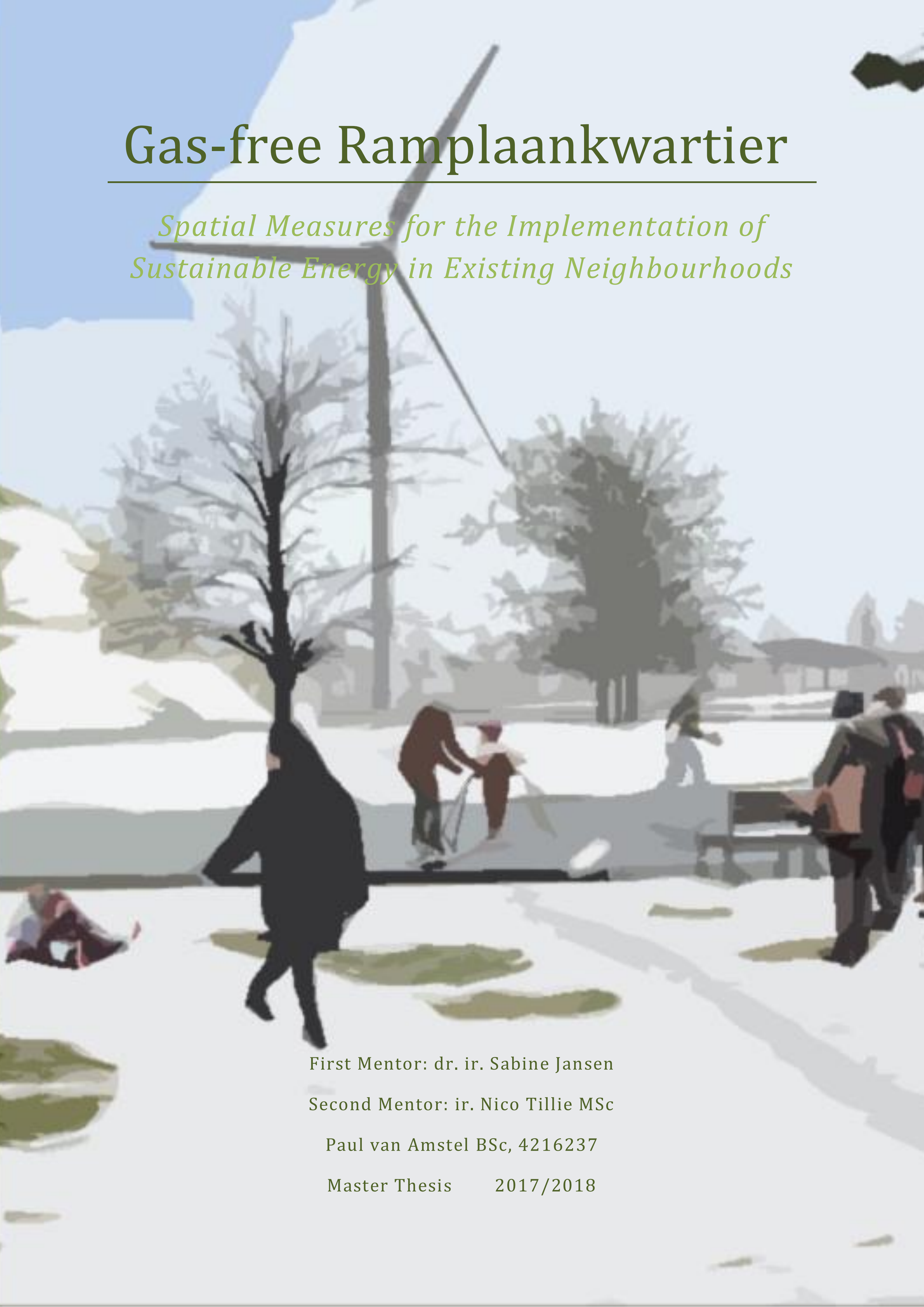

Gas-free Ramplaankwartier

Spatial Measures for the Implementation of Sustainable Energy in Existing Neighbourhoods

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Master Thesis 2017/2018

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Motivation:
Ever since I started here in Delft, I have become more and more interested in sustainability and bioclimatic design. During the different projects, I really came to enjoy the technical part of designing and thinking about subjects like energy efficiency and circularity. I think my generation of (future) architects and engineers are the ones that are going to make a difference, to transform the current way of thinking and really start building the ‘sustainable society’ (because we have to). A big and important part of this challenge will be to change the way we consume energy and adapt our neighbourhoods to accommodate this change. I hope that with this study, and the knowledge that I will gain from doing this, I can make a contribution to this change.

Abstract:
Spatial impact of the energy transition is a subject that has not been studied extensively as of now. Developing a spatial plan for a sustainable energy system in an early phase will provide insight in practical and spatial implications that are related to these systems. This is especially relevant in existing neighbourhoods, where the existing context has to be taken into account.
Energy potential mapping already connects energy production to a spatial component, but it remains theoretical and abstract, often until a late stage in the planning process. An additional step should be taken to assess the spatial impact of the renewable energy production and the district energy system through concrete design proposals; creating the “toolbox”. These designs are different based on the technology and the context of the project, but it should always seek for ways to minimise its negative impact or to benefit its surroundings. By doing this, the components of the system becomes tangible and a tool to discover synergies, make decisions, and convince stakeholders. This will not only improve the feasibility of the project, but also the quality of the final product.

Executive Summary

General Background

There is a major challenge to reduce the use of fossil fuels, mainly to reduce our negative impact on the environment and to reduce our dependence on these finite resources. Changing the energy use in the built environment is an important part of this challenge, as it is for a large part responsible for our fossil fuel consumption; in the Netherlands building related energy use is responsible for 34% of our energy consumption, and 72% of this is through natural gas mainly used for space heating (CBS, 2017).

To reduce the energy and therefore fossil fuel use, several design approaches and strategies have been developed over the last few decades. For instance the Trias Energetica, a popular strategy from the 90s, which consists of three steps: reduce demand, produce renewably and solve the remaining with clean and efficient fossil fuels (Lysen, 1996). This has evolved in the New Stepped Strategy (Dobbelsteen, 2008) to include an additional step, reuse of waste streams, to potentially make the use of fossil fuels completely unnecessary.

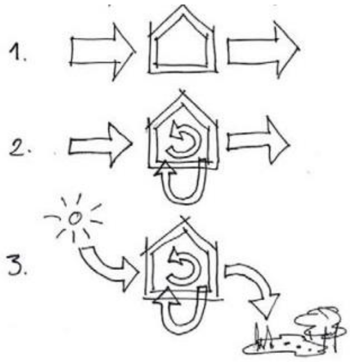

Figure 0.1: 'New Stepped Strategy' (Dobbelsteen, 2008)

Based on the New Stepped Strategy, several theoretical approaches have been developed, such as the REAP (Tillie, Dobbelsteen, Doepel, Joubert, Jager, & Mayenburg, 2009) for the city of Rotterdam, the AGEUP/LES (Kürschner, Hakvoort, Mantel, Dobbelsteen, & Tillie, 2010) for Amsterdam and the Smart Urban Isle or 'SUI' project approach (SUI, 2018), which will be used in this study. These approaches provide a design strategy to transform the energy system in existing cities and neighbourhoods, but often don't go in depth on the practical consequences of these strategies, such as spatial implications. The approach of Energy Potential Mapping (EPM) does connect renewable energy production to its spatial aspects, but generally remains abstract. This is useful in large scale spatial planning, but less so for the development of interventions on a neighbourhood scale or below, due to the lack of detail.

Sustainable District Energy Systems

To be able to reduce our natural gas use, sustainable district energy systems (SDES) need to be developed, which supply our energy demand through renewable sources. Several concepts for such and SDES, were identified from literature and realised projects. These are an 'all-electric' system and three different heat network concepts operating on high (70-90°C), medium (45°C), or low (20°C) temperatures. The performance of each of these concepts was evaluated through a case study of the Ramplaankwartier neighbourhood in Haarlem.

The evaluation was done through the use of several 'Key Performance Indicators' (KPIs), which are criteria that allow for an accurate and reproducible evaluation of each concept. For energy, these include, among others, the total annual renewable supply, share of renewable energy, and CO_2-emissions. For spatial impact, these include footprint, visibility, and noise, as well as an indicator for any quality or function that a system can potentially add to the neighbourhood.

From the evaluation it could be concluded that the low-temperature heat network concept is most promising for the case study neighbourhood, because of the high availability of low-temperature heat sources and the relatively low negative impact on the neighbourhood. This concept was taken as a starting point for the further research.

Intervention Toolbox

To gain better insight into the impact that this energy system has on the neighbourhood, components of the system for energy production, distribution or storage are translated to concrete proposals for interventions in the neighbourhood. This makes it possible to explore consequences of the integration of these elements.

Each component is first assessed on its contribution to the energy system, as well as the spatial impact, in this case with an extra emphasis on the positive or negative effect on the urban quality of the neighbourhood.

This is followed by a brief explanation and visualisations of the interventions in their relevant surrounding.

Figure 0.2: Components from the toolbox: assessment at the top, followed by brief explanation and visualisation(s) (Own ill.)

These proposals together form a toolbox, which can be used to assess their impact and select the most suitable for further development. The interventions from the toolbox are placed in a graph, see figure 0.3, by quantifying the energy performance and spatial impact. This allows for a quick overview of the different possible measures and the selection of the most suitable elements.

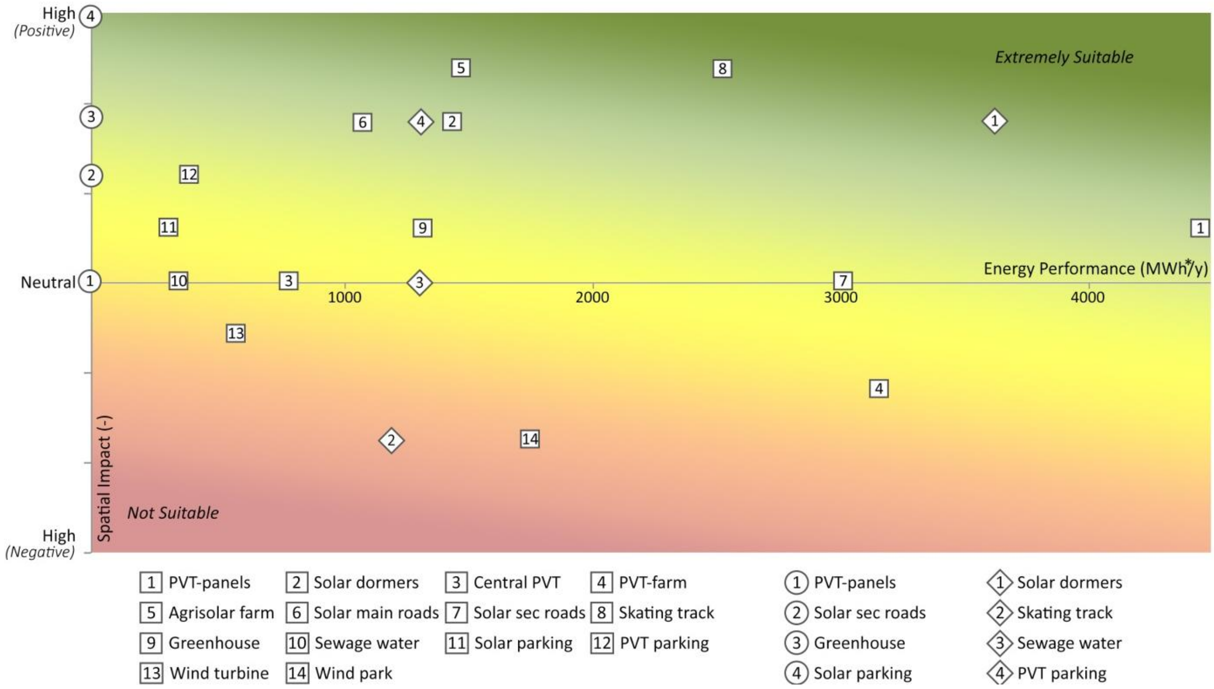

Figure 0.3: Comparison of interventions from the toolbox based on spatial impact and energy performance (Own ill.)

The (creation of a) toolbox is a useful tool to explore which interventions may be suitable for a certain neighbourhood. The comparison graph should be used with consideration however, as it relies on quantifying the estimated impact of a certain system. The spatial impact could be more accurately compared through interviews or workshops with the residents, to get a reliable view on the actual impact of an intervention.

Energy System Design

The most favourable interventions from the toolbox are combined to create the energy system design. This consists of two parts: a spatial plan, in maps and visualisations, to assess the spatial impact and a technical system configuration to assess the energy performance.

For the assessment, two different scenarios are developed as well: a minimal and an optimal spatial impact scenario. The minimal scenario includes several interventions that have a low spatial impact, while the optimal scenario combines those interventions with several high impact measures. These are combined in an 'Energy Park' on an empty plot just outside the neighbourhood. Despite the high impact, the overall effect of these interventions is predominantly positive, due to for instance added functions.

The skating track, see figure 0.4, is an example: Although it produces less energy than a solar farm, it provides an extra function and meeting place for the neighbourhood, both in summer and winter. This added functionality makes it very suitable for implementation.

Figure 0.4: Impression of the 'Energy Park' with the skating track in summer (l) and winter (r) situation (Own ill.)

The renewable heat production in the neighbourhood is in both scenarios sufficient to supply the heat demand on an annual basis. As a result, the electricity demand is more than doubled due to the heat pumps in the system and only a maximum of 50% can be supplied with renewable energy. The system will therefore still depend on external 'grey' electricity.

To supply all the thermal energy, the limiting factor is the power that is required to supply the peak demands, especially on cold days in winter. In the 'minimal impact' scenario, buildings that have no or only a basic improvement will need a back-up system with a high power to supply these peaks. For the 'optimal impact' scenario, it is already significantly improved and only a small back-up is needed. If the peak demand can be supplied with renewable sources, the area can become gas-free.

General Guidelines

The development of a toolbox of spatial interventions is a valuable addition to the already existing approach of energy potential mapping. This includes a study into the technology that is associated with a certain energy source as well as a design study to discover any added benefits that the energy source could provide. The toolbox translates the abstract overview of energy potentials developed with EPM to concrete interventions in their context, which allows for more detailed evaluation of the spatial impact of a certain source on its surroundings.

The toolbox can be useful at many different phases of a development process and can function as a tool for decision-making and convincing stakeholders. After a project, the interventions could be collected in a (online) database that can be used by (urban) designers, spatial planners and engineers to implement renewable sources in an area. Besides offering examples, it could also help to create integrated components for renewable energy production and provide approaches to develop new ideas or to overcome challenges.

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1. Research Framework

The background and scope of the project will briefly be discussed, providing an overview of the relevance of the project in the societal context. The research questions are formulated and the research method, which will be used for the study, is explained.

1.1 Background

There is a major challenge to reduce the use of fossil fuels, mainly to reduce our negative impact on the environment and to reduce our dependence on these finite resources. Changing the energy use in the built environment is an important part of this challenge, as it is for a large part responsible for our fossil fuel consumption; in the Netherlands building related energy use is responsible for 34% of our energy consumption, and 72% of this is through natural gas mainly used for space heating (CBS, 2017).

To reduce the energy and therefore fossil fuel use, several design approaches and strategies have been developed over the last few decades. For instance the Trias Energetica, a popular strategy from the 90s, which consists of three steps: reduce demand, produce renewably and solve the remaining with clean and efficient fossil fuels (Lysen, 1996). This has evolved in the New Stepped Strategy (Dobbelsteen, 2008) to include an additional step, reuse of waste streams, to potentially make the use of fossil fuels completely unnecessary.

Based on the New Stepped Strategy, several theoretical approaches have been developed, such as the REAP (Tillie, Dobbelsteen, Doepel, Joubert, Jager, & Mayenburg, 2009) for the city of Rotterdam, the AGEUP/LES (Kürschner, Hakvoort, Mantel, Dobbelsteen, & Tillie, 2010) for Amsterdam and the Smart Urban Isle or 'SUI' project approach (SUI, 2018), which will be used in this study. These approaches provide a design strategy to transform the energy system in existing cities and neighbourhoods, but often don't go in depth on the practical consequences of these strategies, such as spatial implications or feasibility. What makes this even more difficult is that there are only few realised projects where an innovative system is implemented in an existing neighbourhood.

1.2 Problem Statement

Following from the background, the problem statement is:

There are many different approaches and strategies to develop a sustainable energy system for existing neighbourhoods to supply the energy, especially heat, with renewable sources. The feasibility is often considered, but too little is known about the spatial implications of such sustainable district energy systems, from neighbourhood to building level.

1.3 Scope

Implementing a Sustainable District Energy System (SDES) can be broad and be interpreted in many different ways. It is therefore important to define a clear scope to clarify the limitations.

The study will focus on evaluating the feasibility of implementing a district energy system in **one existing neighbourhood**, the Ramplaankwartier in Haarlem. The Smart Urban Isle research project will form the basis for this study and this thesis will go into the spatial integration of this system.

The term 'district energy system' (DES) is used to describe a supply system for the most important energy flows in the built environment: heating, cooling, electricity and fuels. The emphasis for this research will be on the **supply of heating** as this is most relevant, as is mentioned before.

A DES can be called 'sustainable' when the heat, cold and/or electricity are produced with **renewable sources**, such as solar, wind, geothermal energy or biofuels. To test the impact these sources have on the neighbourhood, sources are limited to those available within the area or its direct surroundings.

The district energy systems (DES), evaluated in this study, are systems using **existing technology**, based on the literature and precedent review. Emerging technology and possible improvements may briefly be discussed, but won't be a major part of the study.

1.4 Research Question

The main research question is:

"What are the spatial implications of the development and implementation of a sustainable district energy system in an existing neighbourhood in the Netherlands?"

This main question is answered with the following sub questions in the next chapters of this report:

- *What is the current state of the art of transforming neighbourhoods into sustainable energy neighbourhoods?*
    - *What existing approaches are there for sustainable transformation of cities and neighbourhoods?*
    - *What sustainable energy systems have already been realised?*
    - *Which available technologies are relevant for this study?*

- *How can the performance of the systems be assessed?*
    - *Which indicators will be used for this study to assess the energetic performance?*
    - *Which indicators will be used for this study to assess the spatial implications?*

- *What energy concepts are promising for implementation in the case study area?*
    - *What concepts are available for the case study area?*
    - *Which energy concept is most promising for further development?*

- *How can the chosen concept be translated to a sustainable district energy system for the neighbourhood?*
    - *Which technologies are feasible for the implementation of the energy concept?*
    - *How can the selected technologies be translated to proposals for interventions in the neighbourhood?*

- *How can the developed system be implemented through a spatial implementation plan for the neighbourhood?*
    - *Which combination of technologies are optimal to select, based on their energetic performance and spatial implications?*
    - *What could a spatial plan for a sustainable energy system in the neighbourhood look like?*
    - *What is the energetic performance of the chosen combination of technologies?*

- *What general conclusions can be drawn from the study?*
    - *To what extent are spatial aspects a limiting factor for the development of a sustainable district energy system?*
    - *What guidelines concerning the spatial integration of sustainable energy systems can be derived from the study to improve the implementation for similar projects in other neighbourhoods?*

1.5 Methodology

The general method of the study is a ‘Research by Design’, which can be defined as “the development of designing, studying the effects of this design, changing the design itself or its context, and studying the effects of the transformations” (Voordt & Jong, 2002, p. 455). It is an iterative process of designing and testing. This is preceded by a pre-design study to ascertain the context of the design and the requirements which should be met.

In this research, see figure 1.1, several energy concepts are extracted from existing literature and are then tested to determine the most promising concept. This concept is then developed into an spatial plan for the Ramplaankwartier in Haarlem, which is then again tested to come to general conclusions regarding the spatial implications and feasibility of sustainable district energy systems in the Netherlands.

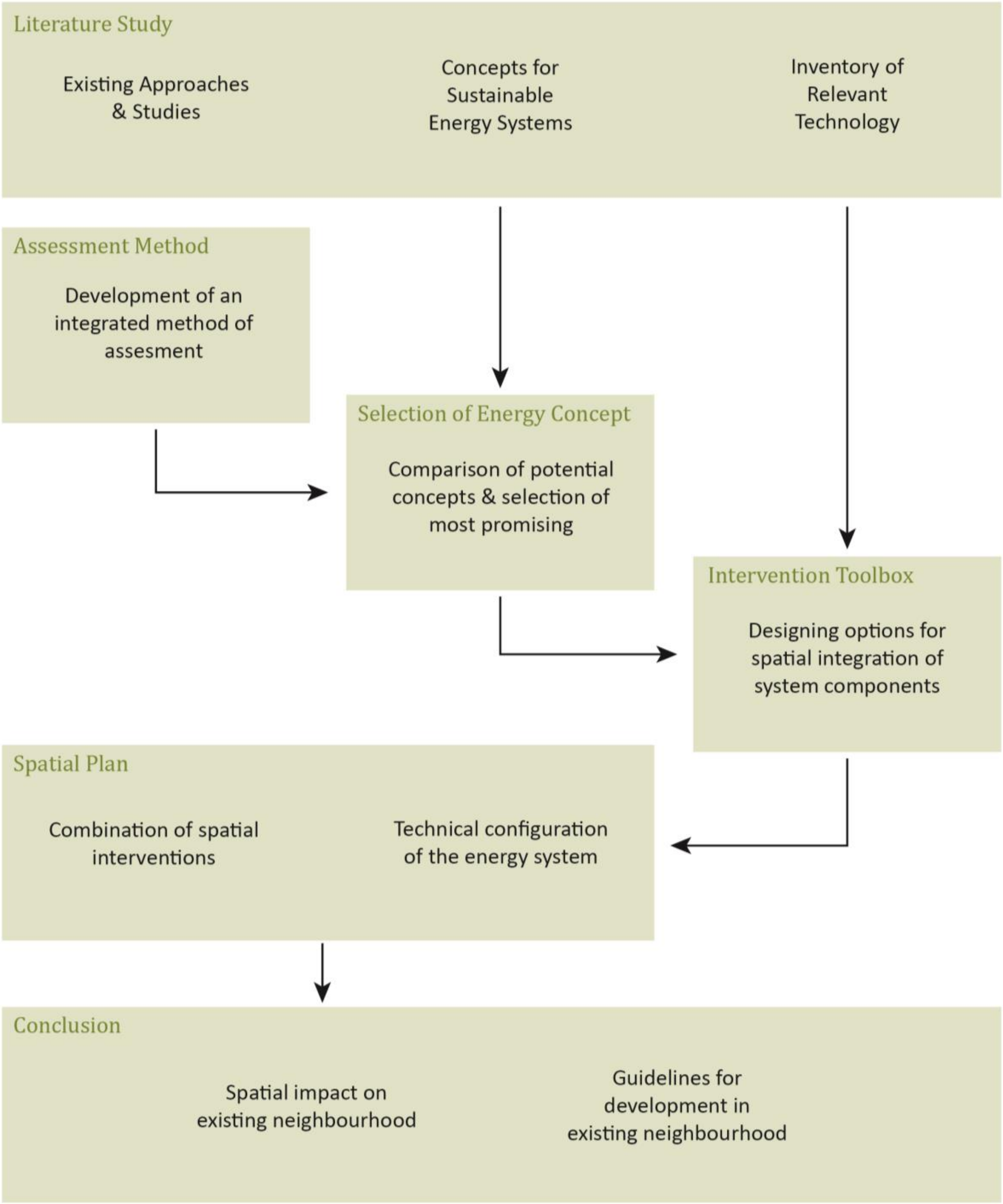


Figure 1.1: Schematic representation of report structure

First the background and context of the project is explored through a literature study. This consists of three main parts: an overview of existing approaches and studies for developing sustainable energy districts, an overview of existing concept for a renewable energy system and its potential using case studies of realised projects, and an inventory of the relevant technologies for the development of these systems.

The method to evaluate the energy system is then determined. This will be formulated in the form of evaluation criteria or 'key performance indicators' ('KPI's'), which can be used to test the effectiveness of the system design, draw conclusions about energetic feasibility and spatial implications, and propose improvements.

The previously described energy concepts are tested using the developed assessment method based on the KPI's in a 'quick-scan' evaluation. This gives an overview of the potential benefits, challenges, and improvements for each energy concept in terms of energy and spatial impact. The different concepts are compared and the most promising system is selected for further study.

Based on components of the improved energy concept developed before, several options for interventions related to the energy system are proposed and combined into a 'toolbox'. The options are assessed on their energetic performance and spatial impact on the neighbourhood and the most promising configuration is selected for further study.

The most promising elements are combined in a spatial plan for the Ramplaankwartier, consisting of a proposal in drawings and sketches and a technical system configuration. The system configuration is then evaluated on its energetic performance and conclusions are drawn about its relation to spatial impact.

Finally, general conclusions regarding energetic performance and spatial impact of sustainable district energy systems will be drawn, as well as the relationship between these aspects. From this conclusion, general guidelines will be developed, which will be applicable to similar projects in other neighbourhoods in the Netherlands.

2. Literature Study

To be able to place this project in its context, a literature study is done into the current state of the art of sustainable district energy systems. First the relevance of sustainable energy systems for the built environment is discussed. Then existing design approaches and studies are analysed, followed by a study of state of the art in sustainable energy systems through case studies of realised projects. Finally an inventory of relevant technologies for the development of a sustainable district energy system is made.

2.1 Current Situation

In the last decades, we have become aware of the major impact we have on our planet by emitting vast amounts of so-called 'greenhouse gasses', mainly due to fossil fuel use (IPCC, 2007). To deal with this, several international climate agreements have been formulated, such as the recent 'Paris Agreement' (United Nations, 2015) and the Kyoto Protocol before that (United Nations, 1997), with the reduction of greenhouse gas emissions and increased use of renewable energy as main goals.

At the same time, the fossil fuels that we rely on are becoming scarcer and therefore more expensive. At our current rate of extraction, our total natural gas and crude oil reserves would be exhausted within a few decades, see figure 2.1 (Knoema, 2017). This not only makes fossil fuels ecologically unsustainable, but also socially and economically, as increasing energy and fuel prices mostly affects the poorer people.

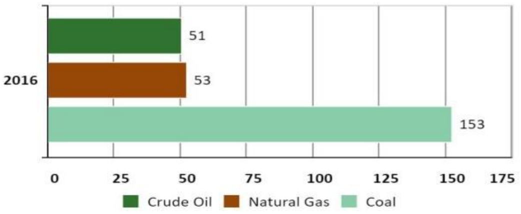


Figure 2.1: Estimated time till exhaustion of known fossil fuel reserves (Knoema, 2017)

Then there is also the difficult political situation in some of the countries and regions that produce a large share of the world's fossil fuels, such as the Middle East (gas/oil), Russia (coal/gas), Venezuela (oil) (Knoema, 2017), and, more specific for the Netherlands, Groningen (gas), see figure 2.2.

deVerdieping
Trouw

DINSDAG

Tim Treffers: Pas als iemand in Japan expliciet vraagt of ik gay ben, zal ik, denk ik, eerlijk antwoorden.
DE VERDIEPING 14|15

Russisch nepnieuws?
Propaganda van binnenuit is zeker zo eng
DE VERDIEPING 4|5

Mooi boek, die Bijbel
Verdwijnt religie?
DE VERDIEPING 10|11

Geen tropenartsen mee
Ziekenhuizen stoppen met opleiding
VANDAAG 3

Zwaarste beving in vijf jaar

Figure 2.2: Newspaper headlines about gas-extraction-related earthquake in Groningen and fake-news from Russia (Trouw, 2018)

An important step towards the goal of reduced fossil fuel use is to change the way we use energy in the built environment, currently responsible for 34% of the total annual energy use in the Netherlands (CBS, 2017). The largest part of this energy is used for space heating and domestic hot water, of which is around 80% is supplied by natural gas-fired boilers and thus relies on fossil fuels (Schoots & Hammingh, 2015).

Although these boilers seem energy-efficient, the hot water (100^{O}C) that is created by burning gas (1500^{o}C) to then heat bath water to 39^{O}C, see figure 2.3, is not very effectively used and there is actually a lot of potential wasted. This is reflected by the term 'exergy', which can be described as 'the potential to do work'. The exergy of gas is high, while the exergy of 39^{O}C water is very low. Even though some processes seem energy-efficient, the exergy efficiency is actually low and potential is still lost. Understanding exergy in the context of the built environment can help to develop better and more sustainable energy systems and allows us to make more effective use of our sources (Jansen S. , 2014).

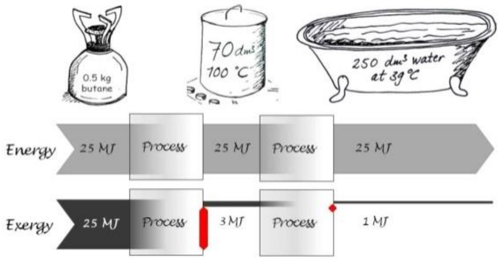


Figure 2.3: Illustration of energy and exergy flows in the same process (Jansen S., 2014)

2.2 Approaches for Developing a Sustainable Energy Neighbourhood

Many different approaches to develop a more sustainable built environment have been emerging ever since sustainability has been a topic of discussion. The most influential approach is the 'Trias Energetica', a design strategy developed in the 80's and 90's. This strategy describes three steps for any sustainable development, which are, when applied to the built environment, as follows: consuming less energy by reducing heat losses, supplying as much energy as possible in a sustainable way, from renewable sources, and finally supplying any remaining demand efficiently and 'cleanly' with fossil fuels (Lysen, 1996).

