DELFT IN TRANSITION

Towards a Sustainable Energy System for Dutch Municipalities

Abstract

This research has two major purposes: (1) to design a roadmap for the energy transition towards energy neutrality of the built environment for the city Delft, with technical interventions, based on local potentials, integrated at all scales of the city and (2) to develop a general approach that can be applied to other Dutch municipalities. The final result is based on both design-by-research (literature study) and research-by-design.

The thesis exists out of three parts. The first part includes the literature study that forms the basis of the later designed approach and roadmap. This literature identifies the available energy sources and technologies that can be used to match the demands with the supplies and an analysis the existing methodologies. The approach for the energy transition of Dutch municipalities is defined in part II.

This approach exists out of 8 steps; starting with the analysis of vision and targets. Followed by the status quo/the starting point. In the next step the local energy potentials are determined, resulting in a scenario for the energy transition of a certain city. Finally the roadmap is designed.

In the last part of this thesis the approach is implemented to the roadmap towards energy neutral Delft.This results in an proposal for the energy systems and interventions. On basis of the results there is concluded that by working through all scales while defining the energy systems and interventions according to the local characteristics and energy potentials an integrated and realistic roadmap towards an energy neutral built environment in 2050 is designed for the city Delft; at the same time the designed approach can also help other municipalities to achieve their energy transition goals.

This thesis hopes to make a contribution to the energy transition of Dutch municipalities in order to achieve their transition goals by making the design process of the roadmap more concrete with clear steps and tools and the case study for the city Delft.

Keywords: Sustainability, climate change, fossil fuels, energy transition, energy neutrality, renewables, energy systems, roadmap, approach, Delft, Dutch cities.

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DELFT IN TRANSITION

Towards a sustainable energy system for Dutch municipalities

Dear Reader,

Before you lies the thesis ''Delft in Transition: Towards a Sustainable Energy System for Dutch Municipalities'', about the energy transition of the city Delft towards an energy system based on renewables. The thesis studies different technologies and sustainable energy sources and the way they should be implemented in the energy system of Delft. This finally results the roadmap of Delft and an approach for the energy transition of Dutch municipalities. The thesis is written as a completion of the master Building Technology, a master track of the faculty of Architecture and the built environment at the TU Delft.

During my studies I gained personal interest in sustainable development and energy systems. With this thesis I hope to contribute to the energy transition of cities and a more sustainable world. I would like to thank my supervisors Siebe Broersma and Regina Bokel for their time, guidance and valuable advice during my graduation period. Finally I am grateful for the moral support by my friends and family during my full study period in Delft.

I hope you enjoy reading my thesis,

Tess Blom

Delft, January 19, 2018

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01
Introduction

1.1. Background & Problem description

1.1.1. Urgency of the transition

Sustainability is a hot topic in the current society. A sustainable built environment is an environment that we can preserve and use to live, work and recreate until infinity. A sustainable world can provide the needs of the current generation; without endangering the future of the next generations (Broersma, Fremouw, & Dobbelsteen, 2011). However this future is currently endangered by high CO_2-emissions and other greenhouse gasses which increase the global temperature. These CO_2-emissions are largely released into the air during the energy generation process of burning fossil fuels. Reduction of the energy demands and increased use of sustainable energy sources are thereby the most important goals of the current energy policies towards a more sustainable world (Gommans, 2012).

There are three main reasons why the current energy system based on fossil fuels should radically change, starting now. The first is the exhaustion of fossil fuels and other materials; this exhaustion leads to a future in which the supply of energy is insecure. In the past the Netherlands had large natural gas supplies, but the end of this reserve is coming. We will get dependent of the energy stock of other countries where fossil fuels are still available, like Russia and the Middle-East. But also in these countries the reserves are running out. The second reason for the required transition is climate change, which is enlarged by several human activities. The biggest contributor to climate change is the expansion of the greenhouse effect by carbon dioxide; mostly originating from energy generation with fossil fuels. The effects of the climate change in Western-Europe will be relatively small; the temperatures will increase and we will face more extreme precipitation. Other parts of the world will encounter droughts or floods. Above that climate change and the increase of land-use per person causes a decline in biodiversity (Broersma et al., 2011; Gommans, 2012; MacKay, 2009).

1.1.2. Sceptics

Although the urgency of limiting the climate change is a common subject in political and scientific debate there are also sceptics mentioning that the human impact on the climate change is negligible. Sceptics of the climate change state that by burning fossil fuels just a relatively small amount of CO_2 into the atmosphere per year is sent compared to the natural flow of CO_2 by the biosphere and oceans into the atmosphere. Indeed it is a fact that natural flows of CO_2 are larger than the additional flow caused by burning fossil fuels. However these sceptics fail to mention that about exactly the same amount that naturally flows into the atmosphere also flows out of the atmosphere, back in the biosphere and oceans. These natural flows have been in balance for millennia. Burning fossil fuels, in contrast, creates a new flow of carbon that misbalances the system (MacKay, 2009). Even when climate change and the influence of CO_2 are denied, this doesn't mean that we shouldn't limit our fossil fuel use. Like Salomon Kroonenberg stated in the conclusion of his book Spiegelzee (a book about the sea level changes during the history of planet earth and the influence of these changes on the life of our ancestors) we should fully commit to the development of sustainable energy sources, because we should keep our oil and gas reserves for the next generations. Not as an energy source, but as the primary material for the production of plastics, cosmetics, medication, paint, etc. Without oil and gas supplies our future generations won't have gasoline, but also no asphalt, skateboards, mobile phones and so on (Kroonenberg, 2017).

1.1.3. International energy transition goals

Finding the urgency in the energy transition, 195 countries signed the Paris climate agreement in 2015 as an attempt to control the global warming. This agreement stated that the total global warming of this century should stay below 2ºC (Ministerie van Economische Zaken, 2016). To succeed this limitation the carbon emissions should be reduced to with 80 to 95 percent by 2050. To reach this level of carbon neutrality all energy should be generated sustainable. No fossil fuels should be used; therefore an energy transition is demanded. This sustainable energy transition is the transformation from an energy system based on fossil fuels to a self-sufficient energy system which is completely based on renewable energy sources (Broersma et al., 2011).

1.1.4. The lagging Dutch energy transition

The European Union set an interim goals as milestones towards carbon neutrality in 2050. They want to generate 20 percent of the European energy demands with renewables by 2020. For the Netherlands this means that 14 percent of the energy should be generated with renewables and that the CO_2-emissions should be decreasedwith 25 percent (Ministry of the Interior and Kingdom Relations, 2008). The need of an energy transition can also be found in the Dutch Constitution, article 21:

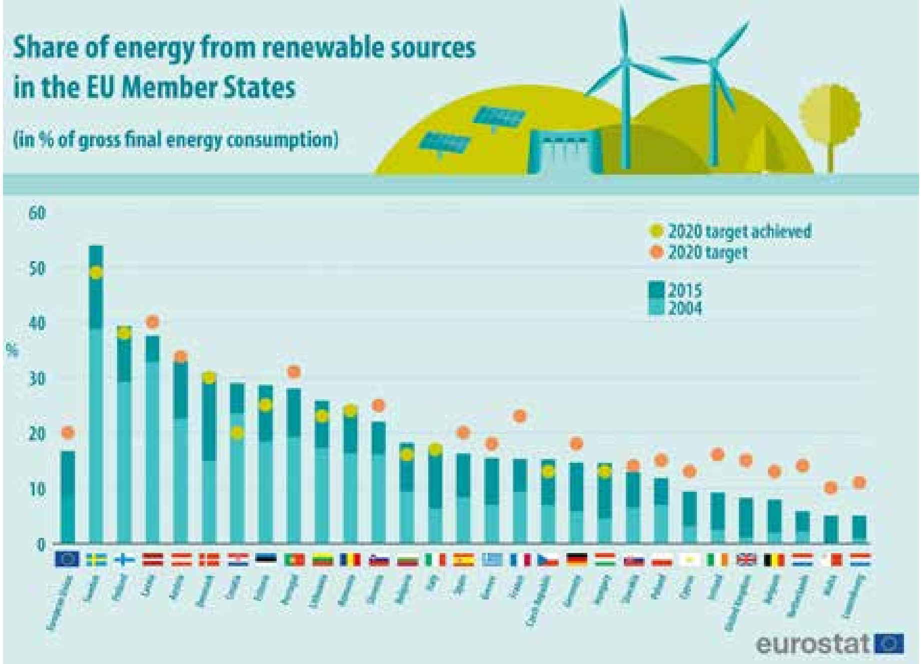
'It shall be the concern of the authorities to keep the country habitable and to protect and improve the environment'.
(Ministry of the Interior and Kingdom Relations, 2008).

Which can be translated to: keeping the country habitable cannot continue without a future resistible energy system.

However on the first of February in 2017 serveral news articles appeared with headers like 'The Netherlands will not achieve the energy goals' and 'EU: The Netherlands is far behind with sustainable energy generation'. These statements where based on the rapport of EU-commissioner Maros Sefcovic. According this report the percentage of sustainable generated energy in the Netherlands is only around seven percent (NOS, 2017).

