


Figure 2. Reading guide

The concluding chapter of this research, Chapter 6, contains the answer on the main research question. Also, the answers on the Sub-questions are defined in Section 6.1. The limitations are described in Section 6.2, followed by the discussion and recommendations in Section 6.3.

2 LITERATURE REVIEW

ANALYSIS OF STATE-OF-THE-ART ARTICLES OF MULTIPLE JOURNALS

The literature review gives understanding about the current situation of the research topic, namely the role of spatial information within the consultancy towards housing associations. In total three aspects of this topic are identified. Firstly, literature about residential energy consumption. Secondly, the different energy systems and the renewable energy resources. And thirdly, the structure of a consultancy process. State-of-the-art articles, methods and applications about the aspects of the topic are elaborated in this Chapter, together with involved spatial information and a reflection on their impact in practice. An overview of the used articles of each section is shown in Appendix B.

First, Section 2.1 provides a brief introduction on the steps of the 'Trias Energetica' which are used in practice by the RVO (Rijksdienst voor Ondernemend Nederland, 2013) and the need for energy improvement. Section 2.2 is about the first step of the Trias Energetica, namely limit the energy demand of the dwellings. Section 2.3 is about the second step of the Trias Energetica, namely fulfil the remaining energy demand with renewable energy resources. The third step of the Trias Energetica is not considered, because fossil energy will not be necessary in an ideal future situation. Section 2.4 is about the consultancy process, because of the key role of a consultancy in the main research question.

2.1 INTRODUCTION

The structure of the literature review is based on the Trias Energetica used by the RVO (Rijksdienst voor Ondernemend Nederland, 2013) for energy neutral buildings. The first step is to limit the energy demand of the dwellings, the second step is fulfilling the remaining energy demand with renewable energy resources and the third and last step is to use fossil energy as efficient as possible in inevitable situations. The last step of the Trias Energetica is not analysed in this research, because in an ideal situation only step 1 and step 2 are applicable.

Housing associations should also think in the same steps as the Trias Energetica has formed. The housing industry is accused for causing the environmental problems, because of its high-energy consumption. More than 21% of all the energy consumption in the European Union (EU) is consumed by the residential building sector (Marta & Beldina, 2017). Regarding worldwide, the residential sector is responsible for 31% of the energy consumption (Swan & Ugursal, 2009). Figure 3 shows the residential energy consumption as a percentage of the national energy consumption. The residential energy consumption is different for a lot of countries, because of the differences in climate, physical dwelling characteristics and tenants' behaviour.

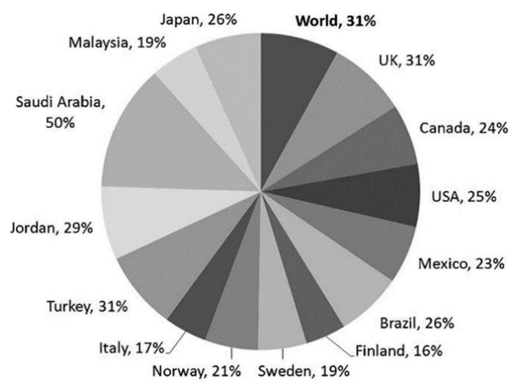


Figure 3. Residential energy consumption (Swan & Ugursal, 2009)

Energy improvements must be made to the existing dwelling stock to fulfil the greater energy efficiency. The EU energy efficiency directive states that the existing housing stock is the single biggest potential sector for energy saving (Aksoezen, Daniel & Kohler, 2015). Policy makers are assigned to set up strategies to increase the renovation rate and reduce the energy consumption of a dwelling by a significant percentage. Important part is analysing the actual energy consumption and the energy structure of the existing dwelling stock. Housing development can be considered as a pioneer to protect the natural resources from running out. The lack of knowledge and unfamiliarity of the use of renewable energy resources have contributed to this high-energy consumption. Depletion of the non-renewable resources has an enormous impact on the environment and ecosystems which are critical for our survival (Seyfang, 2010). Using energy efficient parameters within the dwelling stock can minimise the energy consumption.

To conclude, it can be stated that there is a need of a more energy efficient dwelling stock. Housing associations have a key role in achieving a more sustainable environment. First step is to get familiar with the energy demand of dwellings, next step is to get familiar with the different renewable energy resources. The last step is to get familiar with the field of activity of consultancy companies and the process of consulting.

2.2 ENERGY DEMAND

The objective of housing associations is to satisfy the housing needs of vulnerable households, often the low and middle-low income households. Housing associations are not primarily focused on achieving sustainable goals. Their tenants are often living in dwellings with a higher energy consumption, they do not enjoy the comfort of housing from an environmental point of view (Coimbra & Almeida, 2013). Low-income groups spend a large share of their income on energy costs compared to high-income households, while high-income households have a higher absolute energy consumption. If the energy use of low-income households is below a certain level, energy poverty occurs and in general this means a reduction in comfort. Also, because the low-income households are living in less efficient buildings, the risk of energy poverty is higher (Schaffrin & Reibling, 2015). In EU, the trend shows that the energy share of households is increased with 15% between 2008 and 2012 (Santangelo & Tondelli, 2017). Because of this reason energy use in dwellings can also be considered from the social perspective. It becomes more important to evaluate how the housing associations can achieve a higher energetically efficiency and be more environmentally sustainable.

2.2.1 ENERGY CONSUMPTION

The two key factors for energy consumption in the residential sector are size and location. The amount and type of energy depends on the weather, architectural design, economic level of the tenants and energy systems implemented in the built environment. Residential buildings in Spain consume only 15% of the total energy use, compared to 28% in the United Kingdom (UK). This difference can be explained by the more severe climate Spain has and the difference in building types. The total energy consumption is separated into three aspects, namely installations for space conditioning (Heating, ventilation and air-conditioning (HVAC)), domestic hot water (DHW) and lighting and appliances (LA). Important is the intensification of the use of HVAC systems, the largest end-use in the residential sector. HVAC systems are essential to acquire thermal comfort and are also dominant compared to the other end uses (Pérez-Lombard, Ortiz & Pout, 2008). Table 1 shows the ratios between four investigated countries.

Table 1. Energy consumption in % by end uses in the residential sector (Pérez-Lombard, Ortiz & Pout, 2008)

	SP	EU	USA	UK
Space conditioning (HVAC)	42	68	53	62
Domestic hot water (DHW)	26	14	17	22
Lighting and appliances (LA)	32	18	30	16

Research towards the actual energy consumption of the dwelling stock is helpful in the processes of formulating strategies to increase the renovation rate. Energy consumption figures are often only available for entire neighbourhoods or building clusters. Comprehensive data about actual energy consumption of single buildings do not exist because of privacy issues. Drawing conclusions about the energy demand on individual building level, household level or billing data level requires some degree of generalisation. Up- or downscaling limited information on the building stock has been executed by various energy estimating models. Assumptions about parameters of buildings which have an impact on the energy performance must be made (Aksoezen, Daniel & Kohler, 2015).

MONITORING PERFORMANCE

Monitoring the performance of residential buildings can be used to make comparisons between actual and predicted performance. This research technique is mostly used to get understanding about how energy demands may vary due to occupancy behaviour. Environmental monitoring is executed as pilot study in Gainsborough, UK. This is done by quantitative measurements and qualitative analysis and investigations (Sodagar & Starkey, 2016). The aim of the research in Gainsborough is to investigate the actual performance of four newly built dwellings with a Code for Sustainable Home Level 5. This Code is introduced in 2007 and adopted as policy by social housing providers and has six levels of compliance from level 1 up to level 6. Level 1 has the basic requirements of the building regulations, while level 6 is a zero-carbon dwelling. Code Level 4 is required as minimum for the Homes and Communities Agency in the UK (Pretlove & Kade, 2016). Requirements for Code Level 5 are a 100% reduction in emissions from regulated energy of HVAC, DHW and LA. This is stated in the Standard Assessment Procedure (SAP) under the building regulations (Sodagar & Starkey, 2016).

Identifying the influence of factors which might affect the performance of the houses is an important aspect of monitoring. The energy consumption in electricity in kilowatt per hour (kWh) and gas consumption (in m^3) is monitored. Because of the two different extensions electricity and gas have, m^3 gas should be converted into electricity kWh. Using an average Calorific value of 40 MJ/m^3, a correction factor of 1.02264 and a kWh conversion factor of 3.6 (Sodagar & Starkey, 2016), Equation 1 can be used for the conversion;

Equation 1. Conversion from gas to kWh (Sodagar & Starkey, 2016)

$$kWh = m^3 \times 40 \times 1.02264/3.6 \qquad (1)$$

This monitoring took place over two years, after the installation and monitoring equipment setup was successfully tested. The actual energy consumption is compared with the predicted energy consumption. The predicted consumptions are calculated by SAP with standardised climatic data and national methodology for building regulations. Table 2 shows the energy consumption of the actual situation and the predicted situation.

Table 2. Actual energy consumption and SAP calculated energy consumption (Sodagar & Starkey, 2016)

	Actual		SAP		Increase actual / SAP in %
House	Total	Per m2	Total	Per m2	
H1	5306	78.9	4107	61.1	29%
H2	9045	124.7	4690	64.7	93%
H3	4894	74.5	4211	64.1	16%
H4	6708	66.1	5493	54.1	22%
Average:	6488	86.1	4625	61.0	40%

TENANTS' BEHAVIOUR

The annual gas consumption of the four houses calculated by SAP does not significantly vary between the houses. This is declared by the similar assumptions made during the calculations. Remarkable are the differences of the actual energy consumption between the four houses. These differences vary considerably by the influence of tenants' behaviour. The way the building is used and family typologies are factors causing differences in energy consumption. These findings are also reported by similar cases in the literature (Gill, Tierney, Pegg & Allan, 2010). Gill et al. (2010) conducted research towards tenants' behaviour. Diverse types of energy consumptions show significant differences between maximum and minimum energy consumption of similar households. Figure 4 shows the factors for different energy consumption aspects for the minimum and maximum consumption of dwellings with similar types of households. These factors vary from 2.5 for carbon emissions to 7.75 for water consumption. Also, Pretlove et al. (2016) stated that there is a significant variation in the consumption of gas and electricity of similar households.

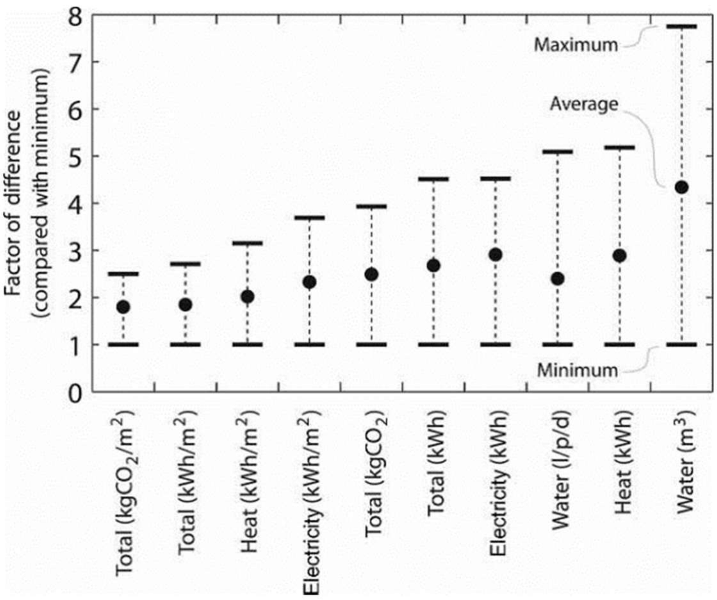


Figure 4. Variation of energy consumption between similar consumers (Gill, Tierney, Pegg & Allan, 2010)

2.2.2 SUSTAINABLE HOUSING

The energy performance of dwellings is just a small part of sustainability seen as a concept. A framework for the integration of environmental policies and development strategies is provided by sustainable housing. Achieving Sustainable Social Housing (SSH) has three aspects, namely social, economic and environmental aspects for satisfying the housing needs (Roufechaei, Bakar & Tabassi, 2014). The integration of these three aspects into planning and decision-making is undertaken to ensure that development serves the need of present and future generations (Goebel, 2007). Research is conducted to the link between energy efficiency and the three aspects of sustainable development.

A state-of-the-art study in the UK towards the success factors of SSH on those three aspects revealed that despite the importance of meeting the housing needs for the low-income households, the social dwellings are far from sustainable (Oyebanji, Liyanage & Akintoye, 2017). A one-way ANOVA tested the critical success factors for housing association to achieve SSH. Outcomes of this study are showed in Appendix C. Adequate funding, provision and affordability of the dwelling are ranked as the most critical condition. This illustrates that social dwellings must be affordable to be sustainable. However, the environmental factors are ranked the lowest in the overall ranking, which is remarkable. Considering the overall mean value (above 3), all the factors are critical. From the three aspects, the economic factor has the highest average mean as Table 3 also shows, followed by the social factors and the environmental factors.

Table 3. Average criticality of economic, environmental and social factors (Oyebanji, Liyanage & Akintoye, 2017)

	Overall		Public Sector		Private Sector			
	Mean	Rank	Mean	Rank	Mean	Rank	f-Stat	Sig
Economic factors	4.13	1	4.05	1	4.17	1	1.47	0.39
Environmental factors	3.64	3	3.55	3	3.69	3	2.17	0.27
Social factors	3.96	2	3.92	2	3.99	2	0.97	0.44

Economic sustainability

Economic factors are the most critical for achieving successful SSH. The main economic drivers of adopting sustainability are improvements of the property performance and the durability, so the operational and maintenance costs during the life cycle of the residential building are lower. Sustainable principles also provide good working spaces what results in an increase of employment. Economic sustainability increases the profitability through efficient use of human, material and financial resources (Roufechaei, Bakar & Tabassi, 2014). Challenges of realising sustainable housing associations are developing buildings within the limits of costs and areas. A comparative study in the district of Porto (Portugal) is conducted to represent the differences between traditional and sustainable housing associations, with similar locations and climate zone (Coimbra & Almeida, 2013).

The cost reduction in energy consumption is quantified by comparing dwellings of two housing association dwellings. The housing envelope and equipment of the sustainable dwelling (Leça, acclimatized floor area of 2300 m^2) and the traditional dwelling (Azenha de Cima, acclimatized floor area of 2583 m^2) are showed in Appendix D (Coimbra & Almeida, 2013). Striking are the differences in values of the thermal transmittance and efficiency. As expected, the sustainable dwelling has a much better thermal transmittance compared to the traditional dwelling. Table 4 shows the average annual costs for the energy consumption of HVAC and DWH for both dwellings.

Table 4. Energy consumption and costs of Leça and Azenha (Coimbra & Almeida, 2013)

	Sustainable dwelling	Traditional dwelling
Global energy needs (kWh per year)	159988	471477
Energy needs per square meter (kWh/m2 per year)	69.56	184.22
Annual energy costs per building	€ 22666	€ 41530
Annual energy costs per square meter	€ 9.85	€ 23.75
Annual energy costs per person	€ 49.51	€ 148.00

According to Coimbra (2013), the additional price of the construction of sustainable dwellings is €31.78 per m^2 higher compared to the construction of traditional dwellings. Depending on the energy consumptions of the households, the savings per year on energy costs can vary between €13.90 and €1.33 per m^2. According to the level of comfort used by residents in their dwelling, this results in a payback period that varies between 2.3 and 24.0 years (Coimbra & Almeida, 2013). This study concludes that housing associations which are targeted at lower and mid-lower class, can construct sustainable houses with high energy efficiency at low costs. With this savings, the dwellings become more affordable for the households, which is according to Oyebanji et al. (2017) the biggest success factor for SSH.

Another research conducted by Mulliner et al. (2013) also concluded that the economic aspects are more important in the criteria for sustainable housing compared to the social and environmental aspects. Appendix E shows the results of the weight (q) of different criteria for multiple criteria decision models. The three aspects with the highest weights are house prices in relation to incomes, rental costs in relation to incomes and quality of housing.

SOCIAL SUSTAINABILITY

The understanding of social sustainability can be defined as sustainable communities where people want to work and live, not only in the present but also in the future. Social homes meet the needs of existing and future residents. Issues as poor health and crime can have a negative influence on the area, because it concerns the human feelings security, safety and conform. Overall, social sustainability is about the quality of life, health and a safe environment (Oyebanji, Liyanage, & Akintoye, 2017).

Santangelo et al. (2017) concluded out of their research that the role of the human factor in effective implementation of renovation programmes is significant. Public governments should have a leading role in demonstrating the feasibility and benefits of renovation programmes. Focus on energy-savings in the housing associations sector is challenging, because of the difficulties within this vulnerable user group. Working with these vulnerable tenants could lead to a multiplier effect in achieving a more socially sustainable environment. Analysed renovation processes show that also private entities are a key factor in the energy efficiency process. Energy-conscious tenants do save more energy if the technological improvements match the household characteristics.

ENVIRONMENTAL SUSTAINABILITY

The housing industry caused a lot of pollution in the surrounding environment. One of the largest polluters and end-users of natural environmental resources is the construction of the buildings (Ding, 2008). Reducing the environmental impact of cities is not primarily a task focused on low-income areas and people. The traditional housing industry must change their building methods and make environmental concerns their main concerns. The increased significance of environmental issues has further complicated the building developments.

This research focuses on achieving more sustainable dwellings of the existing dwelling stock instead of constructing new built dwellings. Because of this, sustainable renovation is considered as more important.

2.2.3 RENOVATION

As mentioned in Section 2.1, the current dwelling stock consumes a lot of energy, because a lot of dwellings are not energy efficient. Analyses of the actual energy consumption of existing buildings facilitate the process of formulating strategies for increasing the renovation rate. Renovations need to be made so the dwelling stock becomes more sustainable and energy-efficient. Agreements on sustainable renovation are challenging for the housing associations. Hauge et al. (2014) conducted a study towards maximizing the changes of sustainable renovations within the housing associations sector. They concluded that visiting all the residents and visualizing the renovation plans create enthusiasm. The awareness of the need for renovation and energy upgrading solutions for the dwelling stock is important for the tenants (Hauge, Löfström, & Mellegard, 2014).

Research towards the importance of energy efficient parameters of sustainable housing renovation is conducted by Roufachaei et al. (2014). Based on mean values, the order of energy efficient parameters which are commonly referred to in literature is shown in Appendix F. According to these findings, the most effective energy efficient parameters are insulation, application of lighting choices and application of passive solar (Roufechaei, Bakar & Tabassi, 2014). Looking at Table 1, HVAC consumes most of the total energy consumption. Insulation can reduce this HCAC consumption, so it makes sense that good insulation is concluded to be the most energy efficient parameter.

Zero Energy Buildings (ZEB) are a realistic solution for the reduction of energy use in the residential sector. As Section 1.1 already pointed out, the Dutch government is aiming for an energy neutral housing stock in 2050. Not only the Dutch government set legislations on future energy consumption, also the USA, UK and EU provide examples of energy performance acts (Marszal, et al., 2011). A definition of a ZEB seen from an international point of view is lacking. Different definitions are possible. A framework for describing the

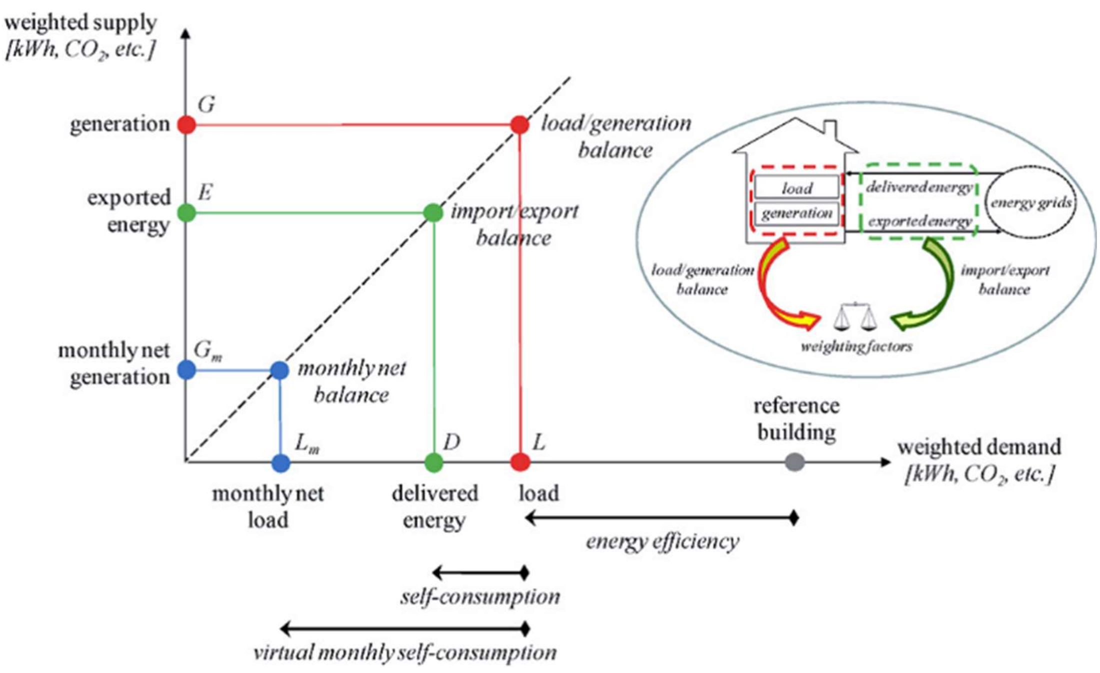


Figure 5. Three types of balances of net ZEBs (Sartori, Napolitano, & Voss, 2012)

characteristics of net ZEBs is developed by Sartori et al. (2012). In addition to the earlier mentioned energy efficiency in, Figure 5 shows the balance between consumption and generation of a building. The energy efficiency and self-consumption are contributing in a ZEB. The load/generation balance, import/export balance and the monthly net balance are intersecting each other on a 45° line (Sartori, Napolitano, & Voss, 2012).

Research towards ZEB is conducted in the UK by Wang et al. (2009). Based on weather data and computer simulations, quick predictions for those buildings are available without spending much money on experiments. Weather data analyses can be important guides for building energy systems and renewable energy system selections. In the case study conducted by Wang et al. (2009), weather analyses to wind speed and sun hours is implemented in the decision-making process of developing ZEB. Table 5 shows the annual electricity consumption and generation of the simulated ZEB in Cardiff, UK. Remarkable is the annual electricity generated with wind turbines. The energy generated with these wind turbines is 91% of the annual electricity generation while the photovoltaic (PV) panels is 9% of the annual electricity generation (Wang, Gwilliam, & Jones, 2009). The remaining electricity can be used for electrical charging of vehicles for transport or sale back to the electricity network. It can also be used for pump circulation in the system.

Table 5. Annual electricity consumption and generation (Wang, Gwilliam, & Jones, 2009)

Annual electricity	kWh
Energy consumption LA	-4672.0
Energy consumption Solar DHW	-401.7
Energy consumption HVAC	-935.2
Annual electricity generated with PV	687.8
Annual electricity generated with wind turbines	6618.1
Sum	1297.0

SITUATION IN THE NETHERLANDS

From the Social Sustainable Housing (SSH) point of view, investment costs for reducing the energy demand of a dwelling may not cause an increase of rent for the tenants. Economic sustainability is marked as the most critical factor for SSH, al already mentioned in Section 2.2.2. Figure 6 illustrates the composition of the rent after renovating a dwelling. Tenants' behaviour is not considered, because this research is focused on the energy demand of the dwellings. In the most optimal form and looking to the energy neutrality in 2050, the dwelling stock consists of only zero-energy buildings. In this case,

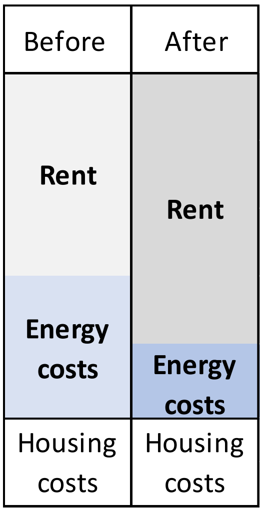


Figure 6. Rent after renovation

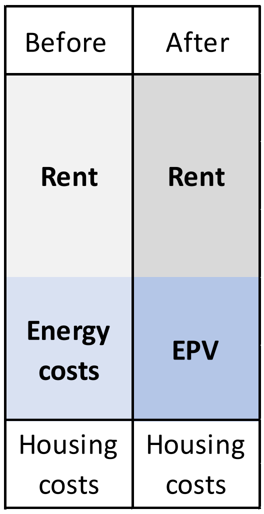


Figure 7. Rent with ZEB

housing associations can ask a fee named the ‘Energie Prestatie Vergoeding’ (EPV) (Rijksoverheid, 2017) of the tenants to cover the investment costs. Figure 7 illustrates the composition of the rent in case of a ZEB. The demand of this dwelling will be as low as possible, while the energy supply will be fulfilled with renewable energy. This corresponds with the second step of the Trias Energetica which is described in Section 2.1.

2.2.4 Conclusions

The residential energy consumption is in potential the biggest sector for energy saving. Reflecting on the steps of the Trias Energetica, Section 2.1 corresponds with the objectives of the first step, namely limit the energy demand of the dwelling. The main energy consumption within a dwelling is the HVAC to give thermal comfort to the tenants, this means in practice that limit the energy demand for HVAC has an enormous impact on the total energy demand of a dwelling. As already mentioned in Section 2.2.3, this can be achieved by a better insulation for the whole building envelope. Less heat loss through roofs, windows, floors, walls and exterior doors is the effect of a better insulation, so the energy demand will decrease. The investment costs for renovating housing associations’ dwelling stock to apply this measurement are very high, but will be payed-back over time by a decrease of the energy bill and an increase in rent or apply EPV.

2.3 Renewable energy resources

Renewable energy is defined by the European Union as (Europese Unie, 2010); ‘Energy from renewable non-fossil resources, namely; solar-, wind-, aerothermal-, geothermal-, hydrothermal energy and energy from the oceans, hydropower, biomass, bulk gas, biogas and gas of sewage treatment.’ As mentioned before, the use of renewable energy resources as energy supply corresponds with the second step of the Trias Energetica. This section is about the different existing energy systems and the diverse resources of renewable energy. The infrastructure of cities regarding to the energy services will face significant challenges to satisfy the growing demand on energy services. With integrating renewable energies, the city can play a significant role for achieving sustainable energy systems. Essential in gaining insight into future energy planning is analysing and modelling the energy systems. Existing models are not always capable in adequately addressing the challenges like transparency, complexity, human dimension and uncertainty which are faced by future energy systems. Modelling Urban Energy Systems highlights important aspects related to the transition of energy systems. Decision making processes in those systems requires the integration of spatial characteristics of energy resources. Developing energy systems with help of spatial information is in its infancy now (Alhamwi, Medjroubi, Vogt & Agert, 2017). Energy models should be transparent and publicly available. Nowadays those models are not transparent and freely or publicly available (Wiese, Bökenkamp, Wingenbach & Hohmeyer, 2014). Two types of planning energy distribution systems exist, namely centralized and decentralized systems (Hiremath, Shikha & Ravindranath, 2007). Moving from centralized electricity generation and costly transmission and distribution to decentralized and cost effective renewable energy production needs modification of the current energy infrastructure. Even though local approaches are motivated by geospatial challenges, the integration of spatial data within energy system planning is still in its infancy (Mentis, et al., 2016). The focus of this section will be the implementation of renewable energy sources in the centralized and decentralized energy systems.

2.3.1 ENERGY SYSTEMS

The current pattern of commercial energy oriented development, focuses on fossil fuels and centralized electricity leads to environmental degradation. The fossil fuel consumption and forest degradation is a result of the adoption of centralized energy planning. Power generation and distribution systems worldwide are structured according large-scale generation and transmission capacities (Hiremath, Shikha & Ravindranath, 2007). Those systems have provided efficient resource allocation and reliable energy transportation. Because of the high level of integration, they can be vulnerable to disturbances within the supply chain. Aging of a complex infrastructure, climate change, geopolitical disruptions, natural disasters and regulatory and economic risks are vulnerable aspects of the current centralised energy supply infrastructure (Bouffard & Kirschen, 2008).

Decentralized energy planning has an efficient utilization of resources and refers to regional energy planning. The decentralized energy systems are off-grid systems that are suitable options for small populations or in case of financial attractiveness. Designing these systems is complex and thus best addressed by mathematical optimization. Optimal designed decentralized systems can lead to a considerable increase of profits and independency for communities. The benefits of the optimal designed systems are case-dependent and vary because of site-specific conditions. Local resource availability and transmission grid access have influence on the increase of profits (Yazdanie, Densing & Wokaun, 2016).

Decentralized renewable energy systems are diffused on large scale, depending on technological appropriateness, energetic feasibility, socio-cultural acceptability, environmental sustainability, institutional preparedness and financial viability. Among all those factors, the financial viability is the most important (Yaqoot, Diwan & Kandpal, 2017). Spatial data can help to find the best site for implementing renewable energy systems. Spatial distribution of electricity consumption and decentralised storage can be modelled. Alhamwi et al. (2017) conducted research towards integrating spatial data with energy planning. Stakeholders create a better understanding of the structural relation between spatial information, like building and district energy infrastructure, and the energy generation and consumption (Alhamwi, Medjroubi, Vogt & Agert, 2017). Urban spaces should be structured in a decentralized system to develop poly-centric spatial and balanced structures. The structural transitions towards a sustainable energy system will be based on the expansion of renewable energy.

2.3.2 ENERGY POTENTIALS

Renewable energy is the fastest-growing source of electricity generation and increases yearly with 3%, which means a share of world electricity generation of 18% in 2007 to 23% in 2035 (Bazmi & Zahedi, 2011). The yearly increase is calculated with 2007 as base, which gives the following calculation: $3462 \times \mathit{yearly\ increase}^{28} = 7972$

Table 6 shows the world net renewable electricity generation in billion kWh by energy source of the five main renewable energy sources, namely hydropower, wind, geothermal, solar energy and surplus heat (part of other).

Table 6. World net renewable electricity generation in billion kWh (Bazmi & Zahedi, 2011)

Region	2007	2015	2020	2025	2030	2035	Yearly increase in %
Hydropower	2999	3689	4166	4591	5034	5418	2.1
Wind	165	682	902	1115	1234	1355	7.8
Geothermal	57	98	108	119	142	160	3.7
Solar	6	95	126	140	153	165	12.7
Other	235	394	515	653	773	874	4.8
Total	3462	4958	5817	6618	7336	7972	3.0

Integrate renewable energy sources into the existing energy systems can be done by many tools. Connolly et al. conducted research towards 37 tools that are used for integrating these sources into the existing energy system. Energy tools are available to support decision makers in the transition from a fossil-fuel world to a renewable energy world. Depending on the specific objectives, each tool has its own drawbacks and advantages. Some of them are free to download and some of them are for commercial purposes. RETScreen is the most used tool and is developed with contributions from government, industry and academia. Useful in this software tool is the comparison between the conventional technology and a proposed case, the renewable energy technology (Connolly, Lund, Mathiesen & Leahy, 2010).

Table 6 already showed the four most likely renewable energy resources. In case of the Netherlands, hydropower has lower potential compared to countries with higher elevation levels. Small elevation changes in the landscape tend to a low efficiency of the energy generation. This research focuses on the earlier mentioned four renewable energy sources, namely wind-, solar-, geothermal energy and surplus heat.

WIND ENERGY POTENTIAL

Spatial information is used to select potential locations for new wind farms. Rodman et al. (2006) conducted research towards the suitability of small wind turbines. Three variables are used which were spatially analysed and ranked in accordance to the effect on wind turbine placement suitability. The three variables are physical features, environmental factors and human impact factors (Rodman & Meentemeyer, 2006). Figure 8 shows the suitability map for small-scale wind potential

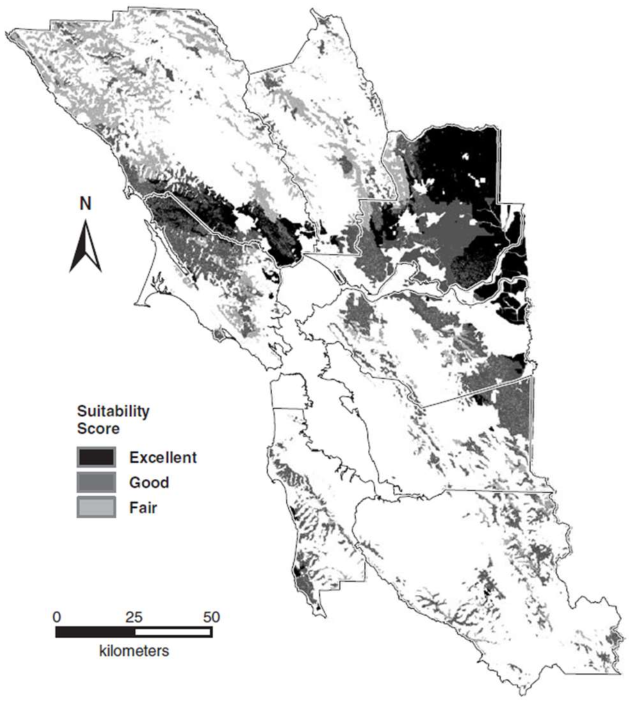


Figure 8. Small wind turbine suitability in North Carolina (Rodman & Meentemeyer, 2006)

after combining the physical, environmental and human impact models. With help of the functionality of spatial analyses, the zones in Northern California where the suitability of small wind turbines scores excellent are visible in the dark spots.

Solar energy potential

Modelling the potential of solar energy on building rooftops is a challenging process. Solar radiation strikes the earth's atmosphere at approximately 1.367 kW/m^2, but the actual solar radiation at a building's rooftop depends on many variables. Seasonal variations, weather, shading, roof size, slope and orientation affects the intensity of the radiation (Kodysh, Omitaomu, Bhaduri, & Neish, 2013). Most of the solar energy potential is located on rooftops of multiple-owner buildings, because of the large-scale surfaces compared to the single-owner buildings (Santos, et al., 2014).