2.2.1 New Stepped Strategy

Because this strategy still implies the use of fossil fuels, it is not a sustainable method to be used in the future. Reducing the use of these finite resources was one of the drivers behind the 'Cradle to Cradle' approach developed by William McDonough and Michael Braungart (2002), which is based on closing (material) cycles and being able to reuse waste as food. Inspired by this approach, Andy van den Dobbelsteen proposed the 'New Stepped Strategy' (2008), which describes a strategy based on the three steps of the Trias Energetica to improve the energy-efficiency of the built environment on a larger scale, as well as incorporating Cradle-to-Cradle elements. The result is 'three' new steps, see figure 2.4:

1. Reduce the demand by smart bioclimatic design,
2. Reuse waste flows both internally and externally,
3. a) Supply remaining demand renewably, and
   b) Let only clean and nutritious waste go to nature

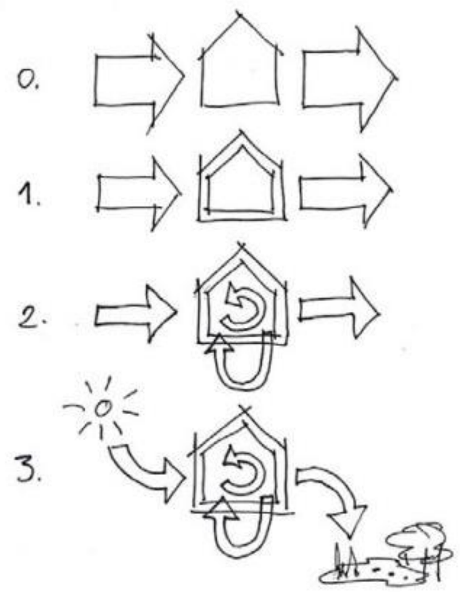


Figure 2.4: Illustration of the 'New Stepped Strategy' (Dobbelsteen, 2008)

2.2.2 Energy Potential Mapping

To translate a general and theoretical strategy to a more applicable form, some comprehensive approaches for energy transformation on a city or neighbourhood scale already exist.

To optimise the use of local renewable energy sources, contributing to step 2 and step 3a of the New Stepped Strategy, it is important to identify and quantify the local potential. A possible tool for this is the method of Energy Potential Mapping (EPM) (Dobbelsteen, Jansen, Timmeren, & Roggema, 2007). This method allows for discovery of potentials early in a planning process and visualisation of these potential sources in maps, making a connection between energy and spatial planning. EPM can thereby support "a better understanding of the relationship between space and energy and form the basis for energy- or exergy-based spatial planning" (Dobbelsteen, Broersma, & Stremke, 2011, p. 171).

Figure 2.5: Energy potential maps, showing the potential of different renewable energy sources (Broersma, Fremouw & Dobbelsteen, 2013)

An example is the EPM-study for the Oostland-area, around Pijnacker (Broersma, Fremouw, & Dobbelsteen, 2013). The production potential of renewable sources is expressed in a series of maps, see figure 2.5, which show the suitability for the application of several sources as well as the production potential. The study shows that there are many energy sources throughout the area, often close to the users, which can be connected using a heat network. Especially the many greenhouses that produce a surplus of heat could contribute to this system. However, it remains schematic and large scale. An additional step, which explores the potential and especially the spatial aspects of these measures on a more detailed level, could give a better indication about the suitability for each of these sources. For an existing neighbourhood, where the existing context needs to be carefully taken into account, a more detailed study of the spatial impact could further improve the feasibility

2.2.3 Rotterdam Energy Approach & Planning (REAP & REAP2)

A more comprehensive approach, that emphasises the relationship between energy and urban planning, is the Rotterdam Energy Approach & Planning (REAP), developed for the city of Rotterdam. The REAP acknowledges the need for using heat from different (renewable) sources and therefore introduces the concept of exchanging 'low-calorific' heat within a building or between a cluster of buildings with different functions. The key vision is that the energy balance should be solved on a higher scale level than just one building, such as a cluster, neighbourhood or district scale. Different functions within a cluster result in different energy use patterns or excess energy that could help solve the potential discrepancies (Tillie, et al., 2009).

The method that is proposed in the REAP study is visualised in figure 2.6. It consists of step 1, 2, and 3a of the NSS and considers these steps on different scale levels, from an urban to building scale. The arrows indicate the order of the steps that should be taken to optimise local renewable production and energy exchange. It is desirable to solve the energy balance on a neighbourhood or district level, as this greatly reduces investment and distribution losses. Only if the demand can't be locally supplied should a multidistrict or city scale be considered. The final step of the 'Trias', to provide the remaining demand cleanly and efficiently, is not considered as an option (Tillie, et al., 2009).

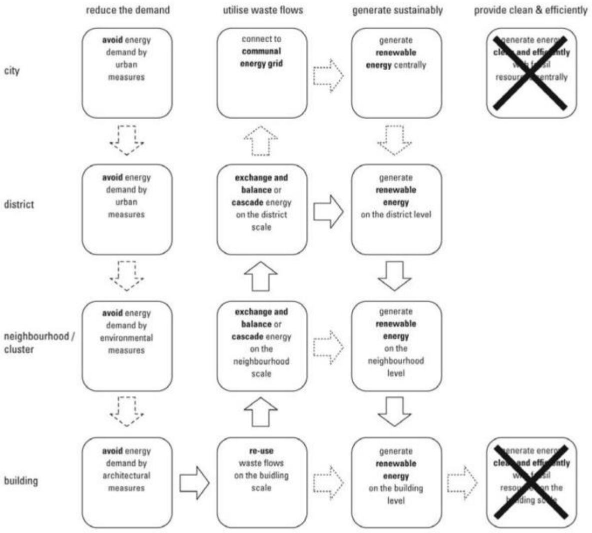


Figure 2.6: Scheme of the REAP-method (Tillie et al., 2009)

The REAP2-study (Dobbelsteen, et al., 2011) elaborates on the initial REAP-methodology for energy and goes into more depth on other aspects, such as technical, spatial, and social consequences. The former harbour-area 'Merwe-Vierhavens' in Rotterdam, see figure 2.7, is used as a case study to test different energy concepts. The goal of the case study is to develop a system that makes the case study area energy-neutral and fossil fuel-free. An elaborate evaluation will give insight in the consequences of this intervention.

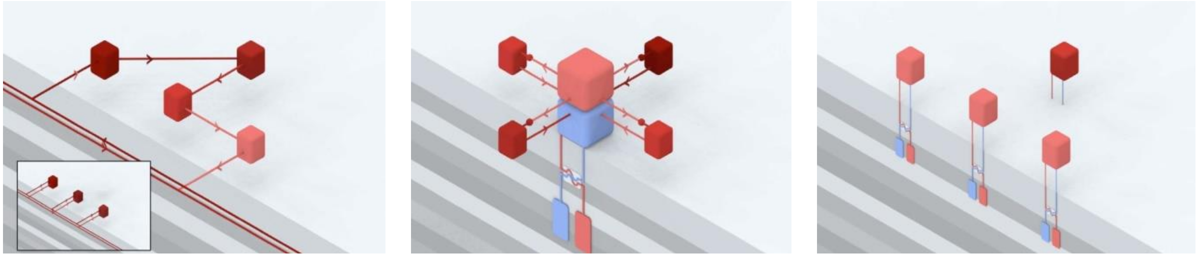


Figure 2.7: The three scenarios: cascading, exchanging, and self-provision. (DSA in Dobbelsteen et al., 2011)

In the study, three different scenarios for energy supply are identified for development in this area: ‘cascading’ energy via a heat network, exchanging surplus heat and cold between buildings, and individual self-provision of energy, see figure 2.7. These three main scenarios – or concepts – are analysed to determine the consequences regarding different themes; technical, spatial, strategic, social, and legal. For each theme, the consequences of the three concepts are studied and conclusions are drawn regarding that theme. These are then combined to come to draw conclusions about the overall feasibility and applicability of these concepts and to put forward a recommendation for a sustainable energy system for the Merwe-Vierhavens-area.

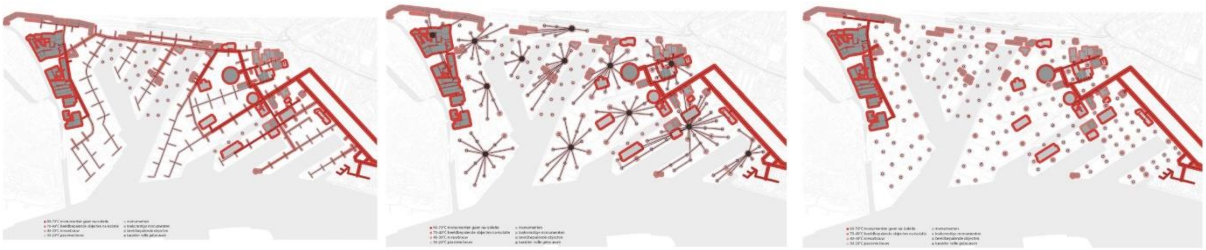


Figure 2.8: Spatial lay-out of each scenario in the Merwe-Vierhavens area (DSA in Dobbelsteen, et al., 2011)

For the spatial evaluation, several possible system lay-outs are proposed for each scenario, see figure 2.8. The impact of the technical aspects and the required infrastructure is assessed, as well as the diversity and flexibility of the program that can be realised. The more flexible a system is, the more it allows for a diverse program and spatial freedom. A flexible system also allows for a diverse group of residents and can therefore contribute to a sustainable neighbourhood in its broadest meaning, including for instance social sustainability (Dobbelsteen, et al., 2011).

2.2.4 Smart Urban Isle (SUI)

Another comprehensive approach is the ‘Smart Urban Isle’ (SUI) approach, which will form a basis for this study. The project aims to develop innovative local energy concepts for urban areas to create ‘Smart Urban Isles’, which can be defined as: “areas around a (public) building, which make use of the synergies between different (building) functions and of the scale advantages for energy (storage) solutions” (SUI, 2018).

The SUI study provides a template to describe the steps of a system development in a structured way and to be able to compare different case studies. The steps are to describe the current situation in the neighbourhood, explore the potential for improvement, and develop a system that capitalises on this potential.

The SUI-approach in itself is generic, but the outcome is project specific and has therefore a wide range of different solutions for different challenges. Many systems, ranging from individual all-electric energy systems to communal district energy systems or hybrid concepts, could be developed using this approach.

2.3 SUI Case Study Ramplaankwartier

In this section the case study, part of the previously conducted and currently running SUI research, will be presented. An overview of the results from the case study, extracted from the 'SUI Template' (SUI, 2018), will be given, and analysed. The current situation of the case study area is presented, following the SUI-approach, which includes a description of the location and the energy status-quo. The most relevant potentials to energetically improve the area are presented, consisting of three parts: bioclimatic improvement potential of the buildings, exchange and cascading potential between buildings of different functions, and renewable production potential within the neighbourhood. This concept will form the starting point for the development of an energy system configuration and the spatial plan.

2.3.1 Status-quo

The Ramplaankwartier is a small neighbourhood in the municipality of Haarlem. It is situated in the periphery of the city and lies relatively remote as the regional road N208 separates the area from the city centre. As of 2017, the neighbourhood had 2840 inhabitants. There are almost 1200 buildings of which by far the most, around 1027, are dwellings. Other functions are scarce, but include: industry, retail, sports & gathering, education, office and health care (SUI, 2018).

The most common building type is terraced housing of up to three floors height, with pitched roofs. The size of the houses is generally around 120 m2 (60%), or slightly lower, between 75-100 m^2 (25%).

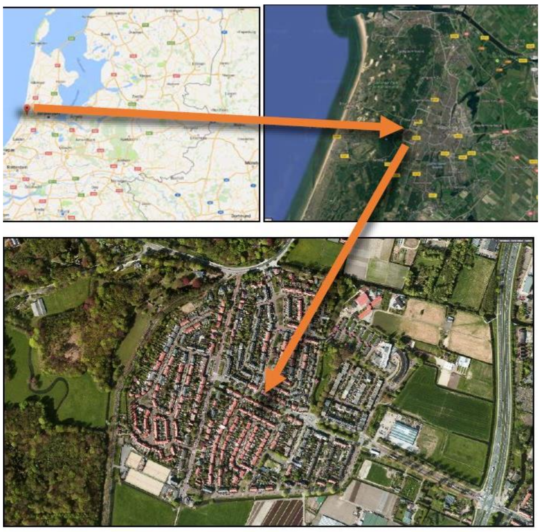


Figure 2.9: Location of the case study area (SUI, 2018)

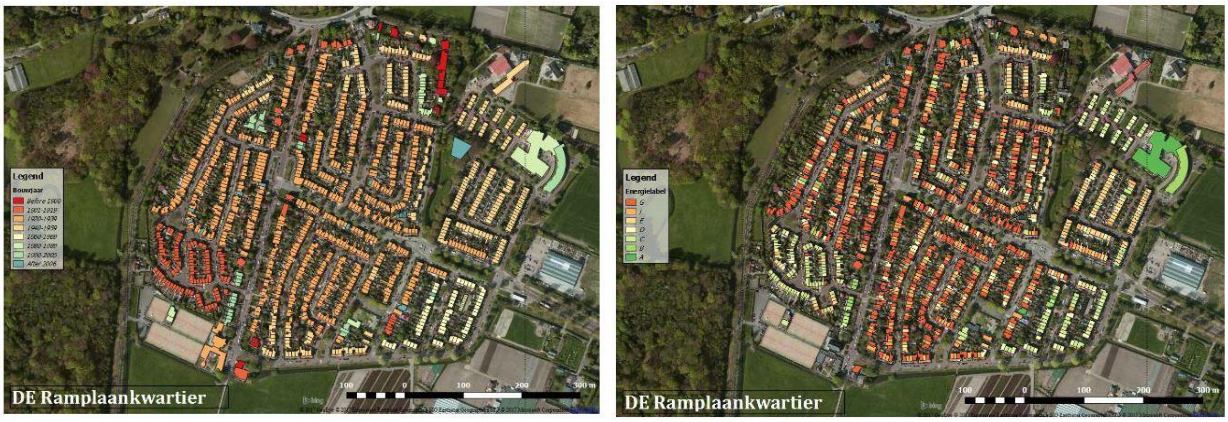


Figure 2.10: Building age (left) and energy labels (right) (SUI, 2018)

The buildings in the area are generally old, see figure 2.10; the largest share of buildings, 55%, is built in the years 1920-1939 and another 10% in the years 1900-1919. The rest is built post-war, but still mostly before 1960. Most of these houses are not or poorly insulated and still have single-glazing, which is also reflected in the 'energy labels', a rating of the building's energy-efficiency ranging from A (Excellent) to G (Very poor). 52% of the buildings have an F- or G-label, with a very high building-related energy usage, 40% of the buildings have an 'average' label (C, D or E) and only 3% have an energy label of B or higher (5% is unknown). An average residential building in the neighbourhood uses 3111 kWh of electricity and 1811 m^3 of gas per year, while the average household in the Netherlands uses "only" 3000 kWh of electricity and 1470 m^3 of gas (Milieu Centraal, 2018). The total energy demand for the building sector is 3627 MWh for electricity and 22 681 MWh for gas. The demand of public lighting is, with 26 MWh/year, almost negligible compared to the building sector. Mobility will not be discussed as this goes beyond the scope of this research.

A fraction of the electricity, 468 MWh/year or 13% of the total electricity demand, is already produced locally by a rooftop solar-PV plant. This has been realised in 2015 by the local energy corporation 'DE Ramplaan' ('Sustainable Energy Ramplaan') on the roof of the local indoor tennis hall and consists of some 1350 PV-panels (SUI, 2018). Assuming that the rest of the electricity demand is supplied by "grey electricity", produced in gas- or coal-fired power plants, this would result in around 2100 tonnes of CO_2 per year. The thermal energy is all supplied by natural gas, which results in almost 4900 tonnes of CO_2 per year. The total CO_2 emission in the current situation is around 7000 tonnes per year.

2.3.2 Improvement Potential

The bioclimatic improvement potential consists of energy efficiency and conservation measurements that passively reduce energy demand, but allow for a similar level of comfort. In this case, the improvement will mostly be achieved by reducing the need for space heating, which is responsible for most of the energy use in the current situation. In the SUI study, four possible scenarios are explored and analysed for their potential to create a Smart Urban Isle fully supplied with renewable energy:

- Status-quo, where no changes are made,
- 'Business-as-Usual' (BAU) renovation, which includes the most common building improvement measures such as insulating the cavity wall and adding double glazing,
- C-label renovation, which includes extra measures to get to at least an energy label of C, and
- NZEB (Net Zero-Energy Building) renovation, which includes even more measures like extra insulation and ventilation with heat recovery to be able to produce the same amount of energy as the annual usage.

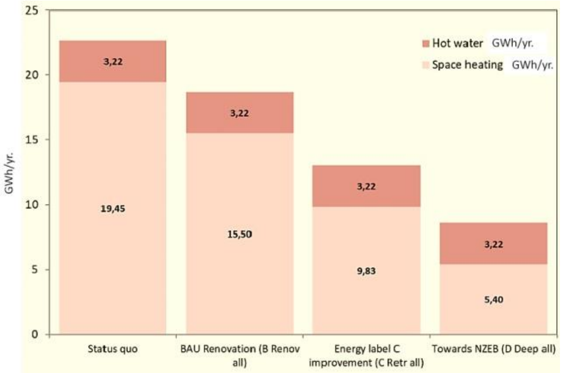


Figure 2.11: Total energy demand according to the improvement scenario (SUI, 2018)

The relative homogeneous composition of the neighbourhood means there is little potential for exchange within the neighbourhood itself. To supply the remaining demand in a sustainable way, the potential for energy production from renewable sources within the area is explored. The evaluated sources and conversion techniques are shown figure 2.12 below.

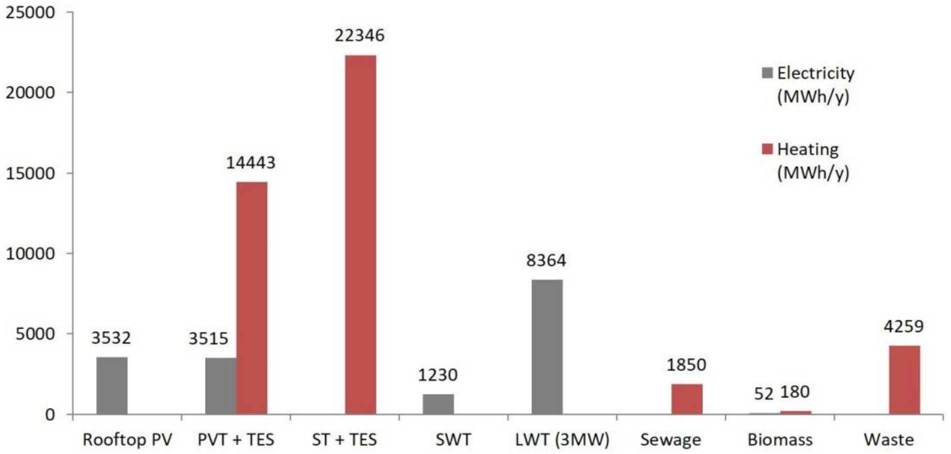


Figure 2.12: Renewable energy prudction potential of different sources (SUI, 2018)

2.4 Sustainable Energy Systems

In the SUI-study of the Ramplaankwartier, four different concepts for energy systems are proposed. The four concepts are an all-electric system and three heat network concepts with each a different operating temperature, referred to as high (70-90^{O}C), medium (50^{O}C), and low (20^{O}C) temperature. These systems can also be recognised in recent developments where the goal is to create a gas-free neighbourhood. In the following section, each energy system will briefly be explored using a case study of a realised project and conclusions regarding the energy performance of each concept are drawn using the Ramplaankwartier case study.

2.4.1 All-Electric Individual Heating

Case study: Stad van de Zon, Heerhugowaard

Key Figures	
Type of project	New construction
No. of buildings	1600
Energy labels	A+ label
Central production	Wind turbines
Decentral production	Solar PV Heat pump / Electric boilers
Distribution	Electricity network

Figure 2.13: Key figures and aerial view (heerhugowaardstadvandezon.nl, n.d.)

In the all-electric concept, the heat demand is supplied through heat pumps or electric boilers in the houses, so only a connection to the electricity grid is needed. This project, called ‘City of the Sun’, is part of the ‘Five-MegaWatt-project’, initiated by the cities of Heerhugowaard, Alkmaar and Langedijk. The aim of the project is to install a total of 5 MW of PV-panels in several new housing projects throughout these municipalities. A total capacity of 3.6 MW of PV-panels is installed on the 1600 dwellings in the neighbourhood, providing a large share of the electricity demand (Elswijk, Kaan, & Bleijendaal, 2008) & (Energie Koplopers, 2016).

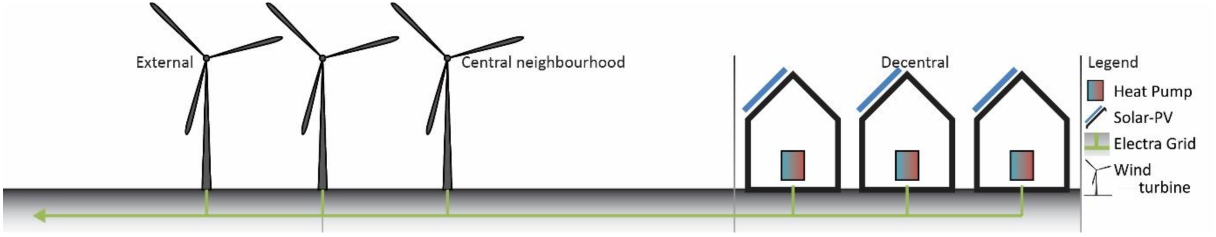


Figure 2.14: Scheme of energy supply system (Own ill.)

The use of solar energy is integrated in the spatial planning of the neighbourhood and building design, through good bioclimatic design (Bakker, n.d.). However, this is specific for new construction, as renovation greatly limits the possibilities for these measures. An all-electric heating system for an existing dwelling would require either higher installed power or an expensive facade renovation for a low-temperature system to be sufficient (Oorschot, 2017).

A lesson from this project concerns the impact this amount of installed capacity has on the electricity infrastructure. The fluctuation and unreliability of the most-commonly used renewable sources, wind and solar, makes it difficult to create an autonomous system and generally still requires ‘grey’ energy from the grid. Moments of peak production of both solar- and wind power can also cause blackouts. An all-electric system with a high amount of local production demands an electricity network that can handle these fluctuations, so the current status of the electricity infrastructure is a determining factor in adapting existing neighbourhoods (Energie Koplopers, 2016, p. 49).

Case study: Ramplaankwartier, Haarlem

The all-electric concept for the Ramplaankwartier is based on supplying all energy demand for hot water and space heating with an individual heat pump in each house. This means there is no need for expensive infrastructural investments for a distribution network. To make this system technically feasible, low-temperature space heating is required to be able to have the heat pump operating with a high COP. It is therefore assumed that the NZEB-renovation is required (SUI, 2018).

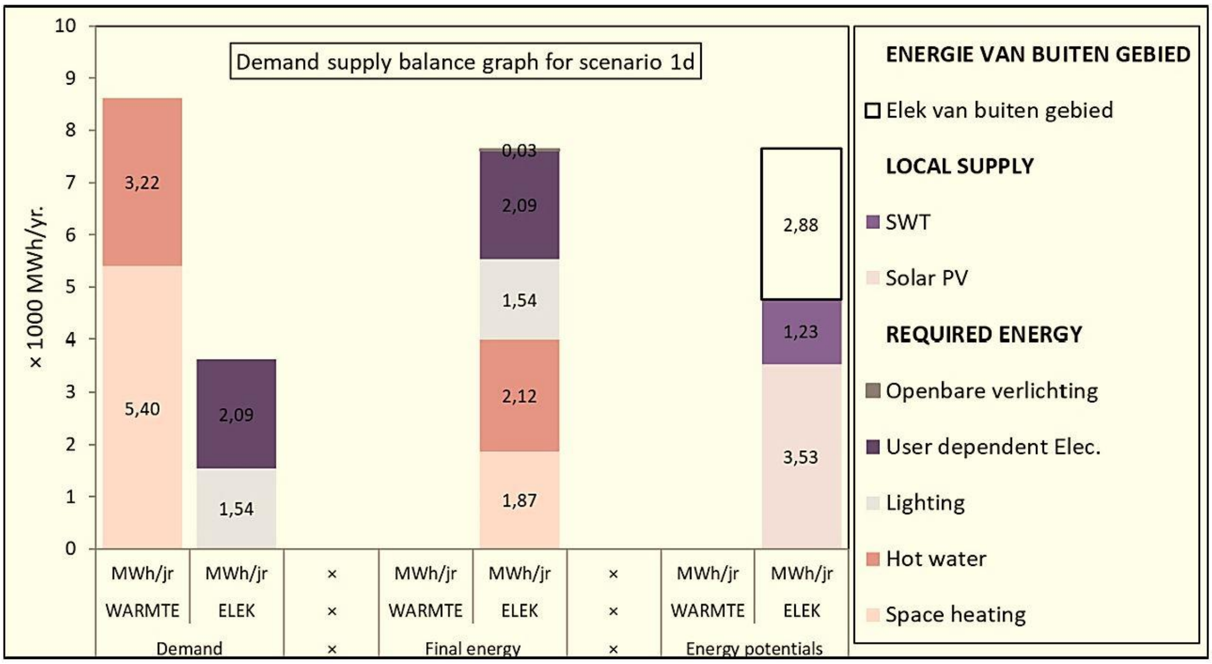


Figure 2.15: Energy balance graph for all-electric concept and NZEB-renovation (SUI, 2018)

As can be seen from the graph, the extra installations double the electricity demand for the area, but as a result there is no thermal energy required. However, the limitation of the system to only electric energy makes it unable to make use of central heat production or exchange, which limits the amount of renewable sources that can be integrated in the system. An alternative to the air-source heat pump is the application of a heat pump with ground or PVT-panels as a source, which are more efficient, especially on cold winter days, but also more expensive.

2.3.2 High-Temperature Heat Network

Case study: Ondiep, Utrecht

Key Figures	
Type of project	Renovation
No. of buildings	22 (1780 total)
Energy performance	A label
Central production	Industrial waste heat
Decentral production	Not specified
Distribution	Heat grid (70-90^{O}C) Electricity network Gas network (only for cooking)

Figure 2.16: Key figures and aerial view of the neighbourhood 'Ondiep' (Google Maps)

In this concept, the heat demand is supplied with sufficient high-temperatures to be used directly for both heating and domestic hot water. In this project, the houses in the neighbourhood ‘Ondiep’ in Utrecht are connected to a city heating network, which will be supplied with waste heat from the nearby electricity plant. The housing corporation Mitros is making a large number of its buildings more sustainable, either by demolishing and rebuilding, or by renovating. The buildings are made less energy consuming with better insulation, to the level of an A-label. (Agentschap NL, 2010).

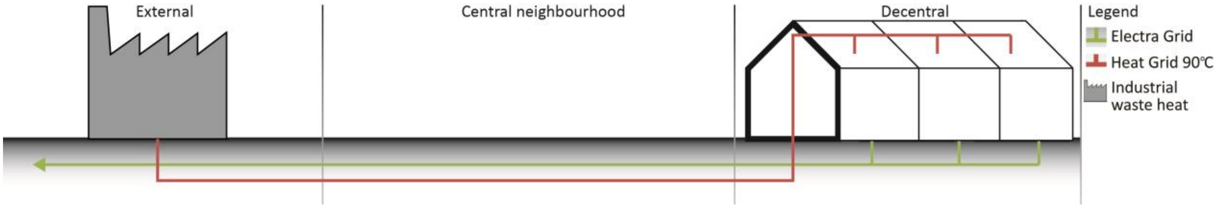


Figure 2.17: Scheme of energy supply system (Own ill.)

A block of 22 renovated houses was to be connected to the heat network, but there was no room for the network to be integrated through the crawl space beneath the houses and making a separate connection to each house from the street was too expensive. Instead, the network goes up to the attic and there the connection is made to the heating system of each dwelling before continuing to the adjacent house. This is a unique way to connect existing buildings to a district heating network and had not been done before in the Netherlands. This method is relatively cheap and it allows the user to choose when to switch to the district heat supply instead of gas, as has been shown in this project as well. This freedom of choice improves the willingness of people to cooperate. Thanks to both this freedom and practical benefits, this type of distribution shows a lot of potential for similar projects that concern the retrofitting of district heating networks (Roos & Manussen, 2011).