This was not the first time the lagging energy transition in the Netherlands was made clear. In June 2015 the sustainability organisation Urgenda, together with 900 other prosecutors, won the Climate case against the Dutch state. In this case the prosecutors accused the state of lagging policies concerning the reduction of CO_2-emissions. With as result that the government was forced by the court to take more measures to significantly decrease the CO_2-emissions. However the state refused and came in appeal (Urgenda, 2015).

Figure 1.1. Share of energy from renewable sources in the EU Member States (eurostat, n.d.).



But how can this lagging energy transition appear in a country that is known for its leading knowledge institutes and innovations? This can partly be blamed by the opposite interest of the government in both fossil and renewable energy. The Netherlands is often seen as the country of gas because it locates a lot in gas trading companies. Thereby the economy of the Netherlands is highly interwoven with fossils. This opposite interest results into discontinuous energy policies, creating an unfavourable investment climate for businesses operating in the sustainable energy sector (Weterings et al., 2013).

Uitstoot broeikasgas voor de rechter

Europees rapport: Nederland gaat energiedoelstellingen niet halen

Figure 1.2. Various newsheaders appointing the lagging energy transition in the Netherlands
a: Urgenda case (Trommelen, 2013). b: (NOS, 2017).

1.1.5. A bottom-up movement by municipalities

At the moment the energy transition measures in the Netherlands are mainly focussed on energy savings on building scale and energy generation on a central level, far away from the built environment (Gommans, 2012). The reduction and production of the energy demands should be integrated to make optimal use of local potentials and the quality of energy. To what extend we make use of these local potentials is mostly the responsibility of the municipalities. They should respond to these available local potentials. However while a lot of potentials are available most of the municipalities do not recognize them, or they don't know how these potentials can contribute to the energy transition. While the energy transition is an important topic for the municipalities the complexity slows down the process. Demands are often unknown; which makes it hard to determine the effect of sustainable measures on the energy transition. The lagging and discontinuous policies of the government are obstructing the energy transition. Quick changes in the energy transition aren't expected to happen soon. The complexity of the energy transition for municipalities should be taken away in order to create a bottom-up movement in the energy transition.

The same situation applies to the city Delft. While the municipality wants to become an energy neutral city in 2050, the road towards this target is undefined.

1.2. Problem definition

According to the EU-report of February 2017 the Netherlands is still far away from reaching carbon neutrality by 2050, to achieve this goal and thereby control climate change a transition to a sustainable and self-sufficient energy system for the built environment is required, because of the importance of the integration of local potentials the interest of municipalities is large; however for most of the Dutch municipalities, like the city Delft, the energy transition is often too complex to make a difference in the transition to energy neutrality.

Sub problems:
- The Dutch government has opposite interests in the energy transition which results in lagging and discontinuity of the energy policies.
- The energy demands and potentials of the city are mostly unknown by the municipality, this also makes it hard to determine the impact of possible interventions.
- The energy transition is a complex process, because of different reasons.

For example:
* There is a lot of different interest; a lot of stakeholders are involved.
* The energy transition will lead to the use of solar and wind energy, which cannot work demand driven; they depend on the daily and seasonal weather conditions.
* The possibilities towards sustainable energy generation and energy retrofitting in Dutch historical city centres are limited.
* Each intervention has its own optimal implementation moment and location, which also depends on all the other interventions that are and will be taken.

1.3. Research objective and final product

The main objective of this research is to develop a roadmap for the energy transition towards energy neutrality of the built environment for the city Delft, with technical interventions based on the local sustainable energy potentials integrated at all scales and of which the general approach can be applied to other Dutch municipalities.

This will be achieved with the following sub-objectives:
- Existing methodologies towards the energy transition will be analysed to derive an approach suitable for the built environment of Dutch municipalities.
- The roadmap will include the location, scale and implementation moment of these interventions.
- In the roadmap the required interventions for the energy transition should be integrated on all scales. Therefor the roadmap will also zoom into two neighbourhoods, showing the consequences of the chosen energy systems on bigger scale for the neighbourhoods and its buildings.
- The roadmap and therefrom derived approach should result into maximal use of the available local energy potentials: generation, conversion, transportation and storage should be done in the most optimal way, to match the energy demands and supplies.
- The roadmap should not only focus on the end result, but should also consider the effects of the interventions during the transition and their moment of implementation.
- The approach will include an overview of possible technologies and potentials that can be implemented in the energy system of the municipality on different scales.

Final product

This research objective will lead to the following final product: a roadmap for the city Delft towards a sustainable energy system that optimally uses the local sustainable energy potentials. The roadmap will show the required interventions at different scales from now till the energy neutrality in the built environment is reached in 2050. Thereby not only a strategy for the energy transition of the city as a whole is proposed, but a strategy for all scales including the districts, neighbourhoods and buildings. Beside the scale of the interventions the roadmap will also show their implementation moment and location. Finally a general approach for the built environment of the Dutch municipalities is derived from this roadmap that will decrease the complexity of their energy transition.

1.4. Hypothesis and boundary conditions

To be able to achieve energy-neutrality in Delft and other Dutch municipalities energy should be generated with renewables. A lot of these renewable energy sources will be needed to furfill the energy demands. Therefor the first step will be minimalizing the energy demands of the built environment, by energy retrofitting of the buildings and by making optimal use of residual energy flows. Each neighbourhood will require a different approach which focusses on their local potentials and characteristics. In historical city centres adaptations at the building to decrease energy losses or to generate energy are less visible. These buildings will still demand high temperature heating. Alternative solutions should be found in the surrounding areas. For new housing areas low temperature heating will be sufficient to heat the buildings. To make optimal use of energy, high temperature sources should only be used if low temperature heating isn't an option; for example for historical buildings and industries. For the energy transition to a sustainable and self-sufficient system conversion, transportation, generation and storage processes should work together to match the supplies with the demands.

Boundary conditions

This graduation project is the final project of the master Building Technology; therefor the thesis will focus on the technical aspects of the energy transition. By concentrating on Dutch municipalities only technologies suitable for this situation will be explored. The energy transition will lead to an energy system where all energy will be generated with renewables. This means that only the energy demands by heating and cooling of buildings, the energy use of industries and processes inside the buildings between the boundaries of the municipality will be included. Energy demands and emissions of for example traffic and transportation will be excluded.

The roadmap for Delft will show the required interventions for the energy transition; concerning location, scale and moment of implementation (what, where, when and why). The roadmap will be separated into three set points; 2020, 2030 and 2050. In 2050 all of the energy should be generated with renewable sources. The time span will be from 2017 till 2050, divided in three time blocks. The first block is from 2017-2020, the second 2021-2030 and finally 2031-2050. Finalizing the roadmap, two neighbourhoods will be chosen in which the proposed interventions will be integrated on neighbourhood and building-scale.

The approach will be useful for the municipalities to achieve an overview of the possible technologies which can be implemented on different scales; urban, district, neighbourhood and building blocks. The approach will thereby give insight where, when and why these technologies can be implemented.

1.5 Research questions and report outline

The main research question is defined as:
'How should the roadmap for the energy transition of the built environment towards energy neutrality for the city Delft look like, with technical interventions based on local sustainable energy potentials integrated at different scales and what is the general approach for the energy transition of Dutch municipalities?'

The report has a clear division between three substantial parts; the first part consist the required basic knowledge to be able to create the roadmap and understand the principles of the energy transition (the literature study). The second part is the approach for the energy transition of Dutch municipalities and the last part the roadmap for the energy transition of Delft. While the approach is designed simultaneously with the roadmap of Delft the approach is described first in the report. There is chosen for this order to demonstrate how to applicate the approach in order to design a roadmap for a Dutch municipality. The main research question will be answered by supporting sub-questions that are divided over these three parts in the report. Their sequence throughout the report will be as showed on the next page. Finally the report will be finished with an overall conclusion and reflection.

PART I – The basics of the energy transition

Q1. What is an energy transition?
Q2. How does the current energy system of the Netherlands work in terms of generation and demands?
Q3. What is the role of the municipality in the energy transition?
Q4. What are the potentials for renewable energy generation in Dutch municipalities and to what extent are they available?
Q5. Which technologies can a municipality use to match the demands with the supplies and what are their optimal implementation scales?

PART II – An approach for the energy transition of Dutch cities

Q8. How should the approach, for the energy transition of the built environment of Dutch municipalities that helps to create a roadmap that integrates technical interventions at different scales look like?

Q8.1. How do existing methodologies and approaches deal with the energy transition?

Part III – The energy transition roadmap of Delft

Q9. How should the roadmap for the energy transition of the built environment towards energy neutrality for the city Delft look like, with technical interventions based on local sustainable energy potentials integrated at different scales?

Q9.1. What are the energy transition goals of the city Delft?

Q9.2. How does the current energy system of the city Delft work, concerning its demands and supplies and which initiatives are already taken towards a sustainable energy-system?

Q9.3. What are the sustainable energy potentials of the city Delft and to what extent can they be applied?

Q9.4. Which energy systems and source are available for the energy transition of Delft and when and where should they be implemented?

Q9.5. What interventions need to be implemented into the two neighbourhoods according to the defined interventions on bigger scale?

1.6 Approach and research method

The research objective is to create a roadmap for the energy transition of the city Delft and to define a general approach for the energy transition of Dutch municipalities.