Kodysh et al. (2013) conducted research focused on the potential solar systems on multiple building rooftops. They developed a digital elevation model (DEM) with help of light detection and ranging system (LiDAR). With this technique, a 3D model can be generated with the help of collecting topographic data by laser light pulses during a flight. This data is used in this study to determine the solar potential estimation. The next step is to extract the building footprints of the model and identify the rooftop outlines. Very detailed rooftop surfaces are now visualized (Kodysh, Omitaomu, Bhaduri & Neish, 2013). Figure 9 shows the outcome of the research conducted by Kodysh et al. (2013). The solar radiation intensity is calculated for each residential building separately. As already mentioned by Santos et al. (2014) multiple-owner buildings has a higher solar radiation intensity as the rooftops researched in the study of Kodysh et al. (2013). After calculating the PV generation potential of each rooftop, Santos et al. (2014) added an estimation of the resident population of each building. This estimation is based on the information from the Urban Atlas. Based on those two outputs, a better energy planning purposes can be formulated (Santos, et al., 2014).

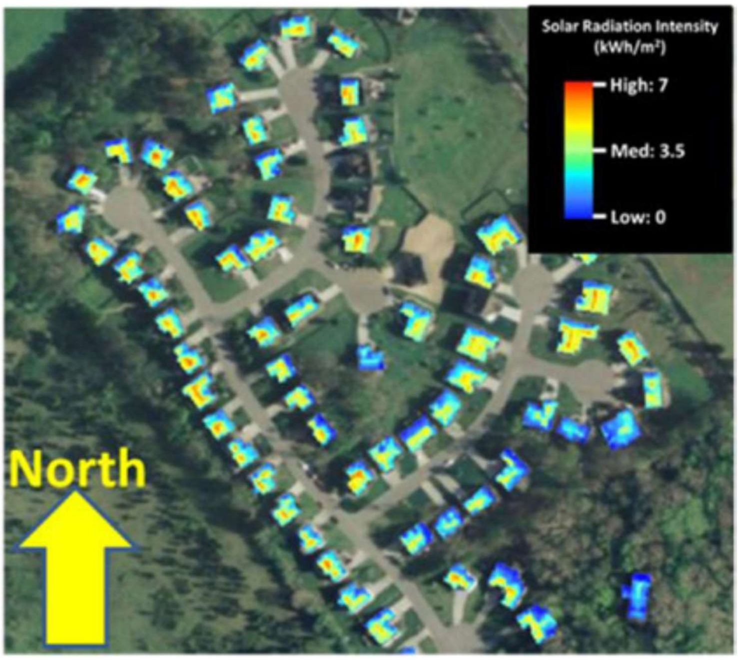


Figure 9. SR intensity (Kodysh, Omitaomu, Bhaduri, & Neish, 2013)

Geothermal energy potential

Geothermal energy adopts the temperature inside the earth, during the winter the ground source heat pump transfers the heat stored in the earth and during the summer it transfers the heat out of the building. This is possible because the earth has a relatively constant temperature, in the winter warmer than the air and in summer cooler than the air. The main advantage of this technique is that this type of energy is a renewable energy source and can provide power 24 hours a day, in contrast to wind or solar energy which fluctuates during the day. Drawback of these sources are the high initial investments, but the operating costs are low so the energy costs are also low (Bañoz, et al., 2011).

Figure 10 shows the outcome of research conducted by Noorollahi et al. (2017). The dark green areas are marked as potentially the most efficient sites for implementing ground source heating, regarding to many variables and equations. Market penetration of geothermal energy is still limited, because of financial reasons. The environmental advantages are pointed out by Tselepidou et al. (2010). The increased share of renewables in the energy market promotes global stability. It makes the energy consumers independent of big oil companies and gas producers. The optimization of geothermal energy applications is very important. For example, pumping costs are smaller when the new wells are placed in a higher transmittivity zone. The total required flow can be reduced when more water is pumped from the highest temperature zone (Tselepidou & Katsifarakis, 2010).

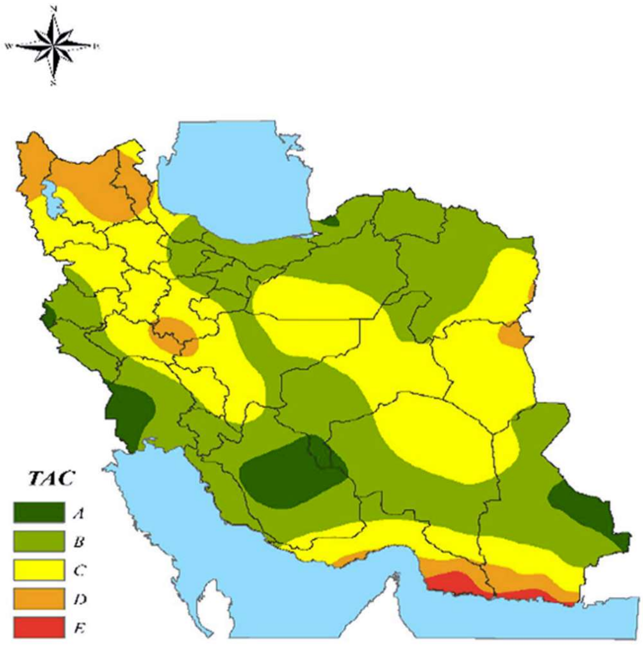


Figure 10. Most efficient sites for ground heat system installations (Noorollahi, Arjenaki & Ghasempour, 2017)

Surplus heat potential

Utilization of surplus heat sources represent well known technologies and is constantly under development. The potential of surplus heat for production, storage and distribution of energy can be divided into two approached, namely intern surplus heat and extern surplus heat. These two approaches differ from system and application.

Large building complexes, for example hospitals, have potential for re-use of their surplus heat- and cool energy throughout the year. The energy supply and demand are modelled with separate tools and timescales. Thermal storage combined with heat pumps and chiller units allow surplus- heat and cool to be recycled. Research conducted at a hospital in Oslo, Norway, by Harsem et al. (2016) has included ground thermal storage and interaction between different energy subsystems. They concluded that it is possible to save 20% to 50% of the energy demand for heating and cooling in hospitals by using surplus heat. This can be achieved by using water twice and serial connections for heating solutions and interaction between climate, local heating and cooling, ventilation, lighting and equipment, domestic hot water and optimizing the combination of integrated energy systems (Harsem, Grindheim & Borresen, 2016). This is typically an example of intern surplus heat and cooling.

Looking at the housing association sector, extern surplus heat is more likely because of the smaller building complexes. Surplus heat produced by industries linked to a district heating (DH) network is more likely for the housing association sector. Out of the 31% of the global energy demand intended for industries, 20% to 50% of this energy ends up as surplus heat released to the ambient (Chiu, Flores, Martin & Lacarriére, 2016).

This surplus heat can be transported from heat source to end users DH. Brückner et al. (2014) conducted research towards the use of industrial and commercial waste heat for a small residential neighbourhood in the city of Hamburg, Germany, called Lokstedt. The area is dominated by residential housing and small to medium sized commercial buildings, no heavy industry. They concluded that the estimated waste heat potential between 0.47 and 0.93 GWh/a does not meet the residential heating demand of 12.8 GWh/a in the specified area. Waste heat sources like small to medium sized commercial buildings cannot cover the whole residential heating demand, but it can still cover a small portion of the demand and can cover a larger portion in case bigger industrial companies can deliver their waste heat. Waste heat potential should be taken into consideration in renovation and refurbishment projects (Brückner, Schäfers, Peters & Lävemann, 2014).

Research towards bigger industrial companies like steel plants is conducted in China by Li et al. (2016). In this study, the payback time of the DH network is also included. In this case, and in other cases, new pipelines need to be constructed to connect the industrial heat waste to the DH. Figure 11 shows the situation in the study case of China (Li, Xia, Fang, Su & Jiang, 2016). New pipelines and new relay pump stations should provide a good DH network so the industrial heat of the steel plants can be used for residential heating. Interesting in this case study is the payback time. When comparing the investments of the project with the economic cost reduction, the cost effectiveness and the payback time can be calculated. Table 7 shows the static payback period in years of the project. In 2016 the static payback period will be 10.1 years. After adding absorption temperature transformers in the substations, the return water temperature can be reduced so more heat can be recovered. This results in a static payback period of 8.1 years in 2020 and 7.0 years in 2030 (Li, Xia, Fang, Su & Jiang, 2016).

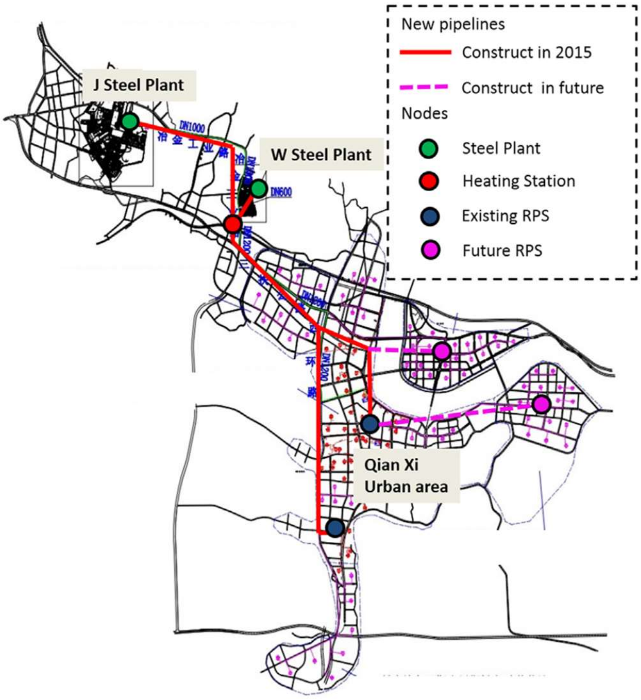


Figure 11. DH network to implement industrial heat waste of steel plants (Li, Xia, Fang, Su, & Jiang, 2016)

Table 7. Static payback period (Li, Xia, Fang, Su, & Jiang, 2016)

Investment (RMB million yuan)	2016	2020	2030
Long-distance transportation pipelines	170	170	170
Devices and pipelines in plants	113	113	128
Heat station	20	20	20
Pipes inside the steel plants	45	45	55
Heat exchangers	30	30	35
Absorption heat pumps	18	18	18
Absorption Temperature Transformers	0	46	146
Total	283	334	444
Cost reduction (RMB million yuan/year)	28	41	63
Static payback period (year)	10.1	8.1	7.0

2.3.3 Conclusions

After limiting the energy demand of the dwellings as mentioned in Section 2.1, there are multiple renewable energy resources which can fulfil the remaining energy demand. This corresponds with the second step of the Trias Energetica. As mentioned in Table 6 and Section 2.3, the most obvious renewable energy resources for the housing associations in the Netherlands are wind, solar, geothermal energy and surplus heat. The shift from fossil energy resources towards renewable energy resources affects also the design of energy systems. Fossil energy resources distribute the energy mainly over centralized energy systems, while renewable energy resources distribute the energy mainly over decentralized energy systems. Differences between those renewable energy resources are the building-oriented and the district-oriented approaches. Geothermal energy and surplus heat are defined as district-oriented approaches, while solar- and wind energy is defined as building-oriented. Spatial information is integrated in all the four mentioned renewable energy resources, differences are the scale. Geothermal energy and surplus heat are dependent of a district heating network to distribute the energy to the dwellings of housing associations. This requires also a more complex subterranean infrastructure compared to building-oriented solar energy. Those two renewable energy resources are still limited because the investment costs for a district heating network are high compared to PV panels and small wind turbines. Spatial information can help to find the most suitable buildings for implementing renewable energy systems. Important is the spatial distribution of energy consumption.

2.4 Consultancy process

Consultancy is not implemented in the Trias Energetica such as Section 2.1 and Section 2.2. The aim of this section is also different, a brief exploration of consultancy within academic papers is set out. Consultancy can be defined as a service economy; a company is outsourcing part of the business or new businesses. Srinivasan (2014) labelled outsourcing as; 'Practice in search of a theory.'

The growth of a service economy is attributed by factors such as the increase in wealth, personal income and the advancement in technology. The growth of service activities is understood as the derived outcome of economic, technological and social developments. The emerging geography of information and consulting services is shaped by negotiation, contestation and interaction between governmental constitutes and the global market forces. It seeks to increase customer satisfaction by designing services for a better match between customer expectations and expectations (Momparler, Carmona, & Lassala, 2015).

2.4.1 MAIN DRIVERS

The main value of consulting firms is their workforce. The degree of satisfaction that consultants generate highly depends on the person who is responsible for the work and not the consulting firm in general (Momparler, Carmona & Lassala, 2015). The professional competences and knowledge of the consultants are the basis for advisory services. In case of environmental assessment (EA) in Sweden, most of the work is done by consultants (Kagström, 2016). They identify themselves as practitioners that have more knowledge compared to developers or local and regional governments. In case of inexperienced clients, the consultants should start by defining the task for the client. Because of this, they are highly involved in making strategic decisions on the issues and impacts are addressed on influencing the quality performance. Another main driver for applying consultancy services is to be sure that a certain level of quality for approval will be reached. Performing below this level of quality will decrease the personal professional reputation of the consultant, which also will decrease their consulting firm's brand image on the long term. There is a mutual understanding between the consultants and the clients that the consultants' primary responsibility and key competence is to know the level of approval and how to achieve this. The research of Kagström (2016) is based on the client's point of view.

The amount of organizations that need and use management consultancy is higher than the amount of organizations that need commercial or financial consultancy. Managerial consultancy is defined as assistance in the form of knowledge related to content, structure, unfolding and performance activities provided by an external company. The consultant is not responsible for the execution and results of the provided recommendations, but can collaborate to implement it. From this definition, five basic features are defined (Nicolescu & Nicolescu, 2016):

1. Consultancy represents assistance in the form of managerial knowledge, content, structure, functionality and performance of the business;
2. Consultancy is provided by one or more specialists who are not direct employees of the company;
3. Consultancy is always paid directly in the form of cash or indirectly in the form of shares or products by the client;
4. Consultant is not held responsible for the results of the recommending approaches, decisions and actions, because he or she does not implement them directly;
5. Consultant can collaborate with the staff of the company by providing assistance regarding the implementation of policies.

2.4.2 Process description

Consultancy is about problem solving and the process of creating change and managing change. This process can be seen within the field of providing economic development support to transforming economies. Özeroğlu (2014) defined consultants as;

> *People who find themselves having to influence other people, or advise them about choices to improve the effectiveness of any aspect of their operations, without having any formal government over them or choosing not to use what government they have*

The consultants are part of the consultancy process which can be described as (Özeroğlu, 2014);

> *The process that happens when someone with a problem, or difficulty, seeks help from someone who has a special skill related to that problem or difficulty, or a process which will enable the problem or difficulty to be successfully addressed*

This whole consultancy process can be divided into eight steps, starting from determining the need of using consultancy service by the company to conducting assessments for evaluation. Figure 12 shows the steps of the consultancy process defined by Nicolescu & Nicolescu (2016). The process of the consultant itself can be roughly divided into three main aspects, namely, monitoring the situation, utilize knowledge and experience and finally introducing recommendations.

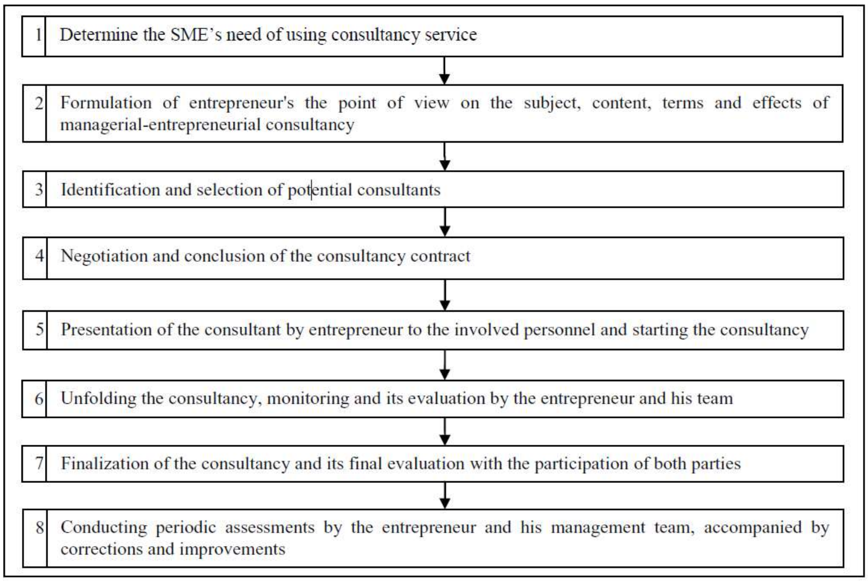


Figure 12. Stages of managerial-entrepreneurial consultancy (Nicolescu & Nicolescu, 2016)

Important for the adviser during all the stages are the ethical aspects. The basic ethical principle for the adviser is to respect the confidential information of the client. Reserach towards he importentness of ethical principles in consulting is conducted by Mingaleva (Mingaleva, 2013). She concluded that trust, ethical principal and quality are the three most important principles in consulting. Table 8 shows the means of the survey conducted by Mingaleva. She also concluded that consluting is carried to a field of activiy in which the ethical code is simply necessary. The adviser's ethics of behaviour is very important.

Table 8. Indicators of ethical principles in consulting (Mingaleva, 2013)

Statements	Observed maximum	Observed minimum	Means	Standard deviation
Trust as the value of management's consultant	10	3	8.46	1.46
Ethical principal is an important value of consulting	10	3	8.95	1.32
Quality of consulting services is an important value	10	3	7.35	1.91
Cooperation of the clients is an important value	10	1	6.48	2.64
Client-orientation is the necessary principle	10	2	6.41	1.99
Durability of client relationship is important	10	2	6.35	2.76
	Range 1-10: 1- totally disagree; 10- totally agree			

2.5 Research gaps

Regarding the first step of the Trias Energetica, a lot of research is conducted in limiting the energy demand of dwellings, sustainable housing and renovating towards energy efficient- and zero energy buildings. Also, multiple researches are conducted to a single renewable energy resource, regarding the second step of the Trias Energetica. Research towards solar-, wind-, geothermal energy and surplus heat, are conducted. Some of them aim at the potential of the energy source and some of them are aimed at the optimization of the energy source. Spatial information appears to be relevant in those articles about the potentials.

The main stated literature gap is how to set up a tool for dealing with energy neutrality in the future, considered the dwelling stock of vulnerable target groups and the use of renewable energy resources. An approach for achieving energy neutrality in the future is also missing. Combining valuable information out of the earlier mentioned articles into one tool which can be used by housing associations. Making their dwelling stock more sustainable will have an enormous impact on the built environment. An appropriate approach is necessary for this task.

Another literature gap is the complexity of multiple stakeholders on the energy transition topic. Dealing with the shift from centralized energy generation towards decentralized energy generation and which stakeholders are involved. Housing associations are facing this task for the first time, so they are employing consultancy companies. What is their role in this process and how can spatial information help in a process where multiple stakeholders are involved. The added value of spatial information is already pointed out in individual cases, but not yet in more complex cases with multiple stakeholders.

A lack of research towards combining data spread across multiple stakeholders is also stated, especially within the built environment. Collaboration between different stakeholders is necessary in the transition towards energy neutrality, so data sharing is important. This research is unique in combining different data about those renewable energy resources with the existing dwelling stock of housing associations.

The aim of this research is to create insight in district-oriented potentials where spatial information appears to be relevant. Looking at practice, housing associations must choose between an all-electric future or a district heating network for their dwellings (Atriensis, 2017). This has not been conducted earlier, so mainly the approach is important, but also the outcomes are important for further research.

3 PRACTICAL STUDY

EXPLORATION OF RECENT DEVELOPMENTS IN PRACTICE

This chapter contains research towards the recent developments on the earlier mentioned energy topics. Main parts are clarifying the complexity between involved stakeholders and determining the phases of the consultancy process. It is important to know the demand of characteristics which are involved, according to experts from practice. Those characteristics are the input for the final GIS-based tool and act as base for the modifications within the GIS-environment. This input is collected from different data sources.

First, Section 3.1 provides a brief introduction on the involved stakeholders, the use of GIS and the qualitative approach to explore practice. Section 3.2 contains the conducted interviews with experts of all the involved stakeholders, including the consultancy company. Also, the results of the interviews and the consultancy process are shown in this section. At the end of this chapter, Section 3.3 concludes the gaps which are stated in practice.

3.1 INTRODUCTION

In this chapter, the target group and stakeholders are brought to light. Important is to set the criteria to give answer on the earlier mentioned sub-questions, formulated in Section 1.3. Main research question is to answer which role spatial information can have within the consultancy process towards housing associations. The approach and the framework determine the quality of the GIS-based tool. Findings of the literature review together with the findings in this chapter, underlie the structure of the framework. Getting familiar with the interests of the involved stakeholders, getting familiar with the consultancy process and knowing what aspects are involved within the documented consultancy are the aim of this chapter.

The literature review shows a lack of research in combining renewable energy resources with the energy transition in the housing associations sector. To gain more knowledge about the involved stakeholders within this topic, conducting interviews and collecting data gives more insight in the complex situation. Figure 13 shows a conceptual overview of the stakeholders involved in the energy transition of housing associations. In this case there are three main stakeholders, namely the utility companies, governments and housing associations. Software companies and consultancy companies support housing associations in their decision-making process and are less involved in the energy transition by themselves.

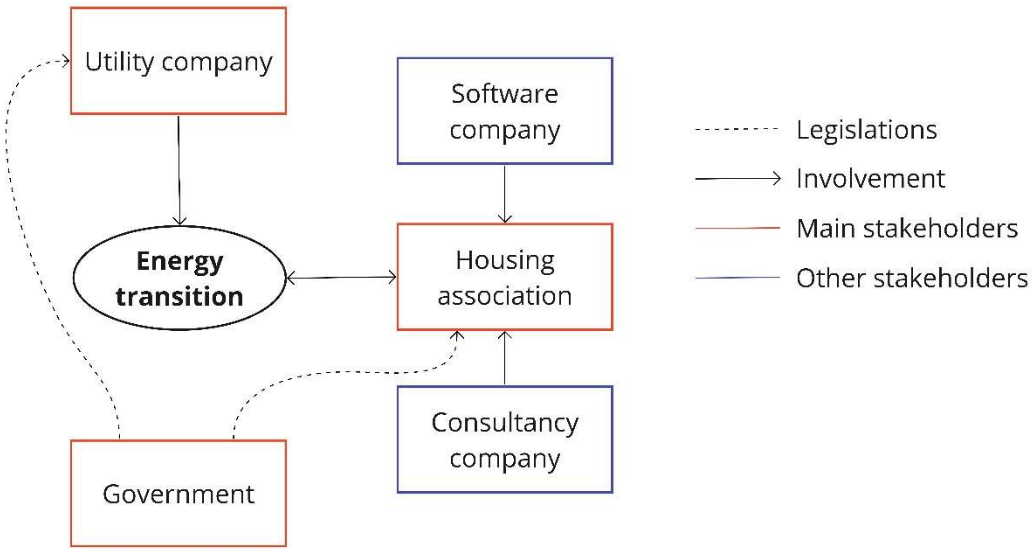


Figure 13. Overview of stakeholders

Regarding to the research questions formulated in Section 1.3, the interest of the involved stakeholders needs to be determined. This can be achieved by conducting interviews with the stakeholders. It is also important to determine the interests during the consultancy process to get insight in the important aspects and necessary steps. These steps can also be overtaken by having an interview with a consultancy company.

3.2 INTERVIEWS

The objective of an interview is gathering information out of the statements of surveyed stakeholders. This information is retrieved using formulated questions, which are semi-structured questions or open questions. In qualitative research, the questions of the interview are fixed, but the answers on these questions are unrestrained. In this case the interview has semi-structured questions with a mix of unrestrained and strained questions, so the possibility of adapting flexible to the situation is still possible. Because of the research topic, namely the role of spatial information within the consultancy process towards housing associations, a focused interview with clearly defined topics for the similar surveyed stakeholders is the best applicable approach for this research (Baarda, de Goede, & Teunissen, 2005). Face-to-face interviews and interviews by phone creates a personal interaction and offers a way to introduce the topic on a proper manner. The main subject and the sub-subjects are based on the literature review and preliminary research. This section deals with the structure of the interview and its components and the stakeholders. Appendix G shows the interview design for the housing association as stakeholder. A mix of open- and semi-structured questions is the best approach. The topic list is formulated as follows; the impact of the governments, sustainability in energy, (non-) spatial data, Geographical Information Systems and the consultancy process. These topics are composed out of the literature review in Chapter 2 and the motives in Chapter 1.

3.2.1 QUESTIONS

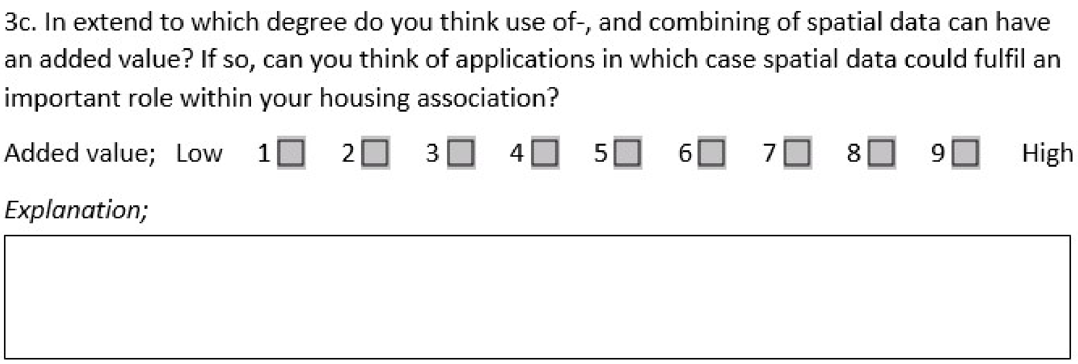
Open questions included the knowledge of the expert. The expert has a lot of knowledge which is not well-known before the interview is executed. It is not possible to establish reliable response categories up front without the possibility to exclude essential information. This type of questions can for example determine the energy strategies of housing associations, utility companies and governments, trace the design of the data flow and find out the opinions of the experts. Figure 14 shows an example of an open question of Appendix G.

3a. How is the information flow of your housing association organized regarding other stakeholders? What types of data are involved within these information flows?

Figure 14. Example of an open question

It is hard to make comparisons between different stakeholders within a qualitative research. Because of this difficulty, the interview also contains semi-structured questions. Those questions contain an open question, followed by a closed question with a ratio as measurement level. For example, this measurement level act as scale to express the feasibility of the agreements stated in the Energy Agreement mentioned earlier in Chapter 1 and level op potency of the earlier mentioned renewable energy resources and the use of

GIS-software. The scale of those measurements will be a ratio variable 9-point scale of 1-9, so the surveyed stakeholder can give a more thoughtful answer compared to a 5-point measurement scale (Baarda et al., 2012). Figure 15 shows an example of a semi-structured question which is applied in the interview for housing associations.


3c. In extend to which degree do you think use of-, and combining of spatial data can have an added value? If so, can you think of applications in which case spatial data could fulfil an important role within your housing association?

Added value; Low 1☐ 2☐ 3☐ 4☐ 5☐ 6☐ 7☐ 8☐ 9☐ High

Explanation;

Figure 15. Example of a semi-structured question

3.2.2 STAKEHOLDERS

To address the interviews to the right stakeholders, visiting congresses about the energy transition towards energy neutrality is a good approach to interact with multiple stakeholders. Each stakeholder can talk about their interests and concerns regarding the complexity. Get to know the potential partners for a collaboration to deal with this energy transition is essential. The main stakeholders for this collaboration are the housing associations, utility companies and governments. The recommended involvement of a software company is also pointed out.

The interviews are slightly different for each stakeholder, because of differences in interests and sphere of activity. Important is the consistency of the questions towards the different stakeholders. The topics are the same so a clear and reliable comparison can be made between the different stakeholders. To gain a national impression of the opinion about spatial information and renewable energy within the housing associations sector through the Netherlands, it is important to interview experts through the whole country as much as possible. The approached stakeholders for an interview are housing associations, utility companies, governments, software companies and a consultancy company.

HOUSING ASSOCIATION

The housing associations are the main stakeholders regarding the main research question. In this case, the consultancy process is focussed on the advice towards energy neutrality for a housing association by a consultancy company. As already mentioned in the problem definition of Chapter 1, housing associations work mostly with non-spatial data and are not always aware of the opportunities spatial data can offer. It is important to get to know the motives behind the business activities and to get familiar with the trends within those business activities. The results of the interview can approve whether the problem definition is grounded or not.

Utility company

The utility companies are also selected as stakeholders next to the housing associations, because of the impact the new energy strategies have on the subterranean infrastructure. As already stated in the literature review in Chapter 2, the movement from centralized energy generation towards decentralized energy generation in the future is going on. Subterranean infrastructure as water-, gas-, and district heating pipe networks must also adapt to this movement. Two types of utility companies are separated in the Netherlands. The most familiar utility companies take care of the water-, and gas pipes and are regulated by the national government. The district heating networks are not yet regulated by legislations but are also provided by a utility company. It is important to get to know the opinions about both types of utility companies, so both types should be interviewed.

Government

The governments have a key role within the energy transition. The current legislations have influence on the entire process and changes in legislations have an impact on the energy transition. It is important to speak to experts across the country. In case of governments, the province Groningen in the North of the Netherlands is suffering from earthquakes because of gas extraction (Nu.nl, 2017). Their opinion about energy transition can differ from the opinions elsewhere in the country.

Software company

Real estate management is complex. Each housing association operates on their own manner to optimize the dwelling stock they are responsible for. Policies and strategies are often based on gathered data about their dwelling stock. Not every housing association is able to collect data by itself, so they employ software companies for their data storage. Taking the right decisions depends on up-to-date data.

Consultancy company

Part of the research question is based on the consultancy process. The main research question is; *'How can spatial information support consultancy towards housing associations in their transition towards district heating networks.* Important part of this section is in the first place to gain understanding in the consultancy process, specific in this case the consultancy process in advising towards energy neutrality. Get to know the separate phases of this process and the characteristics of each phase is important to allocate the role of spatial information in this process. To find out those phases, a qualitative interview with a consultancy company can give a clear overview of the separate phases.

Section 2.4.2 contains the consultancy process description included in the literature review. The eight steps of Figure 12 can roughly be divided into three main aspects, namely 1. Monitoring the situation, 2. Utilize knowledge and experience and finally 3. Introducing recommendations. The interview should show off whether the aspects of the consultancy process found in the literature corresponds with the aspects of the involved consultancy company in this specific case. After this interview, the allocation of the GIS-based tool within the consultancy company can be determined.

3.2.3 CONDUCTED INTERVIEWS

In this case a total of 13 stakeholders are interviewed, namely a selection of six housing associations based on the amount of dwelling stocks, three utility companies, two governments, a software company and a consultancy company. Figure 16 shows the distribution of the different interviewed stakeholders through the Netherlands. The number of interviews is sufficient for a qualitative research approach, because it is about the content of the answers instead of quantitative data collection. Not all the approached stakeholders responded to the mail.

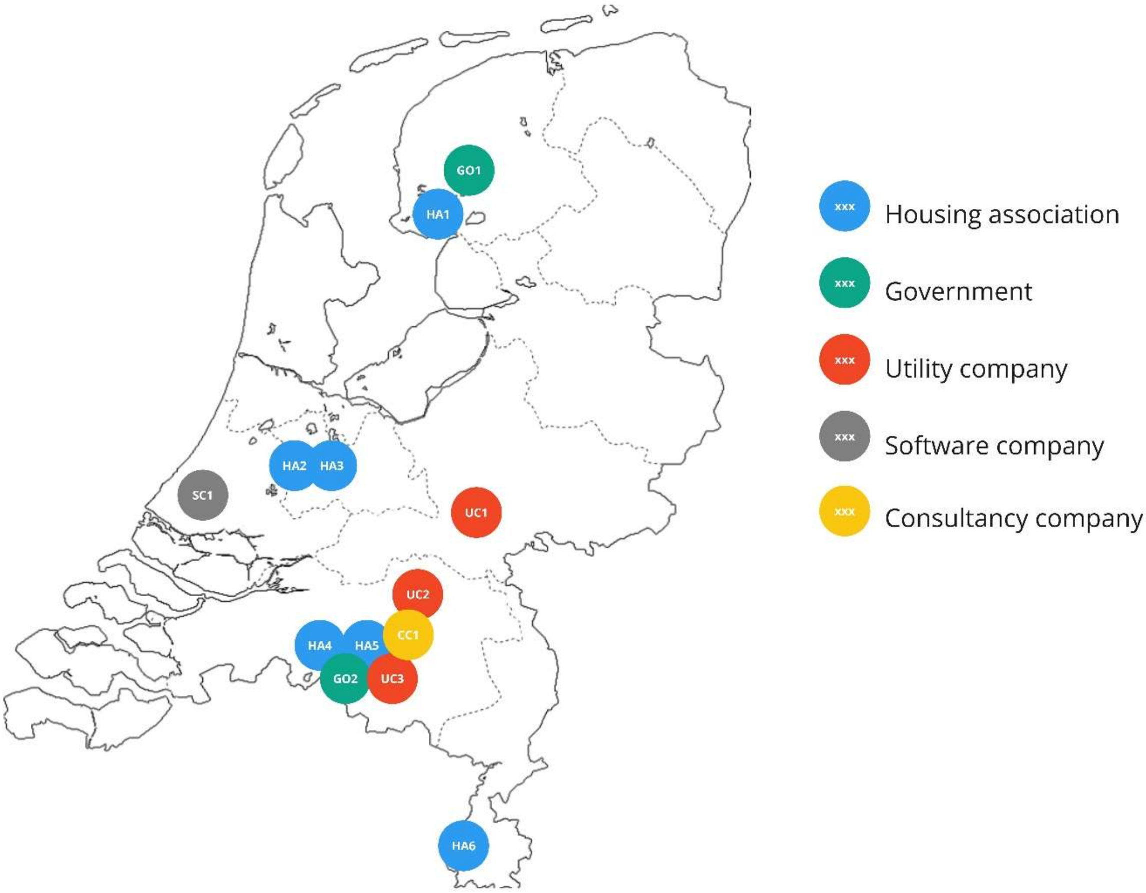


Figure 16. Distribution of stakeholders

HOUSING ASSOCIATIONS

A total of six housing associations distributed through the Netherlands are interviewed. To gain a better insight in the opinions about the topic of this research, housing associations with varied sizes are selected and all the interviewed employees have divergent functions. The employees are all involved in the process of achieving a more sustainable dwelling stock of their housing association. Table 9 shows an overview of the interviewed employees together with the date and time the interview is conducted. The average duration of an interview was approximately 45 min – 1 hour, because of the mix between open-, and semi-structured questions. In this case the interviews are not transcribed but findings of the open questions will be cited in the results in Section 3.2.4.