Case study: Ramplaankwartier, Haarlem

This option assumes the entire heating demand is supplied through a 'classic' high-temperature district heat grid of 70-90^{O}C. All buildings will have to be connected for the system to be feasible, but not all houses have to be improved significantly for this option to be effective. The dwellings in their current state can already use this network without improvements, although it reduces the heat demand significantly. For the better renovation options the high temperature of this network is unnecessary and therefore only the 'BAU'-renovation option is considered,

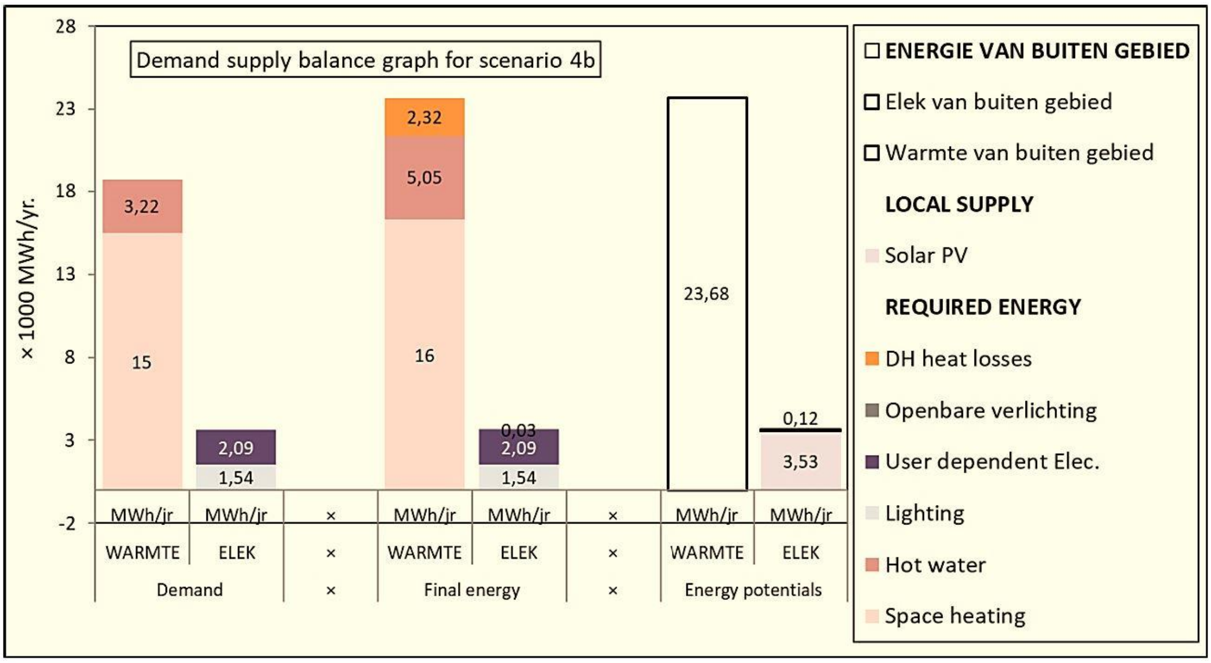


Figure 2.18: Energy balance graph for high-temperature heat network concept and BAU-renovation (SUI, 2018)

The heat grid itself will deliver temperatures of 70^{O}C to 90^{O}C, which results in high distribution losses. The external heat supply often still relies heavily on fossil fuels, as it is generally produced by a 'grey' power plant, waste combustion plant or heavy industry.

Although these high temperatures may remain necessary for existing, poorly-insulated buildings, whether this can be called a 'sustainable energy system' is debatable. The high temperatures needed for such a network are difficult to produce effectively with renewable sources; deep geothermal and industrial waste heat are among the few suitable sources, but the 'renewability' of these sources may be questioned as well.

2.3.3 Medium-Temperature Heat Network

Case study: MijnWater Energie, Heerlen

Key Figures	
Type of project	New construction
No. of buildings	1600
Energy performance	A+ label
Central production	Biomass CHP-unit Geothermal
Decentral production	Solar thermal Heat pump
Distribution	Heat grid (45^{O}C) Electricity network

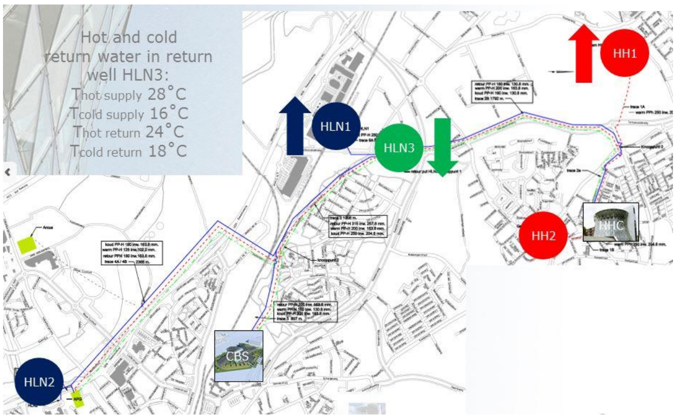


Figure 2.19: Key figures and location of MineWater 1.0 project (Mijnwater.nl)

The medium-temperature heat network concept provides heat directly to the dwelling, similar to the previous concept. The temperatures in this network are much lower however, around 45^{O}C, which is suitable for low-temperature space heating. For domestic hot water, a small additional heat pump is needed in the houses. An example of this concept is the MineWater (Dutch: MijnWater) project in Heerlen, where the mines are used as part of the energy network; first for geothermal heat collection and later for seasonal energy storage.

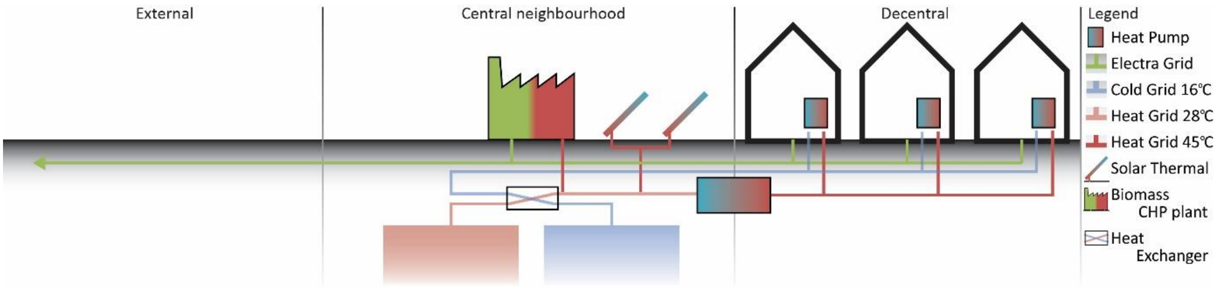


Figure 2.20: Scheme of energy supply system (Own ill.)

The MineWater 1.0 project consisted of extraction of warm water (~28^{O}C) from mine shafts at a depth of 700 meters and cold water (~16^{O}C) from a depth of 250 meters below the surface. This initial pilot project was only based on extraction of geothermal heat and cold from the ground, but was found to eventually homogenise the sources, making them unusable (Verhoeven, et al., 2014).
The Minewater 2.0 project was therefore initiated in 2012, changing the concept of the system to make decentralised production through biomass-CHP and solar collectors possible as well as allowing for direct energy exchange between functions. The extraction wells in the mines are now only used for storage, both short term and seasonal (Verhoeven, et al., 2014). This thermal grid currently supplies a mix of different functions in the neighbourhood Heerlerheide, such as dwellings, a supermarket, offices, and cultural functions (RvO, 2011).
Currently the Minewater 3.0 project is in development, which is mostly focussed on a smart control system for the network, allowing for demand and supply side management. Demand and supply patterns may be recognised based on for instance customer behaviour and weather predictions, which can then be used to make optimal use of the renewable energy (Mijnwater, n.d.).

The first phase of the Minewater project already showed promising results for a lower-temperature grid to supply both heat and cold for a district. The second and third phases of the project also show that this system is technically feasible: it allows for integration of decentral (renewable) production, exchange of heat and cold between different functions and smart measurement and control systems to make optimal use of the produced energy. Besides the technical feasibility, the economic feasibility has also been demonstrated and is therefore a promising system for future development.

Case study: Ramplaankwartier, Haarlem
In this concept, the heat is supplied directly to the houses through a medium-temperature heat grid of 45^{O}C. This is sufficient for low-temperature space heating and is the source for a booster heat pump providing sufficient temperatures for domestic hot water or standard high-temperature radiators. Because of the relative flexibility of this concept, it will allow for all three renovation options.

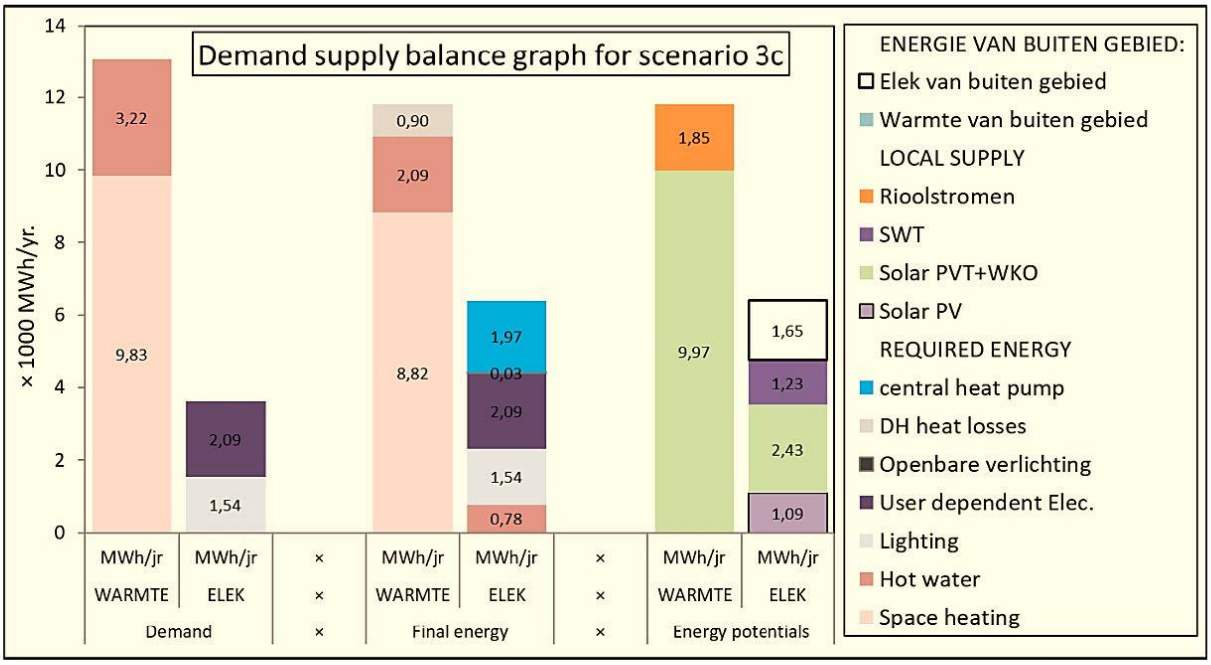


Figure 2.21: Energy balance graph for medium-temperature heat network concept and C-label-renovation (SUI, 2018)

All thermal energy can be supplied with local renewable sources, even for the BAU improvement scenario, due to the high production of rooftop PVT-panels. The heat from these panels may be used directly in the house itself or could be used to deliver heat back to the network to regenerate the thermal storage.

The central heat pump and booster heat pumps for hot water almost double the electricity use of the area. As a result, the amount of external electricity required is much higher than in the high-temperature network, even in the better improvement scenarios. The advantage is of course that all thermal energy, even for the BAU scenario, can be produced with local renewable sources.

In the SUI case study, it is assumed low-temperature space heating at 45^{O}C is sufficient for all heating demand, the booster heat pumps are only necessary for domestic hot water. In reality, the BAU scenario may require higher temperature radiators, which increases the electricity demand even more. For the C-label and NZEB scenarios the low-temperature space heating is sufficient, which means the better improvement scenarios include an extra saving.

2.3.4 Low-Temperature Heat Network

Case study: Hoogeland, Naaldwijk

Key Figures	
Type of project	New construction
No. of buildings	650
Energy performance	A+ label
Central production	Waste-heat recovery
Decentral production	Heat pump
Distribution	Heat grid (16-22^{O}C) Cold grid (10^{O}C) Electricity network

Figure 2.22: Key figures and location Hoogeland (3) with connection to greenhouses Prominent (Vestia, 2013)

The fourth concept also supplies buildings with warm water, but the temperatures in this concept are very low, well below 30^{O}C. The heat can be used by a heat pump to produce usable temperatures. For this project in Naaldwijk, in the 'Westland'-area, waste heat from the many greenhouses can be used to heat the entire neighbourhood of Hoogeland, consisting of 650 dwellings and several other functions (RvO, 2011).

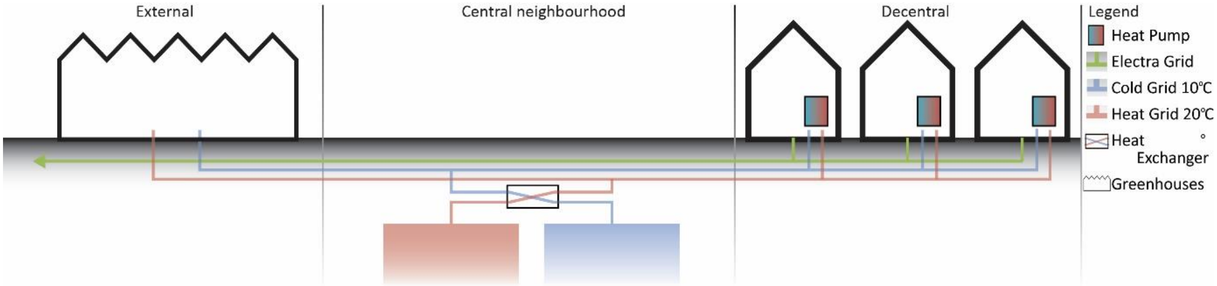


Figure 2.23: Scheme of energy supply system (Own ill.)

In summer, the water temperature produced in the greenhouses is 22^{O}C or above, which is then stored seasonally in an underground aquifer. This water can be extracted in winter at around 16^{O}C and feed the individual heat pumps in the dwellings, which provide the hot water for space heating (45^{O}C) and hot tap water (60^{O}C). The cold return water (~10^{O}C) is stored so it can be used in summer to cool the buildings and greenhouses (Vestia, 2013).

The potential for these systems is huge, as is also recognised by the initiator of the project, the housing corporation Vestia, which is researching possibilities for more developments with the same concept (Vestia, 2013, p. 11). The relatively low temperature does still require local heating with a heat pump, but the water-water system with a feed in temperature of 16^{O}C will be much more efficient than an air-water heat pump that is often used in all-electric houses.

That the system can operate with these low temperatures also means that renewable (waste) heat from other sources than the greenhouses could be integrated into the system to increase capacity. This project consists of exclusively new buildings with a good energetic performance, so to achieve a similar result with a renovation project, much improvement is needed. However, the fact that the temperature can already be raised to 60 ^{O}C using the heat pump (for hot tap water), means it could be sufficient to heat existing buildings with less insulation as well. The heat pump will operate less efficiently at these temperatures, so whether this is still feasible should be assessed.

Case study: Ramplaankwartier, Haarlem

The final option is based on a low-temperature heat network of 20^{O}C or less, which is the source for a heat pump in each house. The heat pump will require a higher capacity than the booster heat pump in the medium-temperature heat grid concept, and is expected to perform less efficient than in that concept, but the advantage is that there is no central heat pump required. For efficient operation, the application of low-temperature space heating is desired, so only the C-label and NZEB renovation options are considered for this concept.

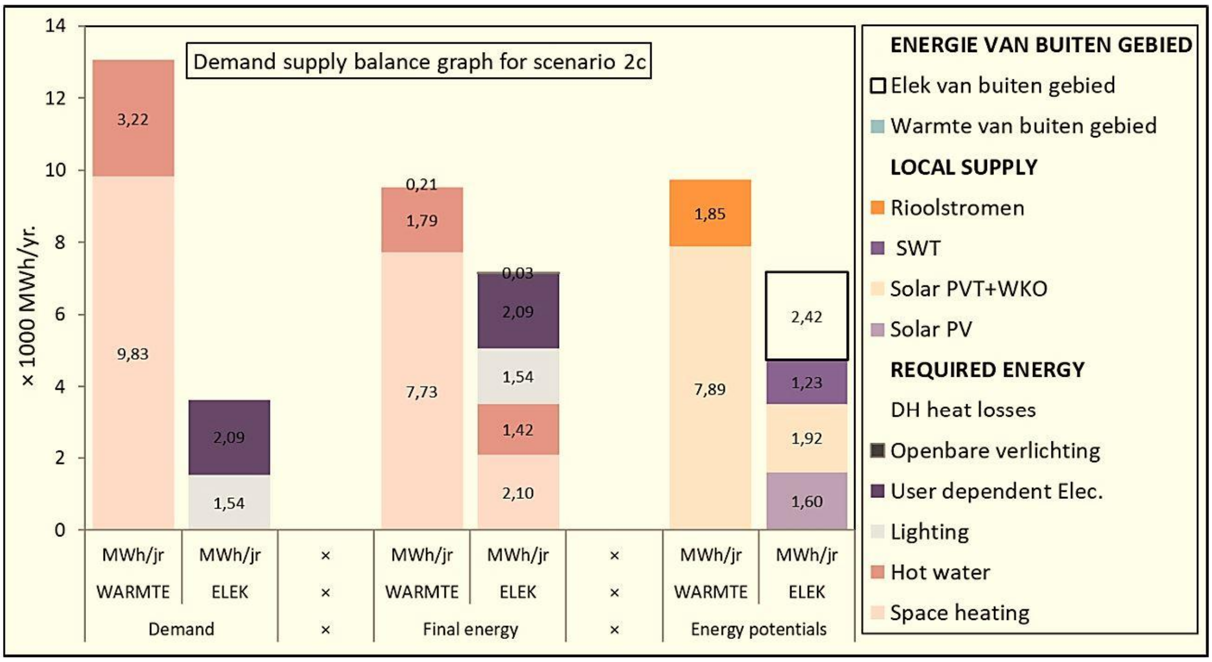


Figure 2.24: Energy balance graph for medium-temperature heat network concept and C-label-renovation (SUI, 2018)

Once again, all thermal energy can be supplied with local renewable sources. However, the electricity demand is doubled due to the heat pumps, resulting in a higher external energy demand than the other heat networks. However, it is still lower than in the all-electric concept, despite the better building improvement scenario in that concept.

2.5 Inventory of Relevant Technology

To come to a well-integrated configuration for the energy system, it is important to understand the working of all separate elements of these systems as well as their potential. This includes general principles and processes, as well as practical information such as efficiency and spatial aspects. The relevant technologies for this study will be explained in the following sections and will form the basis for the energy concept.

2.5.1 Renewable Energy Sources

To actually generate the energy for the district energy system using renewable energy sources, a lot of improvement is necessary. The most promising techniques to provide our houses with hot water and electricity will be described in this section.

Heat Pumps

Heat pumps are probably one of the most promising techniques to replace our current gas boilers and provide sustainable heat for space heating and domestic hot water. Heat pumps use electricity (or gas) to convert a low temperature heat source to a higher, useful temperature.

The efficiency of heat pump is determined by the ratio between useful heat and required electrical input energy, which is called the 'coefficient of performance' (COP). Part of the energy is supplied electrically, the remainder of the energy comes from a different source, like ground(water), solar collector or ambient air. The efficiency increases as temperature difference between source and output is smaller, so a low-temperature system is desirable. To save energy compared to a gas-fired boiler, a COP of at least 3 is required and to save on CO_2-emissions, it should even be as high as 4 (Klimapedia, 2017, pp. 193-198).

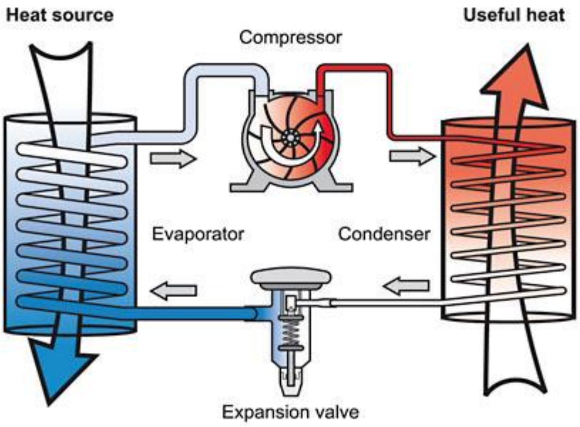


Figure 2.25: Schematic representation of the heat pump principle (Veoliawater2energy.com, 2018)

Heat pump capacity ranges from small individual units for a single dwelling to large collective systems supplying a district heating system, but the general principle is the same. Because of its versatility and compatibility with many renewable energy sources, heat pumps will play an important role in future energy systems, whether this is through individual units in an 'all-electric' house or as one of the base-load suppliers in a district energy system.

Combined Heat & Power

The principle of combined heat and power (CHP) is that in a single unit both electricity and usable heat is produced from a single fuel. In most processes of electricity production, hot exhaust gases are produced as a waste product like in many mechanical processes. The heat from these gases can be extracted using a heat recovery boiler, see figure 2.26.

Alternatively, heat can be used as steam to drive a turbine and produce electricity before supplying heat, which is for instance in case in waste-incinerators supplying the heating grid.

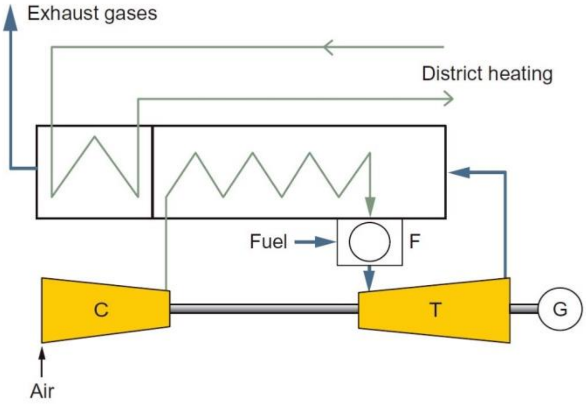


Figure 2.26: Gas turbine CHP plant. F=burner, C=compressor, T=turbine, and G=generator. (Sipilä, 2016)

An example on the smaller scale, referred to as micro-CHP, is the 'HRe-boiler'. This is a gas boiler which also has a small Stirling engine, which also produces electricity in operation. The efficiency of combined heat and power systems (~90% for heat AND ~30% for electricity) is considered higher than that of single-purpose units (<98% for heat OR <48% for electricity), because for the same energy output, less fuel is needed (Klimapedia, 2017, pp. 200-202).

A combined heat and power system, either small or large scale, could be part of a sustainable energy system when it is fuelled with biofuels or biomass, which are considered renewable energy sources. Biological fuels are fuels derived from plants, organic waste or human/animal manure. Energy from biogas or biomass is currently even the leading source of renewable energy worldwide and has a major potential to provide a large fraction in the future as well. These fuels are all considered carbon-neutral as plants capture CO_2 from the air during the growing process, and release this same amount when combusted.

Alternatively to combustion, organic waste products can be treated with anaerobic micro-organisms to create biogas of liquid biofuels such as ethanol. Liquid biofuels may be a valuable replacement for fossil transport fuels, while biogas can be a valuable fuel for a sustainable gas-turbine CHP plant (Sipilä, 2016, pp. 59-60).

There are some considerations involved though, as the processing and transportation of these biofuels does involve fossil fuels and the growing of some energy crops, like palm-oil, actually have a negative impact on the environment because of deforestation and the competition for space with food crops (Klimapedia, 2017, p. 202).

Solar Collector Panel

Solar thermal energy is a well-known technology for hot water preparation and space heating in residential buildings. This can be on a very small scale, where a few roof-mounted solar panels provide one house with hot water, to a very large scale, where large arrays of solar collectors or mirrors aimed at one central heating element are used to generate heat for district heating networks. Solar collectors, both centralised and decentralised systems, are very suitable for integration into a sustainable energy system, as high temperatures can easily be reached at competitive prices compared to fossil energy sources (Pauschinger, 2016, p. 99).

All systems are based on converting solar energy into thermal energy of a working fluid, being air, water or oil, which can then be used to provide hot water or be stored for later use. To make optimal use of solar energy, storage is an important component, because the production of thermal energy is highest in summer, while demand is highest in winter.

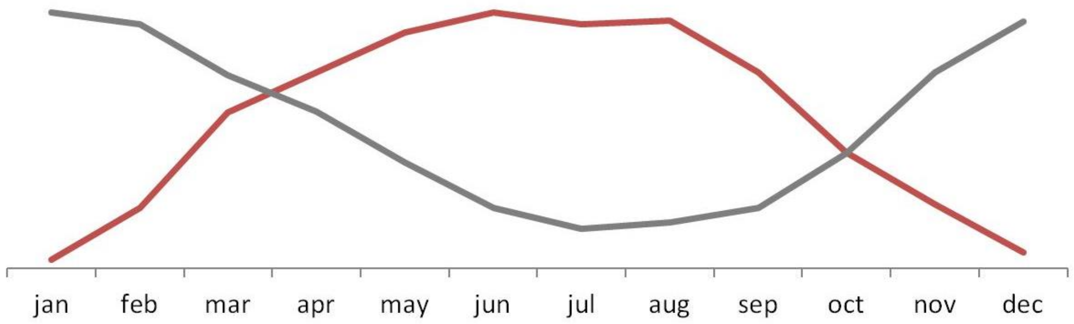


Figure 2.27: Typical annual patterns of heat production (red) and heat demand (grey) (Own ill. based on SUI, 2018)

The most used systems for domestic use are flat-plate (FPC) and evacuated tube (ETC) solar collectors.
Flat plate collectors consist of a black metal absorber plate, with a glass cover on the top and insulation on the back. The absorbed heat is transferred to fluid-carrying tubes on the back or front of the plate.

Evacuated tube collectors consist of an absorber plate placed in a vacuum-sealed glass tube, which minimises heat loss due to convection and transmission. The heat from the absorber plates is either transferred directly to a fluid-carrying pipe within the tube or indirectly using a 'heat-pipe', which transfers the heat from the tubes to a manifold at the top or bottom of the panel, where the working fluid is then heated up (Zambolin & Del Col, 2010).

A special type of domestic solar collector is the hybrid PVT-collector; a solar photo-voltaic and thermal collector. This consists of a PV-module combined with an absorber plate at the back which essentially cools the module, allowing for more efficient operation. At the same time, the extracted heat can be used for hot water production or adsorption cooling (Tian & Zhao, 2013).

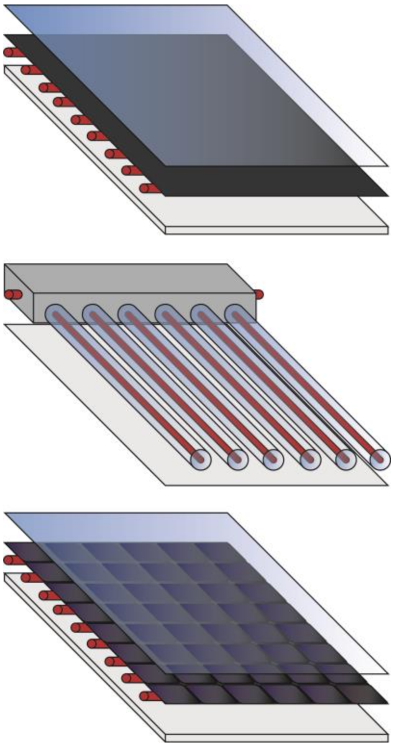


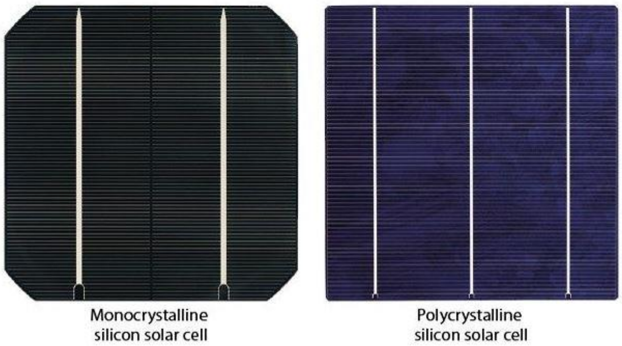
Figure 2.28: Schematic image of solar collectors: Flat plate, evacuated tube & PVT collectors (Own ill.)

Of these three panels, evacuated tube collectors have the highest average efficiency and annual thermal energy yield in real operating conditions, especially in colder climates, because of the tubes' shape and the excellent insulation the vacuum provides. The downside of ETC's is that these are generally more expensive than FPC's, resulting in longer payback periods (Ayompe, Duffy, McKeever, Conlon, & McCormack, 2011).

Solar Photo-Voltaic Panel

Solar-PV is probably one of the best known renewable energy sources and the use of solar-PV has increased spectacularly over the last few years. There is a variety of PV-panels available nowadays with each very different properties and (dis-)advantages. All are based on the photovoltaic-effect, which is the creation of a current in certain semi-conductor materials under the incidence of 'light particles' or photons (Klimapedia, 2017, pp. 259-268).

The most commonly used PV-cells are the crystalline silicon cells, polycrystalline (p-Si), which appearance is different shades of blue, and monocrystalline (m-Si), which is black or dark blue, see figure 2.29. These are followed by amorphous silicon (a-Si) 'thin film' PV-cell. The c-Si PV-cells are currently the most efficient solar cells commercially available, with peak efficiencies between 15 and 20%, meaning that a maximum of 20% of the solar energy that is available is transformed into usable electrical energy (Saga, 2010, p. 97).