In order to design this roadmap first a literature study is preceded. This literature review gives insight in the basic principles of the energy transition. And includes subjects like the current energetic situation of the Netherlands, sustainable energy sources and technologies and case studies. This knowledge is required to be able to design the roadmap and to define the approach. The applied research method is a combination of design by research and research by design. While the roadmap will largely be based on the literature study and the context analysis including demands, current system, potentials, etc. The approach is based on both the findings of the design process of the roadmap and the analysis of existing energy transition methodologies. Both design processes will be performed simultaneously and thereby findings in both designs will influence each other's final outcomes. This is visible in the approach scheme in figure 1.3. Finally in the last phase there will be zoomed into two neighbourhoods to define the interventions at this scale.

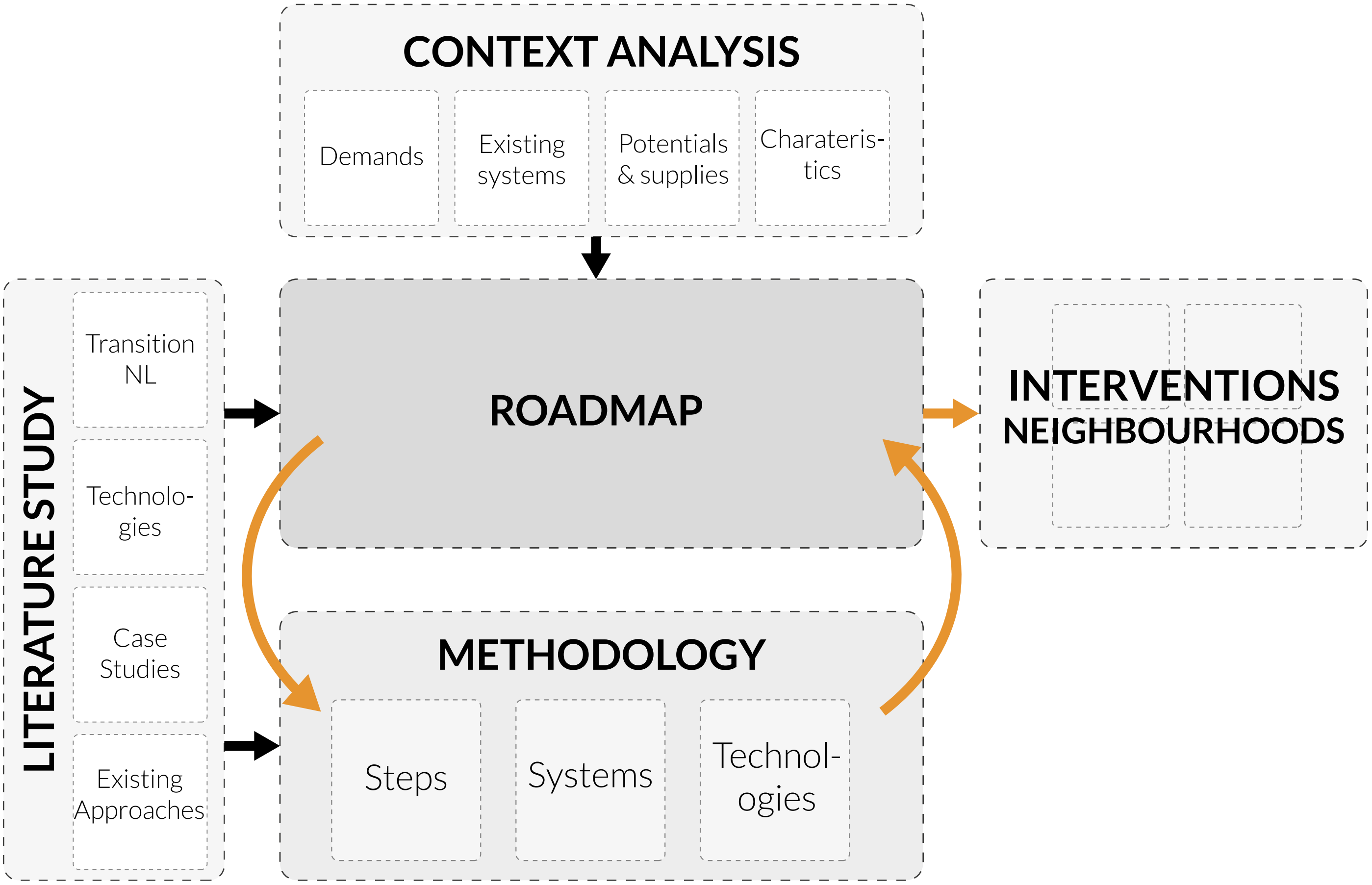


Figure 1.3. Approach scheme thesis (by Author).

1.7 Relevance

With the energy transition to a sustainable energy system the energy goals of the Paris Climate agreements of 2015 can be achieved, this will limit the global warming to 2 degrees Celsius and will make sure the that energy can still be provided to our future generations as well as a healthy environment. Thereby the transition will also lead to a self-sustaining energy system for the Netherlands, which means independency from the (fossil) energy supplies of other countries. This will make sure that conflicts with, between or inside these countries won’t lead to an energy shortage or high energy prices. This thesis will result in a roadmap for the energy transition of the city Delft and an approach for the energy transition of Dutch municipalities. The energy transition to an energy neutral municipality can stimulate the transitions of other cities, transition related policies by the national government and above that it can increase the awareness of the urgency of the energy transition by citizens, companies and institutions. And will thereby become a bottom-up movement in the energy transition of the Netherlands.

For Delft specific the energy transition will lead result in an energy system based on renewables. This will increase that status of Delfts as well-known innovative city even more. By positive publicity about the city and the knowledge institutes in the city, like the TU Delft.

PART I

THE BASICS OF THE ENERGY TRANSITION

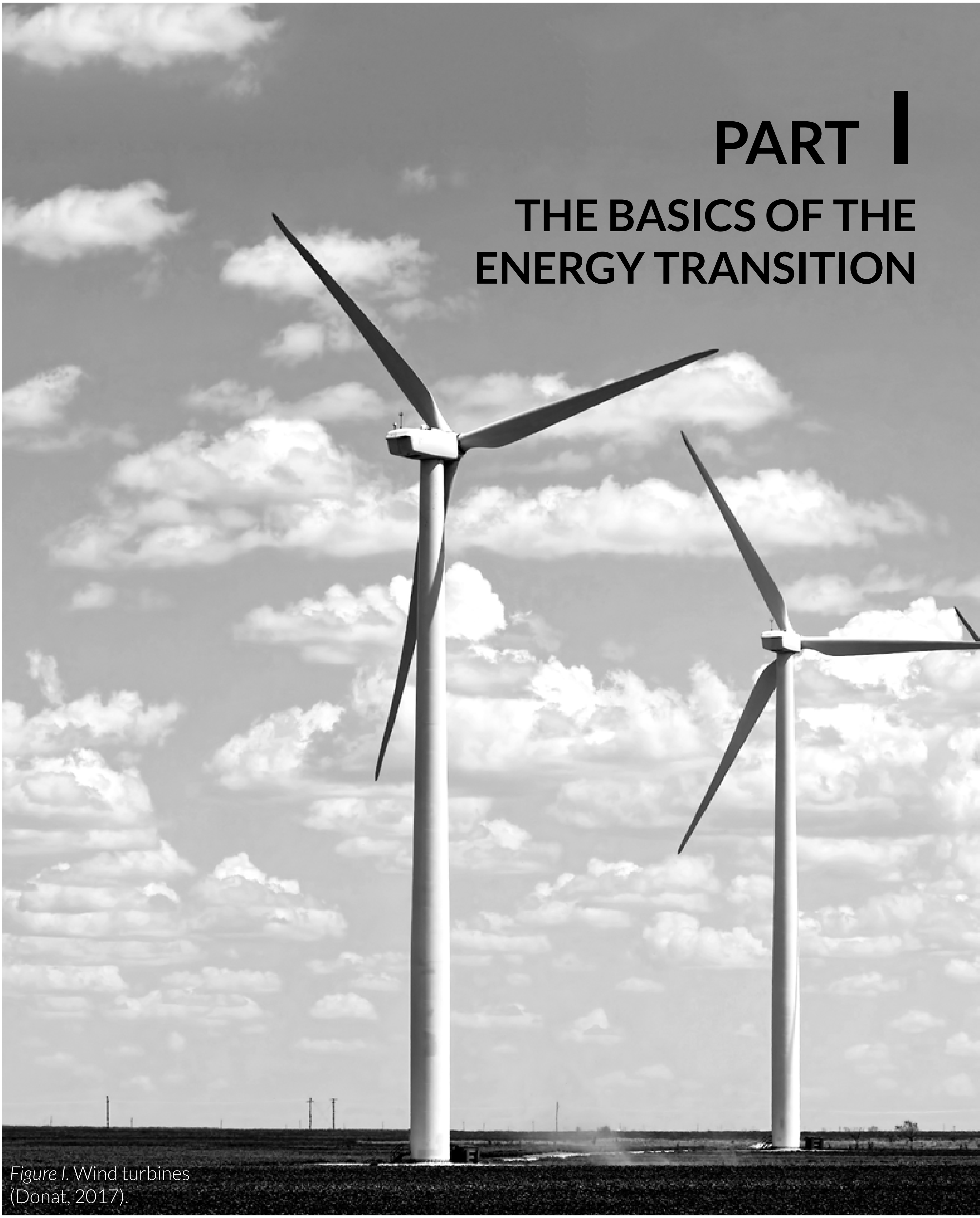


Figure I. Wind turbines (Donat, 2017).