Table 9. Housing association overview

Stakeh.	Stock	Scaled*	Name	Function	Interviewed on	
HA1	2200	Small	Employee1	Coordinator Scheduled Maintenance	20-06-2017	09:30
HA2	12000	Middle	Employee2	Asset Manager	14-06-2017	11:00
HA3	12000	Middle	Employee3	Real Estate Manager	08-06-2017	09:30
HA4	27000	Large	Employee4	Strategy Advisor	01-06-2017	11:30
HA5	8000	Middle	Employee5	Team Leader Real Estate	13-06-2017	15:00
HA6	3800	Small	Employee6	Project Manager Sustainability	07-06-2017	11:00

* Small; <5000, Middle; 5000-20000, Large <20000 (Atriensis, 2017).

UTILITY COMPANY

To get a good overview of the earlier mentioned different field of activities in Section 3.2, both types of utility companies are interviewed about the impact of the governments, sustainability in energy, (non-) spatial data and Geographical Information Systems. Compared to the housing associations, the topic about consultancy process is not relevant for the utility companies and is not included. Table 10 shows an overview of the interviewed utility companies.

Table 10. Utility company overview

Stakeh.	Field of activity	Name	Function	Interviewed on	
UC1	Water/Gas	Employee 7	Senior Relationship Manager	23-06-2017	11:00
UC2	Water/Gas	Employee 8	Account manager	07-07-2017	08:30
UC3	District Heating	Employee 9	Heat Connection Designer	04-07-2017	10:40

GOVERNMENTS

Because of the complexity of the energy transition and the involvement of legislations, two governments are interviewed about their opinion and role in the energy transition. The first interviewed employee of a government focuses on the effects of gas extraction. The other government is chosen because of the efficacy towards renewable energy resources which is brought to light during a congress about the energy transition. Table 11 shows an overview of the interviewed governments.

Table 11. Government overview

Stakeh.	Focused on	Name	Function	Interviewed on	
GO1	Gas extraction	Employee 10	Sustainable Development	25-7-2017	10:00
GO2	Renewable energy	Employee 11	Climate Policy Officer	29-6-2017	13:00

SOFTWARE COMPANIES

To get familiar with this data collecting process regarding the energy transition of housing associations, a software company is also interviewed. Find out the opinion about renewable energy, GIS and spatial data, impact of governments and consultancy from the software company point of view gives a clearer view on the complexity of the stakeholders involved. Table 12 shows an overview of the software company focused on real estate data.

Table 12. Software company overview

Stakeh.	Focused on	Name	Function	Interviewed on	
SC1	Real Estate Data	Employee 12	Technical Director	27-06-2017	10:30

CONSULTANCY COMPANY

In case of Atriensis, the consultancy process is determined with help of an interview. This interview is held with the management of Atriensis and contains open questions and semi-structured questions. The interview differs from the previous interviews with the housing associations, governments, utility companies and the software company, because the most important part is to gain understanding in the consultancy process. The interview design for the consultancy company is shown in Appendix H. Table 1e shows the timestamp of the interview with two employees of the management of Atriensis.

Table 13. Consultancy company overview

Stakeh.	Field of activity	Name	Function	Interviewed on	
CC1	Consultancy	Employee 13 + 14	Management (CEO)	03-08-2017	11:00

3.2.4 RESULTS

The results of the interviews are formulated with the judgements on the ratio scales which are implemented in the interviews, complemented with quotations of the experts. These quotations are arranged with help of sound recording during the interviews. Table 14 shows the outcome of the interviews with different stakeholders together with the different topics.

Table 14. Outcomes of the rating-questions of the interviews

Stakeholder	Potential of renewable energy sources				Spatial information	
	Wind energy	Solar energy	Geothermal energy	Surplus heat	Use of spatial data	Potential of a GIS
HA1	1	9	1	1	1	8
HA2	7	8	5	3	2	7
HA3	6	9	3	6	5	8
HA4	1	9	5	9	5	9
HA5	7	9	3	5	8	8
HA6	1	8	3	8	1	2
Average	*4*	*9*	*3*	*5*	*4*	*7*
UC1	9	9	9	9	9	9
UC2	8	8	6	6	8	7
UC3	na	na	8	9	9	9
Average	*9*	*9*	*7*	*8*	*9*	*8*
GO1	8	8	7	4	5	6
GO2	7	7	9	4	9	9
Average	*7*	*8*	*8*	*4*	*7*	*8*
SC1	6	9	5	7	4	9
Total averages	*5*	*8*	*5*	*6*	*5*	*7*

***** na: Not applicable***

Two different topics are distinguished, namely the potentials of renewable energy sources and spatial information. These results provide also an answer on the Sub-question about the interests of the different involved stakeholders. The interests of each stakeholder are summed up at the end of this section. The result of the interview with the consultancy company is also providing an answer on the Sub-question about the separate phases of the consultancy process, this is described in Section 3.2.5.

POTENTIALS RENEWABLE ENERGY

The four potential renewable energy resources followed out of the literature review are implemented in the interview. The experts of the stakeholders gave their opinion about wind, solar, geothermal energy and surplus heat. Within the housing associations, the potential of solar energy is by far seen as the renewable energy resource with the highest potential, namely an average rate of 9. PV-panels are already integrated on a large scale in the housing associations dwelling stock, this declares the high potential rate for this renewable energy source. Wind, geothermal energy and surplus heat are rated average 4, 3 and 5. Employee5 (personal communication, June 13, 2017) and Employee1 (personal communication, June 20, 2017) declared that wind energy for housing associations is not profitable yet. Small wind turbines on the roofs are too expensive compared to the amount of electricity they can generate. Employee6 (personal communication, June 7, 2017) added that those small wind turbines induce resistance in the neighbourhood and that receiving a permit is difficult. The opinions about geothermal energy and surplus are corresponding with each other. Both resources are dealing with the dependency of the number of end-users and the availability of suitable earth layers and heat generating companies. Employee1, Employee2 (personal communication, June 8, 2017), Employee3 (personal communication, June 14, 2017) and Employee4 (personal communication, June 1, 2017) declared that geothermal energy and surplus heat are restricted in a most of the cases due to a lack of uncertainty for the future. These findings declare the lower ratings of wind, geothermal energy and surplus heat. Apparently, it is difficult to implement renewable energy resources for housing associations due to uncertainties.

The utility companies are more enthusiastic about the potentials of renewable energy resources. Employee7 (personal communication, June 23, 2017) supports the idea of using all the renewable energy sources if possible. A high potential of geothermal energy together with open heat district networks creates a better basis for companies with surplus heat to join. Employee8 (personal communication, July 7, 2017) stated the same, because geothermal energy is expensive and otherwise the business case of the involved stakeholders will not be lucrative. Investments and returns have a key role in de decisions making process of realising a district heating network or not. Employee8 also mentioned that more innovation towards geothermal energy is necessary. Employee9(personal communication, July 4, 2017) stated the same about the need of innovation toward geothermal energy. Now, UC3 started two pilot studies towards new geothermal energy. Surplus heat is already a success according to Employee 9 and there should put more effort into it to make it a broader success and to decrease the difficulties to transport the heat over greater distances, according to Employee8. Geothermal energy and surplus heat are scored with a 7 and an 8 by the utility companies. Wind and solar energy scored both an average of

9, because they are easy to implement into the current energy infrastructure according to UC1 and UC2. The only side node is that the energy infrastructure should be heavier to be able to manage the earlier mentioned shift from centralized energy generation towards decentralized energy generations, according to Employee7.

Governments are more sceptical about surplus heat. Employee10 (personal communication, July 25, 2017) and Employee11 (personal communication, June 29, 2017) stated that surplus heat is still restricted because of the dependency of companies with surplus heat connected to the heating network. The other three renewable energy resources have a higher potential according to the governments, namely a 7 for wind energy, an 8 for solar energy and an 8 for geothermal energy. Employee11 stated that innovation is very important for wind energy to prove the high potential, which was also stated by Employee1 and Employee5.

Employee12 (personal communication, June 26, 2017) stated that software companies are focused on real estate data and are not competent in exploring the potentials of renewable energy resources. Looking from the software company point of view, solar energy has the highest potential because it is already implemented on the rooftops of the dwellings and in real estate management software. Aspects as for example roof surface, gradient angle and PV-panels are integrated in the software. The opinion of Employee12 about heating districts is that the end-user should not pay more for his/her heat compared to the current situation.

Spatial information

The interview includes whether spatial information is integrated in the work activities or not. Employee12 of SC1 stated that housing associations are used to work with data in an administrative manner. The results of the ratio questions about the use of spatial data within housing associations are corresponding with this statement. The housing associations scored the use of spatial data within their company with an average of 4. Remarkable are the low scores of the small housing associations HA1 and HA6, they scored both the presence of spatial data within their company with a 1, compared to the other housing associations, middle and large, with an average of 5. The explanation of Employee1 and Employee6 about the low presence of spatial data is that they can oversee their small dwelling stock and they are well known with the environmental aspects around the dwellings. The bigger housing associations use spatial information for visualizing and mapping their data. Employee4 stated that spatial data is used for liveability of their tenants and realized it can be used for more objectives, the same Employee3 suggested for topics such as social and demographical aspects. Precondition is that there is an initiative to collaborate with other parties in sharing their spatial data. Employee4 stated that there should be put a lot of effort in collaboration within stakeholders and sharing information, because nowadays sharing information is a one-way communication. All the employees stated that they do use GIS for mapping their data. Visualizing data is one of the highest added value GIS can offer, according to Employee5. The potential for using GIS in the field of activity of housing associations is confirmed by the experts. It can help with combining existing data and create more spatial awareness of the situation, according to Employee2. Only Employee6 scored the potential of using a GIS with a 2. Their small dwelling stock can also be managed without using a GIS.

The use of spatial data is for utility companies very important. All the employees of the utility companies stated that spatial data about their subterranean infrastructure is key in their activities of work. This corresponds with their rating of 8's and 9's for the use of spatial data. They also stated that storage of the geographical locations of their water, gas and heating infrastructure is privacy sensitive because of safety issues and only internally available. Employee8 stated that the data of different stakeholders is important in their decision-making plans, because they can have influence on each other. Because of this reason, Employee9 also believes that sharing as much data as possible between the stakeholders has a positive effect on decision-making, planning and implementation of programmes and policies for a more sustainable development. Empoyee7 stated that this collaboration for a more sustainable development is necessary. At this moment, there is a lack of collaboration between the stakeholders. Utility companies confirmed that they use GIS a lot in their field of activity. Mapping their data, mainly visualizing the infrastructure of their gas, water and district heating pipes, is very important for the three surveyed utility companies. Employee7 is convinced of the potential of GIS in case the next four points are applicable, namely; 1. Openness of the GIS data; 2. Stakeholders' willingness to collaborate; 3. Visualizing the topics for discussion and 4. Finishing the funding.

Governments are facing the need of using spatial data and collaboration with other stakeholders. Employee11 stated that the collaboration between the governments and utility companies is in its infancy now. Exploration towards getting rid of natural gas in the dwellings is the first step of the collaboration. Comparing the spatial data of the governments with the spatial data of the utility companies can optimize the phasing of subterranean infrastructure. Employee10 stated that they have a slight lack of using spatial data. Keeping spatial data up-to-date is important according to Employee11. Remarkable is the difference between GO1 and GO2 in rating the use of spatial data. GO2 rated a 9 and GO1 rated a 5. Employee10 stated that a new department is raised to deal with environmental sustainability, compared to Empolyee11 who stated that GO1 has already a department for environmental sustainability for a longer time. They perceive it is the task for the government to ensure all the stakeholders involved are joining the collaboration. Based on the collaboration, they rated the potential of GIS with a 9, compared to the rated potential of a 6 of GO1.

Employee12 stated that their work of activity and data collection is building-bound, so not much spatial data is involved. There is a tendency towards more use of spatial data in software companies, because the clients are more interested into software with spatial data implemented. Employee12 rated the use of spatial data a 4, but confirmed the potential of using spatial data because of the increase in interests. They stated that the client can decide whether they will share their data with other stakeholders or not. Collaboration with sharing data is mainly focused on real estate management and administrative field of activities. Software companies are developing systems towards the needs of the client. They can develop their own software and decide whether it will have GIS-components or not. Influences of legislations can also be implemented into the software. Good decisions are based on valuable data. Conversations with several clients and exchange of documents is progressing and will help creating awareness for an open source (GIS) platform, according to

Employee12 of DC1. It will take some time before all the stakeholders are willing to and able to work with such kind of open source platform.

Overall, the difference between the low rating of the use of spatial data and the high rating of the potential of GIS is remarkable. This confirms the statement made before in Section 1.2 about the low use of spatial data by housing associations. The stakeholders have confirmed the complexity within the energy transition. They are aware of the need for collaboration between the involved party and have also started this collaboration recently

Sub-question 1

Sub-question 1: What are the interests of the involved stakeholders?

The Sub-question is approached with interviews to get insight into the interests of the different stakeholders. The surveyed stakeholders shared their opinion about the potentials of four renewable energy resources and spatial information. The interest within this collaboration of the involved stakeholders are different. With the results of the interviews, Sub-question 1 can be answered. The following statements are formulated with the views and opinions out of the conducted interview mentioned before.

Housing associations

The interests of housing associations in the energy transition are satisfying the legislations about more sustainable dwellings with keeping in mind the affordability of their vulnerable tenants. They are willing to improve the energetic qualities of the dwellings, but their tenants are still the most important factor which need to be considered. Housing as much tenants as possible is the main goal for the housing associations, because their waiting lists are often very long. They need to find the right balance between investing in sustainability and meeting the legislations versus taking care of enough dwellings for the vulnerable tenants.

Utility companies

The interests of the utility companies are to maintain the quality of the subterranean infrastructure and to meet the legislations they should provide electricity and gas for each dwelling. The shift towards more renewable energy resources causes another approach for the utility companies in the future. The electricity infrastructure must be increased and the gas connections will be replaced very likely by heating networks in the future. Key for the utility companies is to adjust their maintenance planning with the plans of the other stakeholders to reduce inefficient investments. Not only the dwellings of the housing associations are important for the utility companies, but also the private dwellings, offices, industries and social buildings.

Governments

The interest of the governments is to ensure the quality of life of all the inhabitants of their municipality, social housing is a part of that. They should take care of the legislations and subsidies for the housing associations. Interesting statement of the other stakeholders was that the governments should take a leading role to bring stakeholders together. They should provide the necessary collaboration and guide the stakeholders through all the legislations. The governments are not yet regulating the investments in the district heating networks, only in gas and electricity connections. Taking initiative in regulating the heating networks could accelerate the transition towards an energy neutral built environment according to all the stakeholders. Housing associations are often waiting for other parties who are taking initiative in creating heating networks.

SOFTWARE COMPANY

The interests of the software company are focused on commercial goals. Their main goal is to sell the software that they have developed to as much housing associations as possible to gain the highest possible profit. They act most of the time autonomous, but sometimes in collaboration with housing associations to adjust the software to their wishes.

CONSULTANCY COMPANY

The interests of the consultancy company are also focused on commercial goals. The main goal is to make profit with their knowledge about achieving a more sustainable dwelling stock. Consultancy companies which are employed by housing associations have also a social duty. They can contribute to a more sustainable society and to affordable housing for vulnerable tenants. Still, their main goal is to make as much profit as possible.

3.2.5 CONSULTANCY PROCESS

The interview with a consultancy company is conducted to get to know the interests of the consultancy company and to get familiar with the consultancy process towards housing associations itself. Both employees stated that the consultancy process of their company globally consist of five separate phases instead of the three phases mentioned in the literature review. The basis of the three phases is the same, but they added two extra phases. One phase before the consultancy process takes place, namely gaining and sharing knowledge. One extra phase after the process takes place, namely offering a helping hand in executing programs and recommendations. The phases they utilise can be described as follows, compared to the phases (between the parenthesis) stated the literature review Section 2.4.2;

1. Gaining and sharing knowledge (pre-process phase)
2. Define context (corresponds with 1. Monitoring the situation)
3. Explore possibilities (corresponds with 2. Utilize knowledge and experience)
4. Develop advice (corresponds with 3. Introducing recommendations)
5. Offering helping hand (post-process phase)

A visual total overview of the process is shown in Figure 17. The answer on the 2nd Sub-question is provided by this figure. The role of spatial information within those phases is also discussed at the end of this section.

Sub-question 2: What are the phases of a consultancy process towards a housing association?

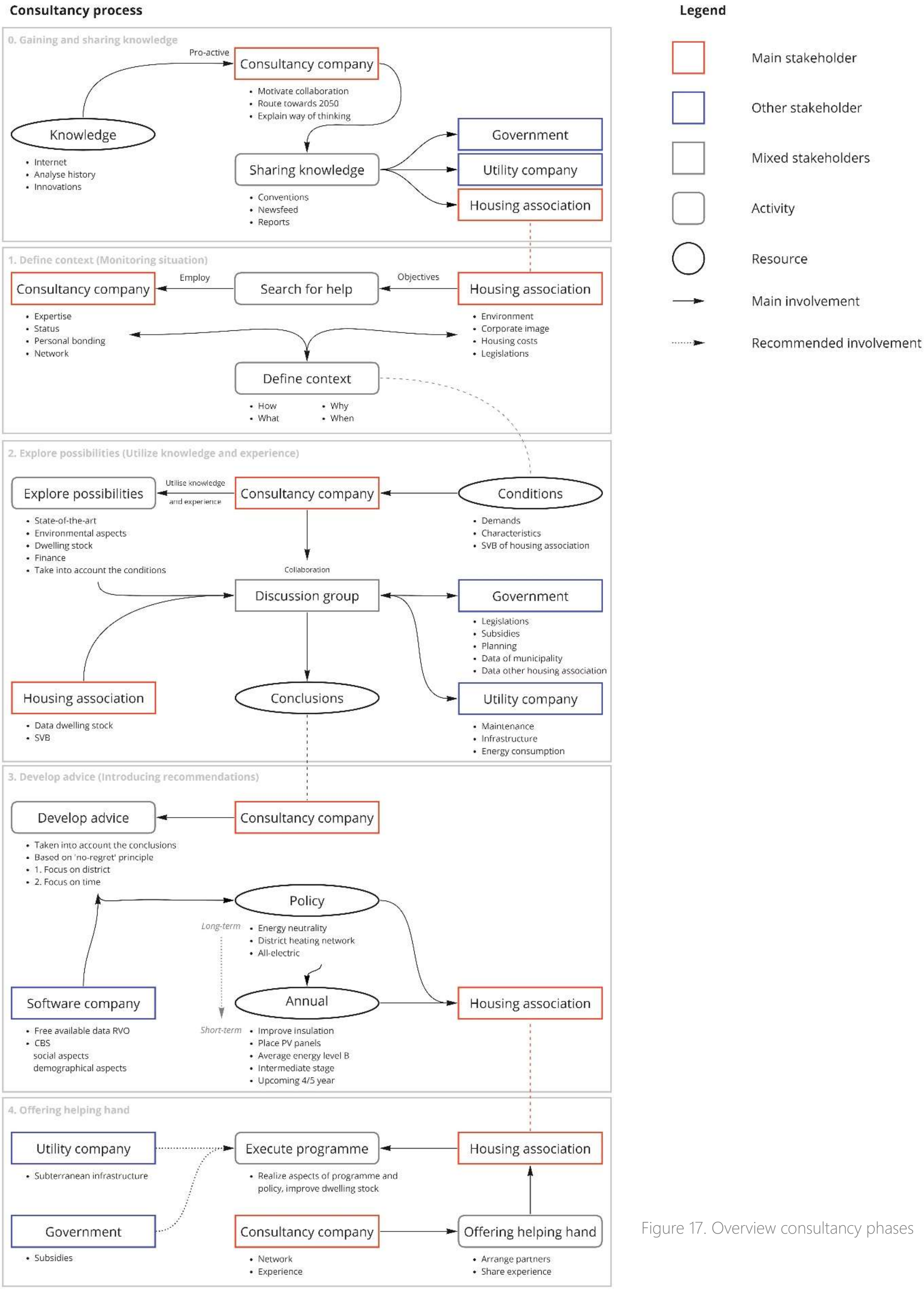


Figure 17. Overview consultancy phases

A more detailed explanation of the different phases of the consultancy process towards housing associations can be found in Appendix I.

OVERVIEW PROCESS

Figure 18 illustrates the process of the specific consultancy company which is employed by a housing association. The red phases are corresponding with the literature review, the blue phases are specific in this case. The process of phase 2 and 3 are together an iterative process, because of the involvement of the consultancy company in the discussion group. Part of the advice can already be developed while the possibilities are still in the exploration phase. Next step is to position the spatial information within the consultancy process**.** Spatial information should be positioned in the most optimal phase or in-between phases. Phase 0 is the knowledge phase and does not contain potential spatial information yet which can be used. Phase 1 is the also not suitable, because the objectives and context of the housing association should be defined first. More interesting is phase 2, because all the stakeholders are involved in this phase together with their potentially usable (non-) spatial information. This phase can be used to suite the diverse types of data for the mutual objectives of the stakeholders. Phase 3 is about the development of the final advice. Ideally, the spatial information should be used in this phase as support for the advice. After the advice is developed and the programme should be executed in phase 4, the spatial information is not necessary anymore. Figure 18 shows globally the five phases of the consultancy process with the spatial information integrated.

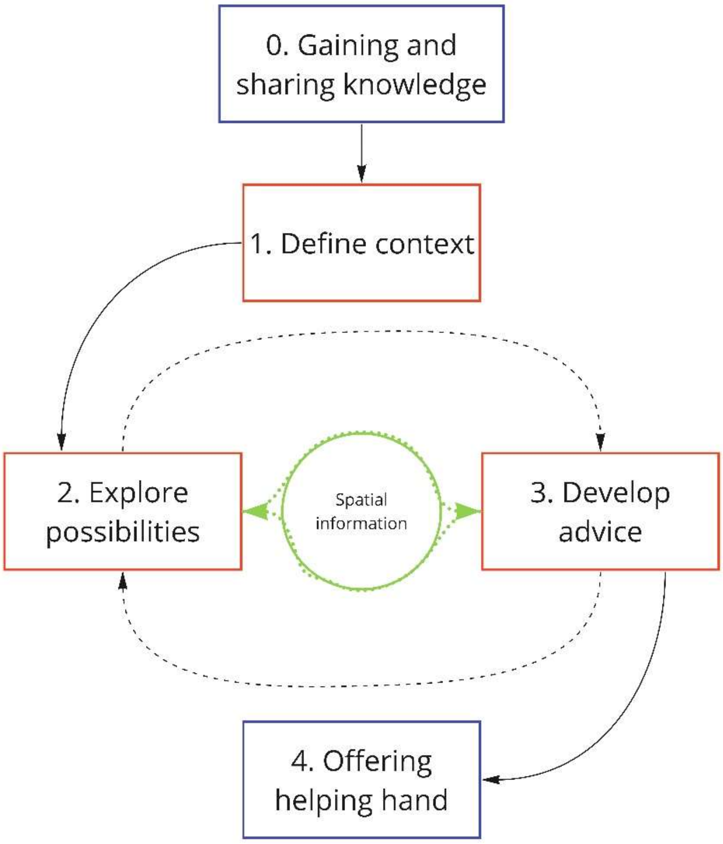


Figure 18. Overview phases of consultancy process

3.3 PRACTICAL GAPS

This section sums up the practice gaps and findings of the multiple interviews with experts in the field. As already concluded in Section 3.2.4, the problem definition about the lack of use of spatial data is confirmed by the interviews with multiple stakeholders. Spatial data is needed to visualize the data for better understanding for the stakeholders (Feteke, Wijk, Stasko & North, 2008). The stakeholders also confirmed that the energy transition is very complex and the need for collaboration between those stakeholders is embraced by all of them. The main practice gap which is stated in this chapter is that only the governments are trying to collect data of multiple stakeholders, but combining those data is still in its infancy. Many of the stakeholders are still reserved in sharing their own data, this complicates the collaboration between those stakeholders. In case of the energy transition, there is a lot of uncertainty about the future. Housing associations, utility companies and governments are all waiting for clear legislations from the government. They are also holding back because of new possible innovations that can be developed in the near future. Because of this, the consultancy company advised to take measurement with the 'no-regret' philosophy. It should be noted that collaboration between stakeholders is still necessary, despite the uncertainties on energy cases. The longer it takes before the forces of several stakeholders are combined, the harder it will be to anticipate on future developments. Policies and views are mainly oriented on the very long term, namely 2050. Other short-term views are oriented on the upcoming 4 to 5 years. There is a gap regarding the middle-term policy towards 2030-2035. Important for this middle-term view for housing associations is to know what the most likely energy-scenario is for their dwellings. The consultancy company defined two main routes towards an energy neutral built environment, namely all-electric or district heating. Measurements on the short-term can affect the view on the long-term. Creating awareness and combine data focused on this middle-term can give good insight in the final energy scenario for the long term. A lack of a supportive tool is stated in de decision-making process whether a dwelling is more likely to be all-electric in the future or begin attached to a district heating network.

4 GIS-BASED TOOL

FRAMEWORK FOR IMPLEMENTING A GIS-BASED TOOL IN THE CONSULTANCY PROCESS

The framework for the tool will be presented in this Chapter, based on the results of the literature review and the findings in practice. Filling a part of those gaps can be supported with the development of the GIS-based tool. A broad description of the fundamentals of the tools and the steps that need to be made are set out in this chapter. Which data is involved and how to combine data of several stakeholders into one GIS-based tool is answered in this Chapter. The main objective of this whole research is to set up a tool, with a well-considered approach, which can be used in the consultancy process towards housing associations.

First, Section 4.1 describes a brief introduction on the existing GIS-software and the functionalities it offers. Section 4.2 provides the focus of the GIS-based tool, because not all aspects of the literature and practice can be implemented into the GIS-based tool due to limitations. The approach on how to set up the framework is described in Section 4.3, followed by the framework itself in Section 4.4. Finally, the conclusions are mentioned in Section 4.5. At the end of this chapter, a clear framework for implementing a GIS-based tool, together with the necessary steps, into a specific consultancy process is given. A building-based suitability map for connecting dwellings to a DH-network is the expected result.

4.1 Introduction

The main research question will be answered with the help of a GIS-based tool. Geographical Information Systems are commonly used in urban and regional scale planning. Integrating energy and environmental models in urban planning tools is recommended for the development of sustainable regions (Manfren, Caputo & Costa, 2011). GIS-models facilitate decision-making in the field of energy transition and can help with achieving sustainable regions by ensuring a realistic basis. Enabling accurate and fast spatial calculations, identifying land constraints and potential sites, calculating spatial energy intensity and providing necessary statistics can be done by GIS tools and can play an increasingly key role in the next years (Manfren, Caputo & Costa, 2011). The computing power of those tools has facilitated multivariable and multi-scale analyses, so the impact of geographical issues can be analysed in multiple disciplines. For example, landscape ecology, geomorphology, population and economic geography and energy planning (Mentis, et al., 2016).

The analytical capabilities are the base of the GIS system. Its spatial analysis functions distinguish a GIS system from other information systems. After the data input is done, which is the most time-consuming part, the GIS can be used. The analysis functions use the (non-) spatial attributes in the database to connect data of different sources based on their geographical component. This model can illuminate the underlying trends in geographic data and make additional information available (Khan, 2016). In case of this research, GIS computations are operated in vector-based maps. Making queries out of this vector-data and retrieving new data is the added value of using a GIS.

The corresponding software of the developed GIS-based tool in this section is QuantumGIS (QGIS). Combining different data of multiple stakeholders will be executed within QGIS. Multiple studies are conducted towards GIS-based activities. Chen et al. (2010) conducted research towards open source GIS software and concluded that QGIS performed extremely well. The functionalities are satisfactory for the most general applications. Table 15 shows an overview of the best open source GIS software packages, with (QGIS) on top. These scores are based on the Market potential, Technical potential and Economical potential (Chen, Shams, Carmona-Moreno, & Leone, 2010).

Table 15. Open source GIS-software

Software	Score		Software	Score		Software	Score
QuantumGIS (QGIS)	82%		OpenMap	67%		JUMP	62%
Thuban	74%		uDig	64%		Kosmo	57%

This open source QGIS software has advantages compared to a proprietary GIS package, namely there is no need for licensing, it will reduce duplication of effort and less duplication means more work towards things that matter and open source allows also for a greater transparency towards other stakeholders (Balter, 2015). Open source is the future and more and more modern and traditional organizations are building open source software.

Spatial queries

Within QGIS, spatial queries can be made to select data out of the database which satisfy specific arranged conditions. Multiple conditions may be combined, for example numbers with text data. A query clarifies the base data, because only the features which are useful in the GIS-based tool are displayed. Data can be selected by using expressions, provided by the integrated operations within QGIS. Spatial joins within the different databases can also be used. Spatial joins can be executed in case data layers do not share a common attribute, but share a common geographical location. These joins can also be specified by arranged conditions (Menke, Smith, Pirelli & Hoesen, 2015).

Vector-based analysis

Compared to the earlier mentioned queries, spatial analyses are based on spatial aspects of the data. Spatial data layers can contain vector-based objects, which can be visualized as polygons, lines or points. Vector-based analysis reveals how unique features of those objects can be related with each other based on geographical allocation. Vector-based analysis which are relevant in this research are buffer analysis, overlay analysis and a nearest neighbour analysis. A buffer analysis and a nearest neighbour analysis can search for specific features within a specified distance to other features and calculate the density or distance of it. An overlay analysis combines attributes based on the spatial relationship between two or more data layers and derives a new data layer with those combined attributes as result (Graser, Mearns, Mandel, Ferrero & Bruy, 2017).

4.2 Focus

The main objective of this research is to define a GIS-based tool which can be used within the consultancy process towards housing associations. A GIS-based tool can be focused on building-oriented and/or district-oriented aspects. Spatial information can be integrated in both approaches. Regarding the four renewable energy resources stated in the conclusion of the literature review, wind and solar energy is assumed as building-oriented and geothermal energy and surplus heat are assumed as district-oriented.

4.2.1 Building-oriented versus district-oriented

Limiting the energy demand of the dwelling is building-oriented, because the energy demand exists of HVAC, DHW and LA. The energy demand of an existing dwelling can be reduced by the parameters shown in Appendix F. Most of the parameters are about reducing the energy demand for HVAC, DHW and LA. Some of them are also focused on generating sustainable building-oriented energy, for example ‘Application of passive solar’ and ‘solar water heating’. The all-electric solution for energy neutral buildings in 2050 as mentioned by the experts of the consultancy company in Appendix I is also building-oriented. Mohammedi et al. (2014) stated that spatial requirements influence the installation of PV panels in urban areas. The potential solar irradiation is a function of building orientation, roof area, roof slope and interaction between buildings and urban vegetation (Mohammadi, Vries & Schaefer, 2014). Mohammedi et al. (2014) also stated that only micro wind turbines close enough to the built-up areas are desirable in urban areas. Geothermal energy and surplus heat are more focused on delivering energy to bigger areas and are more district-oriented. The utility companies, government and housing associations confirmed that renewable energy resources are also necessary for a district-oriented approach. Not every building can be transformed into an energy neutral building with PV panels and/or wind energy, in most of the cases a combination between building-oriented and district-oriented measurements will be applied.

4.2.2 GEOTHERMAL ENERGY AND SURPLUS HEAT

From this point on, the focus is only at geothermal energy and surplus heat, because those resources are more district-oriented. Gas may not be provided anymore in the future. Gas is used for heating and DHW, heath from a district heating network can fulfil this heat demand instead of gas. Geothermal energy and surplus heat are supplying heat for the DH-network. District-oriented and building-oriented solar- and wind energy is not considered, because of multiple reasons. First, district-oriented wind-energy is confirmed to be very difficult by the governments during the conducted interview in Section 3.2. They stated that many municipalities appoint legislations that forbid big windmills in certain areas. Small building-oriented wind-energy is confirmed by many stakeholders as unprofitable. Multiple housing associations and the consultancy company stated that the innovation towards profitable small wind turbines on rooftops is lacking now and they also rated the potential of wind-energy with a 1 as shown in Table 14. Second, building-oriented solar-energy is not considered because of the very different aim and approach it requires as also represented in Section 2.3.2 of the literature review. District-oriented solar energy has also legislation restrictions and is hard to realise in urban environments due to space restrictions. The employee of the consultancy company stated in Section 3.2.4 that the focus should be district-oriented and time-oriented. Geothermal energy and surplus heat are district-oriented solutions for a more sustainable dwelling stock which can be achieved on a long term, while wind energy and solar energy are building-oriented solutions which can be achieved on a short term. Because of the multiple statements mentioned above, geothermal energy and surplus heat are considered as the most applicable renewable energy resources in a GIS-based tool. A schematic overview towards this focus is shown in Figure 19.