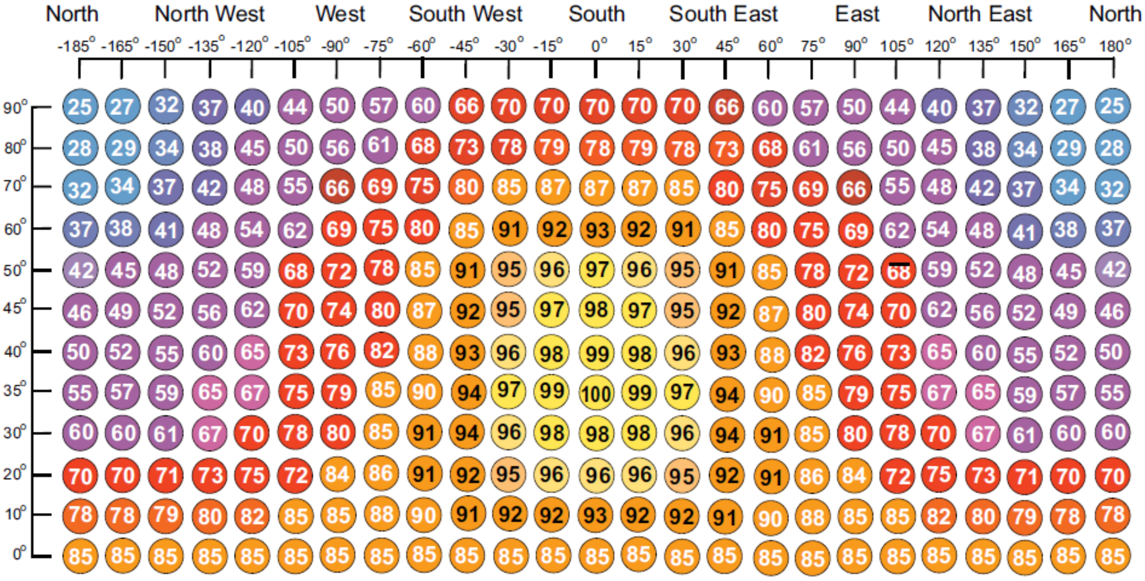
Monocrystalline silicon solar cell

Polycrystalline silicon solar cell

Figure 2.29: Typical appearance of the most common types of PV-cells: Mono- and polycrystalline silicon (Saga, 2010)

The PV-cells are thin ‘wafers’ of 125 mm square (m-Si) or 156 mm square (p-Si), see figure 2.29. These wafers are connected in series in PV-panels or ‘modules’, supported by a frame or laminated in between two glass panes to create a ‘semi-transparent’ PV-module (Klimapedia, 2017, p. 261).

The potential energy that such a panel can produce under standard conditions is expressed in Wattpeak (Wp). This follows from the area of the panel and the efficiency of the cells, multiplied by the 1 kW/m^2 of irradiation. A modern PV-panel (1.6 m^2, 20% efficiency) produces 320 Wattpeak in this circumstance. The actual energy yield for a panel is expressed in kWh/kWp, which means kWh of energy produced per kWp of installed capacity. In the Netherlands, this yield is around 875 kWh/kWp, resulting in a maximum of 280 kWh/year for the previously mentioned PV-panel. However, the actual yield differs per system, as it depends for a large part on angle, orientation and any obstructions, as well as the efficiency of the rest of the system, such as cables and inverters (Klimapedia, 2017, pp. 263-265).



	-185°	-165°	-150°	-135°	-120°	-105°	-90°	-75°	-60°	-45°	-30°	-15°	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°
90°	25	27	32	37	40	44	50	57	60	66	70	70	70	70	70	66	60	57	50	44	40	37	32	27	25
80°	28	29	34	38	45	50	56	61	68	73	78	79	78	79	78	73	68	61	56	50	45	38	34	29	28
70°	32	34	37	42	48	55	66	69	75	80	85	87	87	87	85	80	75	69	66	55	48	42	37	34	32
60°	37	38	41	48	54	62	69	75	80	85	91	92	93	92	91	85	80	75	69	62	54	48	41	38	37
50°	42	45	48	52	59	68	72	78	85	91	95	96	97	96	95	91	85	78	72	68	59	52	48	45	42
45°	46	49	52	56	62	70	74	80	87	92	95	97	98	97	95	92	87	80	74	70	62	56	52	49	46
40°	50	52	55	60	65	73	76	82	88	93	96	98	99	98	96	93	88	82	76	73	65	60	55	52	50
35°	55	57	59	65	67	75	79	85	90	94	97	99	100	99	97	94	90	85	79	75	67	65	59	57	55
30°	60	60	61	67	70	78	80	85	91	94	96	98	98	98	96	94	91	85	80	78	70	67	61	60	60
20°	70	70	71	73	75	72	84	86	91	92	95	96	96	96	95	92	91	86	84	72	75	73	71	70	70
10°	78	78	79	80	82	85	85	88	90	91	92	92	93	92	92	91	90	88	85	85	82	80	79	78	78
0°	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85

Figure 2.30: PV-panel production potential relative to south (evoenergy.co.uk/blog/18520/northwest-facing-pv/)

Asphalt Solar Collector

Another method to collect solar energy is by using asphalt solar collectors. Dark-coloured asphalt has the potential to store a large amount of solar heat, which can be extracted using water-carrying tubes under the top surface. These essentially cool the asphalt layer above and the water is heated up in the process, which can then be used directly or stored for later use. This results of an annual energy yield of around 1 GJ/m^2, or 278 kWh$_{th}$/m^2 (Tauw, 2018, p. 15).

Figure 2.31: Road energy system (Oomsbouw.nl)

Geothermal Heat

Geothermal energy is the heat from the earth’s core that can be used for heating purposes. A distinction can be made between deep and shallow geothermal energy. Deep geothermal concerns the high temperature water or steam (>70^{O}C) that can be found deep underground, at several kilometres below the surface. Shallow geothermal is the relatively low temperature (<30^{O}C) in the first 100 m of the earth’s crust which can be utilised as input energy for a heat pump and a heat exchanger (Klimapedia, 2017). Some areas around fault lines are the exception, as high temperatures can be found relatively close to the earth’s surface; in Iceland for instance, temperatures of up to

250^{O}C can be found within the first 1000 metres below the surface. This geothermal energy supplies 25% of the electricity and 66% of primary energy demand (Orkustofnun, 2015).

In the Netherlands it is difficult to reach the deep geothermal energy sources, as roughly 2 km depth is required to get a sufficient temperature (~70^{o}C) for heating grids. The main advantage of such a system is that it is a reliable source of heat, independent of weather and season, unlike solar power. It could therefore be a valuable addition to a renewable energy system. The heating gradient is on average linear, so at less depth, temperatures are lower. However, even then the investment costs are significant and the risks are high. This can therefore only be feasible if it is part of a large system serving many households (Klimapedia, 2017:203). Despite the high investment cost, it is reported that the levelized cost of heat from geothermal district heating is comparable to other fuel sources, even when the costs of the heating network are included (Tester, Reber, Beckers, & Lukawski, 2016, p. 81).

Using shallow geothermal energy may prove to be more feasible. In this case a heat pump uses the heat extracted from the underground, for instance through a borehole heat exchanger, see figure 2.32, as its heat source. The concept is very similar to a borehole thermal energy storage, where 'heat' is injected into and extracted from the underground, but now with the purpose of (pre-)heating water instead of storing already heated water. This system can already be feasible for a single house as investment cost and risks are much lower. It can also be integrated in a district energy system if more heat exchangers are used, potentially serving a whole neighbourhood (Burkhard, 2001).

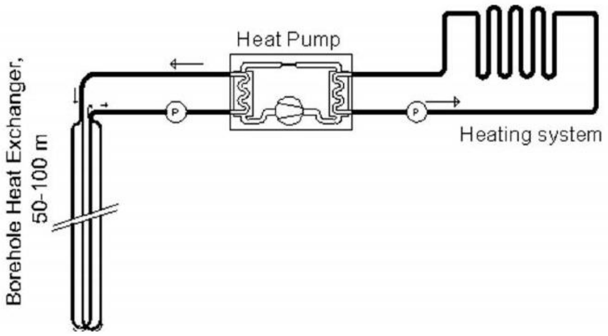


Figure 2.32: Schematic of a ground-source heat pump (Burkhard, 2001)

Wind Turbine

The other major renewable electricity source is wind energy. In wind turbines, the kinetic energy of the airflow, the 'wind', is transformed into rotational energy driving a generator, which in turn produces electrical energy (Ishugah, Li, Wang, & Kiplagat, 2014). When considering wind energy in urban planning, two types of wind turbines can be distinguished; small (SWT) and large wind turbines (LWT).

Large wind turbines (LWTs) are generally the well-known turbines, of up to 220 meters height (Wittrup, 2014), usually producing tens of kilowatts to several megawatts. These are almost always built to provide the electricity grid with energy, to serve a large group of households or large (industrial) consumers. LWTs are not desirable in or near to the built environment, due to noise and visual impact (Barim, Activiteitenbesluit Milieubeheer, 2007) and as the lower wind speeds in urban areas will result in a relatively low annual yield (Klimapedia, 2017, p. 268).

Small wind turbines can be systems of several watts to several kilowatts, specifically aimed at small scale production in an urban context, so for instance for application on roofs. Currently, the most common type is the horizontal axis wind turbine (HAWT). HAWTs are very efficient, but because of its sensitivity for wind direction, low wind speeds and turbulence, yield remains relatively low in an urban context (Ishugah, Li, Wang, & Kiplagat, 2014). Additional downsides to small wind turbines, especially for the application in dense urban areas, are the production of excessive noise that can cause major disturbance to its surroundings, as well as frequent failures, resulting in an unreliable power output (Abohela, Hamza, & Dudek, 2011, pp. 24-25). Retrofitting small wind turbines on an existing structure can also cause issues with structural stability, due to vibrations (Mithraratne, 2009).

A more promising type of SWT in urban context is the vertical axis wind turbine (VAWT). These are independent of wind direction, quieter and less sensitive to turbulence, making them extremely suitable for an urban environment. Other benefits, such as low manufacturing and maintenance cost, have increased the market share of these turbines significantly. VAWTs are currently still in the early phase of development, but it is estimated that these types of turbines will be capable of producing more than HAWTs within the next 2-3 decades (Ishugah, Li, Wang, & Kiplagat, 2014).

2.5.2 Energy Distribution

The aim of the energy transition is to transform this into a system which is eventually fully supplied by renewable sources, to create a sustainable energy system. To be able to make use of the many different renewable sources available, a good distribution network is needed for electricity and

District Heating Networks

District heating grids are distribution networks of a heat carrying medium, usually water. It connects the buildings in a certain neighbourhood, district or city, so heat can be distributed from a centralised plant or several distributed units (Lund, et al., 2014). In the Netherlands only around 20% of heat is currently supplied through district heating systems (Dutch: Stadsverwarming), mostly from industrial waste heat and waste incineration. However, it is estimated that district heating could supply up to 80% of all heating demand in the Netherlands through geothermal and industrial waste heat alone (VDM, 2017, p. 27). While many European countries developed a district heating system to improve fuel efficiencies and reduce the need to import fuels, district heating never became viable in the Netherlands, because of the cheap natural gas from the Slochteren gas field (Woods & Overgaard, 2016). Only a few systems were developed, mostly in the Randstad, around Amsterdam, in Utrecht and in the city and harbour of Rotterdam.

The current district heating systems, referred to as the 3rd generation, see figure 2.33, operate with high temperatures, usually around 120°C at the factory and 90°C at the building input. As buildings and the distribution infrastructure become more energy efficient, this delivery temperature could in the future go down to 60°C or even lower, reducing transmission losses and making it much more compatible with renewable sources such as shallow geothermal and solar energy. If the water from the district heating is used for domestic hot water, the lower temperature will have its limits due to comfort demands and Legionella prevention (Lauenburg, 2016, pp. 226-228).

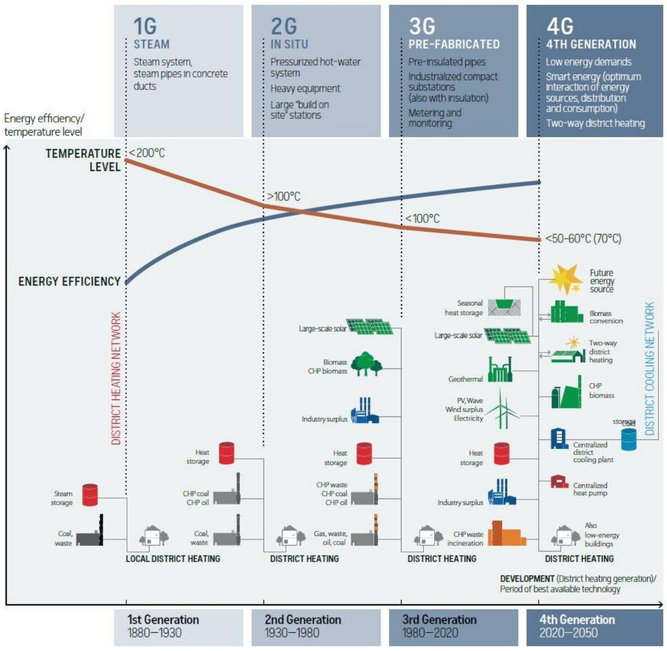


Figure 2.33: Historical development of district heating (UNEP, 2015)

The major challenge for the system is to integrate low-temperature renewable heat sources, which can't deliver the required 60°C or more without extra heating. Future district heating systems, the 4th generation, see figure 2.33, will therefore be based on temperatures around 50 to 60°C. This will allow for 'prosumers', end-users who also produce their own energy and feed any surplus back into the grid, creating a 'two-way district heating system'. The energy production and demand is all managed to create a 'smart thermal grid' (Lauenburg, 2016).

The TKI-OLEC consortium even proposes a '5th generation' system to allow for even more integration of renewable sources. In this system, temperatures well below 50^{O}C are used, resulting in even lower heat losses and energy cost. This can be done by reducing heat demand in connected buildings, so space heating can be solved with very low temperature installations, and locally heating domestic hot water using (booster) heat pumps or electric boilers (TKI-OLEC, 2017).

Smart Electricity Grids

Parallel to the development of smart thermal grids, smart electricity grids are an important part of the future sustainable energy system. A smart electricity grid is a network that digitally monitors and manages the transport of electricity from all generation sources to meet the demand as efficiently as possible (IEA, 2011). This will make it easier to include low-carbon, 'renewable' technology in the grid, like fluctuating renewable energy sources, such as solar-PV and wind power, and electricity storage, for instance in electric vehicles. It also allows for the previously mentioned 'prosumers' in this system, as decentralised production is expected to increase in the coming years, see figure 2.34.

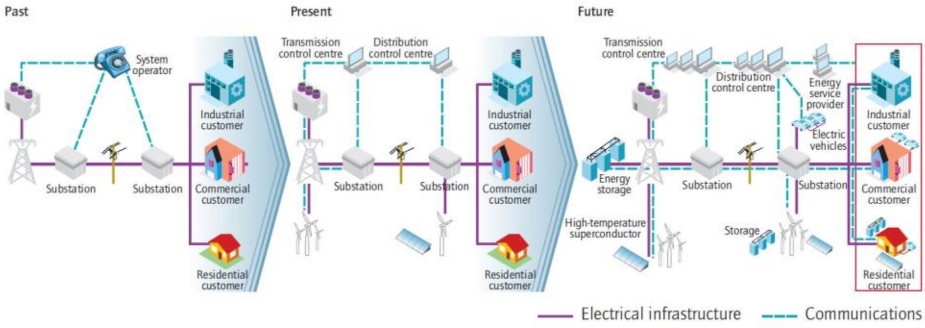


Figure 2.34: Development of electrical grid to a 'smart grid' (IEA, 2011)

2.5.3 Energy Storage

One of the disadvantages of many renewable energy sources is their fluctuating supply pattern; for instance, solar energy is produced only when the sun is shining and wind energy only when a certain wind speed is reached. The result is a mismatch between renewable supply and demand, which can be hourly, daily or even seasonal. To mitigate this mismatch and be able to supply as much local renewable energy as possible, storage can be introduced into the system. The two relevant forms, thermal and electricity storage, will be discussed in the following section.

Thermal Storage

For a fully sustainable heating system, heat and cold storage (Dutch: Warmte-koude opslag, WKO) or 'Thermal Energy Storage' will be an important element in our heating grid, as fluctuating renewable sources like solar energy gain a larger share in our energy system.

Currently, TES is widely used regularly for short term storage by heat producers, to provide a buffer and balance the supply and demand. In recent years, long-term or seasonal storage became more popular as this allows for an easy integration of solar energy into the system. The surplus of solar energy in summer can be stored to be used in winter, when solar energy is much lower but heat demand much higher. Thermal energy storage could even be an effective use for any surplus of electricity production we may have in the future; on sunny and windy days, the renewable sources may produce a surplus of electricity, which can be used to drive electric heat pumps and store this as thermal energy for later use. For CHP applications, TES may be even more interesting, as it allows the operator to produce electricity at maximum capacity at times of high prices, but without producing 'waste-heat' anyway. The heat produced can be stored and sold when heat demand is high instead, increasing financial feasibility of these applications (Klimapedia, 2017, p. 205).

There are several types of storage techniques available, most notably tank, pit, borehole, and aquifer storage, see figure 2.35. Pit and tank storage are well suited for higher temperatures and results in a high potential energy per volume of storage. These storage techniques involve a large reservoir ('pit') or tank, isolated from the soil and groundwater, of up to 100 000 m^3. These tanks can contain only hot water or hot and cold water simultaneously through 'stratification', separation of hot and cold water based on their different densities. Because of its long term storage capability, suitability with high temperatures and the relatively low heat loss, this is the preferred technique for large scale solar thermal plants, although it may be less economical for lower temperature applications (Thomsen & Overbye, 2016).

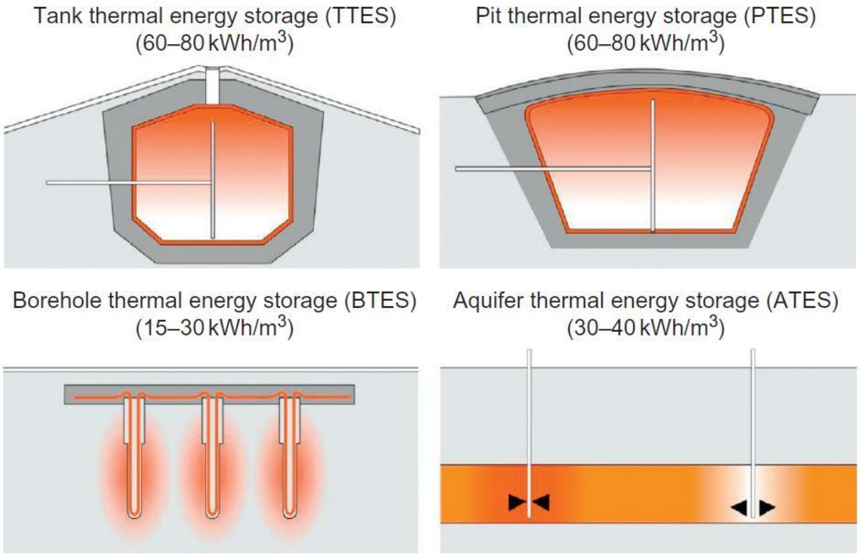


Figure 2.35: Different thermal energy storage techniques with their potential capacity (Solites, in: Pauschinger, 2016)

Borehole and aquifer storage are storage techniques that involve injecting heat into the ground and groundwater respectively. Borehole storage is based on the heat capacity of rock formations in the underground. The hot water is pumped through a closed system, the borehole, into the underground, where it heats up the rocks around it. During the heating system this heat can be extracted again, similar to a geothermal heat exchanger. Aquifer storage relies on isolated groundwater reservoirs for its storage. During the cooling season, hot water is pumped into the underground reservoir through the 'warm well' while cold water is simultaneously extracted through another 'cold well', keeping the aquifer's volume equal. This process is reversed during the heating season, so the hot water is extracted and cold water is injected into the aquifer. Both of these storage techniques are well suited for low-temperature water storage, but because the soil is the only insulation for the store, it is less suitable for higher temperatures. This results in a lower potential energy per volume of storage, as can been seen in figure 2.35. (Thomsen & Overbye, 2016) (Pauschinger, 2016).

Electricity Storage

Just as thermal storage, storing electricity can also contribute to a more sustainable energy supply system; Energy from fluctuating renewable sources, such as wind and solar-PV, can be stored at times of high production for later usage, especially at times of high demand. In this way, locally produced energy can actually be used locally as well, instead of being fed back into the electricity network. The storage also creates a buffer for times of high electricity production, reducing the peak current which could otherwise damage the cables and result in blackouts. Storage becomes an alternative to reinforcing the electricity infrastructure, which can potentially save money and increase the security of the supply.

Electricity storage can have many forms, but the most common is through batteries (Aneke & Wang, 2016). Battery systems in a district energy system can be central, decentral, or a combination.
An example of a central battery system is the "Neighbourhood-battery" (Dutch: "Buurtbatterij") by the firm ATEPS. The neighbourhood-battery is based on Lithium-ion technology and is 'medium capacity', with a few hundred kWh's of electricity storage. The Dutch network-administrator Liander has recently started a trial in the town of Rijsenhout to test the effectiveness of such a system in combination with local solar-PV production. The battery is placed in a small-size shipping container centrally in the neighbourhood and is connected to the electricity grid. A smart grid system manages the charging and discharging of the battery based on production and demand. The initial results are promising: Liander reports a doubling of the usage of locally produced electricity (Liander, 2017).

Figure 2.36: Neighbourhood battery unit (tegenstroom.nl)

Decentral battery systems are based on many small residential batteries (Dutch: Thuisbatterij) instead of a large central one, which together form a significant storage capacity. Study has shown that a specific battery system, the Tesla Powerwall, is expected to almost double the usage of self-produced electricity, from 38% to more than 60% (Truong, Naumann, Karl, Müller, Jossen, & Hesse, 2016). The same study also shows that the economic feasibility of this system is difficult to predict, but as electricity prices are expected to rise and remuneration is expected to decrease in Germany, storage will become more favourable. This could also be true for the Netherlands; if the 'netting-arrangement' is removed and replaced by an alternative remuneration, storage may become more favourable from a financial perspective.

Alternative storage techniques for electricity are for instance mechanical and chemical energy storage. These are unfortunately not or less relevant for application in the neighbourhood due to lack of required topography, in the case of pumped hydro storage, low long-term efficiency, in the case of flywheel storage, and low technology readiness level, for many kinds of chemical storage techniques (Aneke & Wang, 2016).

3. Assessment Method

Based on the existing Smart Urban Isle study (SUI, 2018), the potential of implementing a sustainable district energy system in a neighbourhood in the Netherlands will be explored. In this study, several energy concepts are evaluated for their potential to make the Ramplaankwartier in Haarlem a net zero-energy neighbourhood. To be able to assess the different concepts and the design in a structured and reproducible way, several key performance indicators (KPIs) have been identified. The main emphasis will lie on the assessment of the themes 'energy' and 'spatial', which are directly related to the main research question.

3.1 Key Performance Indicators

An overview of the KPIs and their method of assessment are briefly discussed in table 3.1. An elaboration on each theme and the used indicators can be found in the following sections.

Subject		Description	Indicator
Theme: Energetic Performance			
Energy Systems	**Local renewable energy supply**	The maximum thermal and/or electric energy production of all available renewable sources in the area	Annual production (GWh/y)
	Share of local renewable energy	The fraction of renewable energy produced locally in relation to total area energy use	Share of local RE (%)
	Energy Autonomy	The estimated amount of locally produced energy that can be stored or used directly within the neighbourhood itself	High – Very low
	CO_2-emissions	The CO_2-emissions of the sustainable energy system and reduction of emissions relative to the status-quo.	Emissions (tonnesCO_2/y) Reduction (tonnesCO_2/y and %)
	Adaptability	The potential of the system to adapt to future developments	High – Low
	Technology maturity	The level of development of a technology	TRL
Components	**Energy production**	The maximum thermal and/or electric energy production of the technology	Annual production (MWh/y)
	Renewable energy peak power	The peak power that a renewable energy source can deliver	Peak power (kW or MW)
	Energy usability	The degree to which supply & demand patterns are similar or adjustable and additional conversion is needed for the energy to be usable, for both electric and thermal energy	High – Low
Theme: Spatial Impact			
Components & Energy System	**Infrastructure Footprint**	The area that is limited in its use due to the infrastructure and components of the system	Area (m^2) None – Large
	Visibility	The visibility of the related infrastructure and components	Low – High
	Noise	The noise production by (components of) the system in operation	Low – High
	Urban Quality	Potential of (components of) the system to add urban quality to the neighbourhood	Very positive – Very negative
	Social Acceptance	Degree to which the end-users accept the interventions and renewable energy in general	Positive – Negative
	Promoting Sustainability	The system's potential to promote a sustainable lifestyle and sustainability in general	High – Low

Table 3.1: Overview of KPIs with brief description and method of assessment (quantitative or qualitative)

3.2 Energetic Performance

The ‘energetic performance’ indicators consist of the relevant factors that determine the potential for an energy-autonomous urban area, where as much renewable energy as possible is produced and used locally.

The **local renewable energy supply** concerns the maximum annual energy production from the renewable sources in the system. Local production means it is from energy sources within the neighbourhood itself or just outside, the remaining external energy is supplied through the grid, i.e. natural gas or ‘grey’ electricity from large power plants. For both the electric and thermal energy, the annual renewable energy supply can be determined based on the estimated production of all available sources for a certain system. This indicator will be quantified for both the electric and thermal energy.

The **share of local renewable energy** is indicated by comparing the renewable energy supply to the total area energy use after building improvement measures have been taken. This includes the final energy demand of the buildings and any transmission losses in the distribution system. If this share is 100% or higher, the neighbourhood can be called ‘net zero-energy’.

The **energy autonomy** reflects the degree to which locally produced energy is actually used in the neighbourhood itself. This is an indicator that can only be estimated using elaborate simulations (Jansen, et al., 2016, p. 27), so the energy autonomy is instead quantified based on expected demand and supply patterns, the types of renewable sources included in the system, and the presence of long- and short-term storage. The quantification is as follows:

High	Many renewable sources, demand and supply patterns are similar and storage for both electric and thermal energy included in the system
Medium	Many renewable sources, demand and supply patterns are similar or sufficient storage for either electric or thermal energy included in the system
Low	Limited renewable sources, demand and supply patterns are similar or some storage for either electric or thermal energy included in the system
Very low	Limited renewable sources, demand and supply patterns differ and no storage included in the system

The reduction in **CO_2-emissions** can be estimated for each concept, based on the total area energy use. The emissions depend on the sources of the energy in the final energy mix, with much lower emissions for renewable sources than ‘grey’ electricity or natural gas, as is shown in the table below. The total emissions are estimated based on the annual energy balance of the area and the available energy sources. By comparing this to the estimated emissions of the current situation, the absolute and relative reduction can be quantified as well.

Energy source	Form of energy	Emissions ($kgCO_2/MWh$)	Further comments
‘Grey’ electricity	Electric	649	All ‘external’ electrical energy
Natural gas	Thermal	215	Based on boiler at η=90%, 8.8 kWh/Nm^3
PV/PVT	Electric	70	Including production of panels
PVT/solar thermal	Thermal	0	Including production of panels
Wind	Electric	12	Including production of wind turbine
Biomass	Electric	75	Emission due to biomass-processing
Biomass (thermal)	Thermal	38	Emission due to biomass-processing
Waste incineration	Thermal	95	All ‘external’ thermal energy

Table 3.2: CO2-emissions per energy source (Lijst Emissiefactoren, n.d.)

The **adaptability** indicates whether the system can adapt to future developments and advancement in technology. This flexibility of the system is desired to prevent a 'technological lock-in'. This is a situation where a system can't be adapted to innovations and advancement in technology, because the infrastructure is only designed for this one system. Any changes can only be achieved at significant cost or inconvenience and should therefore be avoided. The adaptability can be determined by the complications due to changes in the system and the possibility to integrate different renewable energy sources. These are qualified in the following way:

High	Little or no complication due to changing the system and the integration of many different sources is possible.
Medium	Some complications due to changing the system or limited amount of sources possible for integration.
Low	Significant complications due to changing the system, a 'lock-in' may be created, and limited amount of sources possible for integration.

The **maturity of the technology** is an important consideration for the feasibility of the design. The proposed (combination of) technology is not always proven to function in practice as it would in theory, at least to a degree that it can reasonably be used for this project. Technology that is not proven or in a very early stage of development involves additional risk that needs to be minimised or at least considered. The standard scale to indicate the maturity of technology is the 'Technology Readiness Level' (TRL), ranging from 1 to 9 (European Commission, 2017, p. 27). The higher the level, the more reasonable to assume this technology will be available for application at this moment or within the next few years. Because this study will focus on technology that is available at this moment, the TRL will be one of the following:

- TRL 7: System prototype demonstration in operational environment
- TRL 8: System complete and qualified
- TRL 9: Actual system proven in operational environment and competitive manufacturing

The **component energy production** should be more than just the electric or thermal energy that is produced. It should also be determined by the form of energy, the similarity of supply and demand patterns, peak power output and, in case of thermal energy, the temperature and additional conversion needed for it to be usable.

The **renewable source peak power** indicates the maximum power that a source delivers at moments of peak demand or peak supply. This is important for two aspects of the energy system:
Firstly it shows the ability of the system to deliver enough energy at moments of peak demand or if an additional system for peak demand is required. Secondly it indicates whether the energy infrastructure is sufficient to cope with the production peaks in the system, otherwise this may lead to system failing, for instance resulting in blackouts.
This indicator is mostly applicable to components of the system, but it can also be determined for a system as a whole if the specifications of all components are known. This indicator is quantified for the thermal energy at the moment of highest demand, in winter, and for the electrical energy at the moment of highest production, in summer.