The introduction appointed the urgency of the energy transition. A transformation to a sustainable world, where the needs of the current generation will be provided without endangering the future of the next generations, will be needed. In order to limit the global warming to two degrees Celsius carbon neutrality should be reached in 2050. This means that the CO2-emissions should be reduced and therefor all energy should be generated with renewables. Therefor an energy transition is required. At the moment the Dutch energy supplies are still largely dominated by fossil fuels. In this part The basics of the energy transition a literature study towards the following research question is done in order to create an overview of the current status of the transition and the available sources and technologies that can be implemented to create an energy system based on renewables: ''***What is the energy transition?***'', ''***How does the current energy system of the Netherlands work in terms of generation and demands?***'', ''***What is the role of the municipality in the energy transition?***'', ''***What are the potentials for renewable energy generation in Dutch municipalities and to what extent are they available?***'' and ''***Which technologies can a municipality use to match the supplies and demands and what are their optimal implementation scale?***''.

02

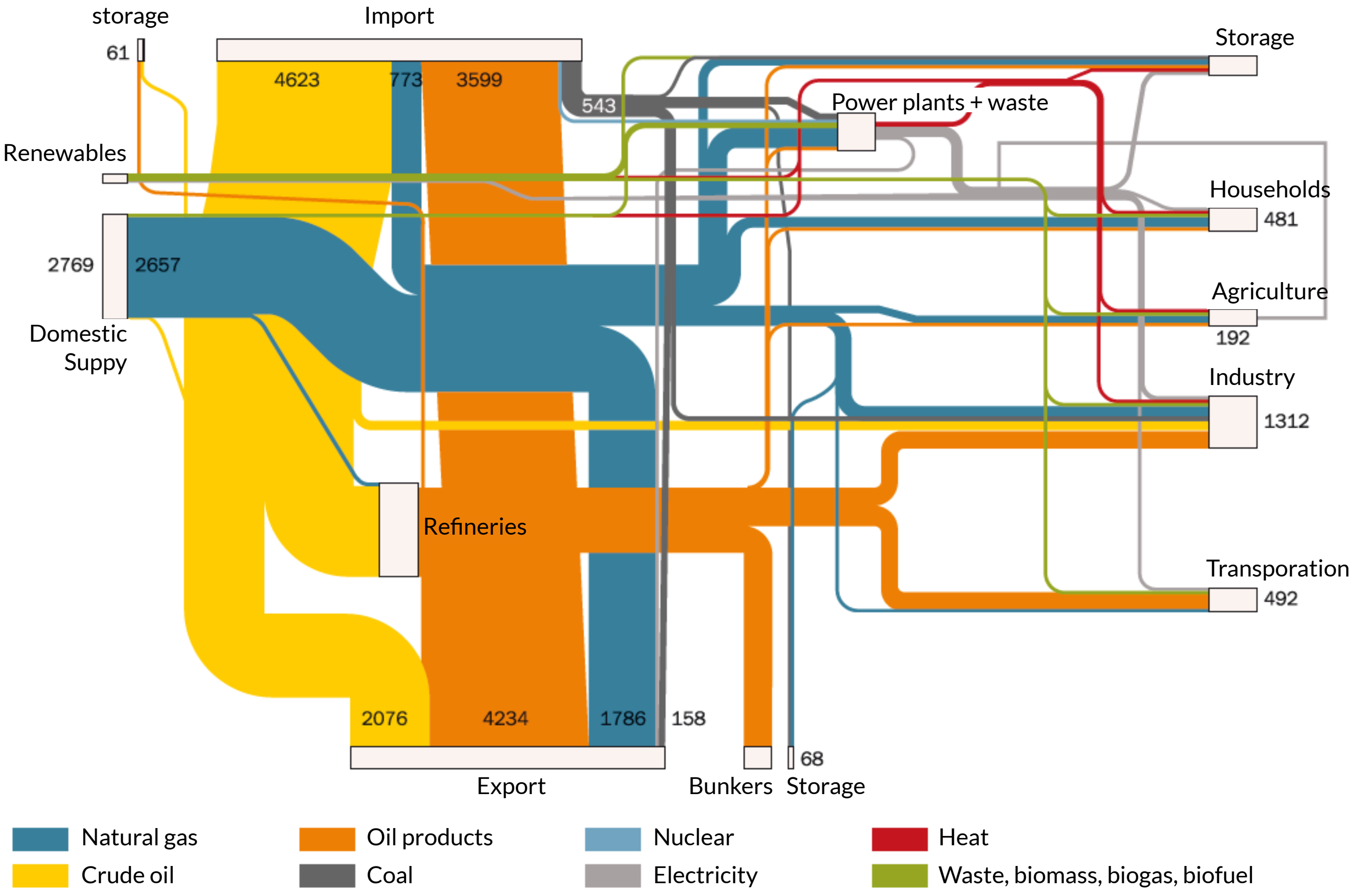
The Dutch energy transition

To be able to create a roadmap for the energy transition of the city Delft an overview of the available energy sources and technologies for Dutch cities should be created. However an understanding of the basics of the energy transition should be generated first. This includes the definition of an energy transition, the role of the municipality and the current status of the Dutch energy transition. Thereby this chapter gives answer to the sub-research questions: ''***What is the energy transition?***'', ''***How does the current energy system of the Netherlands work in terms of generation and demands?***'' and ***"What is the role of the municipality in the energy transition?".***

2.1. The Dutch energy system

The Netherlands is an energy trading country; most of the energy that is imported isn't used to furfill the demands, but is exported to other countries. About 80 percent of the imported energy is exported afterwards (www.cbs.nl). The figure below supports this statement. On top the importation of energy is shown, on the right the much smaller generation. This suggests that the Netherlands is only producing a very small amount of their demands; however this is not true, looking at the exportation of energy shown below. The export of energy is about as big as the importation. This means the Netherlands is importing a lot of energy from neighbour countries. After the energy needed to furfill the demands is used the energy that is left is exported to other countries.

Figure 2.1. Energy flows in the Netherlands, showing the import, export, generation and demands (Weterings et al., 2013, p. 20).



2.1.1. Energy supply & production

The total energy supplies are the result of export, import, generation, bunkering and stock mutation. Natural gas and crude oil do have the largest share in the total energy supplies, only 4,7% is renewable energy (www.cbs.nl). Of this energy supply 22% percent is lost during conversion and distribution processes and by the energy use by the energy-sector (like power plants). After all about 78% percent of the total energy supplies can be used furfill the demands (www.cbs.nl), as can be seen in figure 2.6 and 2.7.

The total energy generation in the Netherlands in 2015 was about 1954PJ. If you exclude the 22% energy loss this is almost enough to furfill the energetic energy demands of the Netherlands. The energy generated in the Netherlands is mostly fossil energy; in 2015 only 7% was generated with renewables (www.cbs.nl).

Most of the energy production in the Netherlands comes from the Natural gas supplies. However this amount is currently decreasing, by the declined gas extraction in Groningen. Here the extraction leads to earth quakes. The gas extraction in Groningen is reduced to 24 milliard m^3 a year in 2016. This means nowadays 50% of the natural gas extraction origins in Groningen (Weterings et al., 2013). This declined natural extraction increases the dependence on the supplies of other countries and thereby urges the energy transition to a self-sufficient and sustainable energy system.

Figure 2.2. (left) Energy production in the Netherlands in 2015 (by Author, based on data: www.cbs.nl).

Figure 2.3. (right) Gas extraction in the Netherlands between 2000 and 2016 (by Author, based on data: www.cbs.nl).