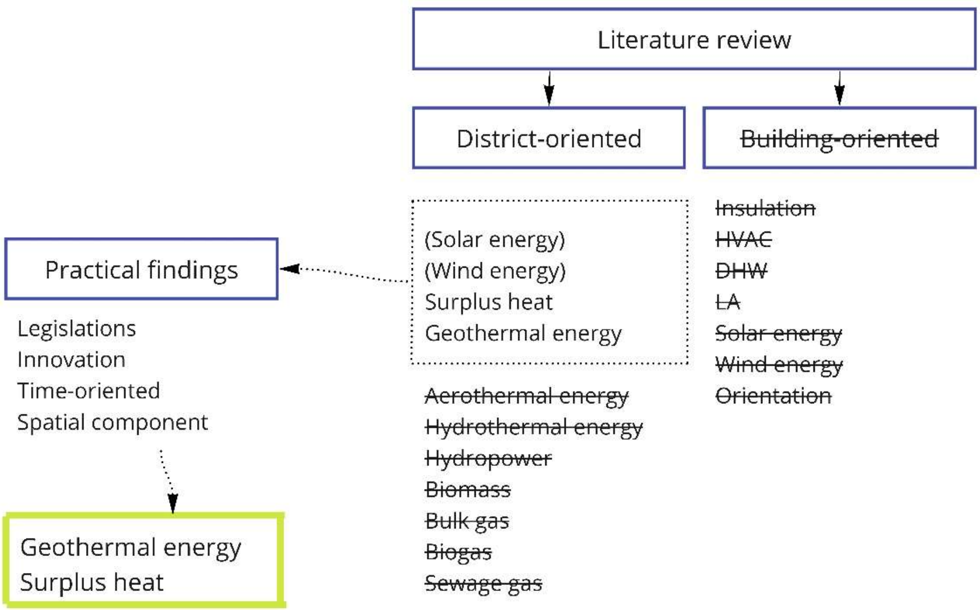


Figure 19. Argumentation for focus

4.3 Approach

In addition to the original overview mentioned in Section 3.2.5, Appendix K shows a more elaborated overview of the presence of GIS opportunities in the second and the third phase of the consultancy company. The housing association can supply data about their dwelling stock for implementing in the GIS-based tool. The governments and utility companies have data about their planning and maintenance structures, infrastructure, legislations and freely available data. Software companies can contribute with their software to make it possible for housing associations to produce data as result of a output of the software. This (non-) spatial data of the diverse stakeholders together can be combined in the GIS-based tool, which can be used by the consultancy company to explore possibilities and to gain additional information for their final advice. To conclude, very diverse types of data can be involved in this process. The framework of the GIS-based tool describes what kind of data from which stakeholder is implemented. The process from implementing data into the GIS-model to produce results is based on a Multi-criteria analysis (MCA).

Multi-criteria analysis

Rikalovic et al. (2014) conducted a GIS-based multi-criteria analysis (MCA) for an industrial site selection. In general, the MCA in the GIS-based tool should be a process of conversion of data to information that adds extra value to the original data. The role of GIS is to geo-reference and analyse feasible alternatives that can be considered in a later evaluation phase during decision making. The main objective of MCA is to produce suitability maps with help the of GIS, based on the value judgements of decision makers. Those suitability maps depend on factors and constraints. The factors are criteria that enhance or detract from the suitability, while constraints serve to limit the alternatives under consideration. Constraints are expressed in the form of a Boolean, namely a 0 in case of excluded from consideration and a 1 in case of open for consideration.

In case of this research, the alternatives are the dwellings of the housing associations. The MCA can help in the decision-making process whether a building is suitable and/or feasible to be attached to a district-heating network. Compared to the approach of Rikalovic et al (2014), this research does not implement an assignment of decision variables to each alternative because there are no multi-attribute decision problems. The following steps need to be taken to conduct a GIS-based MCA (Rikalovic, Cosic, & Lazarevic, 2014):

1. Determining the criteria (consist of factors/constraints);
2. Standardize the factors/criterion scores (example: 0 = least suitable; 1 = most suitable);
3. GIS-based tool to generate suitability score of each criterion;
4. Determine the weight of each factor;
5. Aggregate the criteria to the final suitability map;
6. Verify the results;
7. Recommendation for decision making.

4.4 GIS-BASED TOOL

This section contains a framework for applying the GIS-based tool in a case study. Base for this framework is the focus mentioned in Section 4.2 and the approach mentioned in Section 4.3. The final suitability map represents the suitability for the dwellings (alternatives in terms of MCA) for a potential attachment to a DH-network. The spatial information will be implemented in the tool with QGIS. The framework is shown in Figure 20 and exists of four various steps. Compared to Rikalovic et al. (2014), verifying the results and recommendation for decision making will be discussed after the GIS-based tool is enrolled in a case study. The steps included in the GIS-based tool are based on the steps of Rikalovic et al. (2014) but differs slightly in calculating the standardized scores in step 3. Also, step 1 and 2 mentioned by Rikalovic et al. (2014) are combined in this framework. The following steps are included:

1. Define criteria, scores and constraints;
2. Generate results out of data (within QGIS);
3. Standardize scores and assign weights;
4. Calculate and visualize final suitability (within QGIS).

The different steps are each discussed in the following sections.

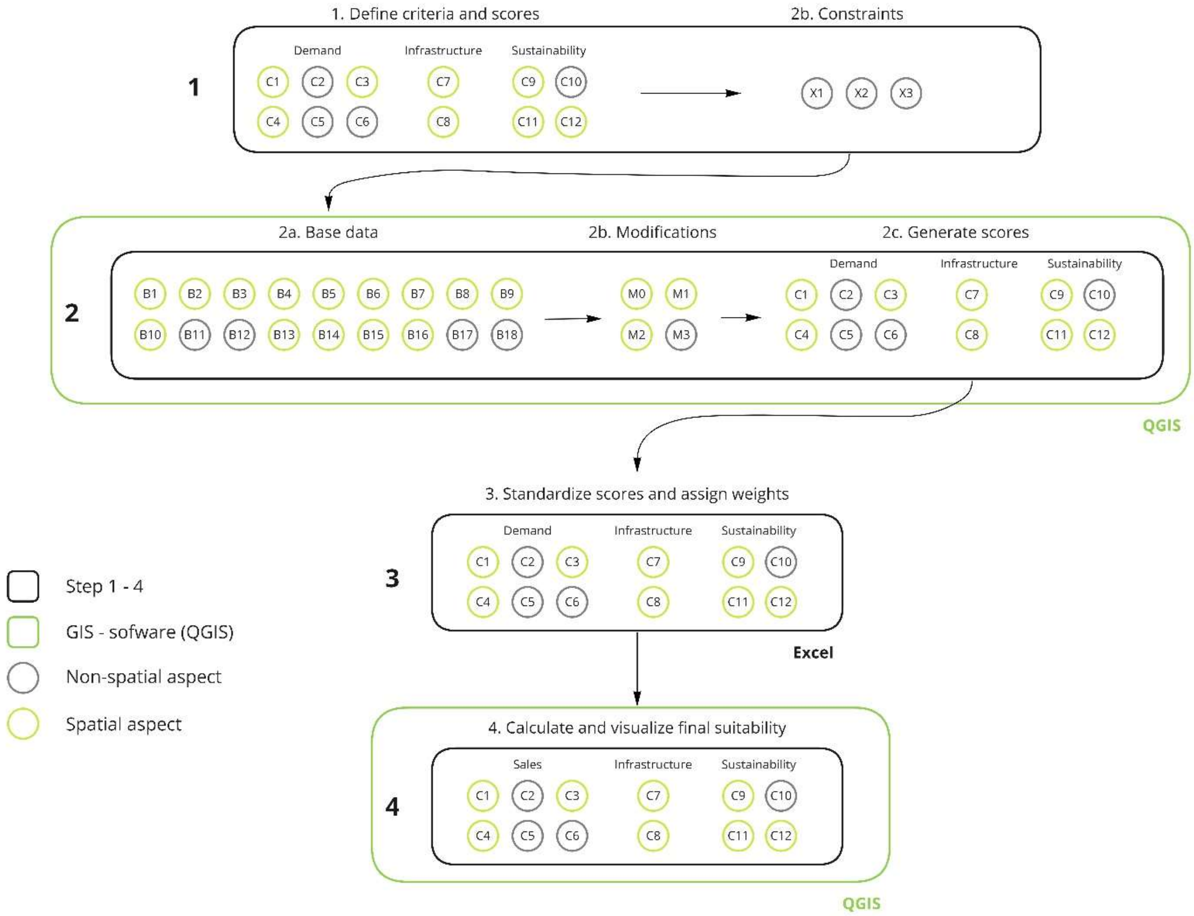


Figure 20. Overview of the framework

4.4.1 Criteria, scores and constraints

The final suitability map is based on multiple criteria. Those criteria contain scores on suitability. In case of this research, multiple aspects of the likeliness to attach a dwelling to a DH-network are translated into criteria. This corresponds with the first step of the definition of a MCA of Rikalovic et al. (2014) mentioned in Section 4.3.2. Determining the criteria is a time-consuming process, because each criterion need to be well underpinned so the result will be as reliable as possible. Findings in the literature review, the practical study and well considered assumptions are used to determine the criteria. Three main aspects for criteria are determined, namely the demand, infrastructure and sustainability. The demand is separated into two sub aspects, namely amount of heat and complexity. The amount of heat is based on the number of households which can be potentially attached to the DH-network. The complexity of the demand is based on the degree of applicability of a (non-existing) DH-network. Infrastructure is an important aspect taking into consideration financial aspects. Sustainability is an important aspect because the DH-network is depending on the available renewable energy sources which can be attached to the network to fulfil the demand for heat. Table 16 shows the overview of the 12 defined criteria together with the range of scores.

Table 16. Overview of criteria and the corresponding scores

Aspect		Criterion		Scores (0 – 1)
1	Demand			
	Amount of heat	C1	Addresses per building	1 (SH) - >50 (MH)
	Amount of heat	C2	Building age	>50 year – 0 year
	Complexity	C3	Private-owner addresses	Within 500 m; >70% - <30%
	Amount of heat	C4	Gas consumption	<400 m^3 - >2000 m^3
	Complexity	C5	Ownership	Ground lease - VvE – full ownership
	Complexity	C6	Heating system	Individual – collective
2	Infrastructure			
		C7	Distance to DH-network	>1500 meter – 0 meter
		C8	Distance to potential surplus heat	>5000 meter – 0 meter
3	Sustainability			
		C9	Existing geothermal energy	Within 1500m: 0 GJ – 600 GJ a year
		C10	Energy label	A – B – C – D – E – F – G
		C11	Existing surplus heat	Within 1500m: 0 – >500 Terajoule
		C12	Geothermal potential	0 GJ – 600 GJ a year

The scores of the criteria are based on a range. Each score is also standardized between 0 and 1. For example, criterion C4 – Gas consumption has a range from 400 m^3 to 2000 m^3. If a building has a gas consumption of 400 m^3 or lower, the building scores a 0 on criterion C4, if a building has a gas consumption of 2000 m^3 or higher, the building scores a 1 on criterion C4. A building with a gas consumption of 1000 m^3 scores 0.375 on criterion C4. This is an ascending range. Criterion C2 – Building age has a descending scoring curve. Building with a higher building age score lower compared to building with a lower building age. Each criterion will be discussed in this section.

DEMAND

The first aspect is about the demand. A total of six criteria are defined regarding this aspect. Three of them affect the amount of heat and the other three affect the complexity.

C1 – Addresses per building: The more addresses a building contains, the higher the demand of heat per building is. A building with only 1 address per building is a single household building and a building with two or more addresses per building is a multiple household building. A high level of urbanism is necessary for a DH-network according to multiple housing associations interviewed in Section 3.2.4. The higher the amount of addresses per building, the higher the score of this criterion is, with a maximum assumed score at 50 addresses or more per building. A single household scores a 0, households with 50 or more addresses per building score a 1. For example, 25 households per address score a 0.5

C2 – Building age: This criterion is about the remaining exploitation of a building. Normally, the older a building is, the less long this exploitation will be. Housing associations write off their dwellings on average over 50 years (Nunen, 2013). The younger a building is, the longer its lifespan, the longer it can import heat of the DH-network. Because of this reason, buildings older than 50 years are assumed to score a 0, newly built buildings score a 1. For example, a building with a building age of 20 scores a 0.6.

C3 – Private owner addresses: This criterion is about the complexity. The more private owner addresses are surrounding a housing associations dwelling, the more difficult it is to attach the dwelling to a DH-network. According to the interviewed housing associations in Section 3.2.4, the more private owner addresses are in a specific area, the less control the housing associations have on decision making towards a DH-network. Often, 70% or more of the total stakeholders need to agree on decision before they can be carried out. The dwelling scores a 0 if 70% or more private ownership households are surrounding the dwelling and scores a 1 if 30% or less private ownership households are surrounding. For example, if a dwelling has 60% private ownership households within 500m, the dwelling scores a 0.25.

C4 – Gas consumption: The higher the gas consumption per dwelling is, the higher the need to replace the heat demand with geothermal energy or surplus heat. Seen from the amount of potential heat delivery, higher gas consumption means a higher heat demand of the dwelling, so it is more likely to attach the dwelling to a DH-network. Dwellings with 2000 m^3 or more score a 1 and dwellings with 400 m^3 or less score a 0. For example, a dwelling with a gas consumption of 1000 m^3 scores 0.375.

C5 – Ownership: This criterion is almost the same as criterion 3. The difference between those criteria are the scale. Criterion 3 is focused on a neighbourhood scale, while criterion 5 is focused on the ownership of the housing association on building-/complex level. Full ownership of the building reduces the complexity in decision making processes. Full ownership is scored with a 1, partly ownership of a complex scores 0.5 and an association of owners (in Dutch: Vereniging van Eigenaren (VvE)) scores a 0, because the control is divided over multiple owners.

C6 – Heating system: According to the interviewed consultancy company in Section 3.2.4, it is easier to attach buildings with collective heating systems compared to individual heating systems. Transform from an individual heating systems to a collective heating system involves more complex modifications to the dwelling. Transforming a collective heating system into a connection to a DH-network does not need modifications on dwelling level. The activities are outdoors. Because of this, collective heating systems score a 1 and individual heating systems score a 0.

Infrastructure

A total of two criteria affect the scores for infrastructure, namely criterion 7 and 8. According to the interviewed utility company mentioned in Section 3.2.4, DH-network have very high initial costs. The more infrastructure is necessary to construct, the higher the costs will be. In this research, costs are not implemented. It is assumed that the more infrastructure is necessary to attach the dwelling to the DH-network, the more this will cost. The potential customers benefit from efficient infrastructure for as low costs as possible.

C7 – Distance to DH-network: The closer a dwelling is located to an existing DH-network, the less infrastructure need to be constructed to attach the dwelling to the DH-network. For this criterion, 1500m or more from the dwelling to an existing DH-network is assumed to score a 0, the closer the dwelling is to the dwelling, the higher the score. There is no information about absolute costs integrated in this criterion due to a lack of key figures because of the divergent findings from practice.

C8 – Distance to potential surplus heat: While criterion 7 looks at the infrastructure of the demand-side of the DH-network, criterion 8 looks at the supply-side of the DH-network. The more potential surplus heat sources are located near dwellings, the more likely it is to attach them to a DH-network, according to the interviewed consultancy company mentioned in Section 3.2.4. The scale for the distance is assumed between 0 and 5000m. This distance is higher compared to criterion 7, because the supply side of the DH-network provides heat for multiple dwellings. This supply is necessary for the DH-network to let it work, so also potentials located further away should be scored within this GIS-based tool. Still, the closer the potential surplus heat is to the dwelling, the higher it scores because of lower infrastructural costs.

Sustainability

The last four criteria cover sustainable aspects. Those criteria are focused on the energetic quality of the dwellings and the use of renewable energy resources. Criterion 8 is also about the use of a renewable energy resources, but infrastructure has a stronger presence.

C9 – Existing geothermal energy: The heat supply of geothermal connections is very high. The more geothermal connections exist, the more dwellings can be fulfilled in their heat demand with geothermal energy. The more existing geothermal energy is available within a range of 1500m, the higher the score for the dwelling.

C10 – Energy label: The better the energy label, the less heat loss a dwelling has. Attachment to a DH-network is for dwellings with a good energy label less necessary than for dwellings with a bad energy label. The heat loss of dwellings with a bad energy label should be compensate with renewable energy to achieve a more sustainable built environment.

C11 – Existing surplus heat: This criterion has the same aim as criterion 9 about geothermal energy, but now for surplus heat. The more surplus heat resources already exist, the more likely it is that they can fulfil the heat demand of the dwellings. The closer an existing surplus heat source is for a dwelling; the less heat will be lost during the heat transmission from the source to the dwelling.

C12 – Geothermal potential: The last criterion for this GIS-based tool is the geothermal potential. According to Tselepidou et al. (2010) mentioned in Section 2.3.2, market penetration of geothermal energy is still restricted because of financial reasons. Optimization of geothermal resources is very important, because higher transmittivity zones can reduce pumping costs. The higher the geothermal potential underneath a dwelling, the more likely it is that geothermal connection will be created in the future near the dwelling, so the higher the score.

CONSTRAINTS

A total of three constraints are defined as already showed in Figure 20. The objective of this framework is to calculate the suitability score for the likelihood to connect a dwelling to a DH-network. Table 17 shows the three constraints together with the scores.

Table 17. Overview of constraints

#	Constraint	Score	Standardized
X1	Connected to DH-network	Yes – no	0 - 1
X2	Obstructing legislations	Yes – no	0 - 1
X3	Residential function	No – yes	0 - 1

Dwellings which are already connected to a DH-network are excluded, because it is not necessary to calculate a suitability score if a dwelling is already connected. In case the dwelling is already connected, a 0 is assigned and if not a 1 is assigned. The second constraint is whether there are legislations which can obstruct the dwellings from being attached to a DH-network or obstruct the construction of new DH-network infrastructure. If there are, a 0 is assigned and if not a 1 is assigned. The third constraint is whether the building has a residential function or not. A 0 is assigned in case a building has no residential function and a 1 is assigned to the buildings which contain a residential function.

4.4.2 GENERATED RESULTS OUT OF DATA

After the criteria are clear, the scores can be calculated. Next step is to determine which kind of data is involved within GIS-based tool. This step will also answer sub-question 3, mentioned in Section 1.3. After the data is collected, determination of the modifications executed within the GIS-software is the next step. How to deal with the (non) spatial data, spatial analysis and the adopted functionalities the software offers for this research. Two data resources are distinguished for this research, namely open data and closed data.

OPEN DATA

The broadest definition of free accessible data is open data. *Open data is data that can be freely used, re-used and redistributed by anyone – subject only, at most, to the requirement to attribute and share-a-like* (Open data handbook, 2017). Open data contains three key details; the data must be available as whole and preferably by downloading over the internet, the data must also be provided under terms that permit re-use and redistribution including the intermixing with other datasets and the data must be able to be used by everyone. Open data is made available by the government. In case of this research, the government is also a stakeholder in the energy transition so they can deliver necessary (open) data if it is not published on the internet yet.

CLOSED DATA

A consultancy company is not collecting data by themselves (first party data). They are always in a position that first-hand information is not available. This is where closed data become useful. Closed data is someone else's first party data, and in case that the closed data is originating of a stakeholder, they are willing to share their customer data (Limon, 2014). Reflecting on the stakeholders within the energy transition, housing associations are willing to share their data with the consultancy company and governments, because all the stakeholders have the same objective of an energy neutral built environment in 2050.

SUB-QUESTION 3

Sub-question 3: Which (non-) spatial data is involved in the GIS-based tool?

To answer this question, findings out of the literature, interviews and well-thought-out assumptions are used to determine which data is involved in the energy transition focused on geothermal energy and surplus heat.

First, data about the level of scale is necessary to determine specific boundaries of data. These five borders are based on geographical information and have spatial components implemented. These boundaries depend the scale and are defined from large to small in the following order:

1. Municipality border
2. District border
3. Neighbourhood border
4. Zip-code border
5. Building border

Second, when the boundaries are determined, the infrastructure can be inserted into the tool. This is data about the infrastructure like roads and DH-networks. The utility company stated that the infrastructure of DH-networks corresponds mostly with the infrastructure of the roads. These datasets also contain geographical information and have spatial components. The following data should be inserted:

6. Trajectory of main roads
7. Infrastructure of existing DH-networks

Third, when the geographical boundaries and infrastructure are inserted, data about the existing buildings should be inserted. In this case, data on building-/complex level such as, housing association dwellings, addresses, energy label, gas consumption and the heating installation of the building is important for further modifications. Those aspects were mentioned in the interview with the consultancy company and housing associations and are important to consider:

8. Addresses
9. Dwelling stock HA
10. Gas consumption
11. Heating installation
12. Energy label

The existing heating network is already mentioned in the infrastructure, but data about potentials and existing connections should also be implemented. This data can be harder to gather, because of uncertainties mentioned in the results of the interviews. The following data is completing the data sources:

13. Geothermal connections
14. Geothermal potential
15. Surplus heat connections
16. Surplus heat potential
17. DH-network connections
18. Legislations

All the above-mentioned data act as basis for further modifications within the GIS-based tool and is the data involved within the energy transition. With this section, Sub-question 3 is answered. All the data should be available, in case the data is not available, adjustment could be made. The more and realistic data involved in the GIS-based tool, the better the result will be in the end. An overview of the base data is summarized in Table 18.

Table 18. Overview base maps

Aspect	Base data	Name	Level of detail
Scale	B1	Municipality borders	Municipality level
	B2	District borders	District level
	B3	Neighbourhood borders	Neighbourhood level
	B4	Zip-code borders	Zip-code level
	B5	Buildings	Building-/complex level
Infrastructure	B6	Roads	Neighbourhood level
	B7	District heating network	Neighbourhood level
Building	B8	Addresses	Building-/complex level
	B9	Dwelling stock HA	Building-/complex level
	B10	Gas-consumption	Building-/complex level
	B11	Heating installation	Building-/complex level
	B12	Energy label	Building-/complex level
Energy	B13	Geothermal connections	Neighbourhood level
	B14	Geothermal potential	District level
	B15	Surplus heat sources	Neighbourhood level
	B16	Surplus heat potential	Neighbourhood level
	B17	Dwellings connected to DH	Building-/complex level
	B18	Legislations	Neighbourhood level

MODIFICATIONS

After the necessary data is set out as input for the GIS-based tool, modifications of the data within the GIS-based tool need to be executed with help of the multiple GIS-functionalities which are already mentioned in Section 4.1. The modifications will combine diverse types of data with each other so they can be implemented into the GIS-based tool that will be developed. The following modifications will be executed to the data mentioned before and are summarized in Table 19.

Table 19. Overview of modifications

#	Modification	Spatial
M0	Adjust all data to a specific scale/region	Yes
M1	Extract housing associations' properties	Yes
M2	Average gas consumption	Yes
M3	Add columns for join functions	No

The first modification is to adjust all the data to the specific scale or region the proposed GIS-based tool is going to be implemented for. As already mentioned in Section 4.4.1, open data is often available on a national level. Implementing data in the GIS-based tool which is outside the borders of the region is causing unnecessary delays for the future analyses. The second modification is to extract the housing associations' properties, because this research is focused on the role of spatial information towards consulting housing associations. The third modification is to calculate the average gas consumption on a specific scale which need to be determined. Gas consumption is, according to the utility company interviewed in Section 3.2.3, not available on a very detailed level due to privacy concerns. Utility gas- and residential gas consumption should also be separated, because otherwise an unreliable gas consumption per housing associations' property is determined. The fourth modification is to create columns to join functions. It is important to combine data of different data sources. The three join columns in this research are based on building ID, zip-code and address ID. Preparing data for joining is part of the modification. This is also necessary to combine non-spatial data with spatial data for further analyses. Vector-based analyses and queries need to be executed within the GIS-environment to carry out the four modifications.

4.4.3 STANDARDIZED SCORES AND WEIGHTS

The final score consists of the scores from the criteria combined with their assigned weights. Determining the weights for the criteria corresponds with the fourth step of Rikalovic et al. (2014) mentioned in Section 4.3.2. Table 20 shows the determined criteria with their corresponding weights based on well-thought-out assumptions. The sum of the assumed weights together is 50. Looking at the three main aspects, the demand is the most important aspect with a weight of 26, followed by infrastructure and sustainability with both a weight of 12. The demand is the most important aspect according to the housing associations interviewed in Section 3.2.4. Uncertainty in the future about DH-networks arises because of a lack of guaranteed demand. According to the interviewed utility company, the investment costs are too high for a lower demand and not feasible. Because of this reason, the amount of addresses per building and the distance to the DH-network have an assumed weight of a 7 and a 9. The remaining exploitation time of a building is weighted with 5. The lifetime can be extended with renovations, so the building age is not always significant for the remaining exploitation time. Private-owner addresses within a range of 500m are also weighted with 5. It is more difficult to make decisions on neighbourhood scale about DH-network compared to building-/complex scale, so it is better that housing associations have a higher share within 500m than within the building. Because of this reason, building/complex ownership is having a lower weight compared to presence of private-owner addresses, namely a weight of 3. Gas consumption, heating system and energy label are also weighted with a 3, because they are assumed to have the same effect on the suitability to attach to a DH-network. Existing geothermal energy has a higher weight (5) compared to existing surplus heat (3) because of the higher energy supply, while geothermal energy potential is weighted lower (1) compared to potential surplus heat (3), because geothermal energy is more difficult to apply due to higher costs and uncertainty about the absolute heat supply.

Table 20. Overview weights

Aspect	Criterion		Weight
1. Demand	C1	Addresses per building	7
	C2	Building age	5
	C3	Private-owner addresses	5
	C4	Gas consumption	3
	C5	Ownership	3
	C6	Heating system	3
		Max demand	*26*
2. Infrastructure	C7	Distance to DH-network	9
	C8	Distance to potential surplus heat	3
		Max infrastructure	*12*
3. Sustainability	C9	Existing geothermal energy	5
	C10	Energy label	3
	C11	Existing surplus heat	3
	C12	Geothermal potential	1
		Max sustainability	*12*
		Max total	50

4.4.4 Final suitability scores

The scores for each criterion can be aggregated into an overall score and presented in a map. This map is the final suitability map and visualizes the score of each individual dwelling of a housing association. This corresponds with the sixth step mentioned by Rikalovic et al. (2014). The suitability scores for each building are based on the standardized score of Table 16 times the corresponding weights mentioned in Section 4.4.3. The dwellings with the highest scores are the most likely ones to connect to a DH-network in the future. As already mentioned in Section 4.4.3, only the dwellings which score three times a 1 on the constraints will have a final suitability score. If they score a 0 at one or more constraints, the final suitability score will also be 0. The final score for a specific dwelling is calculated as follows;

Equation 2. Final score for a dwelling

$$FSS_f = (\sum_{i=1}^{12} w_i c_i) \times (\prod_{j=3}^{3} x_j) \qquad (2)$$

Where FSS_f is the final suitability score of dwelling f, w_i is the corresponding weight for criteria i, c_i is the value score of criteria i and x_j is the score for corresponding constraint j. If a dwelling meets one of the three constraints mentioned before, the final score will always be 0 and will exclude the dwelling. The suitability map can act as decision making tool for policies on the middle-term, as mentioned in Section 3.5. The structure of GIS-based tool shown in Figure 20 sums up this Section 4.4. Important added value is the spatial components it has implemented. Spatial components are marked with green in Figure 20.

Aggregating the final suitability scores for dwellings into final suitability scores for neighbourhoods is the last step of the GIS-based tool before the results can be verified on different scales. The scores of the dwellings need to be aggregated to neighbourhood level. This aggregation can be executed by calculating the average final suitability score of all dwellings within a neighbourhood. Though, wrong interpretations on the final suitability score of neighbourhoods can occur because also neighbourhoods with less dwellings can have a good score. This can indicate that a neighbourhood is unfair scored as likely to be attached to a DH-network and is contradictory with earlier stated arguments about the importunateness of a high demand to make a DH-network more feasible. Because of this reason, the number of dwellings per km^2 with a final suitability score higher than 0 must be added to the neighbourhoods for providing a better insight in the opportunities of a DH-network. Stakeholders have insight in the final suitability score of a neighbourhood based on the average final suitability scores of the dwellings and in the density of the averaged dwellings within the neighbourhood. In this way, the stakeholders can decide by themselves whether to invest in a DH-network in a neighbourhood or not.

MISSING DATA

The results can differ in specific situations, depending on of the available data. The final suitability score is defined in an ideal situation in case all the necessary data is available. The more data is implemented in the GIS-based tool, the more realistic and reliable the final suitability map is. In case of a lack of data, a criterion or more criteria should be dropped from the GIS-based tool. In that case, the final suitability map consists of less criteria so the summed total weight could be less than the total weight of 50 mentioned in Table 20. The final suitability score will be calculated proportional with the total weight.

4.5 Conclusion

The GIS-based tool is developed to calculate the final suitability score for a single dwelling. This suitability score gives the likelihood for a dwelling to be attached to a DH-network in the future, based on spatial and non-spatial criteria. The spatial characteristics of the GIS-based tool are the functionalities within QGIS. Most of the score calculations for the criteria are based on spatial analyses. Criterion 3, and criterion 11 are examples of a buffer analysis which is mentioned in Section 4.1. Criterion 1 is an example of an overlay analysis which is also mentioned in Section 4.1. Depending on the level of detail of data about gas consumption and geothermal potential, an overlay analysis can also be used for calculating the scores for criterion 3 and 12. Criteria 7 and 8 are examples of nearest neighbour analysis. Those analyses demonstrate the core of the use of a GIS, because using those spatial analysis within a GIS-software environment is the only way to gain these results. The scores for other criteria can also be calculated by other information systems, for example Excel.

5 CASE STUDY

IMPLEMENTATION OF THE GIS-BASED TOOL FOR VALIDATION

This chapter shows the results of the GIS-based tool, presented in Section 4.4, in a case study. The intention is to demonstrate the procedure and functioning of the tool, together with the results. Those results will provide an answer on the fourth sub-question, namely how to combine diverse types of data in the GIS-based tool. The case study is focused on the municipality of Tilburg. Interviews with housing associations and the government in Tilburg, mentioned before in Section 3.1, showed that Tilburg is a progressive municipality in the field of sustainability.

A brief introduction on the study case is given in Section 5.1. An extended description of the implementation of the GIS-based tool is presented in Section 5.2. The data sources, modifications, constraints and criteria are described step by step in this section. Section 5.3 contains the outcomes of the GIS-based tool. At the end of this Chapter, a clear overview of the likelihood for connecting to a DH-network of each dwelling of a housing association in Tilburg is shown in the suitability map.

5.1 Introduction

The municipality of Tilburg is chosen to enrol the GIS-based tool mentioned in Section 4.4. Multiple conversations with stakeholders from Tilburg act as base for this enrolment. Interviews with two housing associations located in Tilburg and an interview with the government of Tilburg give a good insight in the ambitions to create a more sustainable built environment. Recent developments on the sustainability topic within the municipality of Tilburg are about renewable energy resources. A new department is created to explore the possibilities for all the private residential buildings and to a lesser extent the housing associations' dwellings. At this moment, this exploration is in its infancy. The awareness of the complexity this question provides is already created. This corresponds with the earlier finding within this research mentioned in Section 3.2.4. A second interview with an employee of the municipality of Tilburg (personal communication, September 9, 2017) confirmed this exploration and he agreed to share some data of the municipality to contribute to this research.

The focus of the case study will be corresponding with the focus mentioned in Section 4.2. Initiatives regarding geothermal energy are in its infancy in Tilburg. Earth drillings for geothermal energy will start in 2018. Drillings of 2,5 km in depth will use groundwater for heating dwellings or industries (Haar, 2017). This renewable energy resource should replace a big part of the gas consumption in the municipality of Tilburg. Figure 21 shows the gas consumption of residential building in the municipality of Tilburg, aggregated on 5 digit-zip code due to privacy concerns. The heat of the renewable energy resources attached to the DH-network already fulfil the heat demand in the district 'Reeshof' in Tilburg, located at the southwest of the municipality. Other districts are still using gas for HVAC and DHW.

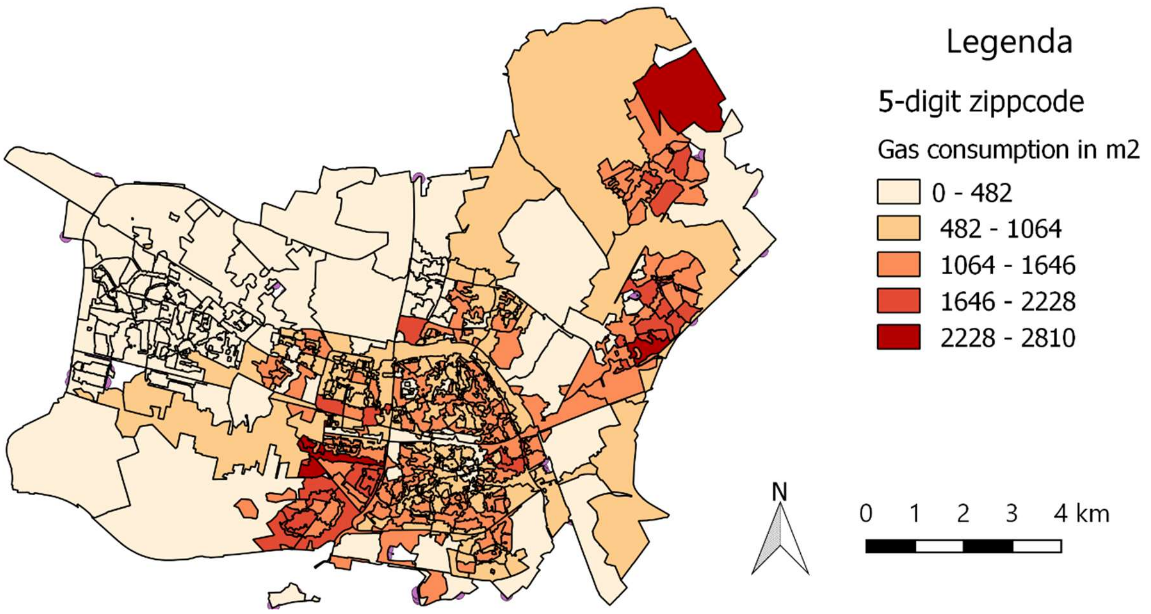


Figure 21. Gas consumption in m2 per 5-digit zip code

5.2 IMPLEMENTATION OF THE GIS-BASED TOOL

The implementation of the GIS-based tool is executed, regarding the steps mentioned in Section 4.4. As Figure 20 already showed, 12 different criteria and 3 constraints are determined, together with the well-thought-out assumptions. 18 base data sources are defined, together with 4 modifications. This section demonstrates how the GIS-based tool can be enrolled on every desirable scale, in this case on a municipality level.