The **energy usability** is determined by the need for conversion and storage, which shows whether the produced energy is directly usable or needs further processing and/or storage. This is qualified based on the daily and annual production pattern, controllability of production, and for thermal energy sources, the temperature level and required conversion for the energy to be usable. This ranges from 'high', energy can be used directly without further conversion, to 'low', energy is of low temperature (20-30^{O}C) and needs both additional conversion and storage.

3.3 Spatial Impact

The 'spatial impact' indicates the implications of the system on the urban space in the area and is directly related to the main research question. This concerns the physical dimensions of the technology, so the actual space it requires, but also how people experience this, so whether it has a negative or positive influence on the neighbourhood.

The **infrastructure footprint** concerns the area that is required for infrastructure and components of the system and that is therefore less usable. For separate components this indicator can be quantified as the square meters (m^2) that are less usable after implementation of this component.
For the systems as a whole it is more difficult to determine the affected area, for instance in the case of the ducts of a heat network. The systems as a whole will therefore be qualified based on the area required for its centralised components for heat distribution, production, and storage, as follows:

None	No central components or distribution network required
Small	Small area for central production and/or storage required, no distribution network
Medium	Some area for central production and/or storage and for distribution network required
Large	Large area for central production and/or storage and for distribution network required

The **visibility** of the components of the energy system can have a large impact on the neighbourhood, as this influences the way people experience the project, be it positive or negative. The visibility is to an extent determined by the size of the components, but mostly by the placement above- or underground, its height of placement, and the distribution throughout the neighbourhood. It is qualified in the following manner:

Low	All components placed underground or above eye-level, little visible parts in few places in the neighbourhood
Medium	Most components placed underground or above eye-level with visible parts throughout the neighbourhood, or at eye-level in few places in the neighbourhood
High	Most components placed above ground at eye-level, highly visible all throughout the neighbourhood

The **noise** production of components in operation will have an even more negative impact, as this causes nuisance to its surroundings. The nuisance that is caused is related to the loudness of the noise and the frequency of occurrence, so it is not sufficient to only quantify the noise level. For wind turbines, the noise level at a dwelling may not exceed 47 dB(A) during the day and 41 dB(A) at night. Beyond these figures, the noise will cause significant nuisance, so this 47 dB(A) is taken as the threshold for 'loud noise'. It is qualified in the following manner:

Low	No noise produced in operation
Medium	Some noise produced, but not loud (<41 dB) and infrequent
High	Noise produced in operation, loud (>41 dB) and/or continuously

The potential of the system to add **urban quality** is quite a broad indicator. Several indicators of the 'BREEAM Area-development'-certificate that are used to assess the urban quality of a certain plan, are combined to explore the potential of components in the system to create synergies and add quality to the neighbourhood (BREEAM-NL, 2012). The assessment is based on the positive or negative effect on the following indicators:

- Synergy and added functionality, the level to which additional functions can be added or are limited by the system or its components.
- Safety, the level to which the system or its components promote social control or the feeling of safety.
- Social cohesion, the level to which the system creates or limits meeting places and promotes a communal feeling.

- Presence of green, the level to which area for trees and accessible green spaces is created or limited.
- Possibility for recreation and sports, the level to which places for sports, recreation and leisure are created or limited.
- Aesthetic quality, the level to which the design, for example through uniformity and adding to the existing identity, can add to or limit

This is done to explore the relationship between energy and spatial quality and find potential synergies, which can be used in later phases of this study. Each of these indicators can be rated as negative, neutral, or positive, indicating whether an intervention has a limiting effect, no effect, or adds quality respectively.

The assessment for the total energy system can be estimated based on the following table:

Very Positive	Predominantly positive effect on at least 3 indicator, no or little (negative) effect on other indicators
Positive	Predominantly positive effect on 1 or 2 indicator(s), no or little (negative) effect on other indicators
Neutral	No or little positive or negative effect on all indicators
Negative	Predominantly negative effect on 1 or 2 indicator(s), no or little (positive) effect on other indicators
Very Negative	Predominantly negative effect on at least 3 indicators, no or little (positive) effect on other indicators

This evaluation remains an estimation for both the energy system and the components, but should be more accurately assessed on its social appreciation through interviews or questionnaires.

The **social acceptance** indicator is used to estimate the expected opinion of residents regarding the application of the system. This is influenced the acceptance of renewable energy in general and any change in behaviour required for the system, but also the spatial integration of the components. The effect of a system can be assessed in detail through interviews or questionnaires with residents, or the expected acceptance can be estimated.

Positive	Good spatial integration of components, no or little change in behaviour required and/or positive opinion of renewable energy in general
Neutral	Acceptable spatial integration of components, some change in behaviour required and/or neutral opinion of renewable energy in general
Negative	Poor spatial integration of components, significant change in behaviour required and/or negative opinion of renewable energy in general

Promoting sustainability and a sustainable lifestyle should be an additional function of the energy system. This can also be quite a broad indicator, as a large variety of subjects could contribute to this ‘promotion’, such as educating people and making them aware of sustainability, and encouraging people to change their behaviour to consume less energy. This indicator will therefore combine several aspects, some of which have already been mentioned before, to estimate the degree to which sustainability is promoted in the system. These are recognisability (is the system or component visible and is it clear what it does?), information (does the system or component provide information about its operation?), and promotion of conscious energy use.

High	The (component of the) system is recognisable, gives information about its operation or sustainability, and/or actively contributes to the conscious use of energy
Medium	The (component of the) system is recognisable, but gives little information about its operation or sustainability, and/or contributes little to the conscious use of energy
Low	The (component of the) system is not recognisable, gives little information about its operation or sustainability, and doesn’t promote the conscious use of energy

4. Energy Concept Evaluation

The different energy concepts discussed in this section are based on the scenarios from the existing SUI research and the reference projects discussed before. The emphasis of the evaluation will be on the spatial impact of the concepts on the neighbourhood. The energy performance is also briefly evaluated based on the results from the SUI case study. Based on the conclusions regarding energy and spatial impact, the most promising system will be selected for further development.

4.1 All-Electric Self-Provision

The all-electric concept has a large impact on building scale; to improve energy performance of the buildings, a high level of improvement is crucial. Despite the reduction of the total energy use to a fraction of the current situation, the high electricity demand limits the possibility to be self-sufficient. Many renewable sources are unavailable for use, due to the reliance on electric energy.

On the urban scale, the impact is much less; it remains limited to an improved electricity network to cope with the increased peak loads, and some central production, such as wind turbines or a small local power plant.

This concept illustrates that a low spatial impact is not per definition positive; the footprint and visibility may be low, but the potential to have a positive is therefore also minimised. There are no or little opportunities to add quality or use components to promote sustainability.

Summary	
Local renewable energy supply	4.76 $GWh_{electric}$/y
Share of local renewable energy	62%
Energy Autonomy	Low
CO_2-emissions	2150 $tonnesCO_2$/y -4850 $tonnesCO_2$/y -69%
Technology maturity	TRL 9
Adaptability	High
Infrastructure Footprint	None
Visibility	Low
Noise	High
Urban Quality	Neutral
Social acceptance	Average
Promoting sustainability	Low

Domestic hot water is supplied by a heat pump, with an electrical boiler as a back-up for times of high demand. The resulting electrical energy demand is more than two times higher than the current electricity demand, so to produce this energy locally is a challenge and the share of local renewable energy is limited.

Because of the dependence on wind and solar energy, the actual autonomy of the area will be much lower. A large share of the produced energy will be fed back into the electricity grid instead of being used directly. This mismatch is difficult to solve locally, so (grey) back-up power will still be needed.
Another major downside from an energetic point of view is the limited applicability of different renewable energy sources in this scenario. Only renewable sources that produce electricity, such as solar-PV and wind, or sources that provide directly usable heat, such as a PVT-panel and heat pump combination, can be considered. The heat pump with PVT-panels reports higher COP's than the heat pumps with air source (Baal, 2014), so these may be the better choice. However, many other energy sources with a high potential, such as waste heat, as well as (seasonal) thermal storage can't be used in this system.

One of the major advantages of the all-electric scenario is ability to adapt to future changes and transform the neighbourhood in phases. Most changes are on a building level and require no or little central interventions, so all buildings could be renovated individually. Residents can choose to renovate their house whenever a home improvement was planned anyway or form a group to have their houses renovated at once for financial benefits. The few central measures, mainly the options for renewable energy production, could be taken in a similar way, so either all at once or phased over a longer period.

Since there is no central infrastructure required and visible components remain limited to the PV-panels and heat pumps, placed above eye-level, the visibility is considered low. However, the noise produced by the air-source heat pump can be as high as 65-70 dB(A), with 49 dB(A) remaining at 5 meters (NSG, 2018). This can cause serious nuisance to the neighbours, so the noise is considered high.

This concept has limited possibility to add urban quality, as there are no urban measures that need to be taken. However, good design and integration of the PV-panels and the heat pumps will also have no significant negative effect on the neighbourhood, so overall its effect would be neutral.

The changes on the building level are significant, so people will need to be convinced that renovating this drastically and investing this much is actually worth it. Generally, the level of comfort will increase in a better insulated house, which is expected to improve social acceptance for renovation. Some changes in behaviour may be necessary, such as not opening windows too often and relying more on the ventilation. This may have a negative effect on the acceptance, but it could also promote a more sustainable lifestyle. The inclusion of a smart grid may further improve this, as the users are encouraged to be more energy conscious is general and use energy when local production is high. This is not (yet) considered for this concept however, so the promotion of sustainability is relatively low.

4.2 High-Temperature Heat Network

This concept has a high impact on the infrastructure of the neighbourhood, but the houses don't have to be improved significantly for this option to be effective. The dwellings in their current state can make use of this network, although some improvement would reduce their energy use significantly.

The high thermal energy demand that is difficult to produce with local renewable sources reduces in a low share of renewable energy.

The large infrastructural impact has a negative effect on the surroundings as a lot of space is required and many components are visible and audible throughout the neighbourhood.

The high temperature in the network does little to promote more conscious energy use, as it allows for the same (unsustainable) behaviour. The heat network may even create a lock-in, making it difficult to adapt to future changes, counteracting sustainable innovation.

Summary	
Local renewable energy supply	4.76 $GWh_{electric}$/y
Share of local renewable energy	15-20%
Energy Autonomy	Low-Medium
CO_2-emissions	4200 tonnesCO_2/y -2800 tonnesCO_2/y -40%
Technology maturity	TRL 9
Adaptability	Low
Infrastructure Footprint	Large
Visibility	High
Noise	High
Urban Quality	Negative
Social acceptance	Neutral
Promoting sustainability	Low

The high-temperature heat is difficult to produce with decentral sources. In the SUI study, only roof-mounted PV-panels and small wind turbines are assumed as production. The entire heat demand of 21.4 GWh is assumed to be supplied externally. This results in an extremely low local renewable share of only 15%, as the heat demand dominates the final energy demand. The energy autonomy of the area will be even lower due to the reliance on solar and wind energy for electricity.

In the scenario proposed by Tauw, the heat demand is instead supplied by a central heat pump with an aquifer thermal storage as source, which will be regenerated by 'drycoolers', air-source heat pumps. This can supply up to 93.7% of the annual heat demand, the remaining 6.3% is supplied with a backup boiler (Tauw, 2018). The thermal energy demand is for a large part electrified, allowing for a larger share of renewable electricity. Despite this significant increase in electricity demand, the share of renewable energy is increased to 20% and the energy autonomy, especially for heat, will improve as well.

The renewable share and autonomy could increase further if the heat is also partly supplied through a small solar thermal farm, which has for instance been done in Almere (IkbouwmijnhuisinAlmere, n.d.) and Braedstrup, Denmark (Pauschinger, 2016). It can be combined with a tank thermal storage to create a buffer, which allows for production of heat at times of high renewable heat or electricity production for later consumption. Locally produced electricity is actually being used locally as well instead of being fed back into the regional electricity grid, further improving the energy autonomy of the system.

The technology for a high temperature heat grid is proven to be effective in the Netherlands and the systems are commercially available. The difficulty with high temperature heat grids lies in the lock-in that is created by the development of such a network; The heat grid is expensive and has a long pay-back time, so little changes can be made to the system during its lifetime. The renewable sources that can directly produce the high temperature heat required for this system are also limited, although the central heat pump could make use of low-temperature renewable sources as well.

Research shows that a high temperature regime, of 90^{O}C supply- and 60^{O}C return-temperature, is relatively expensive per MWh of heat delivered when buildings are energy efficient (Ziemele, Pakere, Chemovska, & Blumberga, 2016). However, the same study also argues that the temperature regime can be reduced using the existing system, to for instance 60^{O}C supply-temperature. This greatly reduces heat losses and operational costs of the system. The conditions for this to be possible are for a large share of the buildings to be energy efficient and for the network to have enough capacity, so this should be taken into account in an early stage of development.

The system requires a lot of space, both underground and above ground. In the system as proposed by Tauw, several central heat stations are required with a large heat pump. Furthermore, 10 sets of 'drycoolers', large air-source heat pumps, are necessary, each of which is roughly 30 m^2 (Tauw, 2018). These can also be placed in one location or distributed through the neighbourhood. Besides this, no additional substations are required in a relatively small neighbourhood.

Especially the drycoolers would have a significant visual impact, as these systems are to be placed above-ground at eye-level throughout the neighbourhood. The spatial integration is a major challenge, and is expected to have a predominantly negative effect. Another difficulty is the noise these systems create in operation; the fans produce noise while operating, so this could be a source of nuisance for the households around the heat stations.

There seems to be little opportunity to integrate this system in the neighbourhood in a way that it adds urban quality. The central heat stations or central production could be integrated with other functions, but considering the amount of space that is needed for technical components, the effect will be predominantly negative.

The social acceptance of this concept will be negatively influenced by the large spatial impact of the system on the neighbourhood. On the other hand, little change in behaviour is needed; the water for space heating and hot water are still supplied at high temperatures, so the shower is still hot within a few seconds and the space heating system will still heat a room to comfortable temperature within a short time.

Partly because of this last argument, this system also does little to promote sustainability or a more sustainable lifestyle. If anything, it prevents the introduction of more sustainability measures and renewable energy sources, because improvement beyond the basic renovation doesn't result in significant savings. The high visibility of the system does result in awareness that this system is there, but good design is necessary for it to have a positive effect on people's opinion of sustainability.

4.3 Medium-Temperature Heat Network

The use of lower temperatures in the network reduces transmission losses and allows for easier integration of renewable energy sources and thermal storage. Since the sources can be based on a combination of electricity and heat, the share of local renewable energy in the energy mix can be much higher. Thermal storage also increases the self-sufficiency of the area.

The spatial impact on the neighbourhood is, like the previous concept, relatively high, because of the heat grid and central heat pumps that are needed.

The variety of available energy sources do allow for optimisation, so negative effect can be minimised and positive maximised.

The lower temperature can be optimally used with low-temperature heating, but a certain level of building improvement is necessary to make this possible and reduce electricity use of the heat pumps.

Summary	BAU-renov.	C-label-renov.
Local renewable energy supply	4.76 GWh_e/y 13.49+ GWh_{th}/y	4.76 GWh_e/y 12.03+ GWh_{th}/y
Share of local renewable energy	73% (43%/100%)	88% (68%/100%)
Energy Autonomy	Medium	
CO_2-emissions	4360 $tonCO_2/y$ -2640 $tonCO_2/y$ -38%	1740 $tonCO_2/y$ -5260 $tonCO_2/y$ -75%
Technology maturity	TRL 7	
Adaptability	Medium	
Infrastructure Footprint	Medium	
Visibility	Medium	
Noise	Medium	
Urban Quality	Positive	
Social acceptance	Neutral	
Promoting sustainability	High	

In this concept, the integration of different renewable sources is much easier than the previous system, which results in a large share of local renewable production. Decentral PVT-panels can supply the entire annual heat demand with a seasonal thermal energy storage in the system. However, the electricity demand is increased significantly.

Especially for the better improved houses, to at least the level of C-label, the energetic performance is promising; low-temperature heating allows for direct use of the supplied heat and therefore drastically reduces the electricity use of the heat pump.

Despite the electricity demand increase, the PVT-panels and wind turbines could still produce 68% of the electricity demand, with a total renewable share of 88%. To produce this energy, only 25% of the CO_2 is emitted per year compared to the current situation. This is only half of the emissions of a natural gas-fired boiler in the same renovation scenario, so the heat network is an enormous improvement.

In both renovation scenarios, the electricity supply is still heavily reliant on fluctuating sources such as solar and wind energy, so the autonomy is low. The autonomy for thermal energy is high, as the PVT panels and thermal storage allow for local production of heat, storage, and use of this locally-produced heat at times of high demand.

Some components of the system also need improvement to make application possible and feasible. The booster heat pumps are currently only available at rated power of around 2.5 kW, which is according to Tauw not sufficient for space heating and domestic hot water of an average dwelling. Booster heat pumps with rated power of 5 kW and 7.5 kW are required and these are currently not available (Tauw, 2018, p. 23).

The adaptability of this concept is one of its major advantages over the high-temperature heat grid. The lower temperatures and possibility to fit each dwelling with an individual booster heat pump makes this system very flexible in operation and allows for each house to be renovated individually with a direct impact on its energy use. The integration of many different renewable sources can easily be achieved and it allows for both central and decentral production of heat and electricity. As part of the heating is realised in each individual building, there is still a large degree of flexibility in this system. It might even be possible for houses at the beginning of the project to heat with their current gas-fired boiler and replace these with a booster heat pump at the end of its lifetime.

The infrastructure footprint for this system is similar to the high-temperature heat grid concept, but the 'drycoolers' are replaced by roof-mounted PVT-panels, which greatly reduce impact on usable space in the neighbourhood.

As the largest part of the infrastructure will be underground or above eye-level, the visibility is low to medium. Only the central heat pumps require some space, although these could also be placed underground, as is for instance done for the MineWater project in Heerlen. The PVT-systems on the roof do have a significant impact on the appearance of the neighbourhood, but whether this is negative or positive is personal.

The system has some potential to add quality to the neighbourhood. The lower temperatures of the network allow for integration of many different energy sources, which are a potential to find synergies and added functions. The negative effect is small.

The social acceptance of this concept is expected to be neutral. The relatively low spatial impact and high flexibility of the system will allow for a good integration of the system in the area. However, some changes to user behaviour may be necessary with this concept; if low temperature space heating is used, this may take longer to react to changes and heat a space to the desired temperature.

In this concept, the application of low-temperature heating becomes very rewarding, so a more energy conscious lifestyle is promoted. A smart grid may be even more promising for this system, as this allows residents to make optimal use of their self-produced electricity and heat, which also reduces the energy bill due to the netting arrangement.

4.4 Low-Temperature Heat Network

The temperatures in this concept reduce the heat losses even further and allow for easy integration of many different renewable energy sources. The impact on the building level is high, as both improvement measures and heat pump are needed. As a result however, the infrastructure impact is lower than in the other network concepts, as there is no central heat pump required. Another benefit is adaptability, as renovations can be carried out for each individual building. The heat pumps produce the largest share of the heat and the network allows for efficient operation, even in winter. It is also possible to use the same network for space cooling in summer, providing extra comfort. Development of a two-way heat network, which allows for feedback of decentral produced heat to the network, is favourable as well.

Summary	BAU-renov.	C-label-renov.
Local renewable energy supply	4.76 GWh$_e$/y 9.74 GWh$_{th}$/y	4.76 GWh$_e$/y 6.25 GWh$_{th}$/y
Share of local renewable energy	86% (66%/100%)	88% (76%/100%)
Energy Autonomy	Medium	
CO_2-emissions	1860 tonCO_2/y -5140 tonCO_2/y -74%	1240 tonCO_2/y -5760 tonCO_2/y -83%
Technology maturity	TRL 7	
Adaptability	High	
Infrastructure Footprint	Medium	
Visibility	Medium	
Noise	Low	
Urban Quality	Positive	
Social acceptance	Neutral	
Promoting sustainability	High	

The optimal building renovation scenario is either to the level of C-label or NZEB, allowing for low-temperature space heating and greatly reducing the heat demand. The share of renewable energy is high in both scenarios, as up to 88% of the area's total energy can be produced locally. As a result, the CO_2-emission is reduced to only 26% or even only 17% of the current situation, which is half that of a gas-fired boiler in the same scenario.

In both cases, the energy autonomy is expected to remain low for electricity, as there is still a high share of fluctuating energy sources and no storage. For heat, the autonomy remains high, as all heat is produced locally and can be stored in the thermal energy storage.

Like the medium-temperature heat grid, the concept of low-temperature heat grids is still not common practice and needs more development to become a valid alternative to natural gas. The technology for this system is also still in development. For example, the water-source heat pumps that will supply the heat in this concept are already efficient, but are not widely available yet, while air-source heat pumps are becoming much more common.

The adaptability of this system is high, although a lock-in is created to a certain extent due to the heat network. The low design temperature does allow for a lot of flexibility, as many different renewable sources can be easily introduced and the temperature regime can be variable as well, depending on the weather.

The spatial impact of the infrastructure will be lower than for the high- and medium-temperature heat grids, as no central heat pumps are needed. The central infrastructure is limited to the distribution network, thermal storage, pumps for the network, and any central renewable production that is introduced.

On the building level the impact is higher than for the other heat grid concepts, as a high level of building improvement and a relatively large capacity heat pump is required. However, as this replaces the existing boiler, this may take no extra space, except when a small buffer storage tank is included in the system, in which case some extra space is required.

As little infrastructure is required in this concept, the visibility is. Renewable production with roof-top PV-panels will have the most significant visual impact, but this is above eye-level and whether this is positive or negative is personal.
The central components produce no noise, and the heat pumps in the buildings produce no more noise than the gas-boilers, so this should not give any inconvenience.

Similar to the medium-temperature heat grid, there is little negative impact on the urban quality of the neighbourhood. There is some potential to add urban quality, mostly through added functions.

The social acceptance of this system is expected to be similar to the other concepts. On the one hand it requires expensive building improvement measures and installations to supply enough heat. It may be difficult to convince people the relatively high investment is necessary. There may also be some behavioural changes required for this system, as it is most effective with low-temperature heating. This reacts slower to changes than current high-temperature systems, so it may needs some adjustment to have a similar level of comfort.
However, this system has a benefit that has not been considered in the SUI study, namely the possibility to use this same system for cooling in summer. This not only increases comfort for the users, but also provides the system with an additional heat source; the feed-back temperature in summer will be higher than the feed-in, which can then be stored in the thermal storage. The comfort increase will have a positive effect on the acceptance.

As the higher level of building improvement is very beneficial to the energy usage and consequently the financial benefits, this concept is expected to promote sustainability and renewable energy production. The high presence of renewable production and integration of smart grid technology in the neighbourhood also raises awareness for conscious use of energy and sustainability in general.

4.5 Conclusion

The evaluation allows for a quick overview of (dis-)advantages of each system, see table 4.1, making it easier to compare the different concepts. The advantages and disadvantages are shown in the table below. The most promising concepts from this evaluation seem to be the low- and medium-temperature heat network concepts. Both of these concepts are estimated to have an outstanding energetic performance and although the spatial impact is still relatively high, this might present options to add function and spatial quality to the neighbourhood.

The building improvement scenario is one of the most important factors for the energy performance of the system, due to the huge influence it has on the space heating demand. The better levels of improvement, such as the C-label or NZEB, are favourable, but also difficult to achieve in the context of an existing neighbourhood with relatively old buildings. The better insulation allows for space heating with lower temperatures ($<45^{O}C$), which is desirable for the low- and medium-temperature heat network concepts and a requirement for the all-electric concept. For the high-temperature heat network, this improvement is not necessary, as the heat is sufficient to use for the current space heating with high temperatures ($>60^{O}C$). Despite all its flaws, the high-temperature heat network may well remain an option for existing neighbourhoods that are limited in their potential for drastic renovation, such as old inner cities, or have producer(s) of high-temperature 'waste heat' relatively nearby, such as in the case study area 'Ondiep' discussed before.

Based on the criteria for energy and spatial impact used for this study, there seems to be little relationship between a concept's energetic performance and the spatial impact. The amount of energy production or conversion on either a building or neighbourhood level could already make more sense, but this mostly influences the infrastructure footprint and visibility, while having less effect on the other indicators.

Instead, the relationship between energy and spatial impact is mostly defined by the amount of available energy sources that can be implemented in the system. The all-electric and high-temperature heat network perform poorly due to the limited amount of sources available, while the other concepts are favourable because they allow for a wide variety of energy sources. This variety makes it possible to choose the most suitable options and optimise these, while still being able to supply enough energy. Although this is specific for the Ramplaankwartier and may be different in other neighbourhoods with a different context, the possibility to make use of sources such as low-temperature waste heat through the use of these networks is an important consideration.

Some of the evaluation criteria are difficult to measure accurately, because these are not quantifiable. Especially the spatial impact indicators, such as urban quality or social acceptance are completely dependent on the further development of the project; a promising system that is developed poorly will eventually be less favourable than a poor system that is integrated very well into the neighbourhood and is fitted to the wishes of the residents.

The most accurate evaluation of the spatial impact would therefore be through a social test, for instance in the form of interviews, questionnaires or workshops, in which residents are involved in the decision-making process. Further development of these concepts, which are currently still abstract, is crucial to make this cooperation possible for people that lack the specialized knowledge.

Criteria	All-electric NZEB	HT-HN BAU	MT-HN BAU	MT-HN C-label	LT-HN C-label	LT-HN NZEB
Energetic performance						
Renewable supply	4.76 GWh$_e$/y	4.76 GWh$_e$/y	4.76 GWh$_e$/y 13.5 GWh$_t$/y	4.76 GWh$_e$/y 12.0 GWh$_t$/y	4.76 GWh$_e$/y 9.74 GWh$_t$/y	4.76 GWh$_e$/y 6.25 GWh$_t$/y
Local share renewables	62%	20%	73%	88%	86%	88%
Energy autonomy	Low	Low	Average	Average	Average	Average
CO_2-emissions	2150 tCO$_2$/y 4850 tCO$_2$/y -69%	4170 tCO$_2$/y 2830 tCO$_2$/y -41%	4360 tCO$_2$/y 2640 tCO$_2$/y -38%	1740 tCO$_2$/y 5260 tCO$_2$/y -75%	1860 tCO$_2$/y 5140 tCO$_2$/y -74%	1240 tCO$_2$/y 5760 tCO$_2$/y -83%
Technology maturity	TRL 9	TRL 9	TRL 7		TRL 7	
Adaptability	High	Low	Average		High	
Spatial impact						
Footprint	None	Large	Medium		Medium	
Visibility	Low	High	Medium		Medium	
Noise	High	High	Medium		Low	
Urban quality	Neutral	Negative	Positive		Positive	
Social Acceptance	Neutral	Neutral	Neutral		Neutral	
Promoting sustainab'ty	Low	Low	High		High	

Table 4.1: Summary of the Key Performance Indicators for each concept: quantified indicators are coloured based on their relative performance

There are some significant differences between these concepts, which would favour one over the other. The advantages of the medium-temperature network are:

- Larger share of heat in the energy balance, lower electricity demand,
- Less impact on houses, as only small 'booster' heat pumps are needed.

The advantages of the low-temperature network are:

- Less infrastructural impact, only the heat network is needed, no central heat pumps,
- Lower heat losses in the network due to lower temperatures, and
- Possibility for space cooling in summer with the same network.

The more favourable concept, mostly from a spatial point of view, seems to be the low-temperature network, as the infrastructural impact is much lower. Energetically, both concepts have a similar performance. The concept that will be developed further is therefore the low-temperature heat network.

5. Intervention Toolbox

To explore the spatial aspects of the renewable energy sources, a brief energy potential mapping study is done, which also provides the opportunity to include additional sources. Based on the renewable energy technology selected in the energy potential mapping study and the chosen system, concrete proposals can be done for the spatial integration of components of the system in the neighbourhood. These will give a better insight into the spatial impact of a system as well as the potential for added quality and functionality. All possible components together form an 'intervention toolbox', which can be used to select the most suitable technology for further development and assessment.

5.1 Energy Potential Mapping Ramplaankwartier

Solar electricity

The roofs of the houses already offer an enormous area for solar-PV production. Some of the large buildings in or just outside the neighbourhood could provide place for central production as well.

Besides roof-mounted PV, there is also the potential to make a local solar power farm by placing an array of PV or PVT panels on one of the empty fields just outside the neighbourhood, which happens to be for sale at this moment. This could increase the area for PV significantly, as the land coverage can be high; 30% of the land can easily be covered with PV (Spruijt, 2015).

Figure 5.1: Map of solar PV(T) potential (Own ill.)

Solar thermal

For solar thermal energy, there are two conversion techniques that are especially promising: PVT-panels and asphalt energy collectors. Decentral production of energy with roof-top PVT-panels can make a significant contribution to balance the thermal storage between seasons. The large available roof area has a huge potential for producing renewable energy, despite the sub-optimal (south-)eastern orientation of most roofs. Central production with solar (thermal) panels in or just outside the area, either on large roofs or as part of a solar energy farm, could further contribute to the self-sufficiency of the area's energy supply. Asphalt collectors are promising because of the relative low impact, despite the large available production area.