■ Crudge oil and products

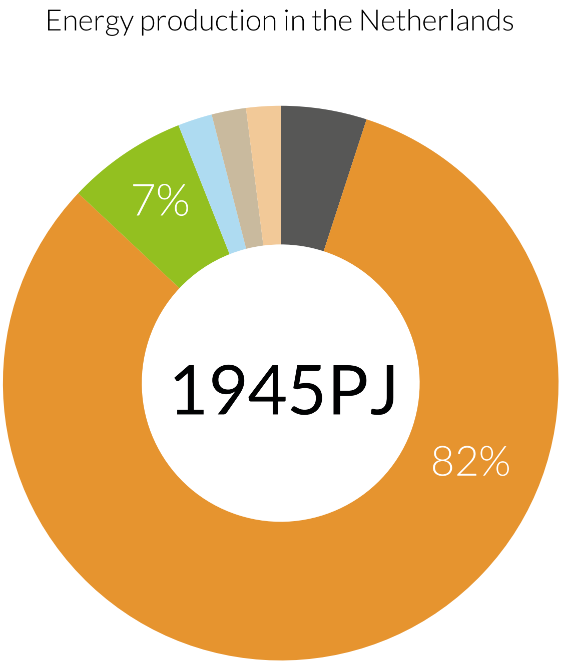
🟧 Natural gas

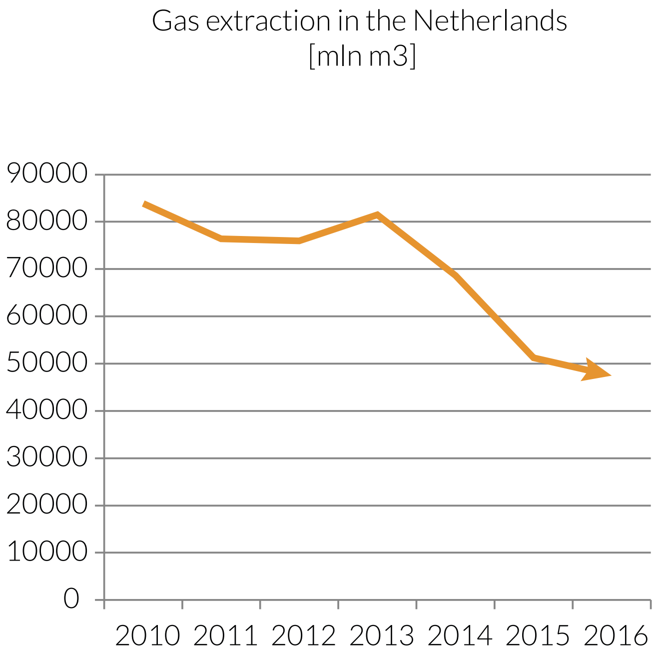
🟩 Renewable energy

🟫 Nuclear energy

🟨 Non biogenic household waste and residues

🟦 Energy from different sources





2.1.2. Energy demands

The total demands of the Netherlands in 2015 were 1791,5 PJ. Of these demands 440PJ is used by the traffic and transportation sector (25%). Which means about 1350PJ of the total demands is requested by the built environment, whereof 22% by the households (www.cbs.nl).

At the moment the energy demands of Dutch households are in decline. While the gas demands were already decreasing for many years, the electricity demand just started to decrease after a long period with a quite stable demand (Gerbus et al., 2016). This is a positive development for the energy transition. However we can do much better, figure 2.5 shows the energy demands of an average household in different countries, while Japan has a climate which is about the same as in the Netherlands their energy demands are much lower. This illustrates the impact of cultural differences in the energy use of households (Gerbus et al., 2016).

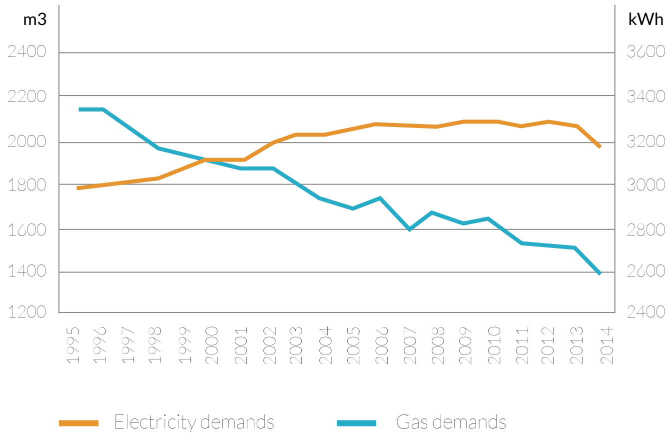
2.2. What is the energy transition?

To prevent the dependence on other countries energy supplies and to limit the global warming a transition of the energy system is required. This energy transition will lead to an energy system based on renewables and will make sure that we can still provide our future generations with energy in a healthy environment.

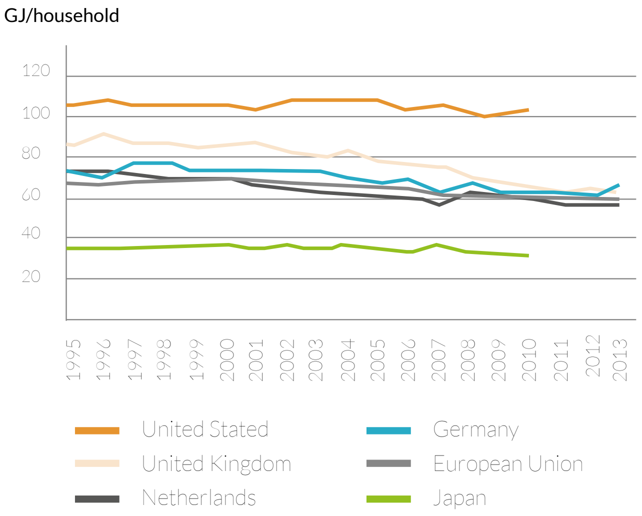
Figure 2.4. (left) Development of the average gas and electricity demands of Dutch households from 1995 to 2014 (Gerdes, et al., 2016, p8).

Figure 2.5. (right) Development of the average demands of households of six different countries between 1990 and 2013 (Gerdes, et al., 2016, p13).

Average gas and electricity demands per household (NL)



Average energy demands per household in various countries



The energy transition focuses on the energy that is used in the human environment: energy that is consciously extracted and generated to supply manmade objects to make them able to perform. Although the energy thesis also includes the energy used for transportation, in this research only the energy demands of the built environment will be taken into account.

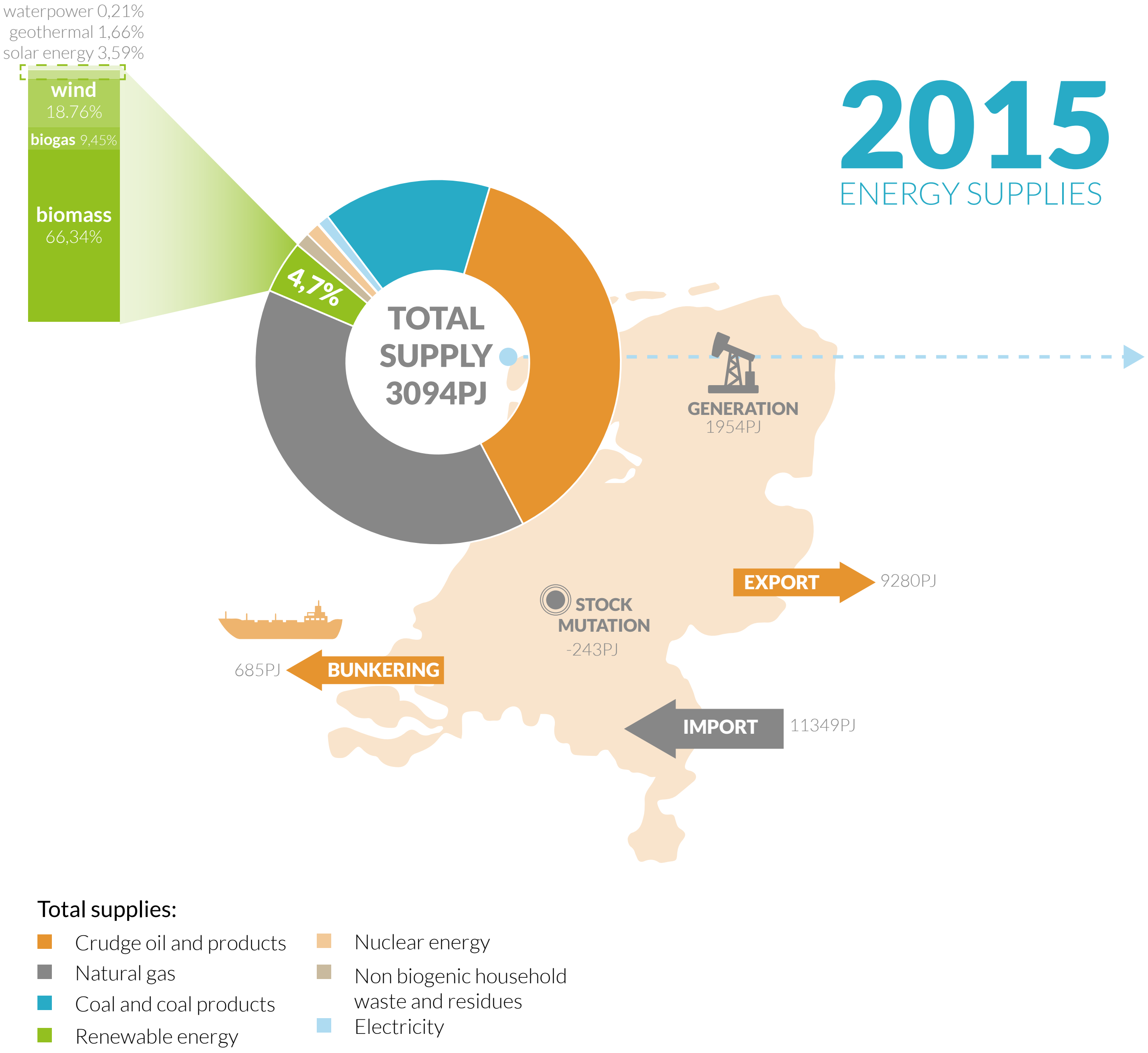


Figure 2.6. The total energy supplies of the Netherlands in 2015 (by Author, based on data: www.cbs.nl).