5.2.1 CRITERIA, SCORES AND CONSTRAINTS

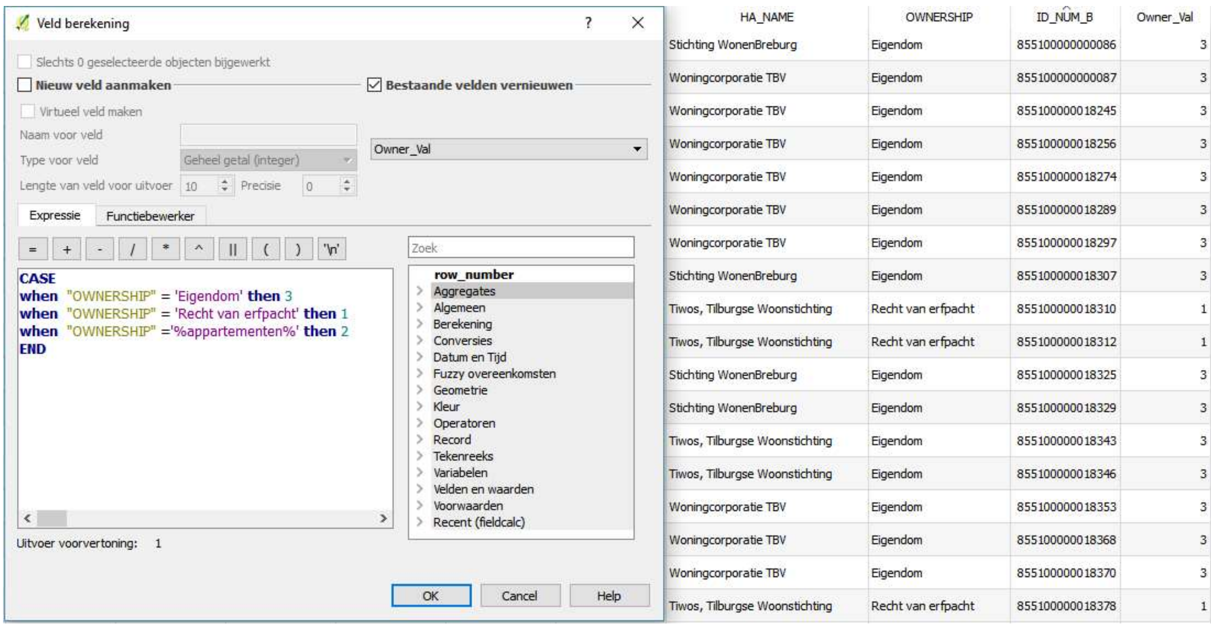
The suitability score of each dwelling individually is based on 12 criteria in an ideal situation. The DH-network has no existing geothermal connections because there are no existing geothermal energy sources in the municipality of Tilburg yet (Geothermie.nl, 2017). This has as consequence that criterion C9 – Existing geothermal connections will not be applicable in this case study. The other criteria are listed in Table 21, together with the GIS-functionality and whether is has a spatial component or not.

Table 21. Overview criteria case study

#	Criterion	GIS-functionality	Spatial
C1	Addresses per building	Overlay analysis	Yes
C2	Building age	Query	No
C3	Private owner addresses	Buffer analysis	Yes
M1	*Buffer 500 of each dwelling*	*Buffer 500m*	*Yes*
	Count private and dwellings	*Sum of points in polygon*	*Yes*
	Calculate percentage	*Expression*	*No*
C4	Gas consumption per dwelling	Overlay analysis	Yes
M2	*Gas consumption per address*	*Join on location*	*Yes*
	Mean gas consumption per dwelling	*Join on location*	*Yes*
C5	Ownership	Query	No
C6	Collective vs individual heating	Query	No
M3	*Assign data to addresses*	*Join*	*No*
C7	Distance to DH-network	Nearest neighbour	Yes
	NNJoin plugin	*Polygon to point*	*Yes*
C8	Distance to surplus heat potential	Nearest neighbour	Yes
	NNJoin plugin	*Polygon to point*	*Yes*
C10	Energy label	Query	No
B8 – B12	*Join on ID_NUM_A*	*Join*	*No*
	Convert letter to number	*Expression*	*No*
C11	Existing surplus heat	Buffer analysis	Yes
	Buffer 1500 of each dwelling	*Buffer 1500m*	*Yes*
B15	*Sum existing surplus heat*	*Join on location*	*Yes*
C12	Geothermal potential	Overlay analysis	Yes
B14 - M1	*Dwellings within potential*	*Join on location*	*Yes*

To calculate the score of each dwelling on a specific criterion, data of multiple base data are combined to use for calculating the score of a criterion. Criterion 1, 4 and 12 are approached in the same manner as the earlier mentioned overlay analysis.

As already mentioned in Section 4.1, a buffer analysis is also conducted in this case study. Criterion 3 about the presence of private owner addresses within 500m and criterion 11 about the existing surplus heat within 1500m are examples of buffer analyses. The buffer analysis is used to combine data into new data. Without it, it is not possible to calculate the ratio of private owner addresses within a range of 500m and the sum of Terajoule of the existing surplus heat sources for each dwelling individually. Criterion 7 and 8 are approached with the nearest neighbour functionality. Normally, this functionality is not available within the standard QGIS software environment, only nearest neighbour for point layers is available. Criterion 7 asks for the shortest distance from a polygon to a line and criterion 8 asks for the shortest distance from a polygon to a point. An advantage of QGIS is the possibility to load plugins that can fulfil this gap. For criterion 7 and 8, the plugin called '*NNJoin'* is used to calculate the shortest distances for all the buildings individually. The other criteria are scores with non-spatial functionalities. The involved GIS-functionality is called '*Query*'. New characteristics are created for the criteria to replace textual aspects of buildings into scores. For example, criterion 5 is based on the ownership of a building, as already showed in Section 4.4.1. Regarding Table 20, full ownership of the housing association for a dwelling is scored with a 1, because only the housing association has control about the dwelling. Out of the data of B9 – Housing associations' properties, three types of ownership are found, namely '*Recht van erfpacht*' (Ground lease, 1), '*Eigendom, xx appartementen*' (VvE, 2) or '*Eigendom*' (Full ownership, 3). The type of ownership is replaced by a value between 1 - 3 with help of the query in QGIS, see Figure 22, and has a standardized score of 0 for ground lease, 0.5 for VvE and 1.0 for full ownership. The same is executed for standardizing the energy label, divided over 7 categories (A; 0.0, B; 0.16, C; 0.33 till G; 1.0).



HA_NAME	OWNERSHIP	ID_NUM_B	Owner_Val
Stichting WonenBreburg	Eigendom	855100000000086	3
Woningcorporatie TBV	Eigendom	855100000000087	3
Woningcorporatie TBV	Eigendom	855100000018245	3
Woningcorporatie TBV	Eigendom	855100000018256	3
Woningcorporatie TBV	Eigendom	855100000018274	3
Woningcorporatie TBV	Eigendom	855100000018289	3
Woningcorporatie TBV	Eigendom	855100000018297	3
Stichting WonenBreburg	Eigendom	855100000018307	3
Tiwos, Tilburgse Woonstichting	Recht van erfpacht	855100000018310	1
Tiwos, Tilburgse Woonstichting	Recht van erfpacht	855100000018312	1
Stichting WonenBreburg	Eigendom	855100000018325	3
Stichting WonenBreburg	Eigendom	855100000018329	3
Tiwos, Tilburgse Woonstichting	Eigendom	855100000018343	3
Tiwos, Tilburgse Woonstichting	Eigendom	855100000018346	3
Woningcorporatie TBV	Eigendom	855100000018353	3
Woningcorporatie TBV	Eigendom	855100000018368	3
Woningcorporatie TBV	Eigendom	855100000018370	3
Tiwos, Tilburgse Woonstichting	Recht van erfpacht	855100000018378	1

Figure 22. GIS-functionality query

As already mentioned in Section 4.4.4, three constraints are formulated, namely whether a building is already connected to a DH-network or not, whether there are obstructing legislations or not and whether it is a residential building or not. Table 22 gives an overview of the GIS-functionalities applied for the constraints. Constraint 2 (X2) is not applicable for this case study in the municipality of Tilburg. There is no obstructing legislation found for the dwellings to connect to a DH-network (B18).

Table 22. Overview of constraints

#	Base maps	Constraint	GIS-functionality	Spatial
X1	B17	Connected to DH-network	Query	No
			Join on ID_NUM_A	*No*
X2	*B18*	*Legislations*	**n/a*	*No*
X3	B5	Residential buildings	Query	No

**n/a = not applicable*

Because of the lack of data about X2, all the buildings are assigned with the score of 1 for constraint 2. In case all the constraints have a value of 1, the building will automatically have a final score.

5.2.2 Generated results out of data

In case of the GIS-based tool, only vector-based data and non-spatial data is used. This data is distinguished in two types of data, namely objects and attributes. The objects consist always of spatial data, while attributes can consist of spatial data and non-spatial data. The objects are pinned on geographical references and the characteristics are pinned on those objects. Those two types of data together act as multiple base map for further analyses. Combining the spatial and non-spatial data is defined in Section 5.2.2. The 18 base data layers can be divided into four types of data, namely the vector-based data polygons, lines and points and the non-spatial data Comma-Separated Value (CSV). Polygons are used for framing dwellings, complex-borders, district-borders, municipality-borders, national borders, gas consumption and geothermal potential. A line is a connection between two points on the map and is used for the roads and the DH-network. A point is a single mark on the map and is used for locating surplus heat industries.

The different data sources are shown in Table 23. The closed data is originating from the municipality of Tilburg and a consultancy company. The open data is originating from Web Featured Services (WFS). This data can be implemented in the GIS-based tool by connecting to an external WFS data base through an URL and load the data into QGIS software (Duivenvoorde, 2013). The visualized base maps are shown in Appendix L, considering the borders of the municipality of Tilburg for this case study. Other case studies can be conducted in other areas in the Netherlands, because the open data is available on a national-level scale. Out of the 18 mentioned data layers, only B13 and B18 are not available for the municipality of Tilburg. NLOG (NLOG, 2017) and Geothermie.nl (Geothermie.nl, 2017) showed that a legislation for geothermal drillings is provided, so the drillings can take place in the future. Obstructing legislations pointed to DH-networks are not found in the municipality of Tilburg. Figure 23 shows a detailed summarization of all the raw base data on a neighbourhood-level.

Table 23. Different data sources

Data	Type of data	Source	Year
B1	Open data	Centraal Bureau voor de Statistiek	2017
B2	Open data	Centraal Bureau voor de Statistiek	2017
B3	Open data	Centraal Bureau voor de Statistiek	2017
B4	Open data	Centraal Bureau voor de Statistiek	2017
B5	Open data	Basisregistratie Adressen en Gebouwen (BAG) – PDOK	2017
B6	Open data	Nationaal Wegen Bestand – Nederlandse Overheid	2017
B7	Closed	Utility company	2017
B8	Open data	Basisregistratie Adressen en Gebouwen (BAG) – INSPIRE	2017
B9	Closed	Housing associations	2017
B10	Open data	Centraal bureau voor de statistiek	2014
B11	Closed	Housing associations	2017
B12	Open data	Rijkstdienst voor Ondernemend Nederland	2017
B13	**n/a*	*NLOG – Geothermie.nl (No geothermal connections yet)*	**n/a*
B14	Open data	Rijksdienst voor Ondernemend Nederland	2014
B15	Open data	Nationaal Georegister	2017
B16	Open data	Nationaal Georegister	2017
B17	Closed	Housing associations	2017
B18	**n/a*	**n/a (No obstructing legislations)*	**n/a*

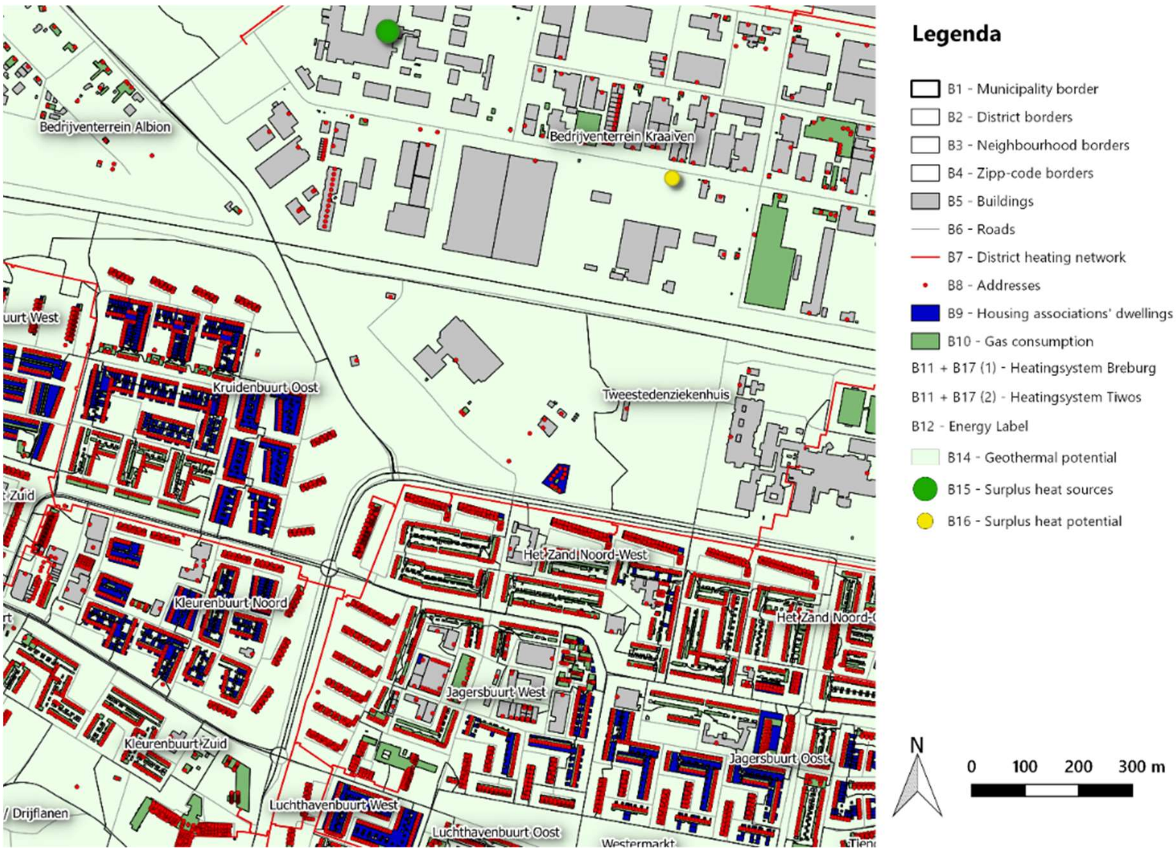


Figure 23. Overview of raw data

Modifications

Not all the raw can be used directly for the criteria formulated in Section 4.4.4. Data on national-level scale is already clipped to the municipality of Tilburg (M0). Data about the housing associations' properties is not usable for the GIS-based tool yet. For example, the polygons of B5 and B9 do not match with each other due to different databases of other stakeholders. A modification is necessary to join the data of the housing associations' properties (B9) with the open data of the BAG about the buildings (B5). How to combine those diverse base data gives an answer on Sub-question 4.

Sub-question 4

Sub-question 4: How to combine (non-) spatial data in the GIS-based tool?

Data can be combined with non-spatial functionalities and spatial functionalities. The GIS-functionalities to combine non-spatial data and spatial data for the modifications and the criteria are shown in Table 24 and Table 25.

Table 24. Overview of modifications

#	Base map(s)	Modification	GIS-functionality	Spatial
M0	All maps	Adjust all data to a specific scale/region	Clip	Yes
M1	B5 – B8 – B9	Extract housing associations' properties	Overlay-analyses	Yes
	B8 – B9	*Addresses within property*	*Join attribute on location*	*Yes*
	B5 – B8	*Assign property to buildings*	*Join attribute on location*	*Yes*
M2	B4 - B10	Average gas consumption per zip code	Overlay-analyses	Yes
	B10	*Create centroid points with average*	*Centroid polygon*	*Yes*
	B4	*Mean of averages of amount m^3 gas*	*Join attribute on location*	*Yes*
M3	B8 – B11 – B12	Add ID_NUM_A to join objects	Query	No

The most common spatial GIS-functionality for the modifications is in this case *Join attribute on location*. This analysis joins attributes which are projected with the Coordinate Reference System (CRS) of the objects. In this research, all the used data is converted to the *EPSG:28892 Amersfoort / RD New* projection. Objects with different CRS can give wrong outcomes of the spatial analyses, because their projection on the earth is not the same. The data of the input layer is extended with the data of the objective layer. Modification M1 is an example of an overlay-analysis, the characteristics of the housing associations' properties (B9) are added to the characteristics of the buildings extracted from the BAG database (B5). An intermediate step to B8 – Addresses is necessary in this case, because point (B8) and polygons are easier and more precisely to join compared to two polygons (B5 and B9). Non-spatial data is joined to spatial objects with help of an expression. M3 is an example of a non-spatial join to spatial objects. Important is to have a corresponding characteristic within the data. In case this is not present yet, it need to be created. CSV data of B11 – Heating installation and B12 – Energy label (Appendix L) is joined to the spatial point object B8 – Addresses with a new corresponding characteristic called *ID_NUM_A*. To summarize the answer on sub-question 4, data can be combined in diverse ways within the GIS-based tool. In case of this case study, data can be combined with help of the spatial functionalities namely buffer-analysis, overlay-analysis and nearest neighbour-analysis. Non-spatial data can be combined by queries and joins on characteristics.

5.2.3 STANDARDIZED SCORES AND WEIGHTS

A score for each criterion is assigned to each building individually, with help of GIS-functionalities. In case all the constraints are scored with the value of 1, a final score is assigned to the building. The scores of the criteria are standardized between 0 and 1 (step 2, according to Rikalovic et al. (2014)). The ranges of the corresponding scores are already showed in Table 16. Table 25 shows actual range of each criterion score for the buildings located in the municipality of Tilburg, followed by the assigned scores between 0 and 1. The dwellings score divided over the full bandwidth of the predefined ranges of Table 16. Only Criterion 8 and 12 are not divided over the full bandwidth. This means for criterion 8 that no dwelling of a housing association is further away than 4098 meters and no closer than 23 meters of a potential surplus heat. Because the predefined range for criterion 8 is between 5000 and 0 meter, the resulting scores are between 0.0046 and 0.8196 (the closer to a potential surplus heat source, the higher the score). Same for the geothermal potential of criterion 12, only a potential of 450 or 500 GJ a year is stated in Tilburg. Table 25 also shows that 45 is the maximum amount of points which can be scored, compared to the predefined 50 as maximum points. Criterion C9 is excluded due to lack of data. It corresponding weight, amount of 5, is also excluded, so the total amount of points is in this case study lower compared to the ideal situation outlined in Section 4.4.3.

Table 25. Overview criterion with absolute ranges

Aspect		#	Ranges (min - max)	Scores (min - max)	Weight
1	Demand				
	Amount of heat	C1	1 - 511	0.000 – 1.000	7
	Amount of heat	C2	280 - 0	0.000 – 1.000	5
	Complexity	C3	99 - 11	0.000 – 1.000	3
	Amount of heat	C4	0 - 2388	0.000 – 1.000	5
	Complexity	C5	1 - 3	0.000 – 1.000	3
	Complexity	C6	0 - 1	0.000 – 1.000	3
	Amount of heat			*Max demand*	*26*
2	Infrastructure	C7	4567 - 0	0.000 – 1.000	9
		C8	4098 - 23	0.0046 – 0.8196	3
				Max infrastructure	*12*
3	Sustainability	C9	*n/a	*n/a	*n/a
		C10	1 - 7	0.000 – 1.000	3
		C11	0 - 953	0.000 – 1.000	3
		C12	450 - 500	0.750 – 0.8333	1
				Max sustainability	*7*
	**not applicable*			Max total	45

In case a range in Table 26 exceeds the predefined range in Table 16 for the corresponding criterion, the standardized score is at its maximum, namely 1 and vice versa for the minimum score of 0. For example, the amount of addresses per building for criterion 1 has a range from 1 till 511. The predefined range in Table 16 was from 1 till 50. 511 is remarkable higher than 50, but the maximum standardized score of 1 is already reached at 50 addresses per building. The valuation of criterion 2, 3, 7 and 8 are contradictory with their assigned score. The lower the range, the higher the standardized scores.

Table 26. Part of final suitability score

ID_NUM_B		X3	X1	C2	SC2	W2	C3	SC3	W3	C4	SC4	W4		FINSUI
855100000019331		1	0	45	0.1000	5	48	0.5500	5		0.0000	3		0.0
855100000019385		1	1	63	0.0000	5	57	0.3250	5	1216	0.5100	3		4.3
855100000019388		1	1	63	0.0000	5	58	0.3000	5	1216	0.5100	3		4.2
855100000019393		1	1	38	0.2400	5	76	0.0000	5	1222	0.5138	3		4.3
855100000019394		1	1	33	0.3400	5	50	0.5000	5	1114	0.4463	3		5.1
855100000019425		1	1	25	0.5000	5	64	0.1500	5	1080	0.4250	3		2.5
855100000019443		0	1	50	0.0000	5	31	0.9750	5	465	0.0406	3		0.0

As Figure 20 already showed, the ranges are produced with help of GIS-functionalities within the QGIS-software environment, the standardized scores are not produced within the QGIS-software. The ranges are exported to a CSV file and imported into Excel, because Excel has more functionalities for adapting the values of the ranges into scores between 0 and 1. Table 26 shows an example of the calculated score of C3 for a specific building in the Excel-software. The constraints (X), the value of the criterion between the ranges (C), the score between 0 and 1 (SC3) and the weight (W) of each criterion is included in the Excel-file. As Equation 1 already showed, this is the input for calculating the final suitability score for a specific building. In case of criterion C3, 30% or lower private owner buildings within 500m scores a 1, 70% or higher private owner buildings within 500m scores 0 points. 1 point is divided proportional between 30% and 70% and the weight is 5 (W3). For example, looking at Table 26, building '855100000019385' has 57% private ownership buildings within 500m. This is calculated with help of QGIS, mentioned in Section 5.2.3. 57% (C3) on the scale mentioned in Section 4.4.3 scores 0.3250 (SC3). The score for this building on C3 is $0.3250 \times 5 = 1.625$ of the total of 45 from all the criteria together. Figure 24 shows how the scores are divided spatially, included the building of the before mentioned example (within the ellipse). Figure 25 gives an example of the spatially divided scores of C10.

Table 26 also shows an empty cell, which means that building '855100000019331' has no information about C4 – Gas consumption. As already mentioned in Section 4.4.5, the criterion is fully excluded of the total score in case of a lack of data. C4 has a weight of 3, so the total score for this specific building has a maximum of $45 - 3 = 42$. Lack of data does not have a negative influence on the total score in this way, because lack of data scores automatically 0.000 so it should decrease the total score because of its weight.

Appendix M shows the spatially divided scores of all the individual criteria.

Figure 24. Example of score criterion 3 for building '855100000019385'

Figure 25. Example of spatially divided scores of criterion 10 - Energy label

5.2.4 FINAL SUITABILITY SCORES

The score of the individual criteria are calculated. The next step, according to Rikalovic et al. (2014) mentioned in Section 4.3.2, is to aggregate the individual scores into the final suitability score. The final suitability score for this case study is the sum of the product of all the criteria times their corresponding weight. The values of the constraints mentioned in Section 5.2.4 determine whether the dwellings get a suitability score or get no score. In case a building has a value of 0 at one of the three constraints, the building is assigned as not applicable (*n/a) in final suitability map.

The formula, mentioned in Section 4.4.6 defines the total suitability score. This total suitability score is extended with a standardized range between 0 and 10. This score is more plausible for stakeholders so they can judge the final suitability score better. This gives the following formula where w_t is the total value of the weights together;

$$FSS_f = ((\sum_{i=1}^{11} w_i c_i) \times (\prod_{j=3}^{3} x_j))/w_t \times 10$$

For example, the final suitability score for building '855100000019385' is;

$$\begin{aligned} FSS_f = ((((&7\times0.0200) + (5\times0.0000) + (5\times0.3250) + (3\times0.5100) + (3\times1.0000) \\ &+ (3\times0.0000) + (9\times0.9100) + (3\times0.9192) + (3\times0.4286) + (3\times0.0000) \\ &+ (1\times0.7500)) \times (1\times1\times1))/\ 45)\times\ 10 = 4.3 \end{aligned}$$

The final suitability score is calculated for each building which is a property of a housing association. This final suitability score represents the likelihood of a specific building to attach to a DH-network in the future. The higher the final suitability score is, the better the building performs on the 11 criteria (12 criteria in an ideal situation if all the necessary data mentioned in Section 4.4.4 is accessible). The final suitability scores vary between 1.0 and 6.8 on a range between 0.0 and 10.0. Buildings with a final suitability score of 0.0 due to constraints are excluded and has an assigned as not applicable. Figure 26 shows the spatially divided final suitability scores for a part of Tilburg.

Aggregating the final suitability scores for dwellings into final suitability scores for neighbourhoods is the last step of the GIS-based tool before the results can be verified on different scales. The final suitability scores on building-/complex level is shown in Figure 26. With help of an overlay-analyses, the GIS-functionality *'Join on location'* takes the average final suitability score of the addresses within a specific neighbourhood and joins that mean to the neighbourhood. Again, the buildings which are not applicable due to constraints are excluded for this aggregation. Figure 27 shows the final suitability score on a neighbourhood level. Only the neighbourhoods with more than the assumed 500 addresses per km^2 have an assigned weight, this for the same reason as mentioned in Section 4.4.4.

As already mentioned in Section 4.4.3, the criteria are divided in three main aspects, namely Demand, Infrastructure and Sustainability. The final scores of each aspect separately is also calculated on the same manner as the final suitability score. Appendix N shows the three separated scores for the several aspects on a building-/complex level and aggregated on neighbourhood level.

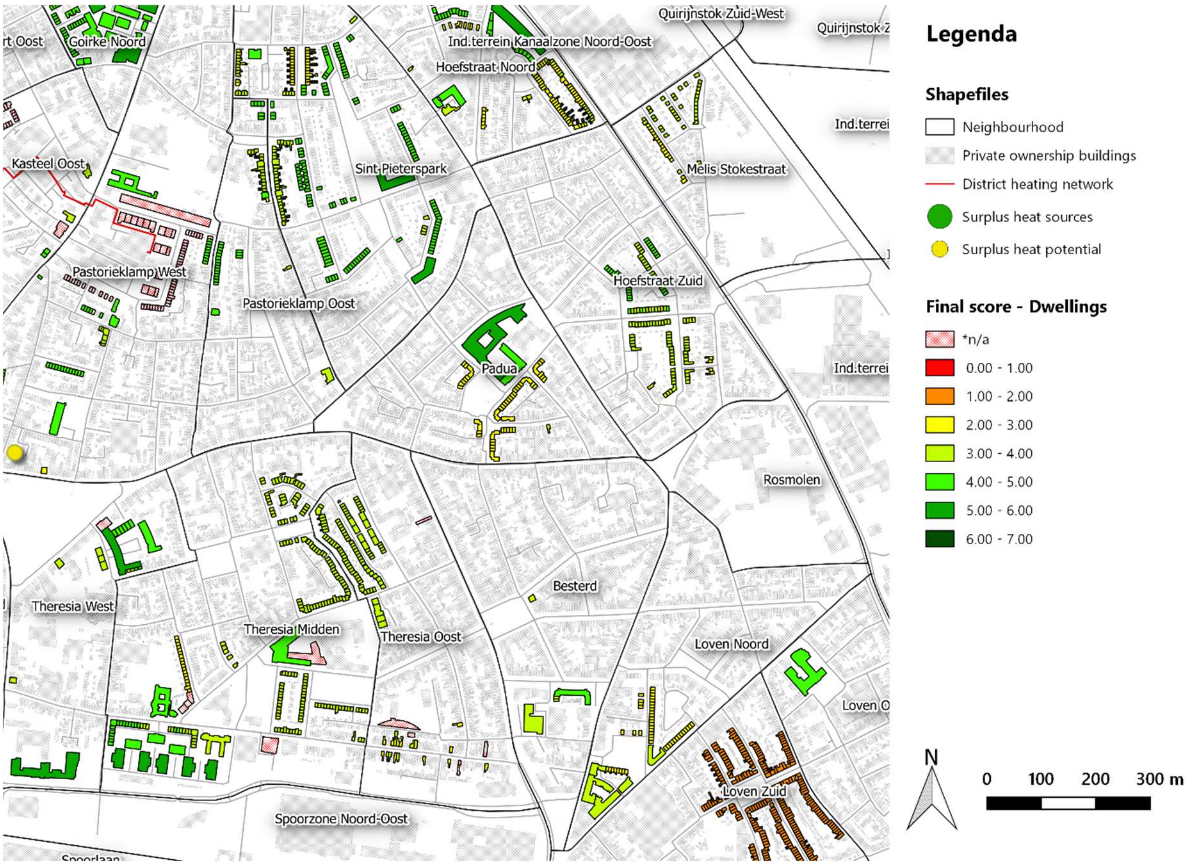


Figure 26. Final suitability score on building-/complex level

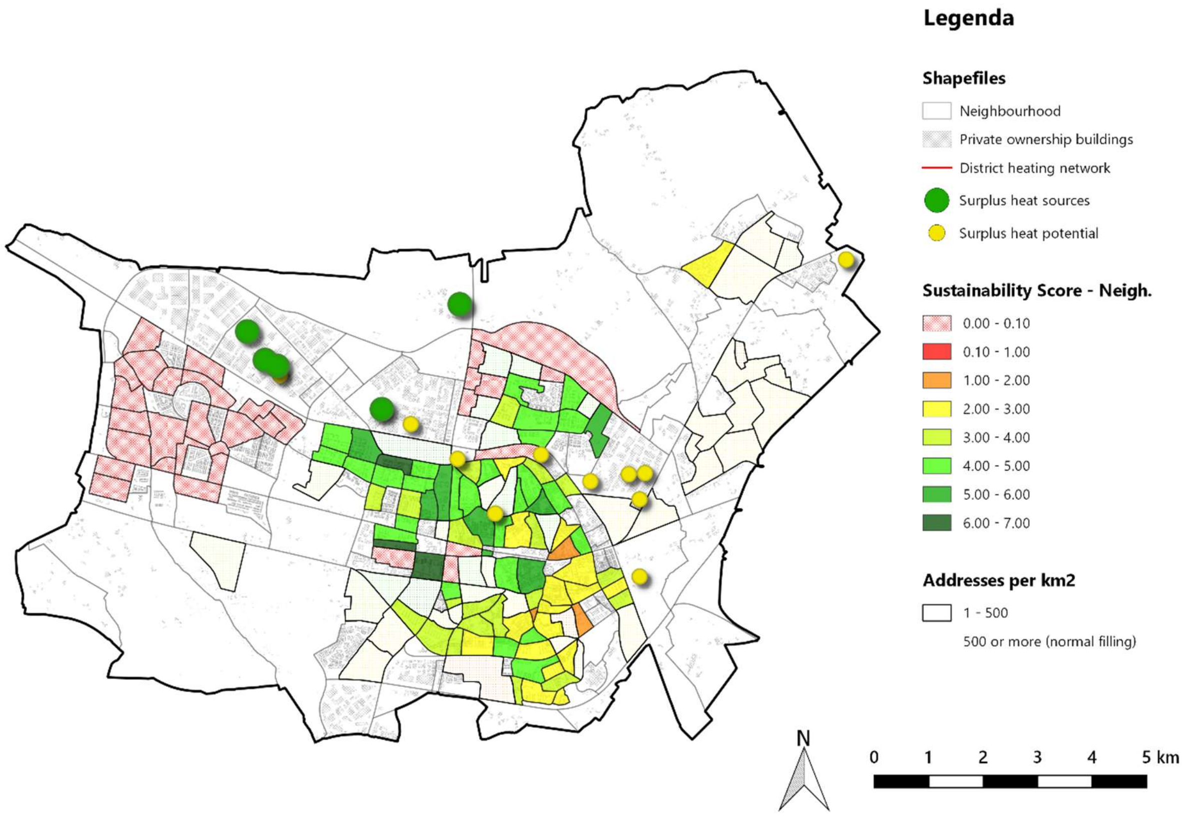


Figure 27. Final suitability score on neighbourhood level

5.3 CONCLUSION

The results of the case study show that combining diverse types of data with help of a GIS-based tool is possible. The need for collaboration for achieving a more sustainable dwelling stock is also confirmed. Focused on the DH-network, the collaboration starts with sharing data. Table 23 shows the different data sources implemented in the GIS-based tool. Open data provided by the government, closed data provided by the housing associations and by the utility company are necessary to visualize the current situation. The power of the GIS-based tool is to store data of the different stakeholders, modify this data with multiple spatial and non-spatial analyses and present the new data in the form of suitability maps with additional information projected. As already mentioned in Section 1.2, visualizing data assists communication. The criteria of the GIS-based tool contain three main topics, namely demand, infrastructure and sustainability. Figure 28 till Figure 30 shows the result of the spatially divided scores on each topic. Successfully attaching a dwelling stock to a DH-network is more insightful in this way. The greener the building, the more likely a potential attachment to a DH-network will be feasible. This is also applicable vice versa, if a building scores low on a specific criterion, measurements can be taken more focused to improve this specific score and so also improving the likeliness of a successful attachment to a DH-network. Based on the criteria and the corresponding ranges, a maximum score of the final suitability of 6.8 out of 10.0 is sufficient, but not very high.