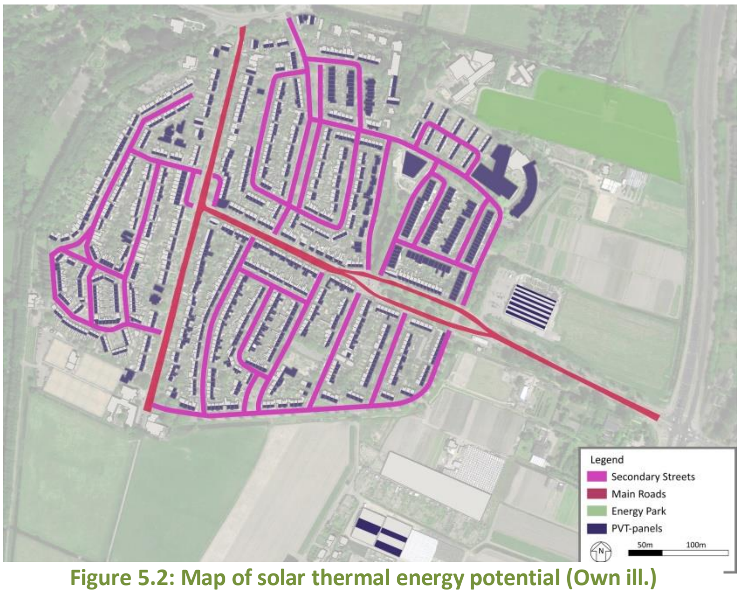


Figure 5.2: Map of solar thermal energy potential (Own ill.)

Greenhouse thermal energy

In addition to the conclusion from the SUI study, there is potential for heat exchange with the greenhouses just outside the neighbourhood. The greenhouses provide opportunity for the use of low-temperature “waste” heat.

In summer, greenhouses capture the sun so effectively that cooling is necessary, usually by venting the surplus heat out. If this surplus heat can be stored instead, it can be used later in a heat grid or for heating of the greenhouse in winter.

In a previous business case study into the potential of renewable energy in the Ramplaankwartier, the potential for heat exchange with these greenhouses was already estimated to be around 900 MJ of surplus heat produced per square meter of greenhouse, or 250 kWh/m^2 of thermal energy (Jansen G. , 2013, pp. 62-64).

Figure 5.3: Map of greenhouse waste heat potential (Own ill.)

Wind energy

Wind energy may be important for the low-temperature heat network concept, despite not producing thermal energy, because a large share of the heat is produced with electric heat pumps. For the wind power potential, the SUI Template distinguishes between small and large wind turbines, representing several kilowatts and several megawatts respectively. More suitable for the project however would be a medium-sized version (MWT), such as a 250 or 500 kilowatt turbine. These would produce around 450 or 1000 MWh/year respectively, assuming an average annual wind speed of 6 m/s at 60 meters height (WES, n.d.) & (EWT, n.d.), see appendix 1.

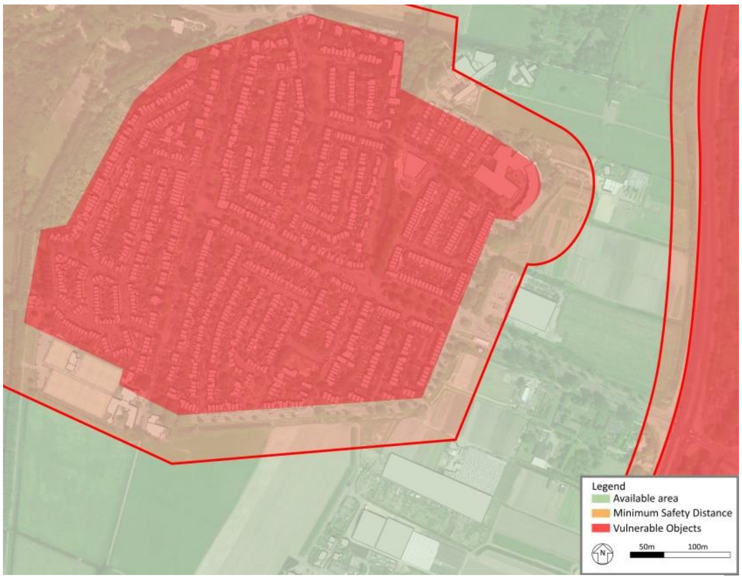


Figure 5.4: Map of wind energy potential area (Own ill.)

5.2 Intervention Toolbox

Solar energy

Integrated roof panels

Renewable energy production	3700 MWh_e/y 14700 MWh_{th}/y		**Added function**	Neutral
			Safety	Neutral
Peak power	2.5 MW_e	- MW_{th}	**Social cohesion**	Neutral
Energy usability	Medium	Low	**Presence of green**	Neutral
Footprint	24500 m^2		**Recreation & sports**	Neutral
Visibility	High		**Aesthetic quality**	Positive
Noise	Low		**Promote sustainability**	Medium

There is roughly 70 000 m^2 of roof area in the neighbourhood. It is assumed that 35% of this total roof area is suitable for application of a PV(T)-system, so an area of 24500 m^2 is either oriented south, south-east or south-west. The panels are estimated to yield 150 $\text{kWh}_e/\text{y}/m^2$ and the thermal part of the PVT-panels is expected to yield around 600 $\text{kWh}_{th}/\text{y}/m^2$ (SUI, 2018). This is low-temperature heat, between 10-25°C, which still needs additional conversion by a heat pump to be usable **(Triple Solar, 2018)**.

Figure 5.5: Map with suitable roofs highlighted (Own ill.)

It would be possible to increase the amount of area by also placing them on less suitable roofs. This could increase the potential to over 100% of the current demand. However, especially the thermal yield is expected to drop rapidly on roofs with sub-optimal orientation, to less than 50% of the maximum potential, so this isn´t financially feasible.

Figure 5.6: Integration of PVT-panels in Abraham Mensstraat (l) and Midden Tuindorpslaan (r) (Own ill.)

Integration of these panels in the roof can be traditional, when standard PVT-panels are installed on a frame above the existing roof, or integrated, by placing special PV roof-tiles or placing the PV(T)-panels in the plane of the roof. These last two options seem the most promising, as this integrates the panel with the roof and means that it also becomes the roof coverage, adding more function than just energy production. The integration will most likely also have a positive influence on the aesthetic quality of the neighbourhood, especially when similar panels are offered to the residents to achieve a consistent look.

Solar dormers				
Renewable energy production	600 MWh_e/y 2400 MWh_{th}/y		Added function	Very positive
			Safety	Neutral
Peak power	1 MW_e	-	Social cohesion	Neutral
Energy usability	Medium	Low	Presence of green	Neutral
Footprint	4900 m^2		Recreation & sports	Neutral
Visibility	Medium		Aesthetic quality	Positive
Noise	Low		Promote sustainability	Low

Another option, specifically for roofs facing north, east, and west, is to include a dormer into the design with a small array of panels at a lower inclination (0^o-10^o). This dormer slightly reduces the available roof space, but can increase the efficiency of the panels by 25% for a west- or east-facing roof and for a north-facing roof by up to 70%, see appendix 2.

At the same time, the dormer adds quality and value to the building, as the usable floor area of the top floor is increased. Therefore it adds both function and energy production to the roof. The available roof area for this option is also 35%, but the dormer can only occupy part of this space and the amount of panels is limited. Assuming around 20% of this space is available for this option, this brings the available are to 4900 m^2.

The dormers can be changed or made larger depending on the roof it’s placed on, so it fits with the building style and creates continuity in the streets.

Figure 5.7: Map with suitable roofs highlighted (Own ill.)

Figure 5.8: Close-up of small solar dormer (Own ill.)

Figure 5.9: 'Solar dormers' in the Abraham Mensstraat (l) and Midden Tuindorpslaan (r) (Own ill.)

PVT-farm				
Renewable energy production	1300 MWh_e/y 5300 MWh_{th}/y		**Added function**	Negative
			Safety	Neutral
Peak power	1.5 MW_e	-	**Social cohesion**	Neutral
Energy usability	Medium	Low	**Presence of green**	Negative
Footprint	7500 m^2		**Recreation & sports**	Negative
Visibility	Medium		**Aesthetic quality**	Neutral
Noise	Low		**Promote sustainability**	Medium

In the energy potential study, it was assumed that PVT-farm on a part of the empty land on the north-east side of the neighbourhood had the potential for 3500 m^2 of PVT-panels. If the entire piece of land (25000 m^2) would be covered, this could be increased to 7500 m^2 of panels, which has the potential to produce 35% and 29% of the current electricity and heat demand respectively.

This does have a significant spatial impact, and maximum coverage limits the double use of the space between or under the panels. The optimal area will therefore be lower, meaning either more space between the panels or only a partial coverage of the land, which leaves space for other activities or methods of production. A good ecological design of the area around the panels could even contribute to the biodiversity of the area, although the maximum production is slightly lower.

Figure 5.10: Potential location for large solar production (Own ill.)

Figure 5.11: Aerial impression of solar farm (Own ill.)

Figure 5.12: Impression of the solar farm from the N208 highway (Own ill.)

Agrisolar farm				
Renewable energy production	600 MWh_e/y 2500 MWh_{th}/y		**Added function**	Positive
			Safety	Neutral
Peak power	700 kW_e	-	**Social cohesion**	Positive
Energy usability	Medium	Low	**Presence of green**	Positive
Footprint	3500 m^2		**Recreation & sports**	Neutral
Visibility	Medium		**Aesthetic quality**	Neutral
Noise	Low		**Promote sustainability**	Medium

With only partial coverage of panels it becomes possible to create a multi-functional energy production area. The introduction of medium scale solar PV(T) will be combined with urban agriculture, which is actually very suitable for this location, because it can add to the existing communal farms of ‘Wij Telen Groente op het Land’ on the adjacent lot.

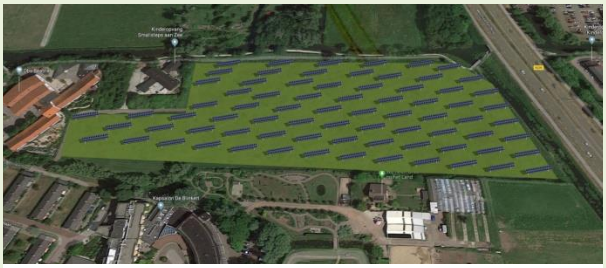


Figure 5.14: Aerial impression of agrisolar farm (Own ill.)

This combination can be achieved by increasing space between the panels and/or elevating the panels above the ground, so the area below can still be used. According to a press release from the Fraunhofer Institute for Solar Energy Research, this does reduces the production potential for both by 20%, but the double function results in a 60% production increase in total (Fraunhofer, 2017).


Figure 5.13: Combined agriculture and solar panels (www.ise.fraunhofer.de)


Figure 5.15: Impression of the Agrisolar farm from the N208 highway (Own ill.)

Solar parking area DekaTuin			
Renewable energy production	800 MWh_{th}/y	Added function	Positive
		Safety	Neutral
Peak power	- MW_{th}	Social cohesion	Neutral
Energy usability	Low	Presence of green	Neutral
Footprint	3000 m^2	Recreation & sports	Neutral
Visibility	Low	Aesthetic quality	Neutral
Noise	Low	Promote sustainability	Low

Parking lots in the area, for example next to the DekaTuin (~3000 m2), could be restructured to areas of energy production, either by adding asphalt collectors in the surface or solar panel covers over the parking area. Asphalt collectors supply around 278 kWh_{th}/m^2 per year, so just this parking lot can produce up to 4% of the total heat demand of the neighbourhood.

The collectors are integrated into the surface, so the spatial impact is low, as this is mostly influenced by the reconstruction of the parking lot, but in operation there is no noise or visual impact.

Figure 5.16: Map with 'solar parking' highlighted (Own ill.)

Figure 5.17: Current situation/asphalt collector option at the DekaTuin (Google Maps)

PVT-roofs over parking DekaTuin				
Renewable energy production	$200\ MWh_e/y$ $600\ MWh_{th}/y$		Added function	Positive
			Safety	Neutral
Peak power	$200\ kW_e$	$-\ MW_{th}$	Social cohesion	Neutral
Energy usability	Medium	Low	Presence of green	Neutral
Footprint	$1000\ m^2$		Recreation & sports	Neutral
Visibility	Medium		Aesthetic quality	Neutral
Noise	Low		Promote sustainability	Medium

Alternatively, solar covers could be added to the parking lot with integrated PV(T)-panels. These can only cover a part of the area, so the total thermal energy production will be similar, but at the same time it also produces 4% of the electricity demand.

The spatial impact is higher, as it has a larger visual impact, but the shade and cover from rain that is provided gives it an added function, so the effect is still predominantly positive.

Figure 5.18: Map with 'solar parking' highlighted (Own ill.)

Figure 5.19: Parking with PVT-roofs option at the DekaTuin (Own ill.)

Restructuring main roads			
Renewable energy production	2700 MWh_{th}/y	Added function	Positive
		Safety	Positive
Peak power	- MW_{th}	Social cohesion	Neutral
Energy usability	Low	Presence of green	Positive
Footprint	9600 m^2	Recreation & sports	Neutral
Visibility	Medium	Aesthetic quality	Positive
Noise	Low	Promote sustainability	Low

The main roads through the neighbourhood, the Vlaamseweg/Rollandslaan (~6000 m^2) and the Ramplaan (~3600 m^2), are suitable to be restructured to allow for the application of asphalt collectors. The maximum potential for these roads is equal to 13% of the current demand, so this can have a major effect.

There is some visual impact, due to the required restructuring of these roads, as the Vlaamseweg and Ramplaan are currently paved. This intervention does offer a possibility to improve the design of the streets through extra green area or separate bicycle lanes. For instance for the Rollandslaan, see figure 5.22 below, the effect may be very positive.

Figure 5.20: Main roads highlighted (Own ill.)

Figure 5.21: Restructuring option for the Rollandslaan, before (Own ill. based on Google Maps)

Figure 5.22: Restructuring option for the Rollandslaan, after (Own ill. based on Google Maps)

Restructuring secondary streets			
Renewable energy production	7500 MWh_{th}/y	Added function	Neutral
		Safety	Negative
Peak power	- MW_{th}	Social cohesion	Neutral
Energy usability	Low	Presence of green	Positive
Footprint	27000 m^2	Recreation & sports	Neutral
Visibility	Medium	Aesthetic quality	Positive
Noise	Low	Promote sustainability	Low

Besides the main roads, there is around 5 km of secondary streets in the neighbourhood. If all these are fitted with the collectors as well, this could produce another 37% of the annual heat demand.

Although this is a very large share of the heat demand, the spatial impact becomes much larger as well; the asphalt streets create a different outlook, require measures to reduce speed throughout the neighbourhood, and may have a negative effect on the number of parking spaces. This intervention does give the same options to i.e. add green or more structured parking spaces.

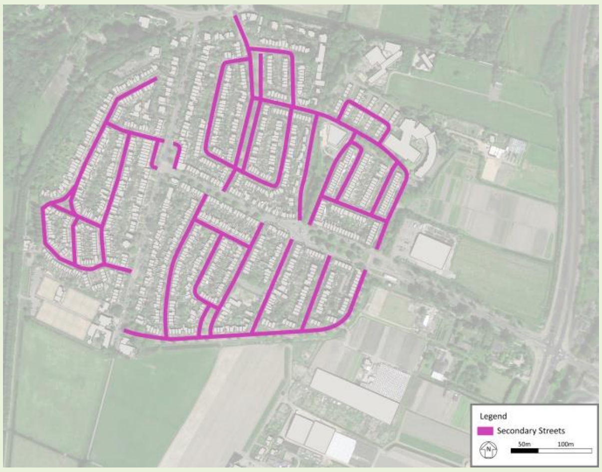


Figure 5.24: Secondary streets highlighted (Own ill.)

Figure 5.23: Restructuring option for the Dickmansstraat, before (top) and after (Own ill. based on Google Maps)

Solar (ice-)skating track			
Renewable energy production	2100 MWh$_{th}$/y	**Added function**	Very positive
		Safety	Neutral
Peak power	600 kW$_{th}$	**Social cohesion**	Positive
Energy usability	Medium	**Presence of green**	Negative
Footprint	6000 m^2	**Recreation & sports**	Positive
Visibility	Medium	**Aesthetic quality**	Positive
Noise	Low	**Promote sustainability**	Medium

Figure 5.25: Aerial impression of skating track(s) (Own ill.)

Another possibility is the introduction of a new skating track on the empty lot just outside the neighbourhood, which could add between 2000 and 6000 m^2 of extra collector area, producing up to 8% of the current annual heat demand, although this does require additional conversion with a heat pump to be usable.

If the track is made so it can be actively cooled as well, it can be used as an ice-skating track on ‘cold days’ (Dutch: Vorstdagen) throughout the winter, even if the temperature is above the freezing point. This adds quality and it produces additional (waste-)heat, which can directly be used in the heat network. Based on the average energy demand for an ice skating track, 1-2 kWh/m^2/day (Ice World, n.d.), and the expected number of ‘cold days’, between 50-100 days per year (KNMI, 2017), this results an extra production of around 75 kWh$_{th}$/m^2 per year. Assuming there is active cooling for 8-10 hours per day, this track could add over 0.1 kW/m^2, so a maximum of 600 kW, to the heating capacity of the network in winter, when the demand is highest. Although this is only 10% of the capacity of the thermal storage, and only 4% of the total capacity to supply 100% of the peak demands, it is a valuable contribution.

This does have a significant spatial impact, as a large asphalt track is added. The effect is expected to be very positive, because of the added function for the neighbourhood and its surroundings. The active cooling does require some extra space for a heat pump that cools the track, so this would have some visual impact and may produce some noise, but this is expected to be minor compared to the benefits.

Figure 5.26: Impression of the skating track (in summer) from the N208 highway (Own ill.)

Central production on large roofs				
Renewable energy production	300 MWh$_e$/y 1400 MWh$_{th}$/y		Added function	Neutral
			Safety	Neutral
Peak power	400 kW$_e$	-	Social cohesion	Neutral
Energy usability	Medium	Low	Presence of green	Neutral
Footprint	2000 m^2		Recreation & sports	Neutral
Visibility	Low		Aesthetic quality	Neutral
Noise	Low		Promote sustainability	Low

As has already been done for the tennis hall, PV(T)-panels could be added to some large buildings, such as the DekaTuin and the warehouses of Verschoor, to centrally produce energy. Both buildings mentioned above have a roof-area of around 1000 m^2 oriented south at a favourable angle that can be utilised for solar-PV(T) production.

Each can increase the local production of electric energy by 150 MWh/year, almost 5% of current demand. Since this is all currently unused roof area and the panels don't affect the current function, the spatial impact is low, but it doesn't have a significant added effect or functionality as well.

Figure 5.27: Map with large roofs highlighted (Own ill.)

Wind energy

Landmark wind turbine

Renewable energy production	450 MWh_e/y	Added function	Negative
		Safety	Neutral
Peak power	250 kW_e	Social cohesion	Neutral
Energy usability	High	Presence of green	Neutral
Footprint	50 m^2	Recreation & sports	Neutral
Visibility	Medium	Aesthetic quality	Debatable
Noise	Medium	Promote sustainability	High

Figure 5.28: Map of potential wind turbine locations with safety distance (Own ill.)

To produce wind energy in the neighbourhood, placing a single solitary wind turbine could be considered. A wind turbine stands out in its surroundings due to its height, which could make it a landmark for the neighbourhood; it is visible from far away and highlights the neighbourhood's ambition for a sustainable energy system. In this case, only one turbine is enough for the desired effect. With a good design, the turbines do have some aesthetic quality, although this is highly subjective.

Due to the restrictions for safety, a medium-size wind turbine such as the WES250, with a rated capacity of 250 kW, is the most effective option. This turbine with a rotor diameter of 30 meters and a tower height of 40-50 meters can produce around 450 MWh per year, 12% of the electricity demand. The affected area around the wind turbine is quite large; the noise emission at 8 m/s and at 100 m is 45 dB, which is just below the legal limit of 47 dB (Barim, Activiteitenbesluit Milieubeheer, 2007), so the minimum distance to the nearest house should be at least 100 m. This area can still be used for any function that is not sensitive to noise, such as agriculture, leisure, or sports. The actual footprint of the turbine is therefore only the foundation, which is only around 50 m^2 at the base of the turbine.

Figure 5.29: Impression of one 'landmark' wind turbine from the N208 highway (Own ill.)

Small wind park			
Renewable energy production	1350 MWh$_e$/y	Added function	Negative
		Safety	Neutral
Peak power	750 kW$_e$	Social cohesion	Neutral
Energy usability	High	Presence of green	Neutral
Footprint	150 m^2	Recreation & sports	Neutral
Visibility	High	Aesthetic quality	Debatable
Noise	High	Promote sustainability	High

To maximise the production, the option for a small wind park can be chosen, where several turbines are placed around the neighbourhood, creating a small-scale wind park. Based on the limitations for noise, there would be space for 5 turbines. The drop shadow on dwellings must also be kept to a minimum. As can be seen from the shadow study below, there are few problems for most of the year, but in winter the shadows might cause problems, especially the ones to the south of the neighbourhood.

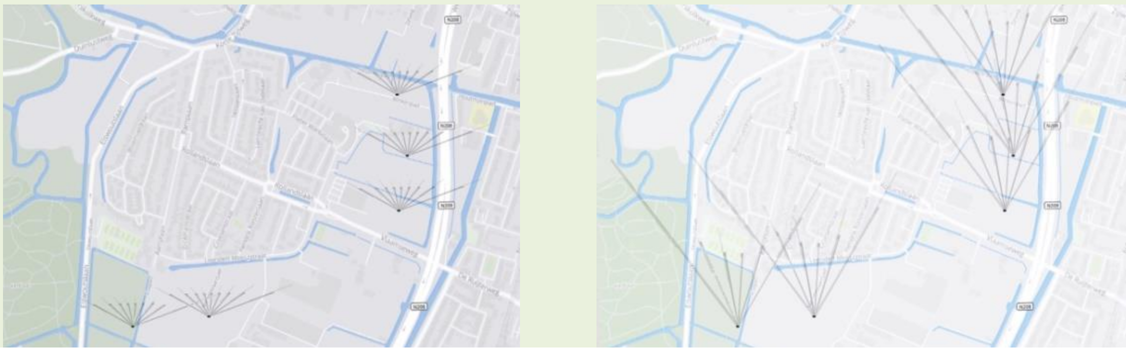


Figure 5.30: Wind turbines' drop shadow at equinox (21-3/21-9) and winter (21-12) (Own ill.)

Another issue with these two turbines is that they have a high visual impact. The two turbines to the south seem inconsistent with the other potential locations and these may also enclose the neighbourhood visually, as the turbines take up a large part of the horizon.

The three turbines to the east are placed in a line along the road, which strengthens this existing line and makes it possible to experience this, also from further away. The line positioning is recognisable and consistent, which is generally considered neutral or positively. If the area beneath the turbines can still be used and the foundation is well integrated in the ground, the negative effect is also minimised (H+N+S Landschapsarchitecten, 2013).

Figure 5.31: Impression of the 'wind farm' in a line formation from the N208 highway (Own ill.)

Waste heat recovery

Using greenhouse waste heat

Renewable energy production	3300 MWh_{th}/y	**Added function**	Positive
		Safety	Neutral
Peak power	- MW_{th}	**Social cohesion**	Neutral
Energy usability	Low	**Presence of green**	Neutral
Footprint	13200 m^2	**Recreation & sports**	Neutral
Visibility	Low	**Aesthetic quality**	Neutral
Noise	Low	**Promote sustainability**	Low

The already existing greenhouses to the south-east of the neighbourhood, of Kwekerij Groenendijk (9400 m^2) and Verschoor (3800m^2), offer a large area for waste heat recovery. The assumed potential is around 900 MJ, or 250 kWh_{th}/m^2 of surplus heat produced per square meter of greenhouse, which can produce 16% of the annual heat demand.

Figure 5.32: Map of waste heat producers (Own ill.)

The footprint of this technique is large, but the spatial impact is relatively small, as the only change that needs to be made is to close the greenhouses, include measures for active cooling and heating, and connect them to the heat network. The space can still be used for exactly the same function at the same efficiency, so the spatial impact is almost none. One of the benefits to the greenhouses may even be that a more controlled indoor environment could lead to a more constant product quality. The effect of this measure might therefore be positive for the greenhouses as well.

Sewage water heat exchange

Renewable energy production	400 MWh_{th}/y	**Added function**	Neutral
		Safety	Neutral
Peak power	60 kW_{th}	**Social cohesion**	Neutral
Energy usability	Medium	**Presence of green**	Neutral
Footprint	10 m^2	**Recreation & sports**	Neutral
Visibility	Low	**Aesthetic quality**	Neutral
Noise	Low	**Promote sustainability**	Low

The maximum sewage flow from the Ramplaankwartier is 6,5 L/s. Tauw estimates that only 2^{O}C can be recovered from the sewage water, which means the daily production is around 1.2 MWh/day, and 430 MWh/year, 2% of the total heat demand. The peak capacity is 55 kW, which is only a very small fraction of the peak demand. The advantage is that the temperature of the sewage water is relatively constant throughout the year, so this can also be add to the energy balance in winter. If the losses in the network are minimised and water from a cold well could be used for the heat exchanger, there might be the potential to increase the heat that can be recovered.

The spatial impact is small; a heat exchanger has to be integrated with the sewage main leading away from the neighbourhood. This only requires a small space and can be placed underground, so it's not visible and audible. There is little potential to add additional functions, but the current function is not hindered.

Heat network

‘Business-as-usual’ underground network

Renewable energy production	Not applicable	Added function	Neutral
		Safety	Neutral
Peak power	Not applicable	Social cohesion	Neutral
Energy usability	Not applicable	Presence of green	Neutral
Footprint	16530 m	Recreation & sports	Neutral
Visibility	Low	Aesthetic quality	Neutral
Noise	Low	Promote sustainability	Low

The heat network itself has little potential for urban quality as well, as these are purely technical and ideally placed underground.

The network consists of main ducts that branch and become smaller closer to the houses. For the higher temperature networks, the lengths are estimated to be 2.3 km for the main ducts, 4.9 km for the secondary ducts, and 9.4 km for the delivery to the houses (Tauw, 2018, 21). The dimensions of the ducts are between 100 and 25 mm, but may need to be slightly larger because a larger volume is needed to deliver the same of energy as a high temperature fluid.

Figure 5.33: Map of possible heat network layout (Own ill.)

Eaves heat network			
Renewable energy production	Not applicable	Added function	Positive
		Safety	Neutral
Peak power	Not applicable	Social cohesion	Neutral
Energy usability	Not applicable	Presence of green	Neutral
Footprint	12000-15000 m	Recreation & sports	Neutral
Visibility	Medium	Aesthetic quality	Positive
Noise	Low	Promote sustainability	Medium

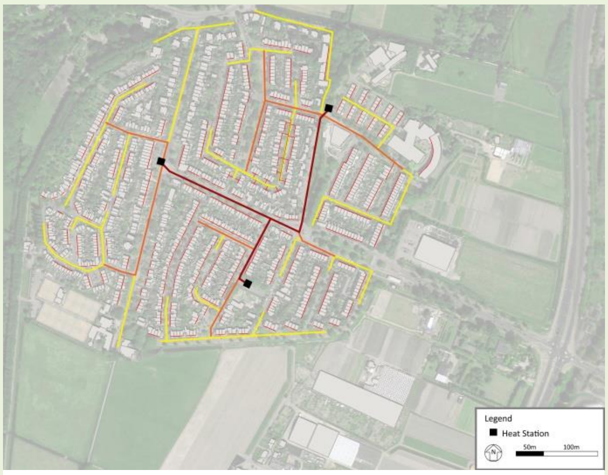


Figure 5.34: Map of alternative heat network layout with connections along the drains and eaves (Own ill.)

An improvement on the current system is a concept where the connection to the buildings is made via a channel along the drainpipes and the eaves, creating a multi-functional 'eave-system'. This system would specifically be suitable for retrofitting on older, terraced houses, which are very common in the area, as it allows the heat network connection to be made on the top floor or attic, where it is most likely the installation is placed. It reduces the complexity of the system in the houses and reduces the excavation costs, as only one subterranean connection would be enough to serve several houses. The total length of the system will be less as well, as the delivery set that is currently estimated at 8 m per house is no longer necessary. Instead the length of the secondary ducts may increase, but this still results at a much shorter length.

Besides the functional benefits, this system could also have aesthetic value when well designed. The existing drains are covered by this new 'eave-system', creating a consistent outlook throughout the neighbourhood. The spatial impact is therefore considered to be predominantly positive.

Figure 5.35: Impression of the 'eave-system' at the Hospeslaan (l) and Midden Tuindorpslaan (r) (Own ill.)

Heat stations			
Landmark pump house			
Renewable energy production	Not applicable	**Added function**	Positive
		Safety	Neutral
Peak power	Not applicable	**Social cohesion**	Positive
Energy usability	Not applicable	**Presence of green**	Negative
Footprint	30 m^2	**Recreation & sports**	Neutral
Visibility	Medium	**Aesthetic quality**	Positive
Noise	Low	**Promote sustainability**	High

Tauw proposes that the medium- and high-temperature networks need a minimum of 3 heat stations of 40 m^2 each. However, for the low-temperature network much less space is needed, as there is no heat pump required, so three small technical spaces of 10 m^2 should be sufficient.

These heat stations are technical space and in itself have little potential to add quality, but one heat station could be made visible to the public as a 'landmark', as has for instance been done for the MineWater project in Heerlen. There the main pump station is designed as a landmark, which draws attention to the innovative energy network and at the same time functions as a cultural centre for the neighbourhood.

Figure 5.36: 'Gen Coel' in Heerlen (www.mijnwater.nl)

This would also be an option for the heat station in the Ramplaankwartier; developing a central building that functions as a meeting place for the neighbourhood, going beyond just its technical function.