The final goal of Paris Climate Agreements is to reach carbon neutrality in 2050. According to the report 'CO$_2$-neutrale steden' of BuildDesk (Roos, Braber, et al. 2007) CO$_2$-neutrality is defined as followed:
"CO$_2$-neutral is the situation where the measured fossil energy use (and the related CO$_2$-emissions), over one year, inside a certain area are at most zero: no more energy is used than the energy that is supplied to the system by sustainable sources."

Figure 2.7. The total energy demands of the Netherlands in 2015, decreased by the conversion, transportation losses and energy-use of the energy-sector (by Author, based on data: www.cbs.nl).

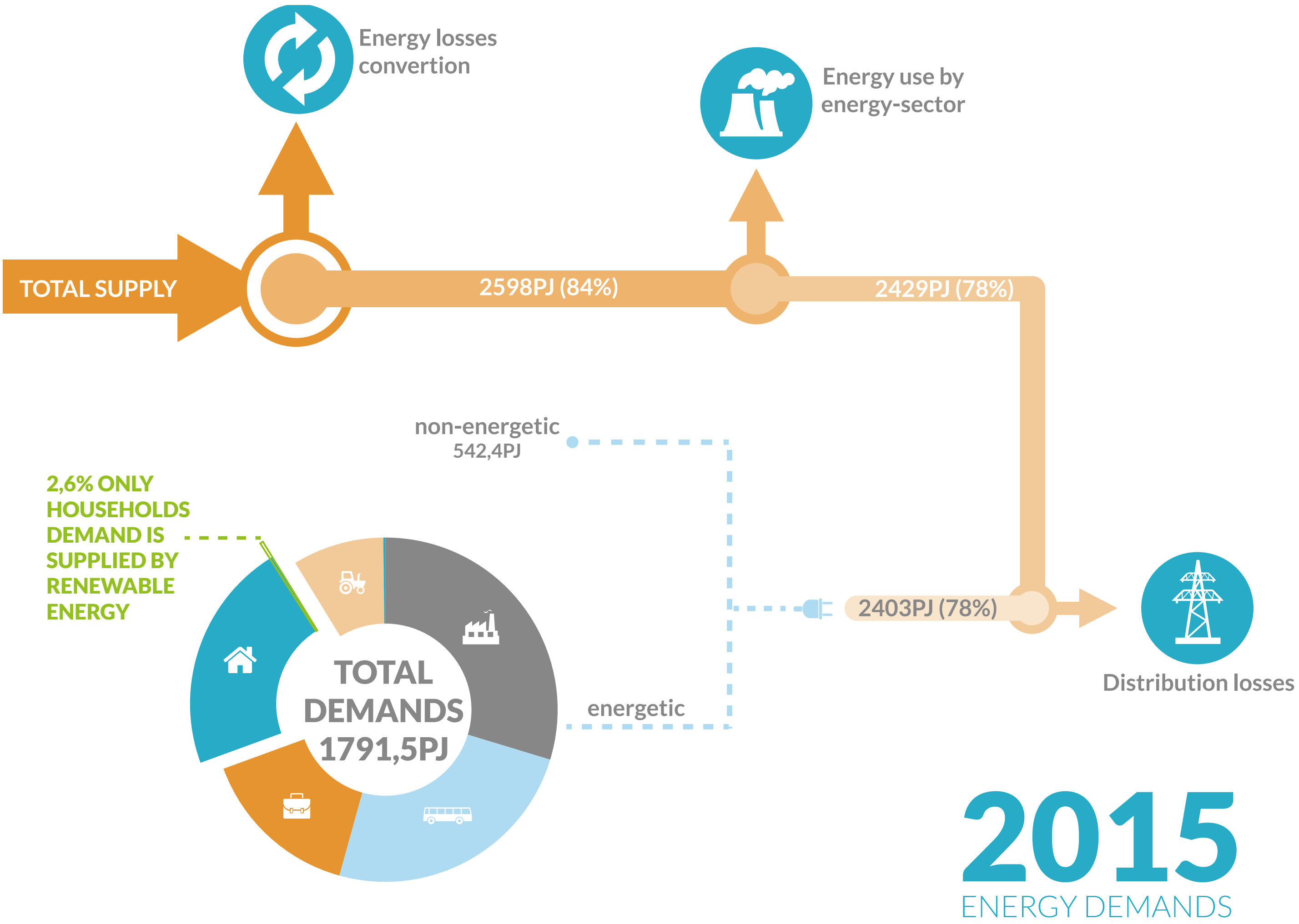


Figure 2.8. Poster against climate change and fossil energy (Delgado, 2009).

2.3. Towards a sustainable energy system

In the introduction the lagging Dutch energy transition was appointed. While according to the EU 14 percent of the energy supplies should be generated with renewables in 2020, the Netherlands was not even at 7 percent in 2015 (NOS, 2017; www.cbs.nl). The government got prosecuted by the sustainability organisation Urgenda in 2005 for lagging policies concerning the reduction of CO_2-emissions. To be able to reach carbon neutrality in 2050 the energy transition should be speeded up. During the climate dialogue in 2016 the Dutch cabinet decided to focus exclusively on the CO_2-reduction goals and doesn't want any separate (binding) national goals about renewable energy and energy savings anymore v(Ministerie van Economische zaken, 2016).

Figure 2.9 shows the total CO_2-emissions between 1990 and 2015. As visible the emissions in 2015 were about equal compared to 1990. Thereby very big steps should be made in the total energy transition of the Netherlands in order to achieve to goals of 2020 (25% reduction) and 2050.

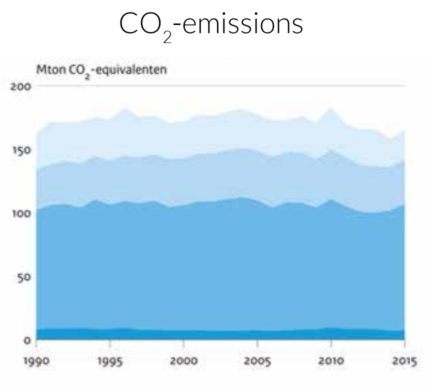


Figure 2.9. CO_2-emissions in the Netherlands between 1990 and 2015 (Compendium voor de Leefomgeving, 2017).

2.3.1 Initiatives of the government

The initiatives of the Dutch government are included in the Energy agenda, published in December 2016 by the Dutch ministry of Economics. The agenda is a continuation of the Energy Accords and shows the plans of the government to achieve carbon neutrality in 2050. The agenda focusses on a few main points, divided in electricity (power and light), thermal energy (high and low temperature) and traffic (Ministerie van Economische Zaken, 2016).

Power & Light

> An international electricity network

The current electricity network in the Netherlands is highly interwoven with the surrounding countries and thereby with the rest of Europe. At the moment the electricity network has connections with Germany, Belgium, Norway and England (TenneT, 2017). Collaboration on international scale will be needed to create a reliable energy system based on renewable sources. In which the favourable characteristics of each country are contributing to the network supplies. Norway for example has the optimal location for the generation of electricity with water-power. By creating this international network the impact of fluctuations in energy supplies by renewables (sun and wind) will be limited. In order to realize this international network the Netherlands is participating in two West-European partnerships: the Electricity Neighbours Group and the Pentalateral Energy Forum (Ministerie van Economische Zaken, 2016).

> Wind energy at the North Sea

The amount of sustainable energy generation should increase drastically. A substantial share of this energy will be provided by wind parks at the

	Construction year	Output
Existing		
Offshore - Egmond aan Zee	2007	108MW
Prinses Amalia	2008	120MW
Luchterduinen	2015	130MW
		358MW
Under construction		
Gemini	2017	600MW
		600MW
In development		
Borssele	2019	700MW
Borssele 2	2020	700MW
Coast South	2021	700MW
Coast South 2	2022	700MW
Coast North	2023	700MW
		3500MW

Figure 2.10. Installed and to be developed wind parks in the Netherlands (Gerdes, et al., 2016, p70).

Figure 2.11 Offshore wind farm: London-Array (Siemens, 2013).

North Sea. In 2023 around 4500MW of power will be installed. The yearly generation will be equal to the electricity use of 5 million households. At the moment the Netherlands has 3 wind parks at the North Sea, with a total output of 1000MW (Gerdes et al., 2016).

High temperature heating

The government finds a lot of potential in residual heat of energy intense companies. The Rotterdam harbour for example produces a lot of waste heat. The realisation of collective heat network should help to utilize this heat. The government expects that involved companies are willing to invest in the capture of their own residual heat (Ministerie van Economische Zaken, 2016).

Gas network

The Dutch government aims to construct all new housing areas gas free. The existing gas network will no longer be expanded. New buildings will almost be energy neutral and the remaining heat demands should be supplied without natural gas. The current law obligates the network administrator to create a gas connection for every requested connection to the gas network. This law will be replaced by a technique neutral right of thermal energy supply. This means that the government will guarantee the presence, quality and affordability of the required energy infrastructure (Ministerie van Economische Zaken, 2016).

At the same time the government is stimulating energy savings in the existing building stock with subsidies.

2.3.2. Role of the municipality

The government is focussing on the transition of the electricity supplies by the realisation of an international electricity grid and wind turbine parks at the North Sea. To speed up the transition the municipality should focus on the transition of thermal energy. Because this transition will mainly take place on local scale; by the divers existing housing stock and variable energy potentials per region. This means that the municipalities will have an important role and responsibility in this part of the transition (Ministerie van Economische Zaken, 2016). At the same time they should try to decrease their electricity demands and increase the renewable electricity generation on collective and individual scale.