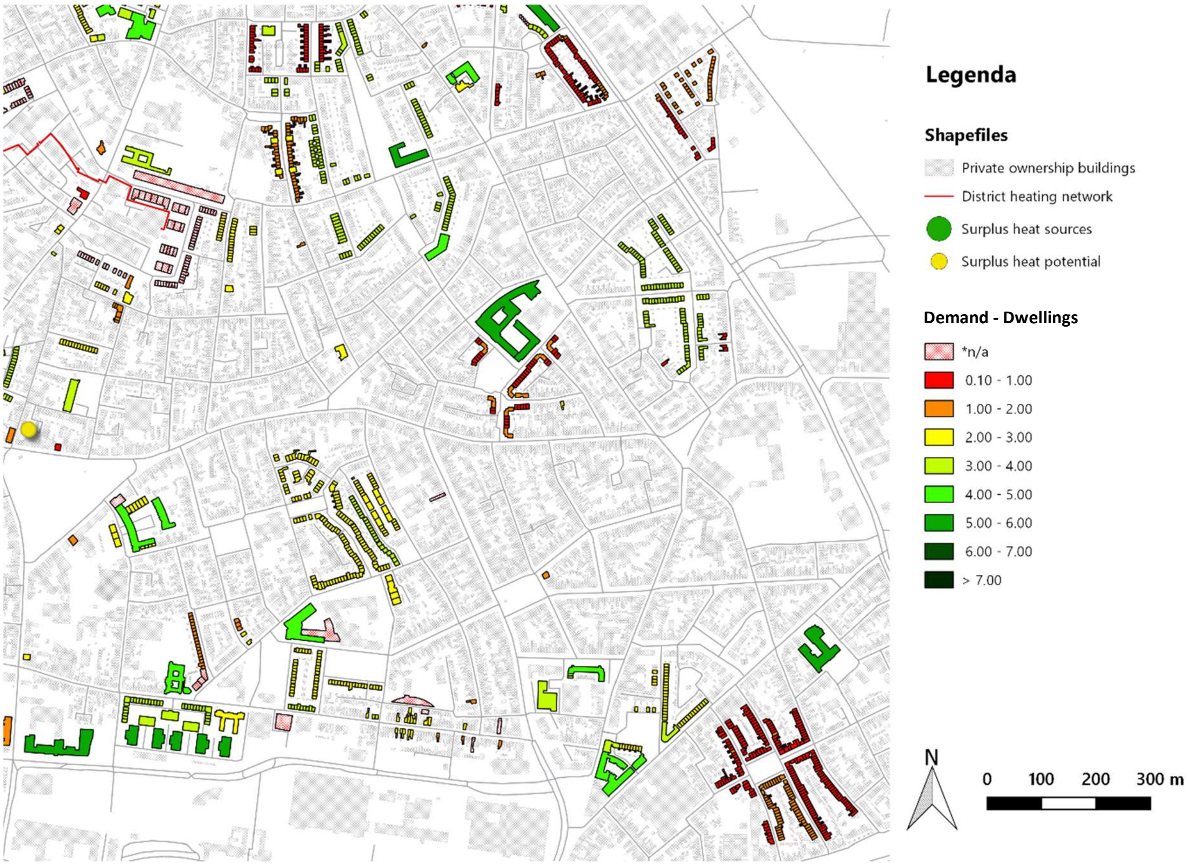


Figure 28. Final score for demand

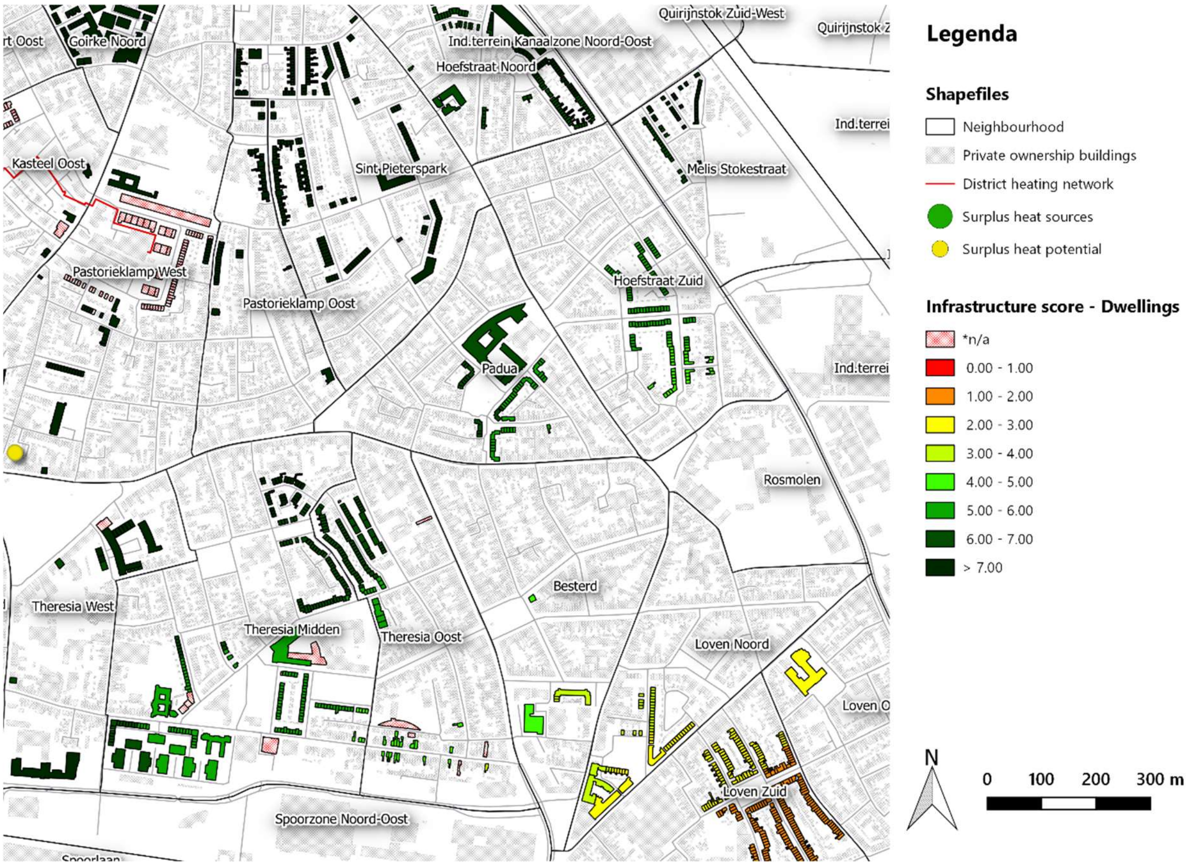


Figure 29. Final score for infrastructure

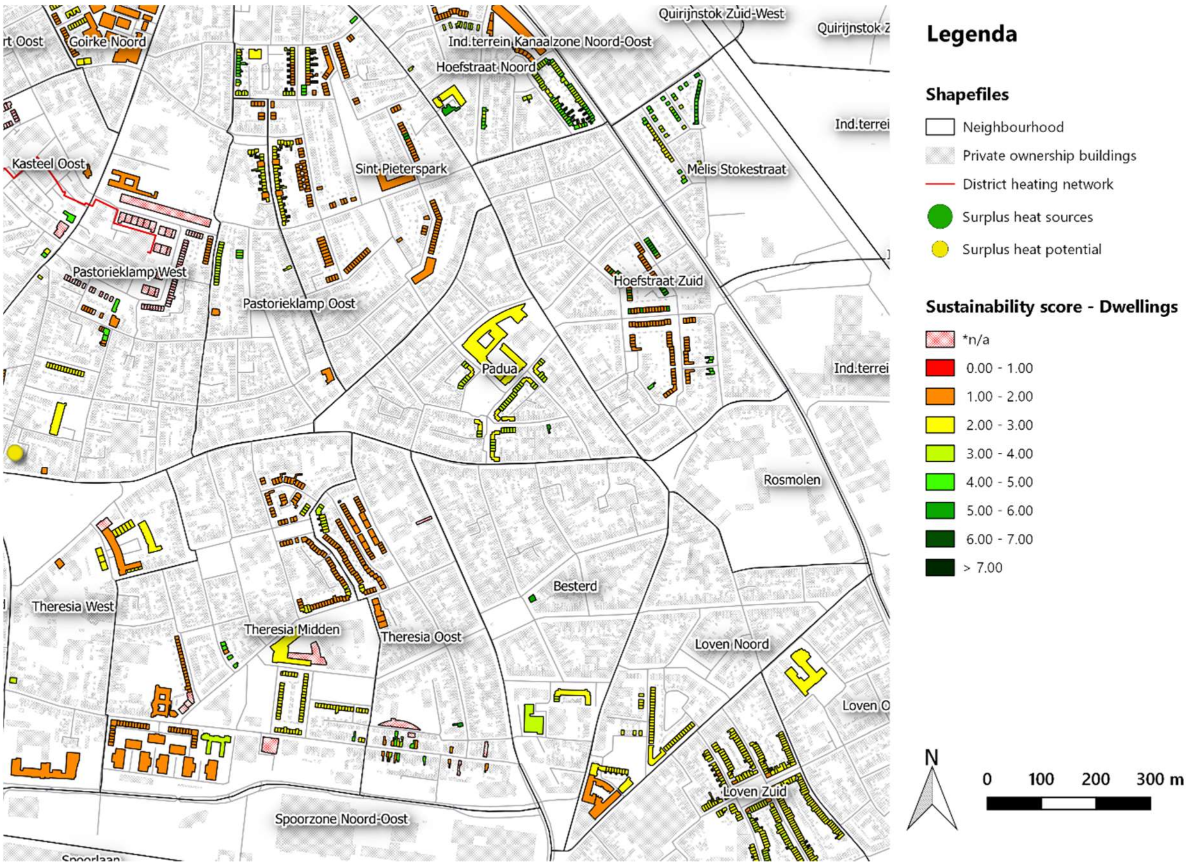


Figure 30. Final score for sustainability

6 CONCLUSIONS

ANSWER ON THE MAIN RESEARCH QUESTION AND RECOMMENDATIONS

The objective of this Chapter is to answer the earlier mentioned main research question and the Sub-questions. Validating whether the GIS-based tool is an added value for the consultancy process, based on the gaps mentioned in Chapter 2 and Chapter 3, is the aim for this Chapter. The conclusions are based on the outcomes of the case study.

First, Section 6.1 provides a conclusion presented as an answer to the main research question, formulated in Section 1.1. The outcomes of the case study are reviewed as well as the usefulness and practicality of the GIS-based tool. Section 6.2 describes the discussion and recommendations, followed by the limitations mentioned in Section 6.3.

6.1 Conclusion

The objective of this research is to analyse how spatial information can support the consultancy towards housing associations in their transition towards DH-networks, see Section 1.2. This is defined because a lack of spatial data within the decision-making process towards a more sustainable dwelling stock for housing associations is identified. This section concludes whether spatial information does generate opportunities based on the existing data of multiple stakeholders. The conclusions are based on the executed a case study mentioned in Section 5.2. This case study provides a onetime executed GIS-based tool for the municipality of Tilburg, based on the framework mentioned in Section 4.4 and the focus mentioned in Section 4.2.

A GIS-based tool which combines data of the different stakeholders assist this collaboration. It is not only sharing data with each other, but also a reaching a higher level of data because of the combinations. In an ideal situation, a collaboration with multiple stakeholders should start to give completion to the GIS-based tool. Each stakeholder with his or her expertise could provide input for the tool or extent the tool where necessary. The 12 defined criteria can be filled in differently, if the intention of the GIS-based tool stays the same. During group meetings and brainstorm sessions, aspects of the GIS-based tool can be adjusted. For example, the range of building age. In case of this GIS-based tool the range varies from 0 to 50. Perhaps some stakeholders think about an exploitation phase of only 30 years, which means the range will decrease from 0 to 30 and so the final suitability score will change. The GIS-based tool is developed specifically for the likelihood of a DH-network, but can also be expanded or shortened. That is a power of a GIS-based tool, it is flexible for adjustments.

6.1.1 Sub-questions

To be able to answer the main research question, the five sub-questions must be answered. The first sub-question provides insight in the interests of the different involved stakeholders. The main goal of the stakeholders is a successful transition towards a more sustainable dwelling stock, attached to a DH-network. Although, the individual interests of the stakeholders are not the same. Despite the different interests, all the stakeholders have revealed the need for collaboration in the future. Answering the sub-question 2, this GIS-based tool can be implemented within the consultancy process. Figure 20 already showed that spatial information can be applied in phase 2. Explore possibilities and phase 3. Develop advice of the consultancy process. The data involved for this GIS-based tool provides an answer on the third sub-question. Data concerning the involved stakeholders is defined in Section 4.4.1. With this data, the interests of the involved stakeholders are guaranteed. Combining the data within the GIS-based tool provides additional information which is useful for all the involved stakeholders, in this case mainly the housing associations. Their vision on their dwelling stock affects the working activities of the other stakeholders. The fifth sub-question is answered in Section 6.1.2 and act as base for the answer on the main research question. To conclude, most important aspect of this research is to provide a GIS-based tool which act as platform for collaboration between the involved stakeholders to achieve the common goal mentioned before. Creating awareness of each other interests and sharing knowledge through data sharing is key for this GIS-based tool. In case of this research, this platform is created within the consultancy process.

6.1.2 MAIN RESEARCH QUESTION

To answer the last sub-question, results of the case study mentioned in Section 5.2 act as base for this conclusion. The consultancy process is described in Section 3.2.5. Research is conducted to the existing consultancy process of a specific consultancy company, without the use of spatial information. Section 4.3.1 provided the position of the use of the GIS-based tool in the process. Based on the focus mentioned in Section 4.4.2, possibilities are explored for a DH-network. A MCA is executed to support the process of developing an advice, based on the Municipality of Tilburg.

SUB-QUESTION 5

The main research question is answered after the fifth Sub-question is answered. The fifth Sub-question is as follows;

Sub-question 5: How to use the GIS-based tool in the consultancy process?

The GIS-based tool can be used in the consultancy process as platform for collaboration. Figure 29 provides an example which illustrates the added value of the GIS-based tool of this research.

Figure 31. Example GIS-based tool in consultancy process

Data which affects multiple stakeholders are implemented for this example. Promising dwellings for potential attachment to the DH-network are mapped in this figure. This detailed map can be used in the consultancy process towards housing associations, as a more detailed supplement compared to Figure 28. This also provides the answer on the fifth Sub-question. This spatial analysis can act as base for meetings with housing associations, utility companies and governments together. For example, the dark green building in the left corner of Figure 29 is highly recommended for an attachment to the existing DH-network, based on the criteria mentioned in Section 4.4.4. Other buildings in the neighbourhood have also positive potential. Creating awareness for opportunities, intersecting multiple stakeholders, is the final result of the GIS-based tool in this research. With the last Sub-question answered, the main research question is also answered.

6.2 Limitations

Limitations of this research are the dependency of available base data as input for the GIS-based tool. In case of the case study of the municipality of Tilburg, only data about geothermal connections and legislations was not available. It is possible that other municipalities have a bigger lack of data regarding heating networks or housing associations' dwellings. In that case, the GIS-based model will be less realistic and less reliable. Another limitation is de exclusion of wind- and solar energy. Those renewable energy resources match the all-electric approach towards an energy neutral built environment in 2050. An all-electric approach will have a more building-oriented approach. Conclusions of the all-electric approach could also be useful in the decision-making process of housing associations.

Assigning scores to the criteria for the GIS-based tool is arbitrary and is based on well-though-out assumptions. These are rough approximations based on the interviews with experts and interpretations. The assumed values for the ranges could not be underpinned by references. Also, the assigned weights to the criteria are rough approximations, also based on interviews with experts. Converting text to nominal data in Section 5.2.1 is also a limitation of this research, because of the chance on misinterpreting the values.

Limitations in time determined the need for a defined focus. This resulted in a district-oriented approach for DH-networks. Perhaps also other renewable resources and the financial consequences of several measurements could be implemented in case time was not a limitation for conducting research.

6.3 Discussion and recommendations

Research concerning the use of renewable energy has gained increasing attention recently according to the literature review of Chapter 2, though combining data to conduct research towards the opportunity of renewable energy for housing associations is lacking. Looking at the research gaps, this research provides an overview of the complexity of the energy transition towards energy neutrality. Housing associations employ consultancy companies to approach this complexity. A GIS-based tool in which data is combined of multiple stakeholders, fulfil the literature gaps to approach a complex energy transition, specific for housing associations with vulnerable tenants.

Practical study gaps, mentioned in Section 3.4, stated that only the governments are trying to collect data of multiple stakeholders. The GIS-based tool mentioned in this research showed that open data of the governments act as base for further spatial analysis, but closed data is necessary for more profound spatial analysis based on the attachment of dwellings to a DH-network. With help of the GIS-based tool, the practical gap of a lack on middle-term policy and views is solved. Middle-term policies can be developed based on figures as Figure 27 and Figure 28. With state-of-the-art knowledge about legislations, innovations and prognoses, new middle-term policies for attaching dwellings to DH-network in 2030 - 2035 can be developed together by housing associations and the consultancy company. This foresees measurements which followed up the short-term views for the upcoming 4 to 5 years and determines the route towards 2050 in more detail.

This research is focused on a DH-network with geothermal energy and surplus heat as renewable energy resource. Recommendation for further research is extending the criteria mentioned before in Section 4.4.4. Parameters about financial aspects of the infrastructure of DH-networks and heat supply are not yet implemented in this GIS-based model. This can act as an in-depth analysis after the middle-term policy is developed. Negotiations about the costs and contracts of new infrastructure are helped with an extended financial GIS-based model. Note, extended research in the financial aspects of DH-networks is necessary for further research, because it is relatively in its infancy and key figures are not very accessible.

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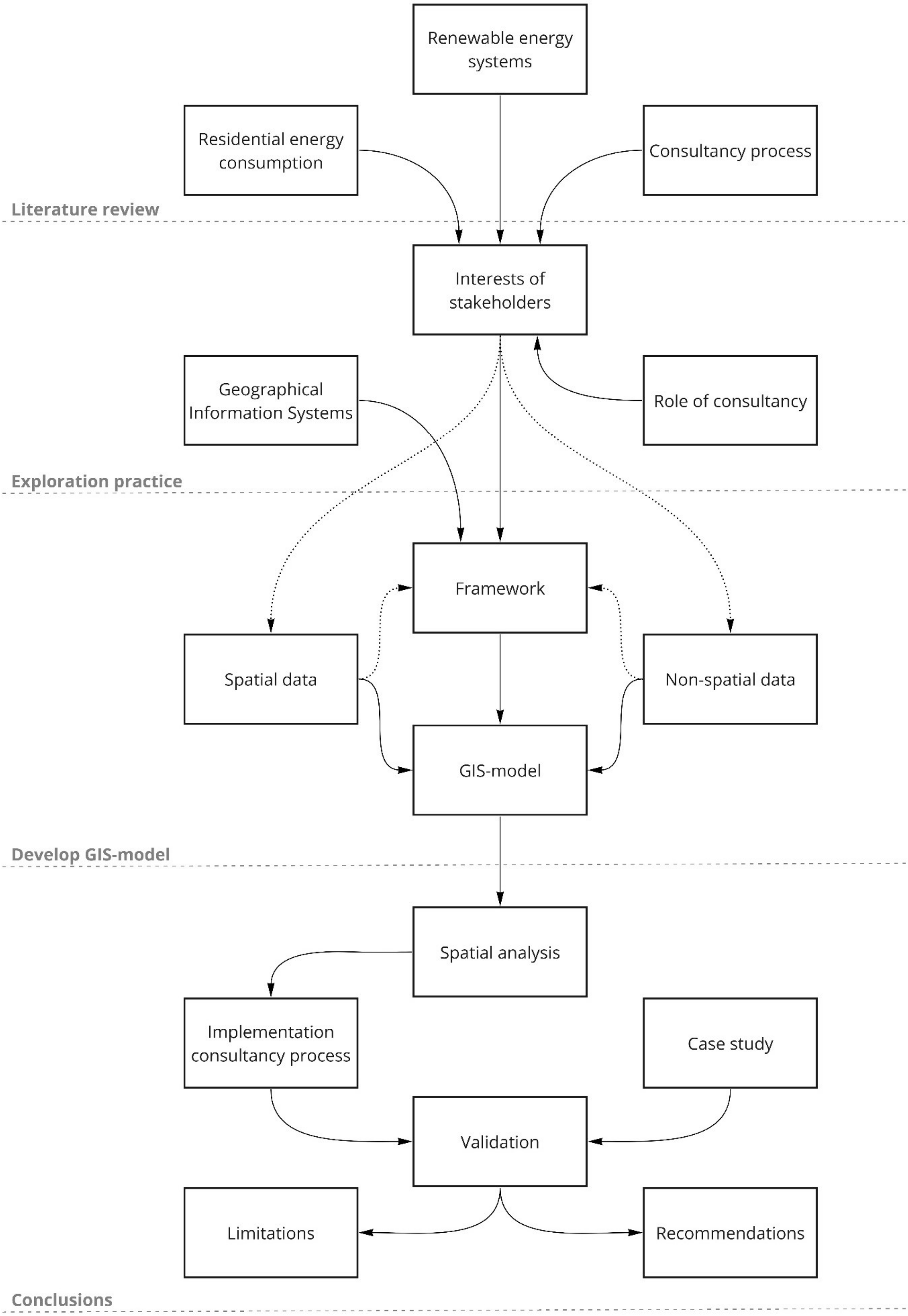
APPENDICES

Appendix A. Research model



Appendix B. Concept matrix

Used articles:

				2.2	2.2.1	2.2.2	2.2.3
Author	**Title**	**Journal**	**Year**	Energy demand	Energy consumption	Sustainable housing	Renovation
Aksoenzen et al.	Building age as indicator for energy consumption	EB	2015	x	x		
Coimbra et al.	Challenges and benefits of building sustainable cooperative housing	BE	2013	x		x	
Ding	Sustainable construction - The role of environmental assessment tools	EM	2008			x	
Gill et al.	Low-energy dwellings: the contribution of behaviours to actual performance	BRI	2010		x		
Goebel	Sustainable urban development? Low-cost housing challenges in South Africa	HI	2007			x	
Hauge et al.	How to maximize the chances of sustainable renovation in housing cooperatives	EP	2014			x	
Marszal et al.	Zero Energy Building - A review of definitions and calculation methodologies	EB	2011				x
Marta et al.	Simplified model to determine the energy demand of existing buildings. Social housing in Zaragoza, Spain	EB	2017	x			
Mulliner et al.	An assessment of sustainable housing affordability using a multiple criteria decision making method	OM	2013			x	
Oyebanji et al.	Critical Success Factors (CSFs) for achieving sustainable social housing (SSH)	SBE	2017			x	
Perez-Lombard et al.	A review on buildings energy consumption information	EB	2008		x		
Pretlove et al.	Post occupancy evaluation of social housing designed and built to code for sustainable homes levels 3,4 and 5	EB	2016		x		
Roufechaei et al.	Energy-efficient design for sustainable housing development	CP	2014			x	
Santangelo et al.	Occupant behaviour and building renovation of the social housing stock: Current and future challenges	EB	2017	x		x	
Sartori et al.	Net zero energy buildings: A consistent definition framework	EB	2012				x
Schaffrin et al.	Household energy and climate mitigation policies: Investigating eneryg practices in the housing sector	EPO	2015	x			
Seyfang	Community action for sustainable housing: Building a low-carbon future	EPO	2010	x			
Sodogar et al.	The monitored performance of four social houses certified to the Code for Sustainable homes level 5	EB	2016		x		
Swan et al.	Modeling of end-use energy consumption in the residential sector: A review of modeling techniques	RSE	2009	x	x		
Wang et al.	Case study of zero energy house desing in UK	EB	2009				x

				2.4	2.4.1	2.4.2
Author	**Title**	**Journal**	**Year**	Consultancy process	Main drivers	Process description
Fuentes et al.	Main drivers of consultancy services: A meta-analytic approach	JBR	2016		x	
Kagström et al.	Between 'best' and 'good enough': How consultants guide quality in environmental assessment	EIA	2016		x	
Larsen et al.	Evaluations of Energy audits and the regulator	EPO	1999		x	
Lin et al.	The new geography of information and consultign services in China: Comparing Beijing and Guangzhou	HI	2011	x		
Mingaleva et al.	Ethical Principles in Consulting	SBS	2013		x	x
Momparler et al.	Quality of consulting services and consulting fees	JBR	2015	x		
Nicolescu et al.	Specificity of Managerial Consultancy for SMEs and its Status in Romania	SBS	2016			x
Özeroglu et al.	Financial Framework of Consultancy Services	SBS	2014			x

				2.3	2.3.1	2.3.2
Author	**Title**	**Journal**	**Year**	Renewable energy	Energy systems	Energy potentials
Alhamwi et al.	GIS-based urban energy systems models and tools: optimisation of flexibilisation technologies	AE	2017	x	x	
Baños et al.	Optimization methods applied to renewable and sustainable energy: A review	RSE	2011			x
Bazmi et al.	Sustainable energy systems: Role of optimization modeling techniques in power generation and supply	RSE	2011			x
Bouffard et al.	Centralised and distributed electricity systems	EP	2008		x	
Brückner et al.	Using industrial and commercial waste heat for residential heat supply: A case study	SCS	2014			x
Chiu et al.	Industrial surplus heat transportation for use in district heating	EN	2016			x
Connolly et al.	A review of computer tools for analysing the integration of renewable energy into various energy systems	AE	2010			x
Harsem et al.	Efficient Interaction Between Energy Demand Surplus Heat, Cooling and Thermal Storage	PE	2016			x
Hiremath et al.	Decentralized energy planning; modeling and application - a review	RSE	2007	x	x	
Kodysh et al.	Methodology for estimating solar potential on multiple building rooftops for photovoltaic systems	SCS	2013			x
Li, Y et al.	Case study on industrial surplus heat of steel plants for district heating in Northern China	EN	2016			x
Mentis et al.	The benefits of geospatial planning in energy access - A case study on Ethiopia	AG	2016	x		
Noorollahi et al.	Thermo-economic modeling and GIS-based spatial data analysis of ground source heat pump systems	RSE	2017			x
Rodman et al.	A geographic analysis of wind turbine placement in Northern California	EPO	2006			x
Santos et al.	Applications of solar maping in the urban environment	AG	2014			x
Tselepidou et al.	Optimization of the exploitation system of a low enthalpy geothermal aquifer with zones	RE	2010			x
Wiese et al.	Open source energy system simulation model as instrument for public participation	EE	2014	x		
Yaqoot et al.	Review of barriers to the dissemination of decentralized renewable energy systems	RSE	2016		x	
Yazdanie et al.	The role of decentralized generation and storage technologies in future energy systems planning	EP	2016		x	

Used journals:

AE	Applied Energy
AG	Applied Geography
BE	Building and Environment
BRI	Building Research & Information
CP	Journal of Cleaner Production
EB	Energy and Building
EE	Energy Environment
EIA	Environmental Impact Assessment Review
EM	Journal of Environmental Management
EN	Energy
EP	Energy Procedia
EPO	Energy Policy
GI	International Journal of Geo-Information
HI	Habitat International
HR	Hydro-environment Research
JBR	Journal of Business Research
OM	Omega
PE	Procedia Engineering
RE	Renewable Energy
RSE	Renewable and Sustainable Energy Reviews
SBE	International Journal of Sustainable Built Environment
SBS	Social and Behavioral Sciences
SCS	Sustainable Cities and Society

Appendix C. Critical Success Factors of social housing. Oyebanji et al. (2017)

	Overall		Public Sector		Private Sector			
	Mean	Rank	Mean	Rank	Mean	Rank	f-Stat	Sig
Economic factors								
Adequate funding and provision	4.43	1	4.24	2	4.52	1	4.54	0.03
Affordability	4.41	2	4.34	1	4.44	2	0.56	0.45
Provision of infrastructure services	4.22	4	4.14	3	4.26	3	0.76	0.39
Appropriate construction technology	4.11	6	4.03	4	4.14	4	0.81	0.37
Economic design and efficient use of resources	4.09	7	3.92	7	4.17	5	4.13	0.04
Good governance and political will	4.06	9	3.98	5	4.09	6	0.53	0.47
Efficient management	4.02	10	3.97	6	4.05	7	0.40	0.53
Effective legal and policy frameworks	3.73	18	3.75	8	3.72	8	0.03	0.86
Environmental SFs								
Use of appropriate materials	3.92	13	3.69	1	4.03	1	5.89	0.02
Appropriate land use and development plan	3.72	19	3.61	2	3.78	2	1.29	0.26
Good accessibility and alternative transport modes	3.59	20	3.49	3	3.63	3	1.02	0.32
Environmental protection	3.34	21	3.41	4	3.31	4	0.47	0.50
Social SFs								
Security of lives and properties	4.28	3	4.15	1	4.35	1	2.65	0.11
Community development and social services	4.17	5	4.08	2	4.22	2	1.18	0.28
Promotes social cohesion	4.07	8	4.08	2	4.06	3	0.04	0.85
Ensuring welfare and quality life	3.94	11	3.86	7	3.98	4	0.64	0.43
Skills acquisition and job opportunities	3.93	12	3.90	5	3.95	5	0.13	0.72
Promotes equity	3.89	14	3.97	4	3.85	7	0.70	0.41
Quality housing provision	3.83	15	3.90	5	3.80	8	0.51	0.48
Public awareness	3.81	16	3.64	9	3.88	6	2.61	0.11
Stakeholders' participation	3.76	17	3.71	8	3.79	9	0.28	0.60

Appendix D. Sustainable versus traditional dwelling. Coimbra et al. (2013)

	Thermal transmittance in W/m2 C	
Envelope / Equipment	Leça	Azenha de Cima
Façade 1	0.53	1.11
Façade 2	0.61	1.47
Inner walls	0.58	1.38
Thermal bridges	0.78	2.09
Exterior pavement	0.99	1.00
Interiour pavement	1.21	0.88
Horizontal roof	0.33	1.80
Glazing	3.00	5.10
	HVAC and DHW	
	Leça	Azenha de Cima
Ventilation (airflow rate in m3/h)	100	60
Space heating (HVAC) (efficiency)	1	1
Domestic hot water system (DHW) (efficiency)	0.726	0.390
Average solar energy (in kWh per year)	958	0

Appendix E. Weights for multiple criteria decision model. Mulliner et al. (2013)

	Sustainable housing affordability criteria	Mean score	Weight. (q)
1	House prices in relation to incomes	8.66	6.36
2	Rental costs in relation to incomes	8.69	6.37
3	Interest rates and mortgage availability	7.18	5.27
4	Availability of social and private rented accomodation	7.71	5.65
5	Availability of affordable home ownership products	7.09	5.2
6	Safety (crime level)	6.62	4.85
7	Access to employment opportunities	7.49	5.49
8	Access to public transport services	6.8	4.99
9	Access to good quality schools	6.75	4.95
10	Access to shops	6.7	4.91
11	Access to health services	6.78	4.97
12	Acces to child care	5.42	3.97
13	Access to leisure facilities	4.94	3.62
14	Acces to open green public space	5.66	4.15
15	Quality of housing	8.36	6.13
16	Energy efficiency of housing	7.42	5.44
17	Availability of waste management facilities	4.52	3.31
18	Desirabiilty of neighbourhood area	5.98	4.39
19	Deprication in area	6.98	5.05
20	Presence of environmental problems (e.g. litter. traffic)	6.71	4.92

Appendix F. Order of energy efficient parameters, Roufachaei et al. (2014)

Energy efficiency parameters	Mean	Rank
Insulation (roofs. windows. floors. walls. exterior doors)	4.52	1
Application of lighting choices to save energy	4.26	2
Application of passive solar (take advance of climate)	3.98	3
Application of natural ventilation	3.72	4
Making clean electricity	3.51	5
Cooling and heating system (HVAC. environmental friendly)	3.45	6
Inegrative use of natural lighting	3.39	7
Optimizing building orientation	3.32	8
Optimizing building envelope thermal performance	3.18	9
Use energy efficiency and renewable energy sources	3.04	10
Ample ventilation for pollutant and thermal control	2.98	11
Application of efficient water heating	2.94	12
Application of solar water heating	2.92	13
Application of green roof technology	2.85	14
Use of efficient type of lighting (outpunt and color)	2.76	15
Application of lighting product	2.71	16
Application of thermostats. ducts and metres	2.63	17
Application of artificial lighting	2.58	18
Insulation tank and pipes	2.46	19
Application of ground source heat pump	2.41	20
Demand tank less water heater	2.39	21
Use wooden logs to provide structure and insulation	2.33	22

Appendix G. Interview design

Housing association; ☐

Dwelling stock; ☐

Scale[1]; ☐ small ☐ medium ☐ large

Name employee; ☐

Job description; ☐

Date; Day; ☐ Month; ☐ Year; ☐ Hour; ☐ Minute; ☐

Thank you for the cooperation regarding my graduation research aimed at how Atriensis can improve its service towards housing associations by using spatial data on the energy level. Aspects like energy transition. renewable energy resources. Geographical Information Systems and the collaboration with a consultancy company will be brought into the light.

The structure of the topics in this interview are as follows;

1. Impact of authorities
2. Sustainability within the energy level
3. (non-) Spatial data
4. Geographical Information Systems (GIS)
5. Consultancy company

It seems interesting to me perceive your experiences and perspectives on these topics. The information you provide will be processed strictly and will be only used for educational purposes. The interview will take maximum half an hour of your time. If you like to I can inform you about the status and the results of my graduation research.

Do you mind if I record the interview so I can transcribe the answers at a later moment?

☐ Yes ☐ No

Once again thank you for the cooperation regarding this research.

Martijn Peters
Intern at Atriensis
Mail: m.peters@atriensis.nl
Phone: 06-11586891

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[1] Dwelling stock of: small; > 5000. medium; 5000-20000. large; <20000 (Groenen, 2017)

1. Impact of government

1a. Every housing association should provide a plan in 2018 on how to achieve an energy neutral dwelling stock in 2050 (Aedes, 2017)[2]. Which scenario does your housing association utilize to reach this goal in 2050?

1b. In what sizes comes the collaboration between different stakeholders about realizing local and/or regional energy strategies (Aedes, 2017)? Stakeholders are for example authorities. utilization companies and housing associations

Collaboration; Low 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ High

Explanation;

1c. What is the current state of achieving the goal for 2020. average energy level B of the dwelling stock. stated in the Energy Agreement (in dutch Energieakkoord) (Energieakkoord, 2017)[3]?

Unreachable 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ Reachable

Explanation;

[2] Aedes. (2017). Woonagenda 2017-2021. Den Haag: Aedes - vereniging van woningcorporaties.
[3] Energieakkoord. (2016. januari 1). Energieakkoord SER. Opgehaald van Rijksoverheid voor ondernemend Nederland: http://www.energieakkoordser.nl/

2. Sustainability within the energy level

2a. Do you know or could you make an estimation which energy level (energy-index. EI) the current dwelling stock has? (Rijksoverheid, 2015)[4]?