Figure 5.37: Impression of landmark heat station in the centre of the neighbourhood (Own ill. based on mijnwater.nl and Google Maps)

Underground heat stations			
Renewable energy production	Not applicable	**Added function**	Positive
		Safety	Neutral
Peak power	Not applicable	**Social cohesion**	Positive
Energy usability	Not applicable	**Presence of green**	Positive
Footprint	30 m^2	**Recreation & sports**	Positive
Visibility	Low	**Aesthetic quality**	Positive
Noise	Low	**Promote sustainability**	Low

Alternatively, this space could be placed underground in a pre-fab container, as has already been done in the Minewater-project in Heerlen.
The space above this container could be used for a different function, for instance as parking area, playground, or even as green space; the only requirement is that the space should still be accessible for maintenance, but this should only require a small hatch.
The footprint is small and visual impact is low, but because of the added functionality, the spatial impact may be larger, yet very positive.

The functions that could be added to each location could be directly related to its surroundings.

The heat station at the Ramplaan is next to some shops and the local supermarket, so this could become a small local square.

Figure 5.38: Prefab container with technical installations in the Minewater project (Verhoeven et al, 2013)

Figure 5.39: Map with heat station locations (Own ill.)

Figure 5.40: Impression of restructured heat station Ramplaan, before (l) and after (r) (Own ill.)

The heat station at the Croesenstraat is right beside a playground and sports field, so here more different functions for children and youth, like a small skate park, could be suitable.

Figure 5.41: Impression of restructured heat station Croesenstraat, before (l) and after (r) (Own ill.)

The final heat station, at the Rollandspad, is in a green space and along the path to the elementary school. This place could therefore be restructured into a green playground, for which the excavated soil can be used to create small hills where children can play on and around.

Figure 5.42: Impression of restructured heat station Rollandspad, before (l) and after (r) (Own ill.)

Energy storage			
Underground inspection pit			
Renewable energy storage capacity	5000-6000 MWh_{th}/y	**Added function**	Positive
		Safety	Neutral
Peak power	6 MW_{th}	**Social cohesion**	Positive
Energy usability	Medium	**Presence of green**	Neutral
Footprint	30 m^2	**Recreation & sports**	Neutral
Visibility	Low	**Aesthetic quality**	Neutral
Noise	Low	**Promote sustainability**	High

For the ATES in the Ramplaankwartier, Tauw estimated that, based on a temperature difference of 7°C (~8°C cold well and ~15°C warm well), at least 6 pairs of wells are needed for a peak power of at least 6 MW_{th}. This can be boosted by the heat pumps to 7-7.5 MW_{th}, enough to supply the entire peak demand for the C-label renovation scenario. For the more probable BAU-renovation scenario, it is enough to supply the demand 93.7% of the time (Tauw, 2018). This leaves 550 hours for which the demand is higher, up to 11-12 MW. A system to supply this peak demand is therefore still necessary.

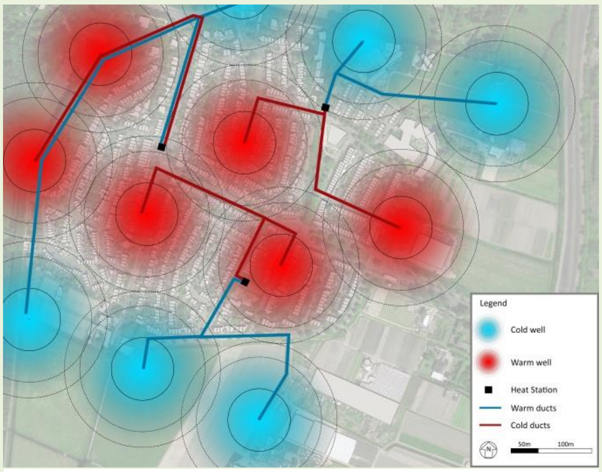


Figure 5.43: Well location study (Own ill.)

The total storage capacity needs to be sufficient to provide enough heat all winter. Based on the estimated energy flows in the SUI study for the low-temperature heat network concept, this should be at least 5000 MWh/y, but preferably more (2018, p. 31).

The spatial integration of the aquifer thermal storage is quite a challenge, as the radius of a well is large, 57 m wide, and there needs to be sufficient distance between different wells to prevent interference, two to three times the radius or 114-171 meter. Directly beneath the neighbourhood there is a zone with warm wells, and to the north and south a zone with cold wells, which should provide enough space for these 6 pairs of wells with sufficient distance in between. The wells are located in line with the flow of groundwater, which is important to prevent heat losses (Tauw, 2018) The well itself is only 0.7 meter in diameter and requires an inspection pit of around 10 m^2. Instead of placing these underground, it could be considered to highlight (some of) these units in the streets, and include elements such as screens to visualise the underground system which provides the heat for the neighbourhood. The inspection pits, like in figure 5.44, could also be made multifunctional, for instance by including seating into the design. In this way, the technical space also becomes part of the street furniture, giving it added quality as well.

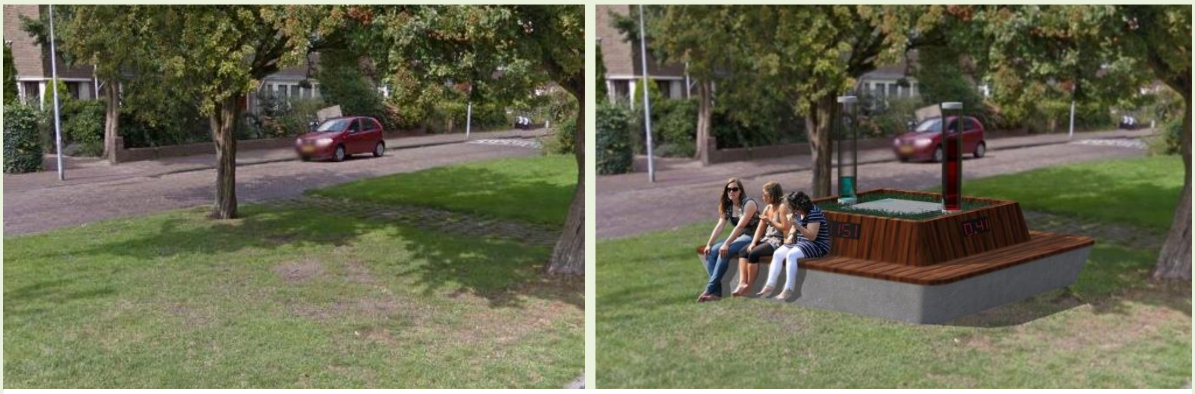


Figure 5.44: Impression of multifunctional inspection pit in the area (Own ill.)

Battery storage			
Renewable energy storage capacity	4 MWh_e 800 MWh_e/y	Added function	Negative
		Safety	Neutral
Peak power	Not applicable	Social cohesion	Neutral
Energy usability	High	Presence of green	Negative
Footprint	300 m^2	Recreation & sports	Neutral
Visibility	High	Aesthetic quality	Negative
Noise	Low	Promote sustainability	Medium

Besides seasonal thermal storage, electricity storage can also improve the energetic performance of the neighbourhood by improving the autonomy and reducing peaks in demand and production. The 'neighbourhood battery' in Rijsenhout mentioned before has a capacity of 128 kWh and serves 35 households, doubling the use of self-produced electricity. Scaled to the Ramplaankwartier, the capacity required is more than 4 MWh.

If the battery is charged and discharged an average of 200 days per year, based on the amount of days with more than 20% sunshine (KNMI, 2017), the annual storage capacity is 800 MWh/y.

Figure 5.45: Neighbourhood battery unit (tegenstroom.nl)

This large capacity also needs quite some space; the Rijsenhout battery is placed in a 10 foot container, which takes around 10 m^2. Scaling this up would result in a total area of around 300 m^2, so it would require significant space or many distributed units.

Other major downsides of batteries are the cost and the use of valuable and rare materials, especially the Lithium-ion battery that has the highest potential for this type of storage, because of its relatively high energy density and high efficiency. At the current cost of roughly €400/kWh, this would require an investment of almost €2 million euros (Nykvist&Nilsson, 2015, 330). Due to the current netting-arrangement, it doesn't have any financial payback. Even when this is replaced by a different form of remuneration, such as a standard feed-back price of ~12 €cents/kWh (based on German situation, from Truong et al., 2016), the financial benefits are expected to be negative with current electricity prices. Due to the cost and spatial impact, the application of a large scale battery system is expected to be unfeasible for this project.

Underground tank storage			
Renewable energy storage capacity	1100 MWh_{th}/y	Added function	Neutral
		Safety	Neutral
Peak power	2 MW_{th}	Social cohesion	Neutral
Energy usability	Medium	Presence of green	Neutral
Footprint	650 m^2	Recreation & sports	Neutral
Visibility	Low	Aesthetic quality	Neutral
Noise	Low	Promote sustainability	Low

As the stored water has a temperature of 90^{O}C and the heat network operates at 20^{O}C, there is a temperature difference of 70K. This stored high-temperature water would only be used for a relatively short time each year, 550 hours, but it can have a positive impact on the energy balance in the neighbourhood and the energy autonomy. The peak demand of 4-5 MW is only required for a very short time, on average the required peak power is around 2 MW, which means the maximum capacity is around 1.1 GWh. This could be achieved with a tank of 13000 m^3, which would require an area between 300 and 650 m^2, depending on the tank height and shape.

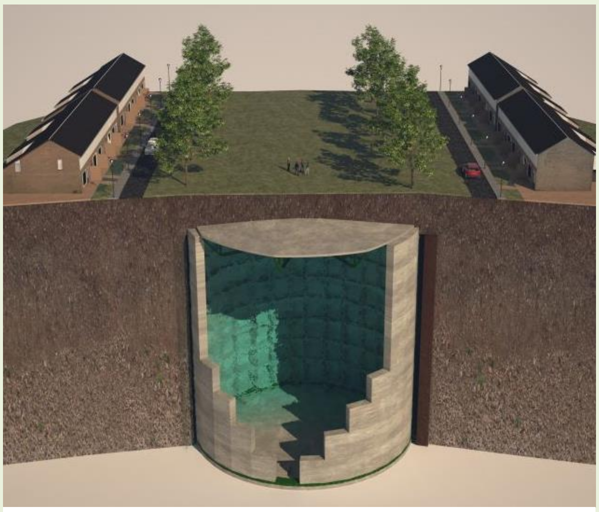


Figure 5.46: Ecovat underground tank storage (www.ecovat.eu)

The tanks by Ecovat are generally placed underground, so the area above can still be used for a large variety of functions. Only a small technical space for a heat pump will be needed to be able to charge and discharge the storage.

Above-ground tank storage			
Renewable energy storage capacity	1100 MWh_{th}/y	Added function	Positive
		Safety	Neutral
Peak power	2 MW_{th}	Social cohesion	Positive
Energy usability	Medium	Presence of green	Neutral
Footprint	650-1000 m^2	Recreation & sports	Positive
Visibility	Medium	Aesthetic quality	Debatable
Noise	Low	Promote sustainability	Medium

An alternative is to place the same tank (partially) above ground and cover this with soil, creating a landscape element instead.

The empty area to the north-east would have enough space for this intervention. This would actually fit really well with the surrounding dune landscape and could be an interesting element, highlighting the potential for renewable energy production in the area. It also creates a favourable slope for the placement of solar panels, which could combine production with storage in a single element.

Figure 5.47: Map with potential storage locations (Own ill.)

This does have its spatial impact, as the visual impact will be much higher than for an underground storage tank, but the extra functionality and landmark quality give it a positive effect. The exact dimensions for the tank can be determined based on the desired size, required storage capacity, and even on the shape of the 'dune'.

Figure 5.48: Impression of tank energy storage options from the N208 highway (Own ill.)

5.3 Conclusion

The interventions from the toolbox are compared in a graph, see figure 5.49. The energy performance, on the horizontal axis, depends on the annual energy production, the power that can be delivered at moments of high demand and the energy usability. To compare the techniques, the total energy performance has been quantified by translating these last two aspects into factors, indicating their effect on the energy supply.

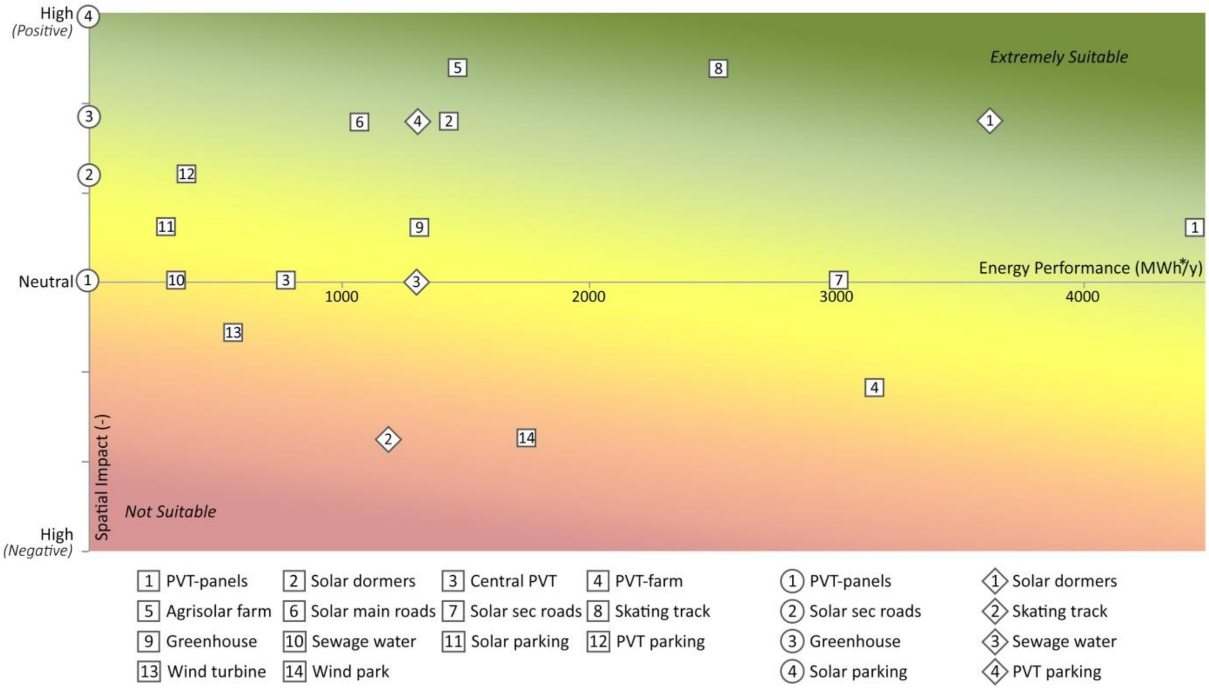


Figure 5.49: Comparison of interventions from the toolbox based on spatial impact and energy performance (Own ill.)

The high usability has a factor 1.0, as this is directly usable, which is electric or thermal energy that can be controlled or produced at moments of high demand. The medium usability concerns high-temperature (>60°C) thermal energy or electric energy, which may need some conversion or storage and therefore has a slightly lower factor of 0.8. The low usability concerns low-temperature (<60°C) heat, which needs conversion to be usable and therefore only has a factor 0.4. This corresponds to the difference in exergy content between high- and low-temperature heat. The power that can be supplied at moments of high demand, mostly for thermal energy, is extremely valuable and therefore has an additional factor of 1.5 been assigned for these sources.
The combination of these factors results in the energy performance, which is measured as MWh*/y.

The spatial impact, on the vertical axis, can be estimated by combining the indicators and see whether there is a predominant positive or negative effect. This includes the indicators for 'urban quality', but the visibility, noise and promotion of sustainability are also considered in this case. All indicators are all judged equally; the urban quality indicators are rated from very positive to very negative, the visibility and noise are rated low to high, and finally the promotion of sustainability is rated low (0), medium (+1), and high (+2). The total sum (positives + negatives) indicates the total spatial impact, which can then be placed in the graph.

Energy Usability	
High	1.0
Medium	0.8
Low	0.4
Peak power	
>1 kW_{th}	1.5
Urban Quality	
Very pos.	+2
Positive	+1
Neutral	0
Negative	-1
Very neg.	-2
Visibility/noise	
Low	0
Medium	-1
High	-2
Promote sustainability	
High	+2
Medium	+1
Low	0

Comparing these different interventions indicates whether an intervention is appropriate or suitable in the neighbourhood. There are some considerations for this method however.

It is difficult to translate qualified aspects to quantifiable factors and this should therefore be used with consideration and caution. For the spatial impact, the value of the different indicators may also be adjusted based on their relevance or importance for the neighbourhood; the rating for 'social cohesion' and 'recreation and sports' may for instance be halved, due to the similarity of these indicators. The development of a method that allows for an accurate translation would be a whole new study however and this goes beyond the scope of this research.

Although the estimated spatial impact can give a good indication, the most suitable interventions and system for a neighbourhood can only be developed in cooperation with its residents. The creation of a toolbox is a valuable addition, as it translates an abstract energy potential to concrete proposals that are easy to understand and place in their context. The low threshold makes it possible to involve all stakeholders and residents in the planning process from an early stage, which greatly increases the achievability of a project.

Only similar techniques can be compared, either interventions for production, storage or distribution. The latter is a separate category entirely, as the factor 'energy' is not applicable to these interventions. In addition, many of the interventions from the toolbox cannot be seen separately from others. The largest share of the solar heat can for instance only be used when there is a distribution network and seasonal energy storage. At the same time, seasonal energy storage is only applicable if there is sufficient energy production. It means the different interventions can only be seen as part of the system and not as separate components that can be freely chosen, although some components may be exchangeable and usable in different configurations.

6. Energy System Design

A combination of the interventions described in the previous chapter will form configuration of the energy system. The total spatial impact of the design is shown through visualisations and maps, after which the technical system design is explained in more detail and the energy performance of the total system is assessed.

6.1 Spatial Plan

For the design of the energy system, the low-temperature heat network, two possible scenarios will be described and evaluated: A 'minimal' and an 'optimal' spatial impact scenario. Both scenarios have a system configuration based on a selection of the interventions from the toolbox. These are shown in the table below with their energy production, spatial impact and suitability.

Minimal Spatial Impact Scenario			
Technology	**Energy**	**Spatial impact**	**Suitability**
PVT-panels on roofs	3600 MWh_{e}/y + 14700 MWh_{th}/y	Medium	Very suitable
Central PVT production	340 MWh_{e}/y + 1400 MWh_{th}/y	Low	Suitable
Solar parking area	834 MWh_{th}/y	Low	Suitable
Collectors in main roads	2670 MWh_{th}/y	Medium	Suitable
Greenhouse waste heat	3300 MWh_{th}/y	Low	Suitable
Aquifer thermal storage	5000 MWh_{th}/y (storage)	Low	Very suitable
Optimal Spatial Impact Scenario (All the above plus 'Energy Park')			
Agrisolar PVT farm	204 MWh_{e}/y + 840 MWh_{th}/y	High	Very suitable
Skating track	1110 MWh_{th}/y	High	Very suitable
Wind turbine	450 MWh_{e}/y	Medium	Less suitable
Tank thermal storage	1100 MWh_{th}/y (storage)	High	Very suitable

Figure 6.1: Map with interventions highlighted of the minimal and (plus the energy park) optimal scenario

The ‘minimal spatial impact’ scenario includes the measures that have a low impact on the neighbourhood, by either requiring little (usable) space or by having a proportionally positive impact, and at the same time contribute significantly to the energy balance of the area. These interventions are specific for the Ramplaankwartier, but are also applicable to similar neighbourhoods.

The ‘optimal spatial impact’ scenario adds several extra interventions that would further improve the local production and use of renewable energy. Their spatial impact is considered higher, but this is mostly positive and in proportion to its energetic performance. These measures are all proposed to be implemented into an ‘energy park’, where energy production is combined with other functions like sports, leisure, and agriculture. It could be a showcase or pilot project showing the potential benefits of renewable production when properly designed to be combined with other functions. By putting an emphasis on the positive aspects of these systems and showing that their spatial impact can actually contribute to the neighbourhood in a positive way, it can improve social acceptance, thus improving the business-case. This is specific for the Ramplaankwartier, which has a large area possibly available for development just outside the neighbourhood, but may be less applicable to other neighbourhoods.

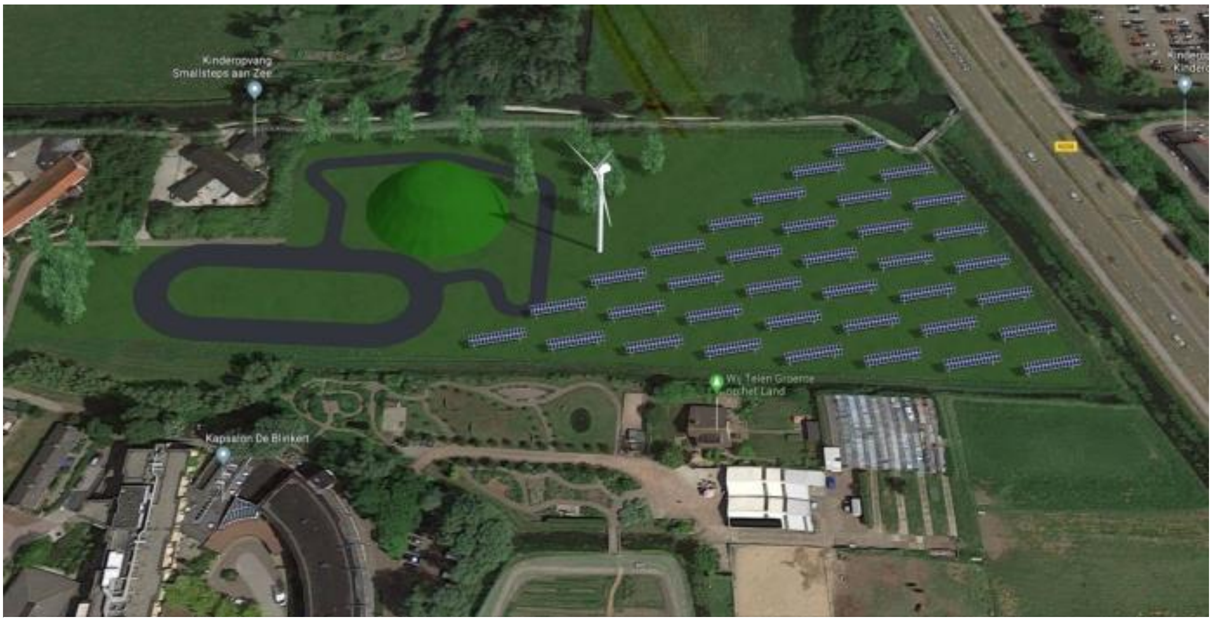


Figure 6.2: Aerial view of proposed 'Energy Park' (Own ill.)

The basis of the system will be formed by an underground heat network for the distribution with underground heat stations where temperature and pressure is monitored and where exchange with the thermal storage is regulated. These have, with the exception of the construction phase, little impact on the neighbourhood and offer the possibility to use the space above for different purposes.

The option for the alternative distribution system, along the eaves of the buildings, may be explored for some of the streets where this is suitable to serve an entire housing block of 5 or more houses. For many other streets, this system may have a disproportionate impact and therefore negative effect. Only if the social acceptance and energy performance of the system are very positive, it could be considered to implement this in other, less favourable streets as well.

Figure 6.3: Distribution system underground (top) or via the eaves (bottom) (Own ill. based on Google Maps)

In both scenarios, the largest share of the heat will be produced with PVT-panels on the roof of the dwellings. This has a significant visual impact on the outlook of most streets due to the large area that is proposed to be covered, even though it is generally placed well above eye-level. Whether the visibility of these panels is positive or negative is debatable, as this is a personal opinion. However, the aesthetic quality of the panels could be controlled by supplying the whole neighbourhood with the same or similar panels. This creates a continuous appearance throughout the neighbourhood, which may have a positive effect on the social acceptance.

Figure 6.4: Solar panels integrated in the roof (Own ill.)

Another producer of thermal energy, which is used to regenerate the thermal storage, is through asphalt collectors in the main roads and large parking lot(s). This measure also has little impact besides the construction, but allows for a positive improvement of the streets; especially for the Rollandslaan it could mean an improvement in safety and appearance of the street.

Figure 6.5: Rollandslaan before (l) and after (r) the application of asphalt collectors (Own ill. based on Google Maps)

The use of waste heat, in this case from the greenhouses on the edge of the neighbourhood, can also contribute to the regeneration of the thermal storage. This requires some changes in the connected greenhouses, such as installation of different heating and cooling systems. The positive effects of the system is expected to be significant however, as the better regulated temperature results in a more constant quality of products and the connection to the heat network results in less energy use for heating in winter.

All heat in this scenario is produced through solar energy, but the patterns for production and demand are completely different. This mismatch can only be solved by including seasonal heat storage into the system. The soil below the neighbourhood is suitable for aquifer thermal storage (Dutch: WKO) and there is sufficient space for six well-pairs. These wells have very little impact, only a small (underground) technical space is required, of which only a hatch would be visible.

In the proposed 'Energy Park', a large portion could be dedicated to combined solar energy and crop production, as part of the 'Wij Telen Groente' communal farm, which is located right beside the park location. This combination of growing crops and energy production, also called an 'agri-solar farm', allows the production of crops and energy on the same plot of land, only slightly reducing the potential of both. The ouble use reduces the negative spatial impact and tackles one of the main challenges of solar farms: reducing space for food production.

Figure 6.6: Agri-solar farm concept (Fraunhofer ISE)

Another addition to this park would be an (ice-)skating track, which creates a place for recreation throughout the year. The track has a system similar to the asphalt collectors underneath, which can extract solar heat as the asphalt heats up due to solar radiation. In winter, the connected heat pump can be used to actively cool the track to sub-zero temperatures, causing water that is poured on the track to freeze and create an ice rink.

In summer, the track could just be used for skating or cycling, but in winter an outdoor ice-skating track is created which will probably serve a much larger area than just the Ramplaankwartier alone. The track can be used all winter, almost independent on the outdoor temperature, because it is actively cooled. There is space to make the track as large as a standard skating track, which would even allow for the organisation of official races and events.

Figure 6.7: Impression of the 'Energy Park' with the (ice-)skating track in summer (l) and winter (r) situation (Own ill.)

Two other elements that are integrated into the park are a high-temperature thermal energy storage and a single wind turbine. These both have a high visible impact and are therefore considered to be landmarks for the energy park, emphasising the identity of the park as renewable energy producer.
The thermal storage can be part above ground and, as it is covered with soil, it becomes a landscape element in the park. Stairs and a small viewing platform on the top make it an even more special part of the park, as it allows for an impressive overview of the surroundings, with views to the sea in one way and the centre of Haarlem in the other.

6.2 Technical System Configuration

To be able to assess the technical aspects of the system, the technical configuration will briefly be discussed. The operation in different seasons will be discussed, which is completely different in the different seasons, which is one of the major advantages of this system; it is possible to use the heat network for both heating and cooling, as well as delivering heat and cold back to the grid.
This is followed by the assessment of the energy performance of the entire system, based on the previously developed evaluation criteria.

6.2.1 Seasonal Operation

In a winter situation, it is assumed only heating is required and there is little or no decentral production. Heat is extracted from the hot wells of the aquifer thermal storage to heat the water in the heat network to a temperature of 20^{O}C, which is then supplied to the dwellings through the heat network. The heat pump extracts heat from this supply, cooling the water down to around 8-10^{O}C, to produce hot water for space heating and domestic hot water.
In the scenario that includes the high-temperature energy storage, heat from this can be used to supply peaks in demand on cold days. This could be done by using the stored heat to raise the temperature of the heat network, improving the effectiveness of the heat pumps.

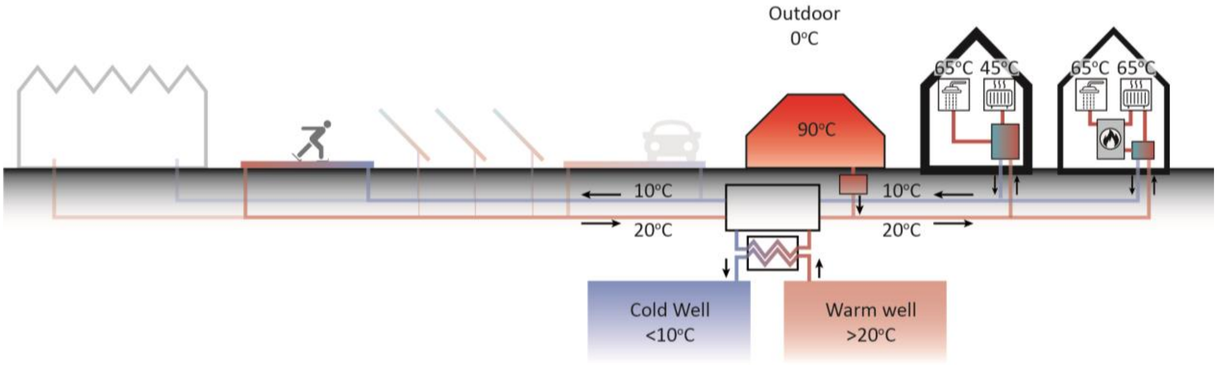


Figure 6.8: Schematic system configuration in winter situation: only warm well used (Own ill.)