Most municipalities have set their own goals for the energy transition. However to reach these goals the effort of the municipality should be large. At the same time the success of the municipality depends on the energy policies of the higher authorities and the participation of stakeholders in the local community (Leguijt et al., 2011).

However the municipality should choose for an active role in this transition by the following reasons:
- A lot of energy saving measures are cost efficient and have a payback period of just a couple of years and do locally create employment opportunities.
- Locally, close to the citizens and companies; is the optimal level to initiate and create specific projects.
- The effort and perseverance of municipalities in the past have regularly led to quicker realisation of national and international policies.
- (inter)National profiling as sustainable municipality/city.

(Leguijt et al., 2011)

2.4. Conclusion

In this chapter a literature study towards three sub-research questions was done: ***"What is an energy transition?"***, ***"How does the current energy system of the Netherlands work in terms of generation and demands?"*** and ***"What is the role of the municipality in the energy transition?"***. The energy transition will lead to an energy system based on renewables. This transition will make sure that we can still provide energy and a healthy environment to our future generations. The final goal of the energy transition is carbon neutrality in 2050. Carbon neutral means that no more energy will be used then is supplied by renewable energy sources.

However the current energy system of the Netherlands still mainly focusses on fossil fuels; 82 percent of the total energy supplies is originating in natural gas. As being an energy-trading country fossil fuels are highly interwoven with our economy. This results in lagging and discontinuous energy policies by the government. However to reach to energy goals for 2020 and 2050 the energy transition to a system based on renewables should be speeded up.

In the, in 2016 published, Energy Agenda the Dutch government showed the initiatives towards the energy transition. The government mainly focusses on sustainable electricity supplies with the development of an international electricity grid and with the construction of wind parks at the North Sea. The municipality should start playing an active role in the transition of the thermal energy, which depends on local potentials and the locally variable building stock. By taking an active position in the transition the municipality will encounter employment opportunities and international publicity as sustainable city, which both will indirectly lead to economic growth. And above that the energy transition of a city result in faster realisation of international and national energy policies, which will accelerate the total transition to carbon neutrality.

In this chapter current position towards the energy transition and the importance of the involvement of the municipality is made clear. The next chapter will focus on the sustainable energy potentials and the available technologies that the municipality can implement to match the demands and supplies for both electricity and thermal energy.

03

Renewable energy sources & Technologies

The Netherlands is an energy trading country. Thereby the country is economically dependent of fossil fuels. This results in lagging energy policies. In the Energy Agenda the government defined goals and set points for the energy transition. Because of the importance of local potentials and the local differences in the existing building stock the municipality will have large influence of this transition. According to the Energy Agenda the municipality should play an active role in the thermal energy transition. The transition of the electricity network is mainly the responsibility of the government because of the international character. But still the municipality should try to decrease the demands and increase renewable generation of electricity. Thermal energy should be supplied self-sufficiently inside the boundaries of the municipality. Thereby this chapter will give answer to the sub-questions: ''***What are the potentials for renewable energy generation in Dutch municipalities and to what extent are they available?***'' and ''***Which technologies can a municipality use to match the demands with the supplies and what are their optimal implementation scales?***''.

To answer these questions energy potentials and technologies concerning energy savings, conversion of energy, storage and transportation will be discussed.

3.1. Future energy = renewable energy

We need to get off our fossil fuel addiction, we should get addicted to another energy source which isn't damaging the earth and endangering our future generation's life on earth. Sustainable energy is the outcome. Sustainable energy is the energy which uses renewable sources (de Jong, 2016).

Almost all of the sustainable energy is a product of the sun. The solar radiation on the earth is converted to different energy sources. Solar energy is there by the biggest primary exergy source for the earth. Rotation, gravitation and geothermal energy are the other primary energy sources. But their supplies are just a fraction of the supplies by the sun (Gommans, 2012). In this paragraph the sustainable energy sources that have the potential to be implemented into the energy system of Dutch cities will be described.

Figure 3.1. The primary source of sustainable energy supplies (Gommans, 2012, p39).

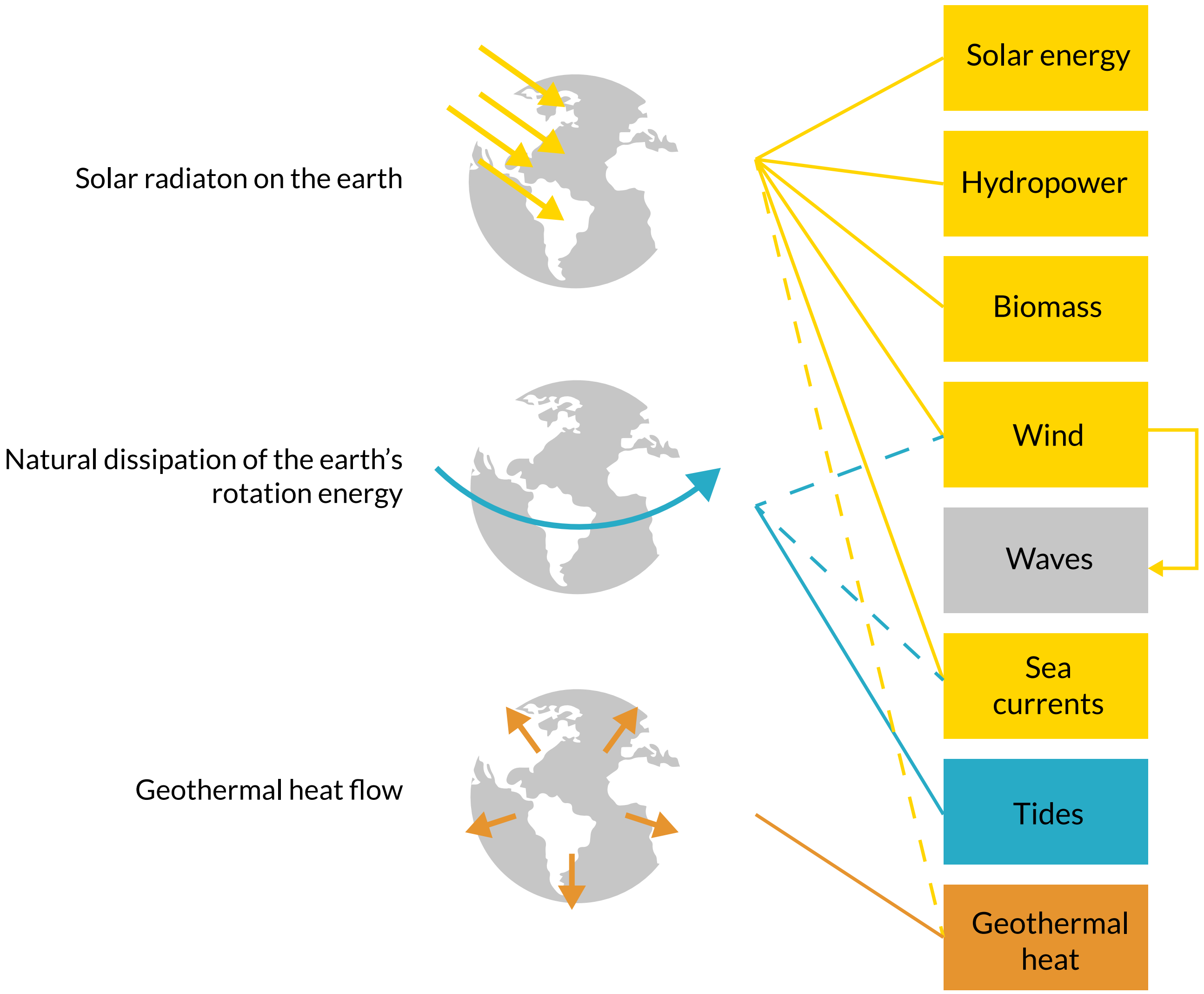


Figure 3.2. Photovoltaics on building roofs (Haasservice, n.d.).

3.1.1. Solar energy

The energy of the sun can be converted into useful sustainable energy sources in three ways:
1. Solar photovoltaic: generates electricity from the sun.
2. Solar thermal: using the sun for direct heating of our buildings or water (thermal energy).
3. Solar biomass: using trees, bacteria, algae, corn, soy beans or oilseed to make energy, fuels, chemicals or building materials.
(MacKay, 2009)

Photovoltaic generation

Photovoltaic panels can convert solar radiation into electricity. The panels are often connected to the electricity grid. When more energy is generated then demanded the electricity is delivered to the public network. At the moment commercially available PV-panels do have an efficiency of 19%, in 2020 efficiencies above 20% are expected (Gommans, 2012).

Covering the roofs of residences with photovoltaics will only provide enough energy to reduce a sufficient part of the personal electricity usage of the resident. But this will not be sufficient to supply the total energy consumption of a whole country. Therefor the solar photovoltaics should be applied on large scale; like solar photovoltaic farms.