A ☐ *(EI<1.2)* B ☐ *(1.2<EI<1.4)* C ☐ *(1.4<EI<1.8)* D ☐ *(1.8<EI<2.1)* E ☐ *(2.1<EI<2.4)* F ☐ *(2.4<EI<2.7)* G ☐ *(EI>2.7)*

2b. How do you take care of the awareness from the energy consumption of the dwelling stock from the housing association point of view? Which measures do you take to make the energy consumption more sustainable?

2c. Natural gas will disappear on the long run out of the dwelling stock. How do you estimate the potentials of the following four renewable energy resources out of the literature review and why? In this case a potential of 1 is low and 9 is high.

Wind energy	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐
Solar energy	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐
Geothermal energy	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐
Surplus heat	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐

Explanation;

[4] Rijksoverheid. (2015. Januari 1). Energieprestatie van mijn woning. Opgehaald van Rijksoverheid: https://www.rijksoverheid.nl/onderwerpen/huurprijs-en-puntentelling/vraag-en-antwoord/energieprestatie-woning-en-huurprijs

3. (non-) Spatial data

3a. How is the information flow of your housing association organized regarding other stakeholders? What types of data are involved within these information flows?

3b. Spatial data is data which contains a location-based component (Knibbe, 2016)[5]. In extend to which degree is this location-based component represent in your information flow and if so. on which manner?

Presentence; Low 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ High

Explanation;

3c. In extend to which degree do you think use of-. and combining of spatial data can have an added value? If so. can you think of applications in which case spatial data could fulfil an important role within your housing association?

Added value; Low 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ High

Explanation;

[5] Knibbe. F. (2016. Januari 6). Ruimtelijke data op het web: Hoezo? Opgehaald van Geodan: http://www.geodan.nl/ruimtelijke-data-op-web-hoezo/

4. Geographical information systems (GIS)

4a. Geographical Information Systems (GIS) have the functionality of combining different types of data to provide spatial analysis for new relations and insights between different layers of data. (Manfren, Caputo, & Costa, 2011)[6]. Are you familiar with those GIS-functionalities? If so. in which cases do you use it?

☐ Yes. we do already use GIS ☐ Yes. but we don't use it ☐ No. not familiar with it

Explanation;

4b. In extend to which degree are environmental factors for renewable energy taken into account during strategy determination for a more sustainable dwelling stock? If so. how is data collected about the earlier mentioned four renewable energy resources and in what extend are they taken into account? Scale from: 1; not taken into account to 9; high degree of taken into account;

Wind energy	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐
Solar energy	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐
Geothermal energy	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐
Surplus heat	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐

Explanation;

4c. In extend to which degree do you think a GIS-tool can add value and provide support to the strategy determination when combining the earlier mentioned environmental factors? In this case a potential of 1 is low and 9 is high

Low potential 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ High potential

Explanation;

5. Consultancy company

5a. Atriensis collaborates with your housing association to achieve a more sustainable dwelling stock. What were your main considerations to engage a consultancy company for this question?

5b. Aspects like professional competence. knowledge. responsibility and quality assurance are characterized as the added value of a consulting company (Kagström, 2016)[7]. How would you rank these aspects where 1 is lowest and 4 the highest rank?

☐ Competence ☐ Knowledge ☐ Responsibility ☐ Quality assurance

5c. Do you believe a consultancy company should map the earlier mentioned environmental potentials to take into account during the strategy determination or do you think this should be provided by other companies/authorities? Please explain.

5d. In extend to which degree are you satisfied with the service of a consultancy company in achieve a more sustainable dwelling stock? Is there some room for improvement? In this case unsatisfied is scaled as 1 and satisfied is scaled as 9.

Unsatisfied 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ Satisfied

Explanation;

Appendix H. Interview consultancy company

Name employee(s);	
Job description;	

Date; Day; ☐ Month; ☐ Year; ☐ Hour; ☐ Minute; ☐

Thank you for the cooperation regarding my graduation research aimed at how Atriensis can improve its service towards housing associations by using spatial data on the energy level. Aspects like energy transition. renewable energy resources and the collaboration with a consultancy company will be brought into the light.

The structure of the topics in this interview are as follows;

1. Impact of authorities
2. Sustainability within the energy level
3. (non-) Spatial data
4. Consultancy company

It seems interesting to me perceive your experiences and perspectives on these topics. The information you provide will be processed strictly and will be only used for educational purposes. The interview will take maximum half an hour of your time. If you like to I can inform you about the status and the results of my graduation research.

Do you mind if I record the interview so I can transcribe the answers at a later moment?

☐ Yes ☐ No

Once again thank you for the cooperation regarding this research.

Martijn Peters
Stagiair Atriensis
Mail: m.peters@atriensis.nl
Tel: 06-11586891

1. Impact government

1a. Every housing association should provide a plan in 2018 on how to achieve an energy neutral dwelling stock in 2050 (Aedes, 2017)[8]. How does Atriensis responds to this?

1b. In what sizes comes the collaboration between different stakeholders about realizing local and/or regional energy strategies (Aedes, 2017)? Are the conventions you organize an example of motivating collaboration between the different stakeholders?

Collaboration; Low 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ High

Explanation;

[8] Aedes. (2017). Woonagenda 2017-2021. Den Haag: Aedes - vereniging van woningcorporaties.

2. Process Atriensis

2a. How is the consultancy process of Atriensis generally organized? Are the decisions made regarding specific steps? What are the questions of the housing associations towards Atriensis and how are you dealing with those questions?

2b. On which level is can your advice be implemented. for example strategic. tactical. operational? Which information do you need to have. and on what kind of level. of the housing association to develop a proper advice? For example on a municipality level. city level. neighbourhood level. complex level? Do you need to collect this information by yourself?

2c. What is the current state of achieving the goal for 2020. average energy level B of the dwelling stock. stated in the Energy Agreement (in dutch Energieakkoord) (Energieakkoord, 2017)[9]?

Unreachable 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ Reachable

Explanation;

2d. How do you take care of your knowlegde so it will be state-of-the-art? Do you follow the innovations in your field of activity? And how are these developments involve the consultancy process?

[9] Energieakkoord. (2016. januari 1). Energieakkoord SER. Opgehaald van Rijksoverheid voor ondernemend Nederland: http://www.energieakkoordser.nl/

3. (non-) Spatial data

3a. Natural gas will disappear on the long run out of the dwelling stock. How do you estimate the potentials of the following four renewable energy resources out of the literature review and why? In this case a potential of 1 is low and 9 is high.

Wind energy	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐
Solar energy	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐
Geothermal energy	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐
Surplus heat	1 ☐	2 ☐	3 ☐	4 ☐	5 ☐	6 ☐	7 ☐	8 ☐	9 ☐

Explanation;

3b. How is the information flow of Atriensis organized regarding other stakeholders? What types of data are involved within these information flows?

4. Consultancy

4a. Atriensis collaborates with housing association to make the existing dwelling stock more sustainable. What were the motives of the housing associations to employ Atriensis?

4b. Do you think Atriensis should map environmental aspects which can be used in developing policies for housing associations. or do you think this is a task for the authorities or other stakeholders? Please explain.

Appendix I. Overview of the consultancy process

GAINING AND SHARING KNOWLEDGE (PHASE 0)

The added value of a consultancy company for other companies is their knowledge and experience. It is important to gain state-of-the-art knowledge about the field of activity the consultancy company is involved. A pro-active search for information benefits the amount of knowledge. Employee 14 of CC1 (personal communication. August 3. 2017) cited: *''Primarily. we share information. Sharing means learning new things. It is like refining knowledge with additional information''.* Sharing knowledge with other stakeholders is important. because the route towards energy neutrality in 2050 requires a more collaborated way of thinking. This view on the future of the consultancy company is transformed into a model and spread out by conventions. newsfeeds and reports. Stakeholders such as governments. utility companies are involved in this collaboration. but the main stakeholders are the housing associations. This phase is a pre-process phase compared to the literature review.

DEFINE CONTEXT (PHASE 1)

The housing associations set objectives for their future plans. These plans can have different point of views. for example improving the environment. a better corporate image. lower housing costs for the tenants or because of established legislations. Housing associations have other core businesses than the future plans mentioned before. Employee 13 of CC1 (personal communication. August 3. 2017) cited: *''Housing associations make future plans what do want to achieve. The tenants in their dwellings are the only ones they should take into account. other activities are disregarded. So. they employ a consultancy company to accomplish their future plans.''* Housing associations are employing consultancy companies because of their expertise. status. personal bonding and their broad network. Employee 14 of CC1 cited: *''The housing associations are aware of the state-of-the-art knowledge we possess. Sometimes we know more about the neighbour-association than they know by themselves.''* Next step for the consultancy company and the housing association is to define the context together. What does the housing association want. why and how does he want it and when are included in the context of the future plan? This is done by conversations with multiple individuals with various positions within the association. for example the manager real-estate. person who deals with the quality of life. a financial manager and more. In short. a broad interaction with the whole organisation. After that. a working group is established for feedback and further defining of the context. This corresponds with monitoring the situation. stated in the literature review.

EXPLORE POSSIBILITIES (PHASE 2)

After the context is defined. the conditions for the programme of the future plans can be established. These conditions contain the demands. some specific characteristics and the strategic stock policy of the housing association. Employee 14 of CC1 cited: *''The strategic stock policy of a housing association contains characteristics about the building age. housing types. allocation. energy consumption. state of renovation and future renovations. Because of the differences between housing associations. there is not one single approach. It requires a specific approach for each project. which makes our profession very specialized.''* The consultancy company utilise their knowledge and experience to explore the possibilities for the programme. which corresponds with phase 2 stated in the literature review. State-of-the-art knowledge. environmental aspects. strategic stock policy and financial consequences are considered. As mentioned before. multiple stakeholders are involved. It is important to involve the different stakeholders in this exploration phase. The consultancy company. together with the housing association. government and utility company forms a discussion group on how to approach the future plan and create an optimized programme. Important in this discussion group is the collaboration of the different stakeholders. The housing association has information about their dwellings. the government has information about legislations. subsidies. data and planning of the municipality and data of other housing associations. The utility company has information about the energy consumption of the dwellings. subterranean infrastructure and the maintenance planning of it. Employee 14 of CC1 cited: *''For example Utrecht and Amsterdam. they have multiple housing associations in the same city and they have also similar dwelling stocks. Those stakeholders need to collaborate in discussion groups to make a corresponding view. The trend nowadays is that the governments of bigger cities is taking on this role to establish collaborations and are appointing heat directors for this task. I do think the government is the designated stakeholder for this task.''* The collaboration within the discussion group produces conclusions which are determined with help of all the stakeholders so a more integrated view is created.

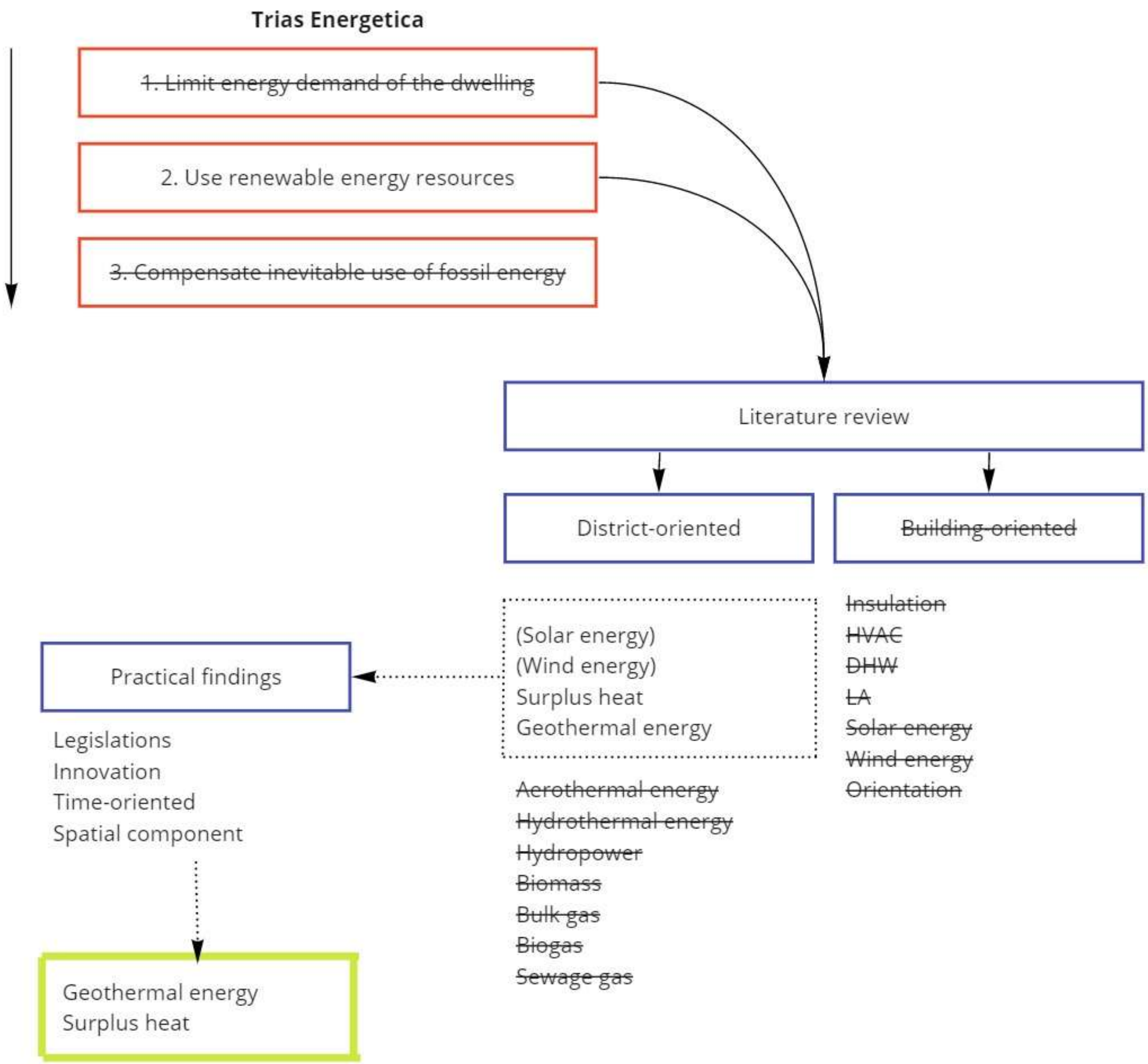
Develop advice (phase 3)

The context. conditions and possibilities are familiar for the consultancy company in this phase and the developing of the advice can start. The basic thought of the consultancy company in this case is advice a housing association based on the 'no-regret' principle. which means advising measures which will be safe to apply considered uncertainties in the future. Employee 13 of CC1 cited: *''Also remarkable. housing associations have difficulties to decide whether a building complex will still be exploited in 2050. if you can look 20 years forwards we can say; just improve the insulation and stick on the use of gas and after then we can look again. This is a pure example of a no-regret measure.''* Employee 14 of CC1 added to this cite: *''I distinguish two types of focusses. namely focus on district and focus on time. Enhancing sustainability is a process over time. not over single measurements.''* Because of this process over time. the consultancy company develops a policy on long-term and annual programme for the short-term. First start with the long-term view and after that short-term views for the upcoming 4 á 5 years. Employee 14 of CC1 cited: *''These short-term programmes can be different programmes. for example for tenants' behaviour. insulation of dwellings and newly built energy neutral houses. The legislations prescribe that housing associations should make programmes for the next 5 years.''* Long-term advises are about energy neutrality. district heating networks and all-electric solutions. Short-term advises are about improving the insulation. mounting PV panels. reaching Energy Level B and are often an intermediate stage towards the long-term solutions. These advises are addressed as policies and annual programmes to the housing association. This phase corresponds with the last phase of the literature review. namely introducing recommendations.

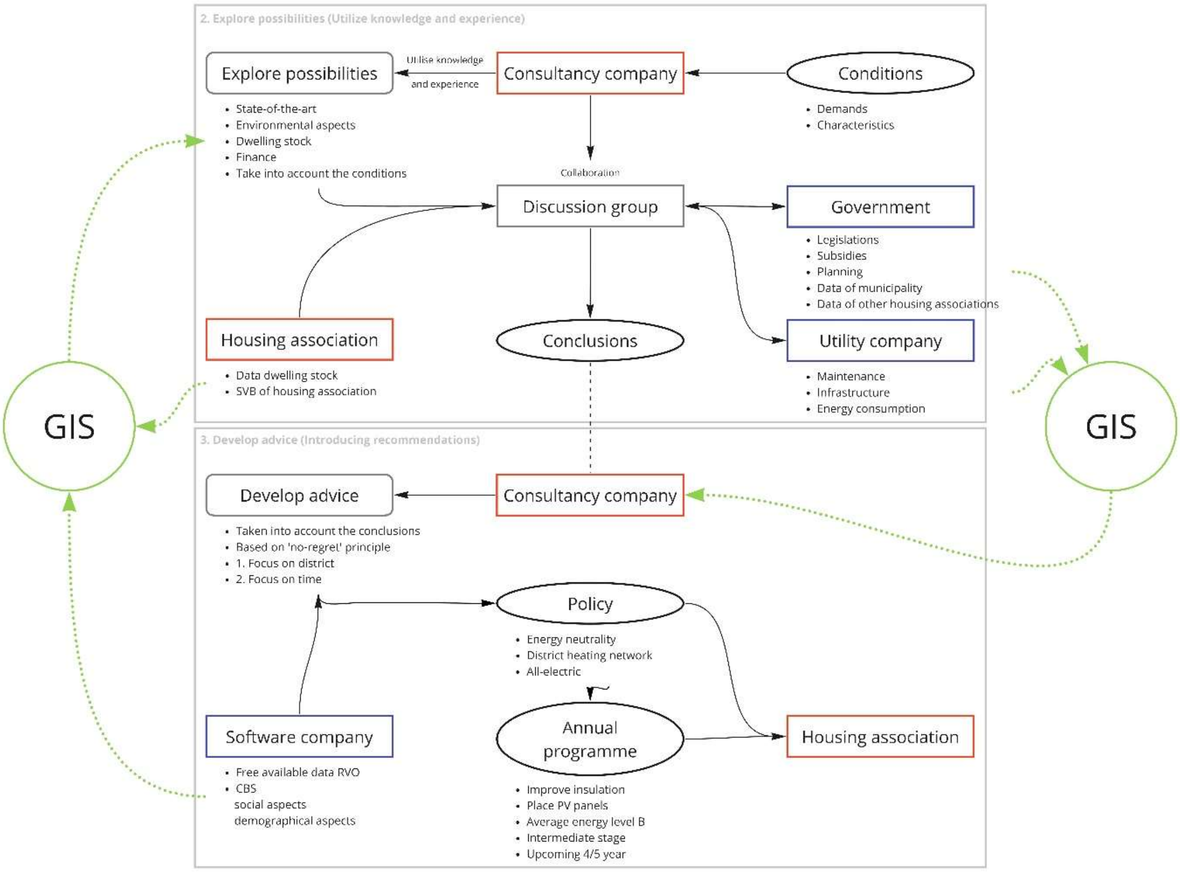
Offering helping hand (phase 4)

From this point on. it is the task of the housing association to execute the programmes and policies for improving their dwelling stock. received from the consultancy company. In this case. the consultancy company offers a helping hand. which is a post-process phase compared to the literature review. The consultancy company can offer their experience and network to arrange partners for realising the programme. for example contractors. Also. the stakeholder of the discussion group formed in phase 2. explore possibilities. are involved in executing the programme. The utility company can co-ordinate their subterranean plans together with the plans in the programme and the government can help executing the programme by providing subsidies and sharing their subterranean plans.

Appendix J. Overview of process towards the focus

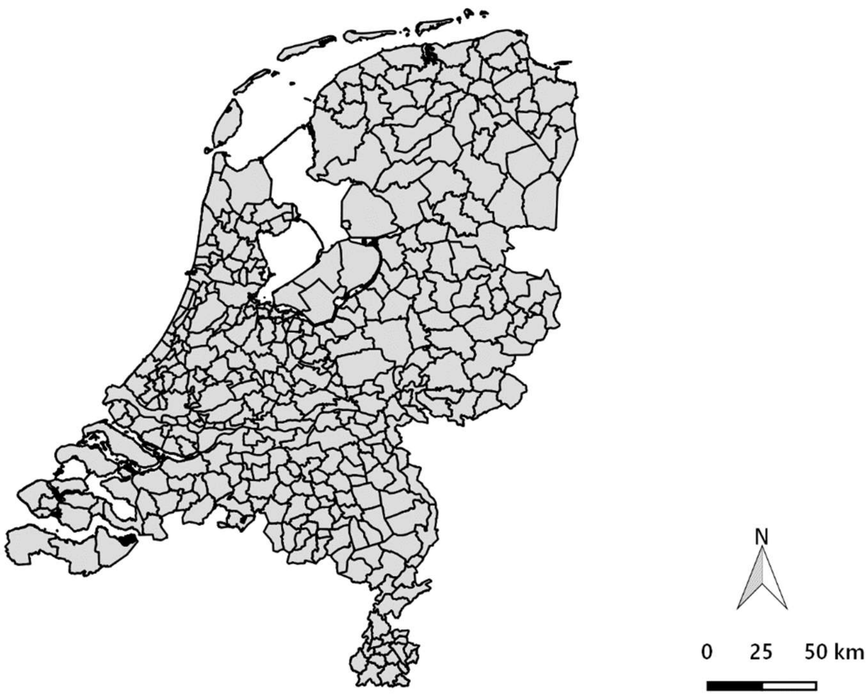


Appendix K. GIS integrated in the consultancy process phase 2 and 3

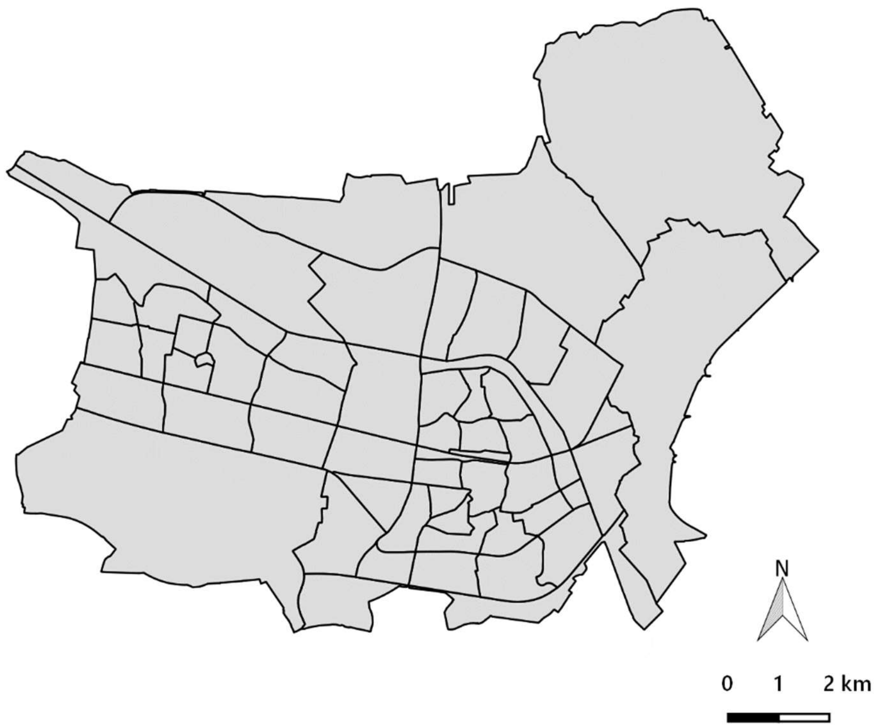


Appendix L. Base maps

B1. Municipality borders, Centraal Bureau voor de Statistiek (2017)



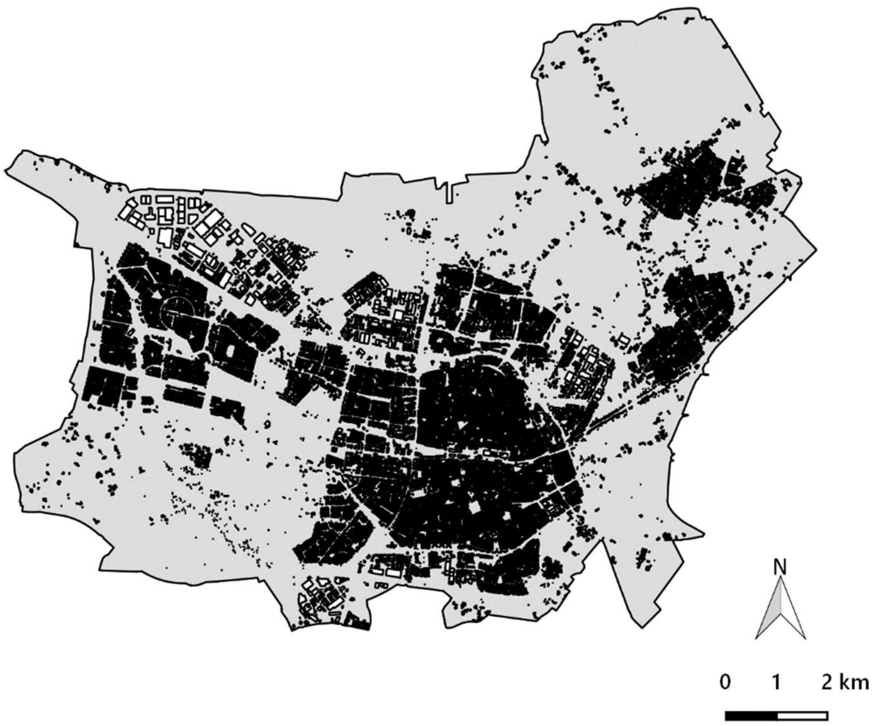
B2. District borders, Centraal Bureau voor de Statistiek (2017)



B3. Neighbourhood borders, Centraal Bureau voor de Statistiek (2017)

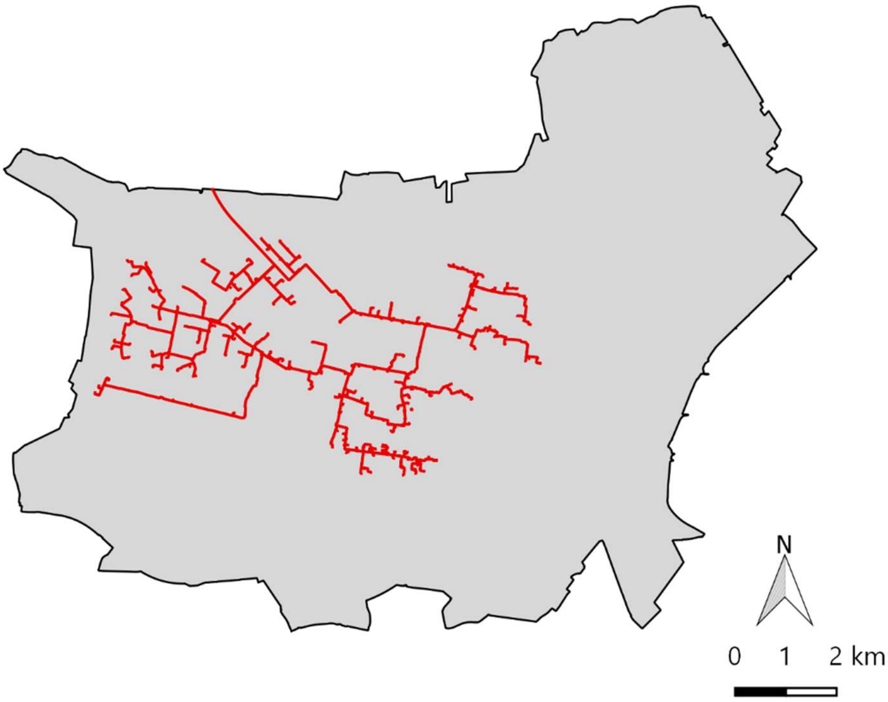
B4. Zipp-code borders, Centraal Bureau voor de Statistiek (2017)

B5. BAG Buildings, Basisregistratie Adressen en Gebouwen (BAG) – PDOK (2017)



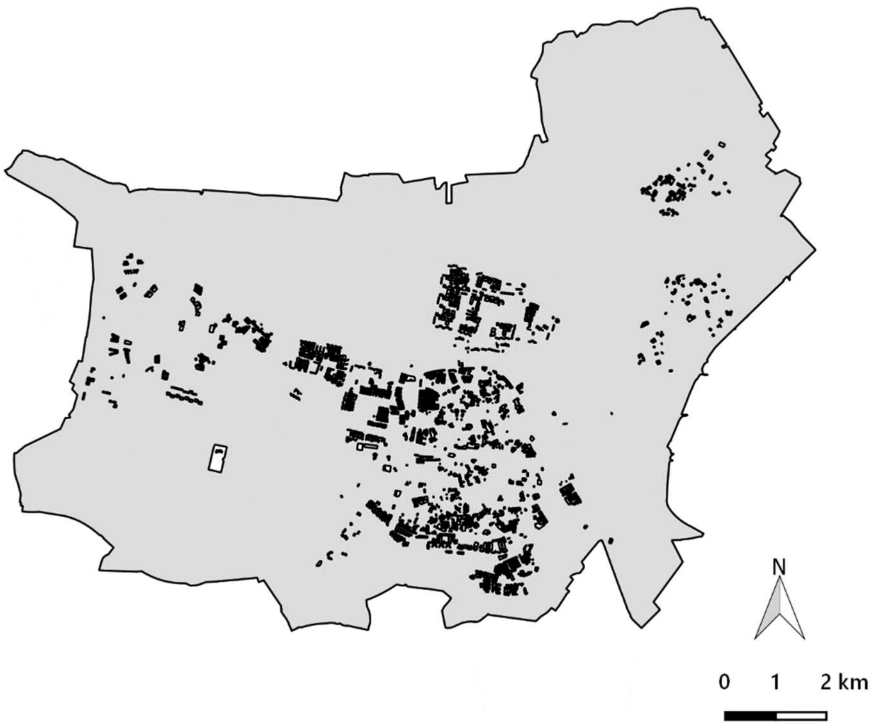
B6. Roads, Nationaal Wegen Bestand – Nederlandse Overheid (2017)

B7. Heating network, Utility company (2017)



B8. BAG Addresses, Basisregistratie Adressen en Gebouwen (BAG) – INSPIRE (2017)

B9. Housing associations' dwelling stock, Housing associations (2017)



B10. Gas consumption, Centraal bureau voor de statistiek (2017)

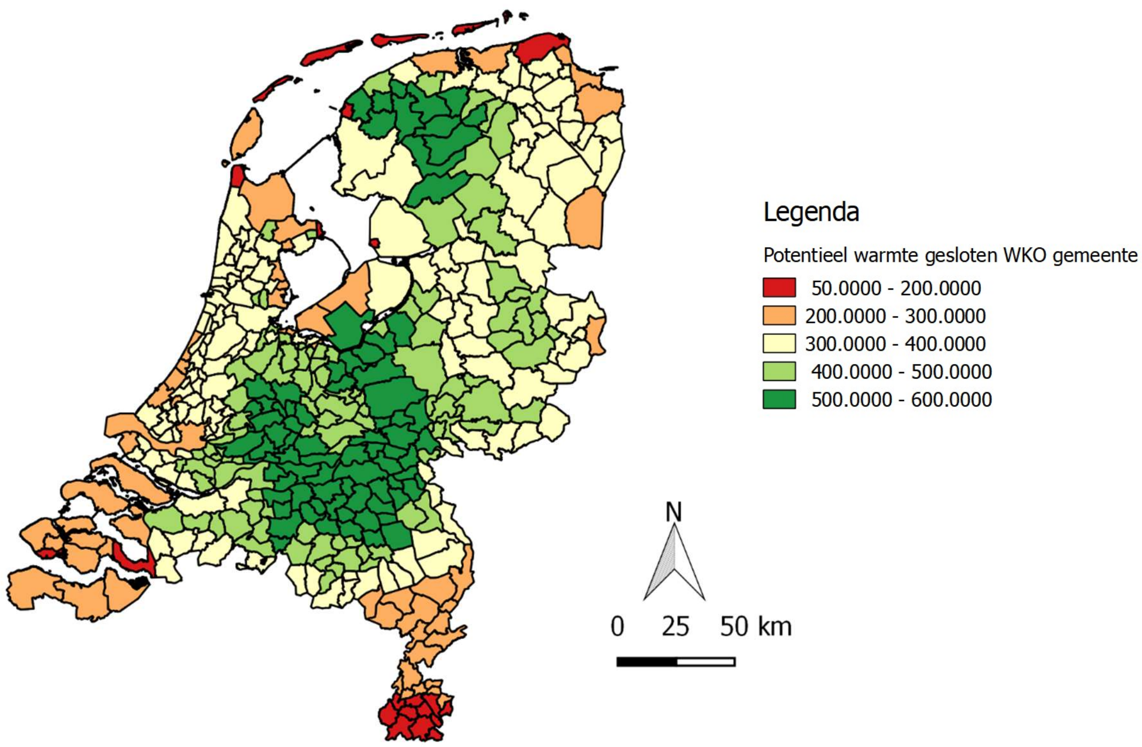
B11 + B17. Heating installation + Connected to DH-network, Housing associations (2017)

	A	B	C	D	E	F	G
1	Straat	Nr	Toev	Volgnr	Postcode	Plaats	Verwarmingssysteem
2	Eccardstr	1			5011AK	Tilburg	Individueel
3	Eccardstr	3			5011AK	Tilburg	Individueel
4	Offenbach	12			5011EJ	Tilburg	Warmtelevering derden
5	Offenbach	14			5011EJ	Tilburg	Warmtelevering derden
6	Offenbach	16			5011EJ	Tilburg	Warmtelevering derden
7	Offenbach	18			5011EJ	Tilburg	Warmtelevering derden
8	Offenbach	20			5011EJ	Tilburg	Warmtelevering derden
9	Schuberts	702			5011CW	Tilburg	Collectief
10	Schuberts	704			5011CW	Tilburg	Collectief
11	Schuberts	706			5011CW	Tilburg	Collectief
12	Schuberts	708			5011CW	Tilburg	Collectief
13	Schuberts	710			5011CW	Tilburg	Collectief
14	Eccardstr	29			5011AK	Tilburg	Individueel
15	Eccardstr	31			5011AK	Tilburg	Individueel
16	Eccardstr	33			5011AK	Tilburg	Individueel
17	Eccardstr	35			5011AK	Tilburg	Individueel
18	Eccardstr	39			5011AL	Tilburg	Individueel