In a spring and autumn situation, some heating is necessary and some (decentral) solar energy can be produced. During the day, heat from the network can be pre-heated using the PVT-panels and this is used by the heat pump to produce water for domestic hot water, which can then be stored for later use. In this way, a large part of the hot water is produced with your own renewable energy. Heat from the heat network is only necessary for space heating or if not enough hot water is produced. Should the PVT panels already produce more heat than necessary, this could be delivered back to the grid in two ways: Firstly the return water can be heated using the PVT-panels as it is fed back into the network, raising its temperature, which means less energy is required to heat it back to the desired 20^{O}C. Alternatively, cold water from the network could be heated up using heat from the PVT-panels and then be fed back into the 'warm' network.

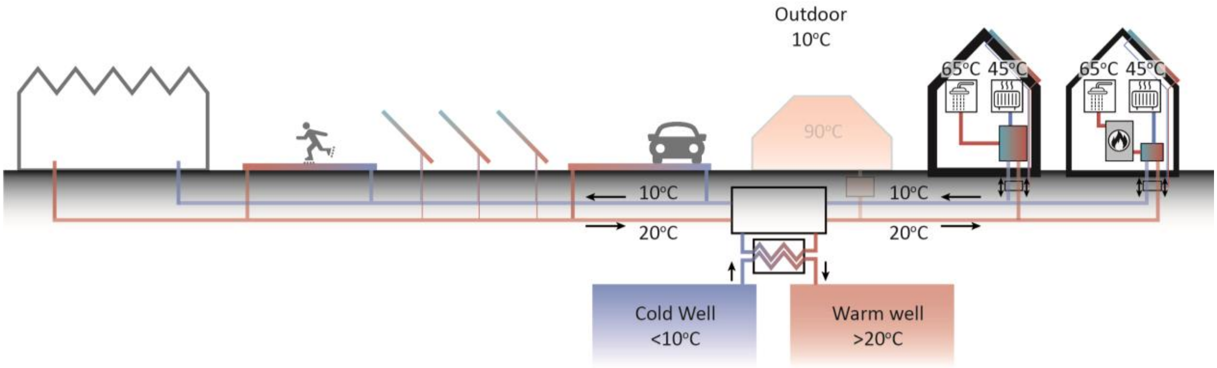


Figure 6.9: Schematic system configuration in intermediate season situation (Own ill.)

In a summer situation, heat is only required for domestic hot water and the production of (decentral) solar energy exceeds the demand. In this situation, the heat network is reversed; water from the cold wells of the thermal storage is used to cool the water in the heat grid to around 15^{O}C, heating up in the process and stored in the warm wells. The cold water is then delivered to the houses, where it can be used to actively cool the dwelling or it can be heated with the PVT-panels and fed back into the 'warm' network. During times of high solar production, heat from the PVT-panels can also be used to produce domestic hot water, which is then stored for later use. If the production is not sufficient to supply the demand for DHW, warm water could also be extracted from the network and used by the heat pump.

In the optimal scenario, at moments of peak heat and electricity supply, the high-temperature storage can be regenerated using a heat pump, storing the energy for peak demands in winter. This could be connected as part of the network or it could directly be connected to the PVT-farm, using its thermal energy and electricity directly for the heat pump.

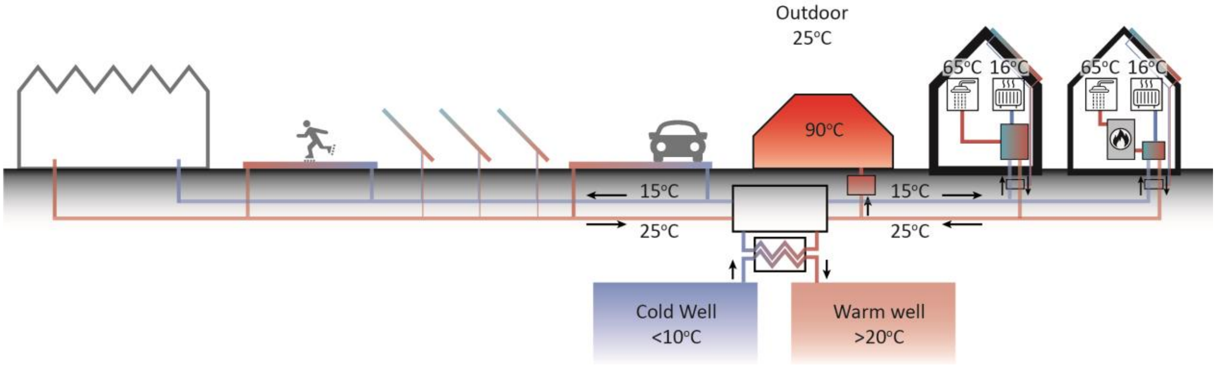


Figure 6.10: Schematic system configuration in summer situation (Own ill.)

6.2.2 Energetic Performance

Based on the optimal energy production for each renewable energy source, the energetic performance of the proposed implemented system is assessed. Because of the high investment costs related to the C-label and NZEB building-improvement scenarios, it is expected that only a small part of the neighbourhood, at most 25%, will be renovating to this level. The largest share, around 75%, is expected to renovate to the BAU-level or even less. This results in an annual electricity demand of 3.7 GWh_e/year and thermal energy demand of 17.3 GWh_{th}/year. After the conversion of the heat pumps and the thermal losses, the total area energy demand is 9.2 GWh_e/year for electricity and 11.9 GWh_{th}/year for thermal energy.

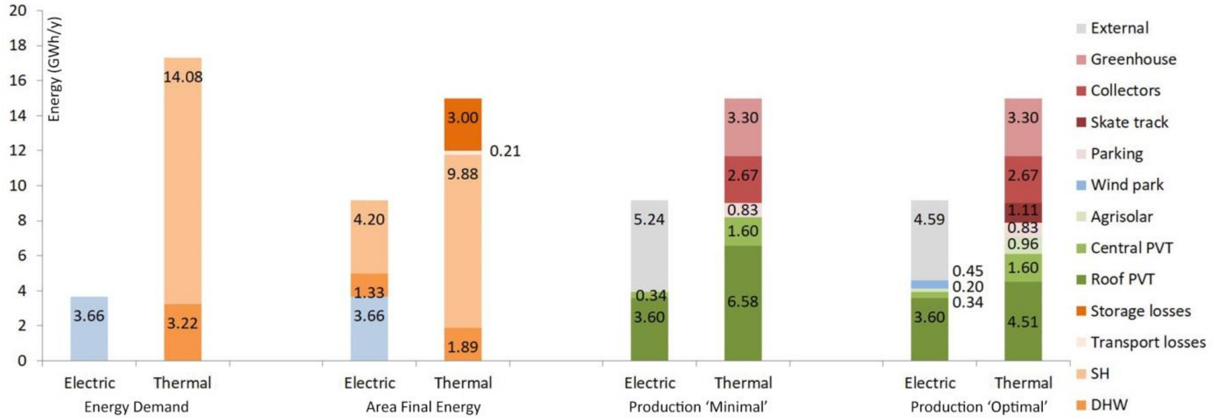


Figure 6.11: Energy balance of the minimal and optimal scenario (Own ill.)

For both scenarios, the total annual production of heat is more than sufficient to supply the entire heat demand for the neighbourhood, even for the 'minimal scenario'. However, the electric energy can't be fully produced within the neighbourhood. For the 'minimal' scenario, around 43% of the electricity can be produced locally. In the 'optimal' scenario, the share of local electricity production is slightly increased to 50% annually. The amount of electricity that can actually be used locally will be low, because the used renewable sources have fluctuating supply patterns that differ from the demand. A large share of the electricity will therefore be fed back to the regional electricity grid.

In the 'optimal' scenario, the high-temperature storage makes it possible to use peaks in renewable electricity production to produce hot water and store this for later use, when there is a high demand for heating. This could make it possible to use almost all locally produced electricity within the neighbourhood itself, although the efficiency may be relatively low.

Besides the production of thermal energy on an annual basis, the installation of sufficient power to supply peak demands is a limiting factor for a fully renewable heat supply. The heat loads throughout the year and their occurrence can be shown in a load curve, from which the maximum required power for the area can be estimated. In the SUI-study this has been done for both the BAU- and the C-label improvement scenarios (SUI, 2018), which are shown in figure 6.12 below. As actual building improvement is assumed to be between these two scenarios, the maximum peak load is expected to be between 14 MW_{th} (BAU) and 9 MW_{th} (C-label) for the entire neighbourhood, around 13 MW_{th}.

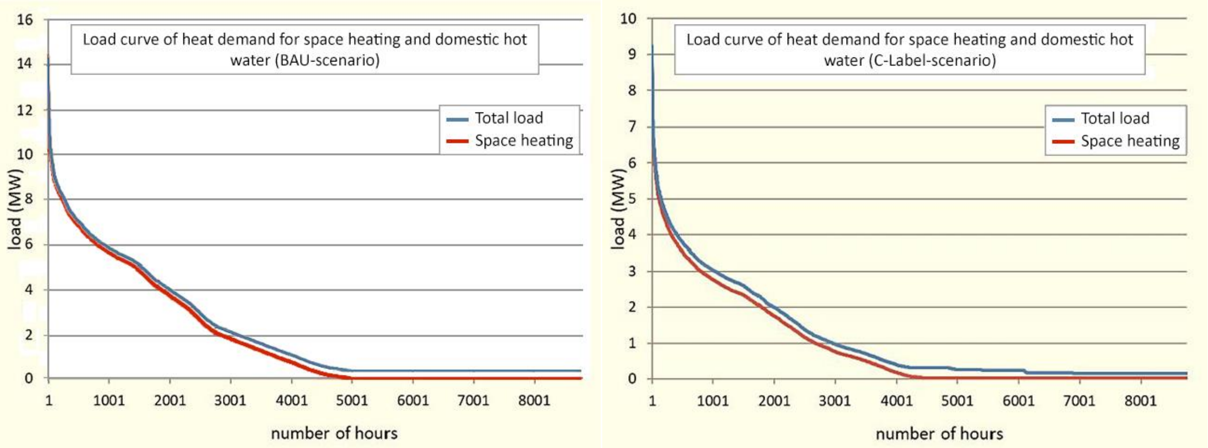


Figure 6.12: Load curves for the BAU (l) and C-label (r) improvement scenarios (SUI, 2018)

Each of the renewable sources has a certain capacity to supply these demands, shown in the table below. For the sources based on solar energy however, these are highly dependent of the season and moment of the day. The high peak demands are generally on very cold days in winter, when there is little sun and therefore little solar energy available. The contribution of solar energy sources is therefore none or little. This could be optimised with a smart controller, which can produce domestic hot water at times of solar energy production, so the use of self-produced energy is optimised.

'Minimal' Scenario	Power Output in Winter (MW_{th})
ATES	6.0
'Optimal' scenario	Above plus:
Skating track	0.6
Tank thermal storage	2.5

In the 'minimal' scenario, only the thermal storage supplies heat and the six well pairs have a limited capacity of around 6 MW_{th}. With this supply, the heat pumps can deliver around 8 MW_{th} of usable heat (COP 4). This is enough to supply the heat load for a BAU improved building for 93.7% of the year and for a C-label improved building 99.5% of the year, estimated from the graphs. A solution for the remaining peak load is therefore necessary, which could for instance be an electric boiler in each house or a central boiler operating on biomass or biogas.

In the 'optimal' scenario, the heat from the ice-skating track and high-temperature thermal storage can supply part of the maximum peak loads as well, increasing the maximum capacity to 9.1 MW_{th}. With this supply, the heat pumps can deliver 12 MW_{th} of usable heat (COP 4). This is more than enough to supply all heat for C-label improved house, and enough to supply the heat for a BAU improved house for just over 99% of the year. A small electric boiler in each of these houses could then be enough to supply the remaining peak loads.

6.3 Conclusion

By making spatial implementation an integral part of the energy system development, it is possible to minimise the negative impact of the interventions. If any positive effect or added functionality could be added, this can even contribute to the urban quality of the neighbourhood, despite a high spatial impact.

For the Ramplaankwartier, this was already shown through the development of the toolbox, which explored potential benefits and synergies to the different technologies. The two scenarios also show the benefits of these synergies: the ‘minimal spatial impact’ scenario, with interventions that have little effect on its surroundings, is probably less favourable than the ‘optimal spatial impact’ scenario, which includes several elements with a high impact. Despite the higher impact, the effect on its surroundings was considered more positive, due to for instance added functionality, as well as having a more promising energetic performance.

The renewable heat production in the neighbourhood is sufficient to supply the heat demand on an annual basis, assuming an average building improvement level that is slightly better than the BAU-renovation. However, the electricity demand is more than doubled as a result of the heat pumps and only a maximum of 50% can be supplied with local renewable sources. The dependence on external ‘grey’ electricity remains significant and is even slightly increased in comparison to the current situation.

The limiting factor in this case is the power that is required to supply the peak loads; with a minimal spatial impact system, the buildings that are improved to a ‘BAU’-level or less require a back-up system with a high power to supply the peaks in demand. With the optimal spatial impact system, which adds several central renewable energy sources, the capacity of the system is increased and only a small back-up is needed to supply the peak loads. If the peak demand can be supplied with renewable sources, the area no longer needs natural gas.

The assessment of the energy system also shows that there isn’t always the freedom to choose only ‘minimal spatial impact’ measures. Assuming that buildings in existing neighbourhoods often have a limited potential for improvement, the measures that have a minimal impact will often be insufficient to make an area energy-neutral. This means that sustainable energy system will almost always require several ‘optimal impact’ measures that combine their high impact with either high energy production and/or positive effect on their surroundings.

7. General Conclusion

In the following sections the main research question will be answered through the following sub-questions:

a) *To what extent are spatial aspects a limiting factor for the development of a sustainable district energy system?*

b) *What guidelines concerning the spatial integration of sustainable energy systems can be derived from the study to improve the implementation for similar projects in other neighbourhoods?*

7.1 Spatial Impact

With the approach of energy potential mapping (EPM), renewable energy production can already be connected to a spatial aspect. The emphasis of this approach is to quantify the energy potential in a certain area based on the maximum available space. This is often done on a very large scale and remains schematic until a late state of a project, so this can only be used as a planning tool. By incorporating an extra step into the energy potential mapping, creating a toolbox with possible interventions, the impact that a certain technology has on an area can be determined in more detail on a much smaller scale. This toolbox consists of designs for each intervention, visualising the spatial impact, but also allowing for the discovery of added value, such as the integration of other functions with the energy source. By combining the energy (production) potential with this spatial impact, it can not only be determined whether an intervention is feasible, but also whether it is suitable for implementation. Interventions and systems with a positive effect and additional functionality may become more favourable than negative interventions, even if the energy production potential is lower. At the same time, it shows that a low spatial impact should not be favoured at all times; if the impact is considered high and positive, this could still be a suitable intervention. If the impact is negative, but the energetic potential is proportional, it could also still be a suitable intervention.

The spatial impact of an energy system is in this study expressed in several aspects reflecting both negative and positive aspects: the physical dimensions of a system's components, any nuisance due to its visibility or noise caused by its operation, as well positive effects on its surroundings, for instance by adding aesthetic quality or additional functions to an area.

The indicators identified in this study can be used as a first estimation of the spatial impact of an intervention. Apart from financial aspects, spatial aspects of an energy system are probably the most important factor for the social acceptance of a system, because this indicates how it will affect someone's environment.

To come to the most suitable system that has the most beneficial effect on the neighbourhood, the opinion of the residents is a crucial element. The development of an energy system with a high social acceptance can only be achieved in cooperation with the residents of the neighbourhood. It is difficult, if not impossible to quantify spatial aspects just based on the positive or negative influence that a certain intervention has on the neighbourhood. This is where the involvement of stakeholders is already of major importance, as this will give a much more reliable indication of the effect of the interventions. At the same time, good spatial integration of the components and making use of the potentials for added quality create social support.

The toolbox forms an excellent method to offer several options to create a system suitable for the specific location; it becomes a communication tool that can be used to translate an abstract and technical system into a visual aid.

7.2 General Guidelines

Guidelines can be developed based on the previous conclusions, providing considerations for similar projects, which can help with the development and implementation of a sustainable district energy system in other residential neighbourhoods.

The development of a toolbox of spatial interventions is a valuable addition to the already existing approach of energy potential mapping. This includes a study into the technology that is associated with a certain energy source as well as a design study to discover any added benefits that the energy source could provide. The toolbox translates the abstract overview of energy potentials developed with EPM to concrete interventions in their context, which allows for more detailed evaluation of the spatial impact of a certain source on its surroundings.

This toolbox can be useful from an early phase in an energy system development process. Before the selection of a concept, spatial aspects should already be part of the assessment, besides for instance the energy performance and financial feasibility. The toolbox could already give an indication of the spatial impact that certain sources have on the area and which are most suitable. Then the concept could be selected partly based on the most suitable energy sources for the area, after which this could be developed in more detail. In this way the toolbox plays an important role in the decision-making process.

Later in a development process, when the concept and (some of) the energy sources are known, the toolbox could also be useful. A more detailed toolbox could be developed, in which several options are designed for each of the sources. The emphasis of this study is mostly on the discovery of synergies and added quality. In this case, the toolbox gives an overview of the possibilities for the system and the most favourable configuration can be developed. The toolbox can be used as a decision-making tool, as well as a tool to convince stakeholders.

The interventions from the toolbox(es) can be collected to form a database, providing examples and references of ‘well-integrated’ renewable energy sources. This database can be a design tool that can be used by (urban) designers, spatial planners and engineers to implement renewable sources in an area. Besides offering examples, it could also help to create integrated components for renewable energy production and provide approaches to develop new ideas or to overcome challenges.

The development of approaches to overcome specific challenges or use local potential of a neighbourhood is a crucial part, because this makes sure the resulting proposals are suitable for that specific neighbourhood. This can be seen from the energy park in the Ramplaankwartier, which is possible because of the favourable location of the neighbourhood on the periphery of Haarlem; there is enough space available for the development of these high-impact measures. For many other neighbourhoods, for instance in city centres, this may not be possible. For these neighbourhoods it may be more challenging to become self-sufficient in their heat supply, but these might have other potentials for renewable energy production.

Reflection

My topic was difficult to place within the department of building technology alone; it had some elements of several different chairs, such as ‘Climate Design & Sustainability’ and ‘Building Physics & Services’, but because of the emphasis on spatial impact on the neighbourhood-scale, it also has elements of several urbanism chairs, such as ‘Landscape’ and ‘Environmental Technology & Design’. The positioning ended up between these different themes, combining sustainable technology with spatial aspects and design on building to neighbourhood scales.

The development of the research approach was not clear until quite far in the process. Some of the steps were logical, such as the literature study to provide context and an assessment of existing concepts to find an optimal. The outcomes of the study, as well as any emphasis, remained open until these steps had been taken. Only then it became clearer what the focus of the research should be and how to integrate this with the design. The initial idea was to focus on the development of a sustainable energy system, but further in the process, the emphasis shifted towards the assessment and implementation of existing systems rather than new development.

The design was therefore an integral part of my method, as it was used as part of the assessment of the proposed system. By designing options for implementation of several components of the energy system, the spatial impact can be evaluated and it could potentially be used for an evaluation of the social acceptance as well. The design was therefore an important step in my research and takes a central place in the conclusion as well.

The thesis has a strong emphasis on practical issues and continuously connects the results from the research to practice. The conclusion also provides clear practical recommendations that could be useful to researchers, but also to designers, spatial planners and engineers.

The innovation of this research is not so much in the development of an innovative energy system, but focusses more on the method of assessment to determine a project’s feasibility and which factors contribute to this. It also provides recommendations to improve the feasibility for future projects, making the implementation easier. This is also where the relevance of the project for society and practice is; making the energy transition easier, specifically for existing neighbourhoods, which is currently one of the main challenges to create a more sustainable environment. In this way, the study can contribute to sustainable development in the built environment.

The initial study includes all three aspects of sustainable development in the assessment, but as the economic feasibility study went beyond the scope of this research, this is not part of the final report. Instead, the emphasis is more on renewable energy, ‘planet’, and its resulting spatial quality and social benefits, ‘people’, although the quality and benefits could fit with prosperity in its broadest meaning as well, even though it may not include direct monetary benefits.

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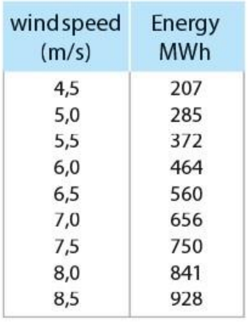
Appendices

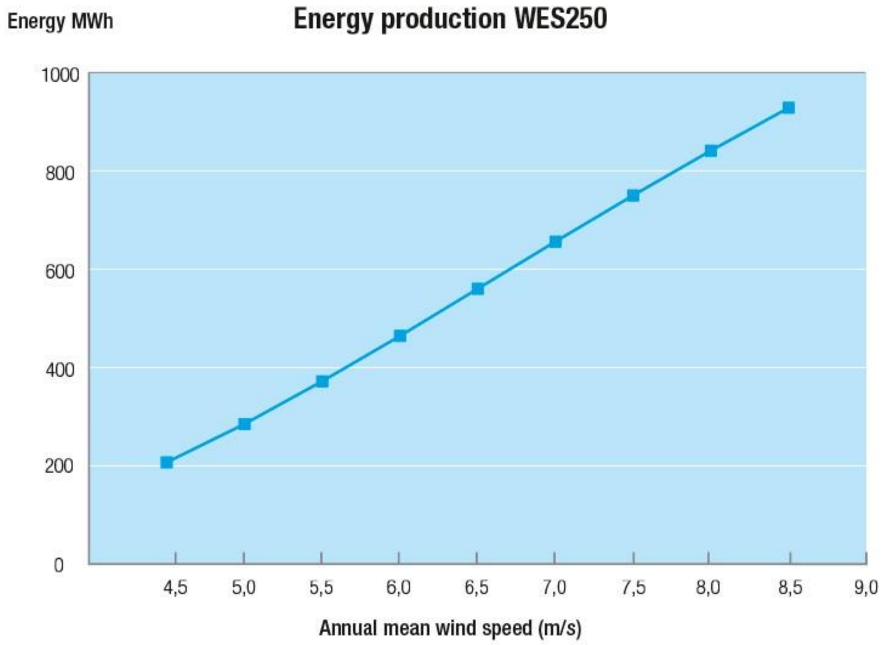
1. Efficiency graph for WES250 and EWT DW52 wind turbines

2. Efficiency of solar cells relative to south

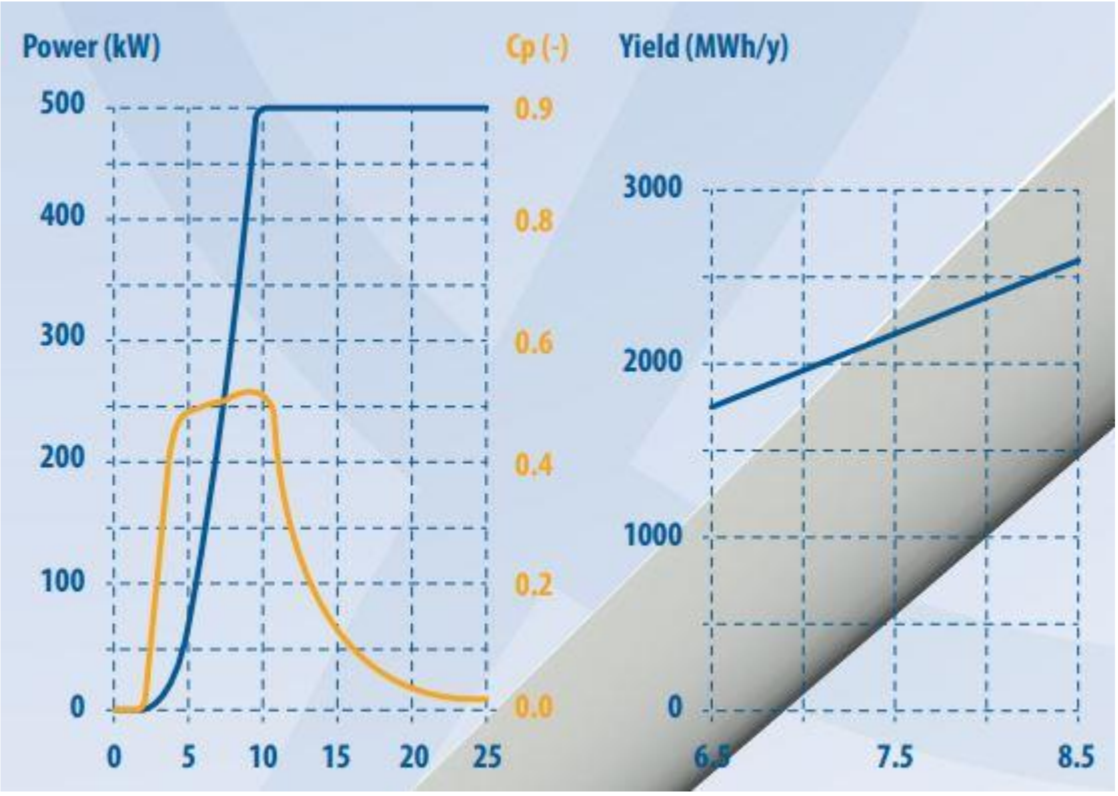
Appendix 1: Efficiency graph for WES250 and EWT DW52 wind turbines



windspeed (m/s)	Energy MWh
4,5	207
5,0	285
5,5	372
6,0	464
6,5	560
7,0	656
7,5	750
8,0	841
8,5	928



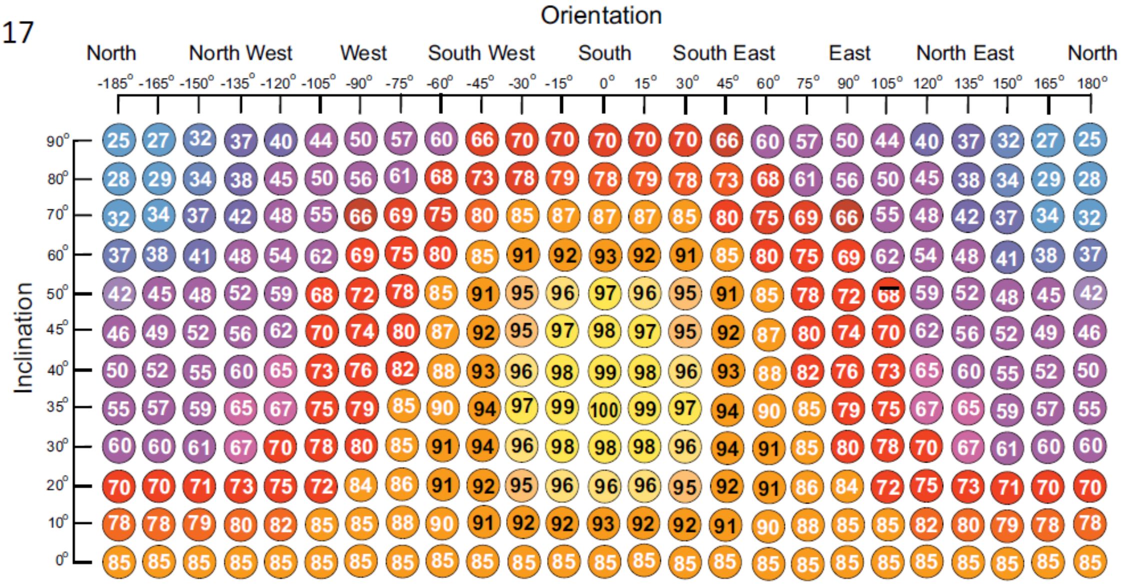
Source: WES, n.d.



Source: EWT, n.d.

Appendix 2: Efficiency of solar PV cells relative to south

Fig 17



Orientation

Inclination	North			North West			West			South West			South			South East			East			North East			North
	-185°	-165°	-150°	-135°	-120°	-105°	-90°	-75°	-60°	-45°	-30°	-15°	0°	15°	30°	45°	60°	75°	90°	105°	120°	135°	150°	165°	180°
90°	25	27	32	37	40	44	50	57	60	66	70	70	70	70	70	66	60	57	50	44	40	37	32	27	25
80°	28	29	34	38	45	50	56	61	68	73	78	79	78	79	78	73	68	61	56	50	45	38	34	29	28
70°	32	34	37	42	48	55	66	69	75	80	85	87	87	87	85	80	75	69	66	55	48	42	37	34	32
60°	37	38	41	48	54	62	69	75	80	85	91	92	93	92	91	85	80	75	69	62	54	48	41	38	37
50°	42	45	48	52	59	68	72	78	85	91	95	96	97	96	95	91	85	78	72	68	59	52	48	45	42
45°	46	49	52	56	62	70	74	80	87	92	95	97	98	97	95	92	87	80	74	70	62	56	52	49	46
40°	50	52	55	60	65	73	76	82	88	93	96	98	99	98	96	93	88	82	76	73	65	60	55	52	50
35°	55	57	59	65	67	75	79	85	90	94	97	99	100	99	97	94	90	85	79	75	67	65	59	57	55
30°	60	60	61	67	70	78	80	85	91	94	96	98	98	98	96	94	91	85	80	78	70	67	61	60	60
20°	70	70	71	73	75	72	84	86	91	92	95	96	96	96	95	92	91	86	84	72	75	73	71	70	70
10°	78	78	79	80	82	85	85	88	90	91	92	92	93	92	92	91	90	88	85	85	82	80	79	78	78
0°	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85	85

Source: https://www.evoenergy.co.uk/blog/18520/northwest-facing-pv/

Gas-free Ramplaankwartier

Sustainable District Energy System for the Energy Transition of Existing Neighbourhoods

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