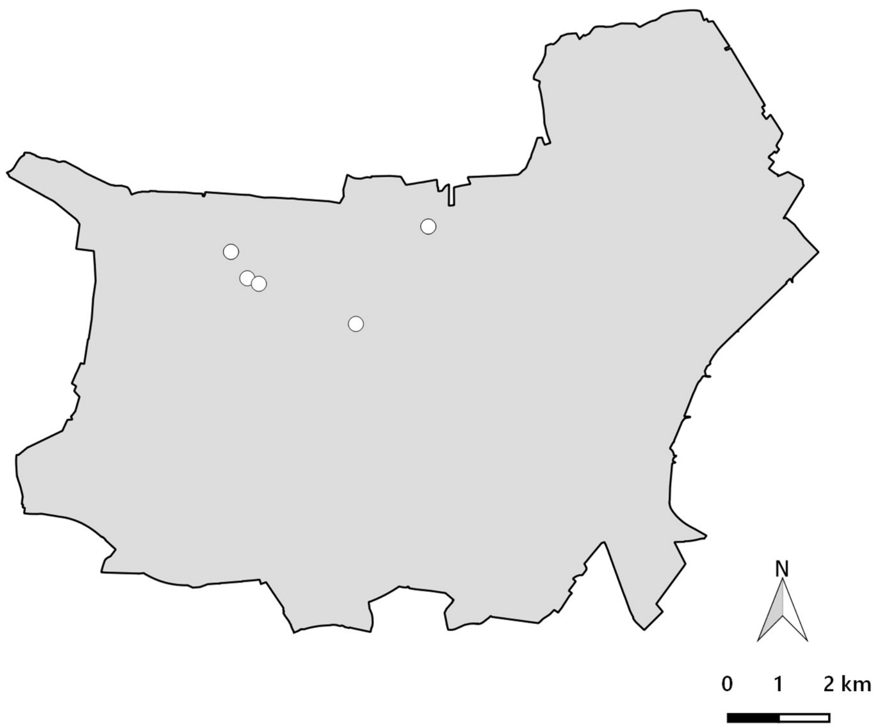
B12. Energy label, Rijkstdienst voor Ondernemend Nederland (2017)

	A	B	C	D	E	F	G
1	POSTCODE	HUISNUM	HUISNUMMER_TOEV_WONING	OPNAMEDATUM	EP	LABEL	REGISTRATIEDATUM
2	0000AA	83		2010.01.14	1,69	D	2010.01.19
3	1007KE	70238		2012.08.07	1,25	B	2012.11.13
4	1011AG	99	B1	2016.01.08	2,08	E	2016.01.11
5	1011AG	99	B2	2016.09.05		F	2016.09.05
6	1011AG	99	B3	2016.09.26		F	2016.09.26
7	1011AH	100	2LIN	2011.08.16	2,55	F	2011.08.25
8	1011AH	102	1	2015.06.04	1,79	E	2015.06.10
9	1011AJ	106	1	2008.03.03	1,60	C	2008.03.06
10	1011AJ	106	2	2008.03.03	1,53	C	2008.03.06
11	1011AJ	106	3	2008.03.03	1,59	C	2008.03.06
12	1011AJ	107	1	2016.11.30	1,08	A	2016.12.04
13	1011AJ	107	2	2016.11.30	1,08	A	2016.12.04
14	1011AJ	107	3	2016.11.30	0,97	A	2016.12.04
15	1011AJ	107	H	2016.11.30	1,02	A	2016.12.04
16	1011AN	125	A	2016.03.10		D	2016.03.10
17	1011AN	125	B	2015.01.25		E	2015.01.25
18	1011AN	126	A	2015.11.04	1,28	D	2016.01.05

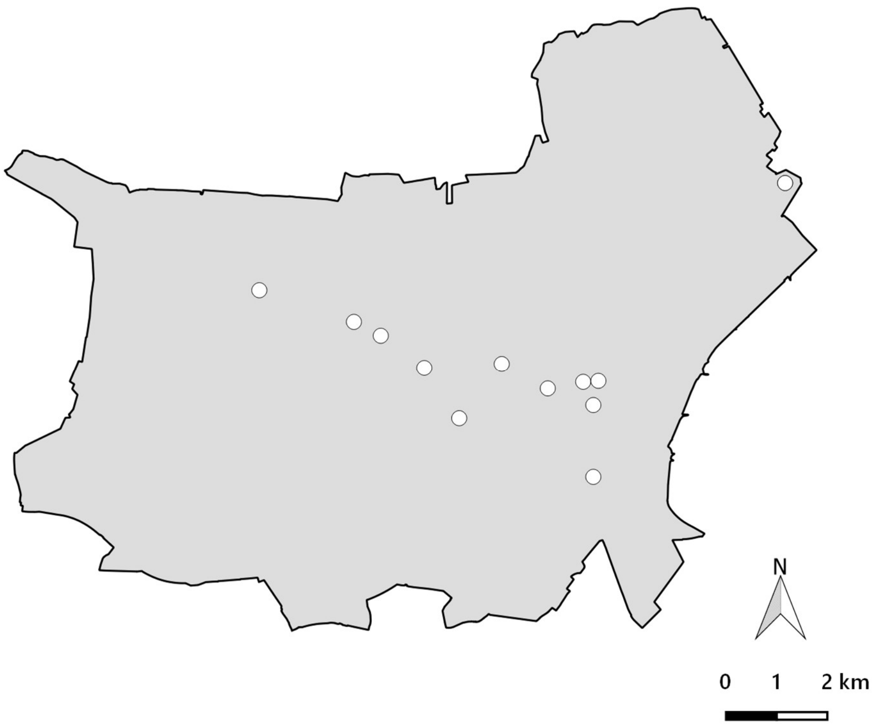
B14. Geothermal potential, Rijksdienst voor Ondernemend Nederland (2014)



B15. Surplus heat sources, Nationaal Georegister (2017)



B16. Surplus heat potential, Nationaal Georegister (2017)



Appendix M. Criterion scores on building-/complex level


Legenda
Roads
Private ownership buildings
Criterion 3 - Private owner buildings
0.0000 - 0.2000
0.2000 - 0.4000
0.4000 - 0.6000
0.6000 - 0.8000
0.8000 - 1.0000
N
0 25 50 75 m


Legenda
Roads
Private ownership buildings
Criterion 4 - Gas consumption
0.0000 - 0.2000
0.2000 - 0.4000
0.4000 - 0.6000
0.6000 - 0.8000
0.8000 - 1.0000
N
0 25 50 75 m


Legenda
Roads
Private ownership buildings
Criterion 5 - Ownership
0.0000 - 0.2000
0.2000 - 0.4000
0.4000 - 0.6000
0.6000 - 0.8000
0.8000 - 1.0000
N
0 25 50 75 m


Legenda
Roads
Private ownership buildings
Criterion 6 - Heating system
0.0000 - 0.2000
0.2000 - 0.4000
0.4000 - 0.6000
0.6000 - 0.8000
0.8000 - 1.0000
N
0 25 50 75 m


Legenda
Roads
Private ownership buildings
Criterion 7 - Distance to DH-network
0.0000 - 0.2000
0.2000 - 0.4000
0.4000 - 0.6000
0.6000 - 0.8000
0.8000 - 1.0000
N
0
25
50
75 m

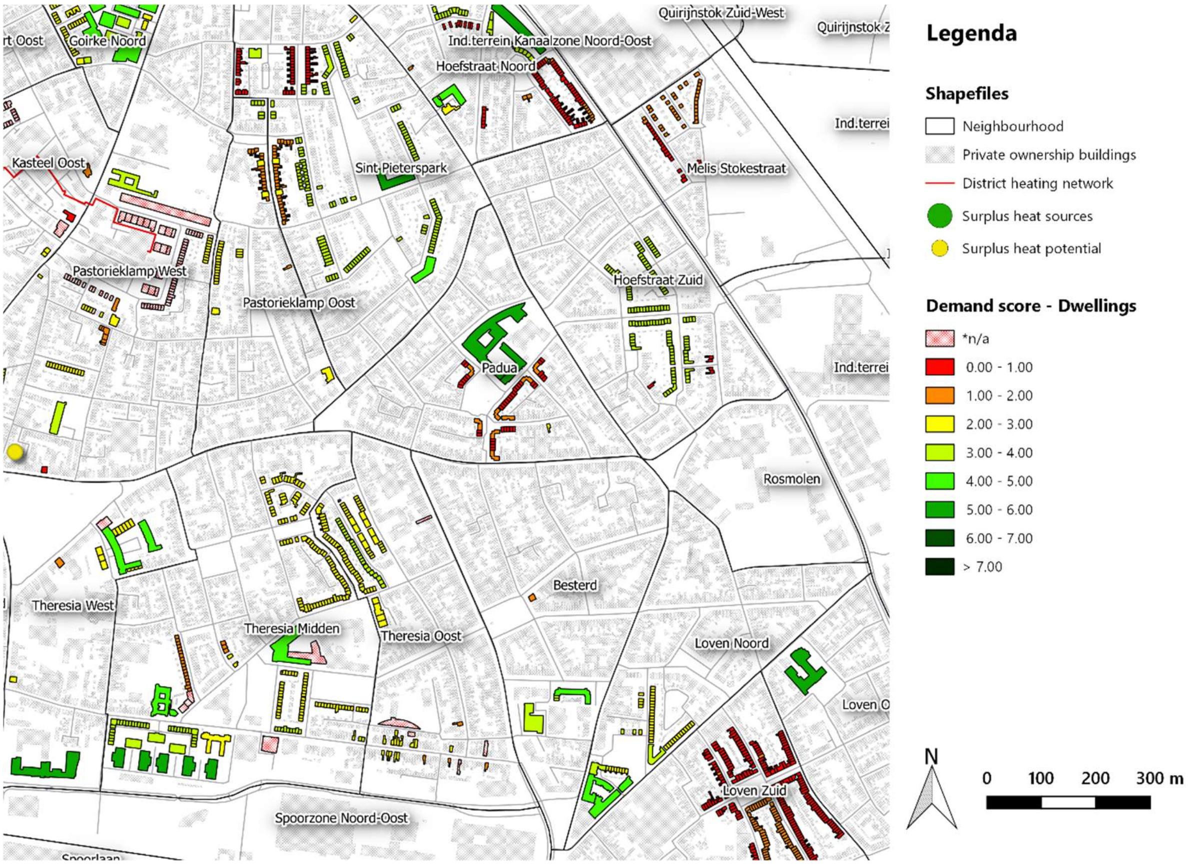

Legenda
Roads
Private ownership buildings
Criterion 8 - Distance to potential SH
0.0000 - 0.2000
0.2000 - 0.4000
0.4000 - 0.6000
0.6000 - 0.8000
0.8000 - 1.0000
N
0
25
50
75 m

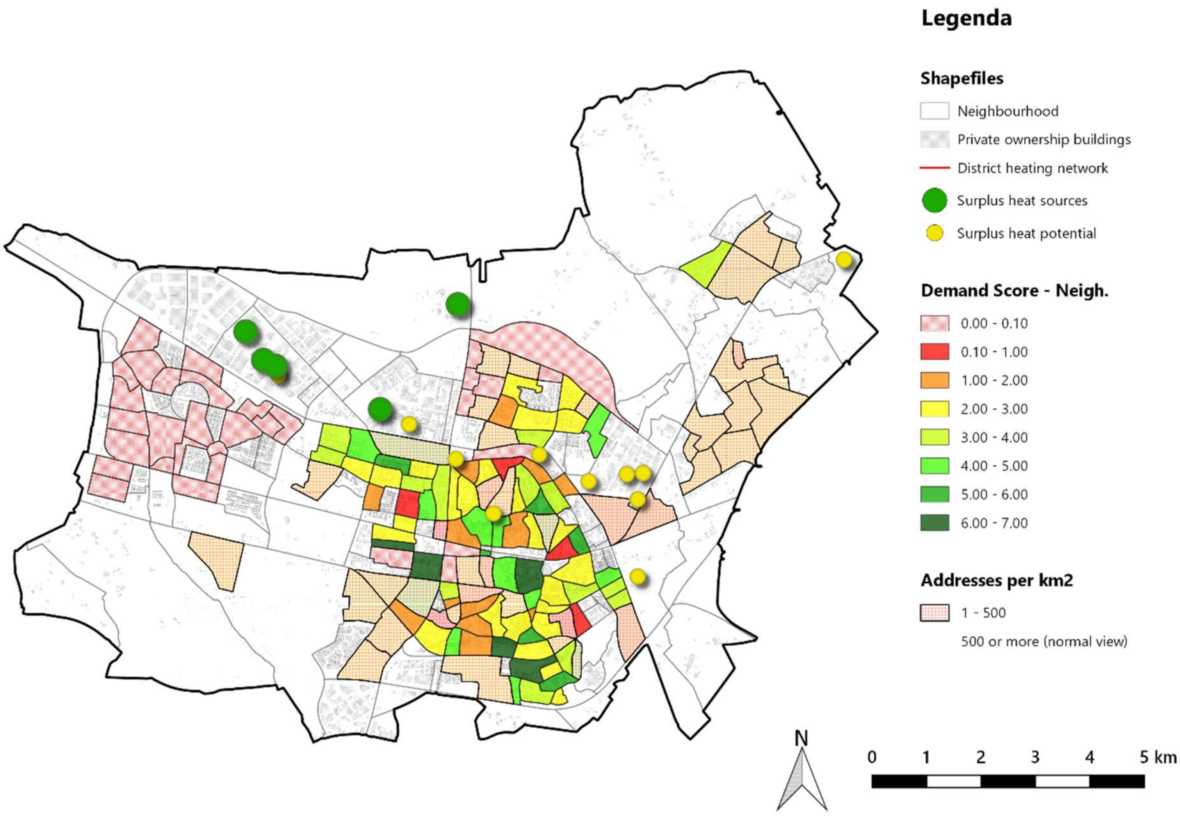

Legenda
Roads
Private ownership buildings
Criterion 10 - Energy level
0.0000 - 0.2000
0.2000 - 0.4000
0.4000 - 0.6000
0.6000 - 0.8000
0.8000 - 1.0000
N
0 25 50 75 m

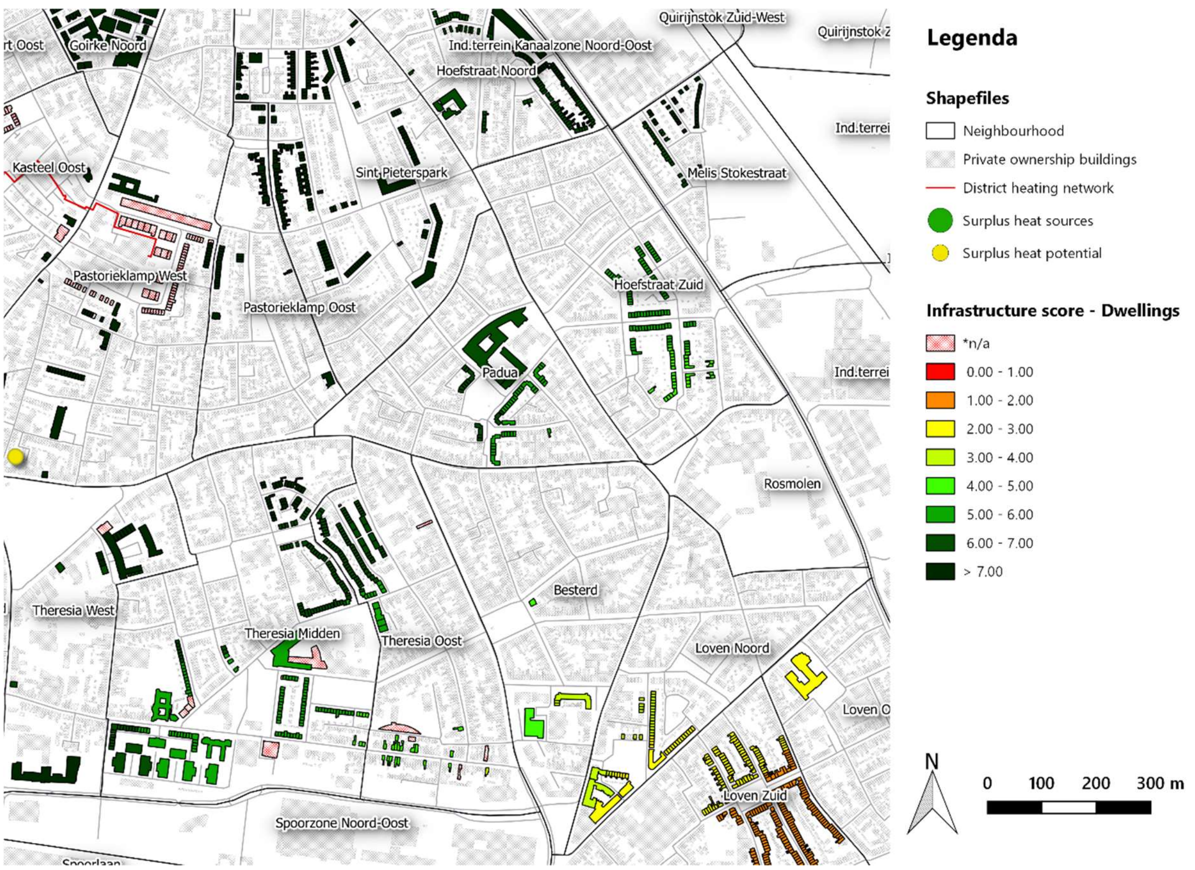

Legenda
Roads
Private ownership buildings
Criterion 11 - Existing surplus heat
0.0000 - 0.2000
0.2000 - 0.4000
0.4000 - 0.6000
0.6000 - 0.8000
0.8000 - 1.0000
N
0 25 50 75 m


Legenda
Roads
Private ownership buildings
Criterion 12 - Geothermal potential
0.0000 - 0.2000
0.2000 - 0.4000
0.4000 - 0.6000
0.6000 - 0.8000
0.8000 - 1.0000
N
0
25
50
75 m

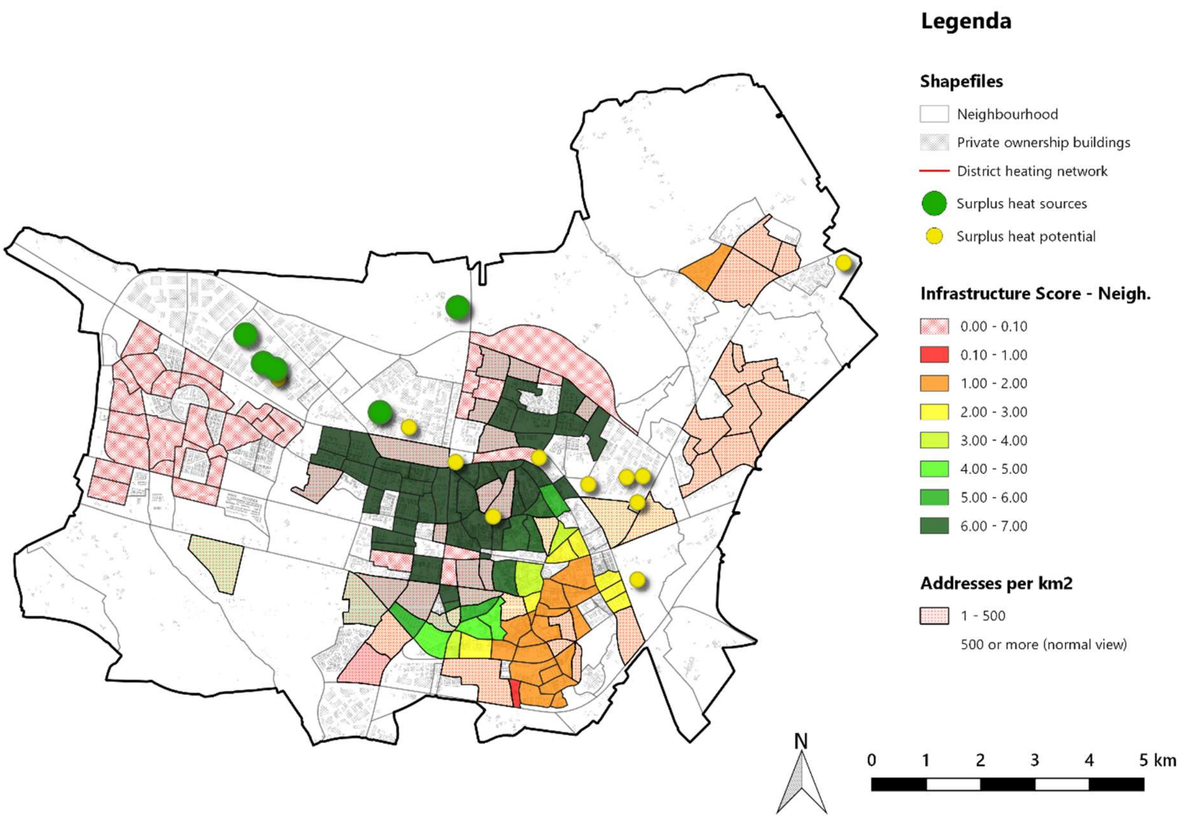
Appendix N. Final suitability scores for each aspect separately



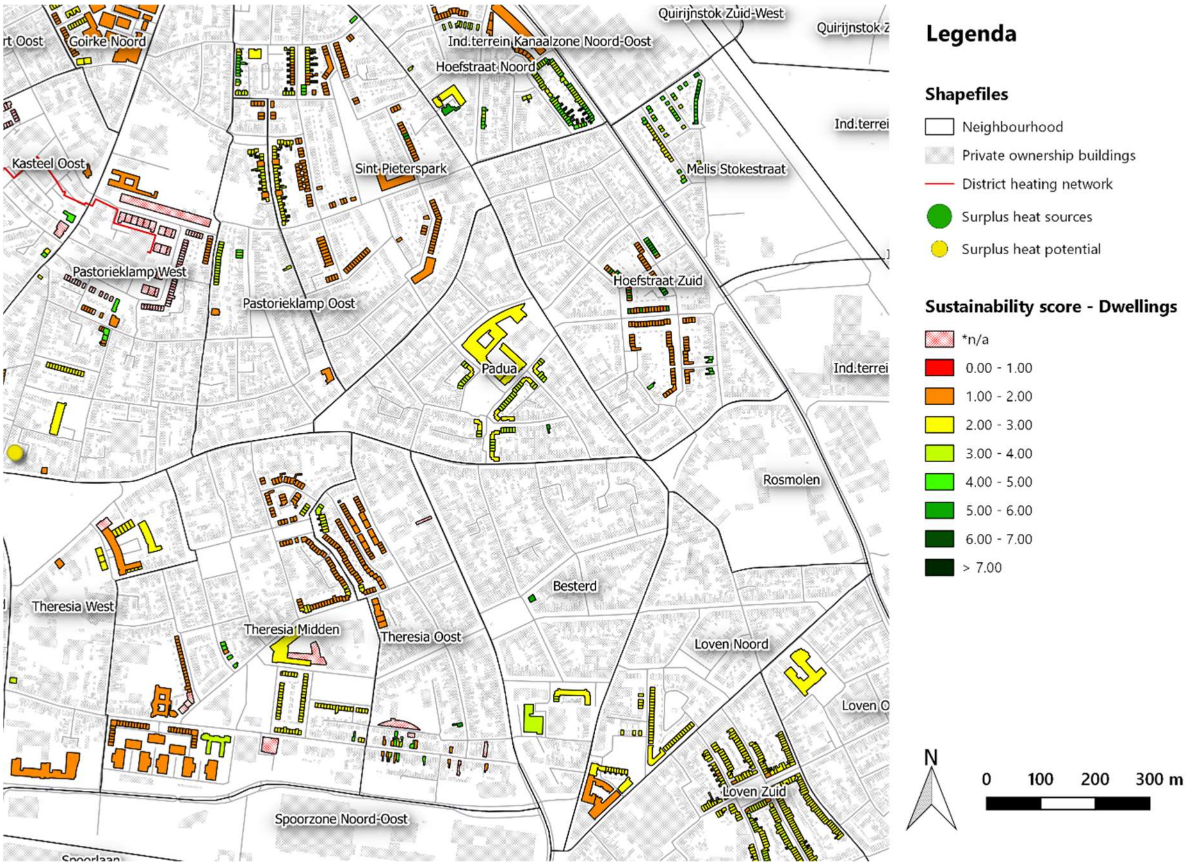


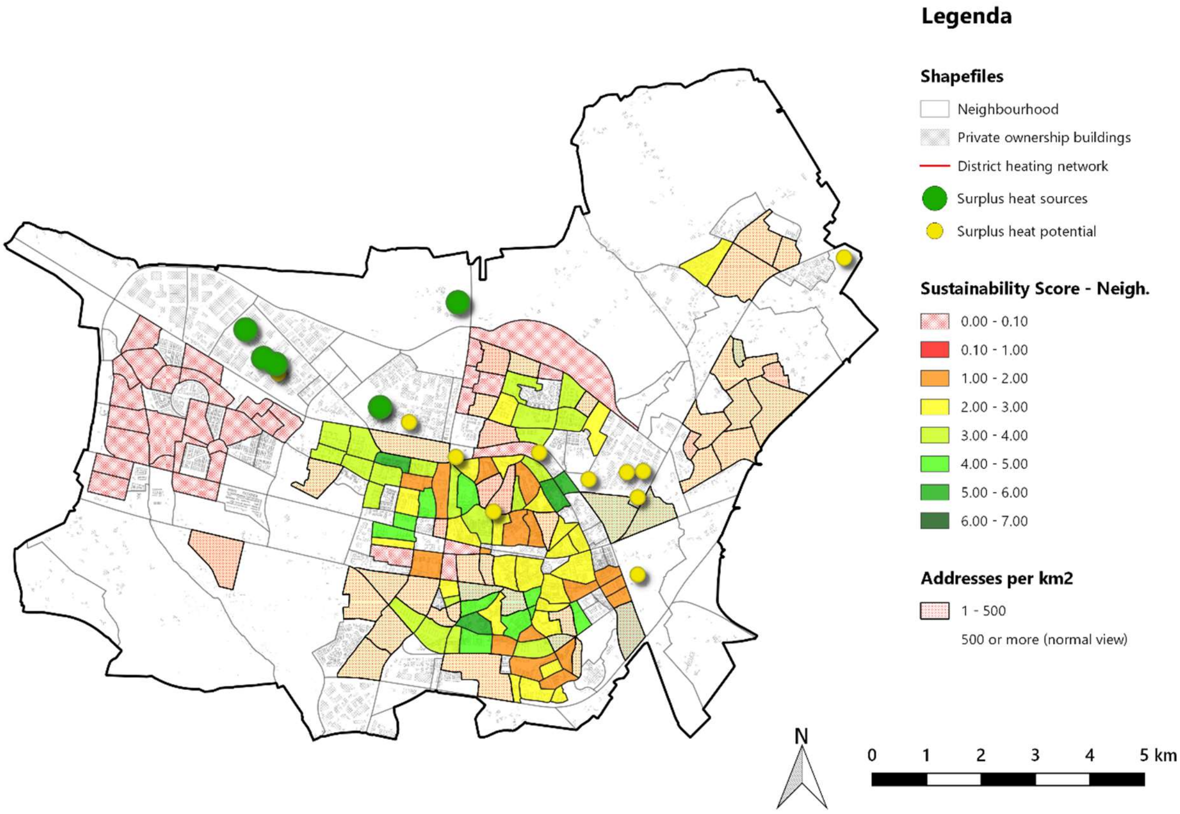


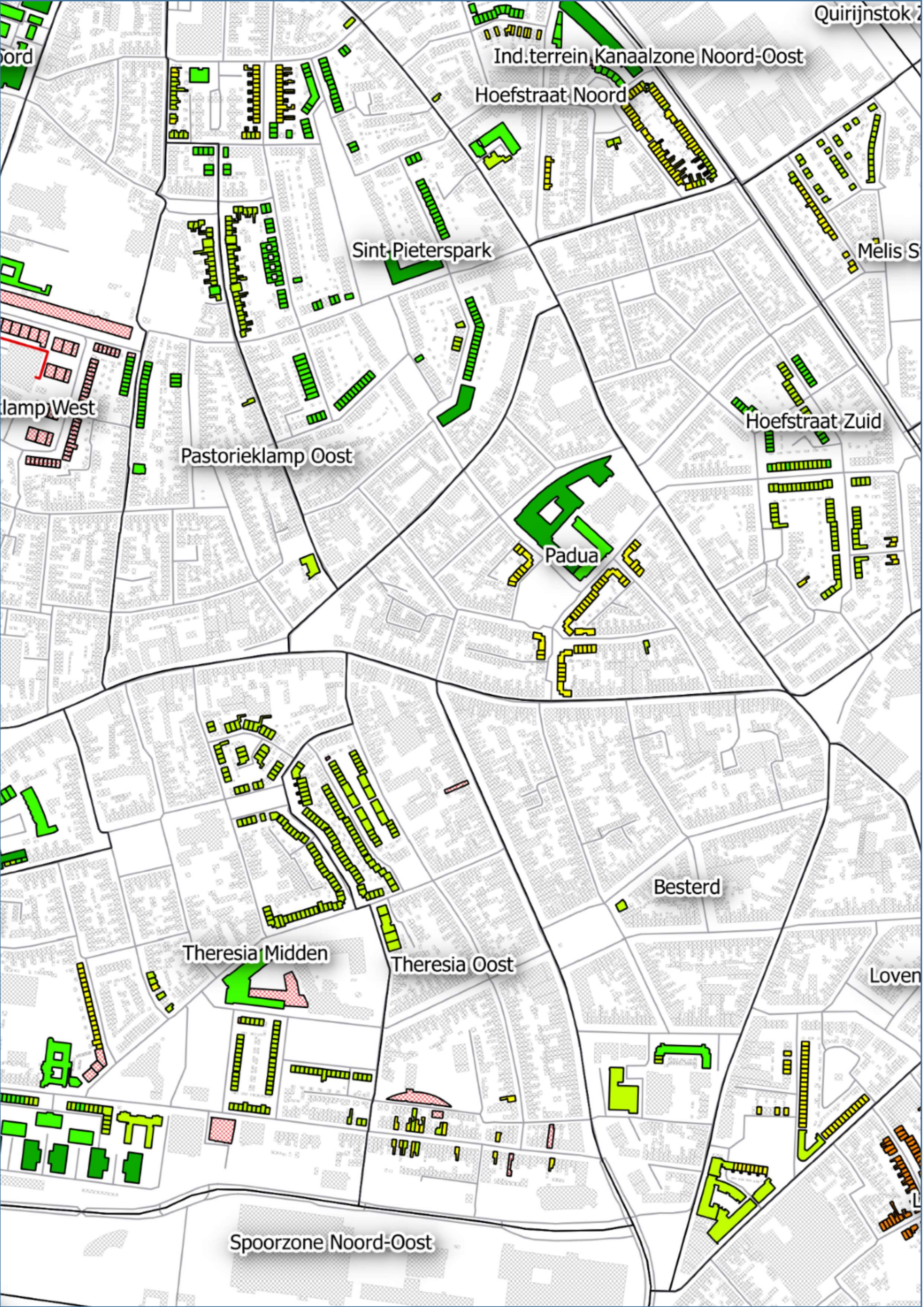
Quirijnstok Zuid-West
Goirke Noord
Ind.terrein Kanaalzone Noord-Oost
Hoefstraat Noord
Kasteel Oost
Sint Pieterspark
Melis Stokestraat
Pastorieklamp West
Pastorieklamp Oost
Hoefstraat Zuid
Padua
Rosmolen
Theresia West
Besterd
Theresia Midden
Theresia Oost
Loven Noord
Loven Zuid
Spoorzone Noord-Oost
Legenda
Shapefiles
Neighbourhood
Private ownership buildings
District heating network
Surplus heat sources
Surplus heat potential
Infrastructure score - Dwellings
*n/a
0.00 - 1.00
1.00 - 2.00
2.00 - 3.00
3.00 - 4.00
4.00 - 5.00
5.00 - 6.00
6.00 - 7.00
> 7.00
N
0 100 200 300 m



Legenda
Shapefiles
Neighbourhood
Private ownership buildings
District heating network
Surplus heat sources
Surplus heat potential
Infrastructure Score - Neigh.
0.00 - 0.10
0.10 - 1.00
1.00 - 2.00
2.00 - 3.00
3.00 - 4.00
4.00 - 5.00
5.00 - 6.00
6.00 - 7.00
Addresses per km2
1 - 500
500 or more (normal view)
N
0 1 2 3 4 5 km


Goirke Noord
Ind.terrein Kanaalzone Noord-Oost
Quirijnstok Zuid-West
Hoefstraat Noord
Kasteel Oost
Sint-Pieterspark
Melis Stokestraat
Pastorieklamp West
Pastorieklamp Oost
Hoefstraat Zuid
Padua
Rosmolen
Besterd
Theresia West
Theresia Midden
Theresia Oost
Loven Noord
Loven Zuid
Spoorzone Noord-Oost
Legenda
Shapefiles
Neighbourhood
Private ownership buildings
District heating network
Surplus heat sources
Surplus heat potential
Sustainability score - Dwellings
*n/a
0.00 - 1.00
1.00 - 2.00
2.00 - 3.00
3.00 - 4.00
4.00 - 5.00
5.00 - 6.00
6.00 - 7.00
> 7.00
N
0 100 200 300 m


Legenda
Shapefiles
Neighbourhood
Private ownership buildings
District heating network
Surplus heat sources
Surplus heat potential
Sustainability Score - Neigh.
0.00 - 0.10
0.10 - 1.00
1.00 - 2.00
2.00 - 3.00
3.00 - 4.00
4.00 - 5.00
5.00 - 6.00
6.00 - 7.00
Addresses per km2
1 - 500
500 or more (normal view)
N
0 1 2 3 4 5 km


Quirijnstok
Ind.terrein Kanaalzone Noord-Oost
Hoefstraat Noord
Sint Pieterspark
Melis S
Pastorieklamp Oost
Hoefstraat Zuid
Padua
Besterd
Theresia Midden
Theresia Oost
Loven
Spoorzone Noord-Oost