Solar thermal collectors

Another type of active solar energy generation is the conversion from solar radiation into heat. Solar thermal generation is the most efficient when warm water is needed throughout the whole year. Thereby systems that connect space heating to the solar thermal generation are less efficient. The efficiency can be increased when the system is combined with heat cold storage system in the ground. In the paragraph 3 this principle will be explained. The overall efficiency of the solar water heater depends on the temperature that is requested and the time when the demands are needed.

The higher the demanded temperature, the lower the efficiency and the more energy will be lost. This makes solar thermal generation mostly suitable for buildings with low temperature heating (Gommans, 2012).

Asphalt collectors

Beside placement on building roofs there can also be thought about new ways for solar thermal generation. An example is road thermal generation by placing water pipes in the reinforced top layer of asphalt roads. The sun will heat this top layer and thereby the water in the pipes. The average potential for heat production from asphalt thermal generation is 0,8GJ/ m^2. The potential of road thermal collector will increase when combined with heat cold storage. When the summer heat is stored with vertical heat exchangers the storage temperature can reach 20 degrees Celsius at the beginning of the winter period. After the winter period this temperature will be decreased to 8 degrees (Broersma et al., 2013). There should be kept in mind that asphalt thermal generation isn't applied a lot in practice yet. Mostly it is used to keep bridges ice-free.

Combined solar thermal and photovoltaics (PVT)

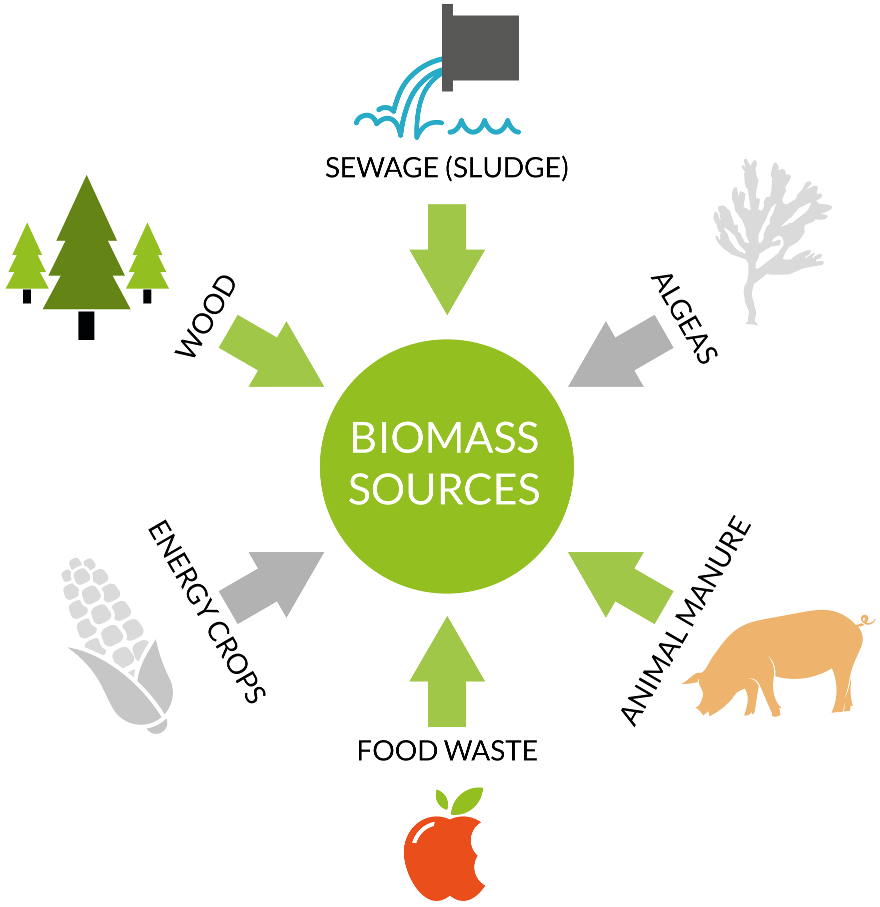
Using the roof space for solar thermal or solar photovoltaics should be well considered. Solar photovoltaics do have a lower efficiency than solar thermal panels and above that solar collectors are much cheaper. However PV panels do deliver high-grade energy (MacKay, 2009). A new option to combine both thermal energy and electricity generation is the PVT-cell. These cells will have a higher efficiency than normal PV-cells, because the water will cool the collector. The heat of this cooling can be used for space heating and domestic hot water (Gommans, 2012).

Solar biomass

The conversion from solar-energy to biomass takes place by photosynthesis: the plant converts CO_2 and water into sugar. Biomass does include all products that are biodegradable. This can be products or residues of agriculture, households, companies etc. The energy inside biomass can be released with burning the substance. When biomass is fermented biogas will be created.

Biomass can be divided into three types. The first type consist energy crops. An energy crop is vegetation that is cultivated to create energy (Gommans, 2012). These crops can conflict with the land-use for food production or by forests and biodiversity and is thereby not considered as a sustainable energy source in this thesis. The second type is residual biomass, like wood waste, household waste and (animal) manure. The last type is the production of algae to produce biofuel. In this study only sustainable energy sources for the built environment will be implemented. Thereby there should be focussed on the second type of biomass. Only the waste that will still be available when we live in a world with a circular economy will be included; wood from forest or garden maintanance, food waste, sludge and manure.

Figure 3.3. Biomass sources (a2z Energies, 2016).



The advantage of biomass is that energy is stored inside the biomass (photosynthesis). The energy doesn't have to be used immediately. The high energy ratio to its volume makes transportation simple. Biomass is gradually available; it doesn't depend on the weather conditions like solar and wind energy (Gommans, 2012).

When the biomass is fermented to biogas and upgraded to green gas with the same properties as natural gas it can be transported in the existing natural gas network. In this network the biogas can also be stored. Biogas has an attractive characteristic concerning sustainable energy: it can be quickly modulated; thereby it can immediately respond to the energy demands and the flexible supplies of wind and water energy (Gommans, 2012).

3.1.2. Wind

As being a country with a relatively long coast line, the Netherlands always had a history with energy production by wind energy. In de past windmills where used for different energy requesting applications. Nowadays wind turbines are also a large potential for the generation of energy. The wind activates the rotation of rotor blades which make the generator rotate as well, thereby electricity is produced. The maximum power that the wind turbine can generate in optimal condition is 1MW (its capacity). A wind turbine starts running with wind speeds between 3-5m/s and stops when the wind speeds exceeds the 25m/s. The actual power that will be delivered by a wind turbine is the capacity multiplied by a factor that described the fraction of the time that wind conditions are near optimal: the typical load factor. In the Netherlands this factor at an optimal location is 22 percent (MacKay, 2009). This means that an average wind turbine at a good windy location in the Netherlands can generate around 0,22MW.

On land wind turbines are a good option to generate a substantial share of the sustainable electricity demands. However there is also a lot of resistance with complaints like horizon pollution, noise and shadows of the rotor blades. Beside these large wind turbines also small wind turbines on buildings can generate electricity, however these generators are less cost-effective.

3.1.3. Hydro-electric

In order to generate hydro-electric power altitude and rainfall are required. Substantial height drops in rivers are a must. With hydro-electric generation the gravitational energy of the water mass is generated when the water falls down to a lower level (Gommans, 2012). A dam is placed between the higher and lower height level in a river, in this way the height level doesn't decrease fluent but abrupt. While flowing to the lower height level the water will pass a turbine which generates electricity. Although the Netherlands has a lot of water the potentials for hydropower are very small due to its flat landscape. Only in the province Limburg there is somewhat potential for hydroelectric power generation.

3.1.4. Currents

With the generation of electricity out of currents, the natural flow of the water in the oceans or rivers is used. By placing turbines underneath the water surface not the energy of the waves, but of the currents can be generated.

Figure 3.4. Hydro-electric generation (Earth possible, 2016).

Figure 3.5 Geothermal plant (Ivarsson, 2007).

3.1.5. Geothermal

Beside the traditional role as supplier of fossil fuels the soil of the earth also has the potential as a sustainable energy supplier: geothermal heat. The inner part of the earth consists out of magma which constantly generates heat. This inner part is covered with the relatively thin earth crust (5-50km) with a high insulation value. The heat in this layer can be extracted with a doublet system: consisting out of a production and an injection pipe. The production pipe pulls warm water up that will be injected back in the earth layer after usage. In the Netherlands the pipes need to reach a depth about 2000m to generate heat with a temperature of 60°C or more. With very deep geothermal at 4km depth also electricity can be generated with a turbine that is activated by the released steam. However the implementation of very deep geothermal isn't feasible in the Netherlands yet.

Sustainability of geothermal energy

Geothermal is attractive because of his constant availability and independency of the weather and climate circumstances. Another advantage is that the generation can be switched on and off when needed (MacKay, 2009); unlike energy generation with fossil fuels which should be done gradually over the year to be efficient. This creates a high potential for geothermal energy use next to wind and solar energy. The use of thermal energy generation with geothermal heat is still at the beginning of its development. Geothermal is probably one of the most cost-effective ways of sustainable energy extraction. Above that it has the advantage that the spatial visual impact is minimal, with the sequel that minimal social resistance is expected (Vermeulen & Willemse, 2016). However the high investment cost is currently a large barrier.

Another barrier in the growth of the application of geothermal is the discussion about the sustainability. Geothermal works with two vertical

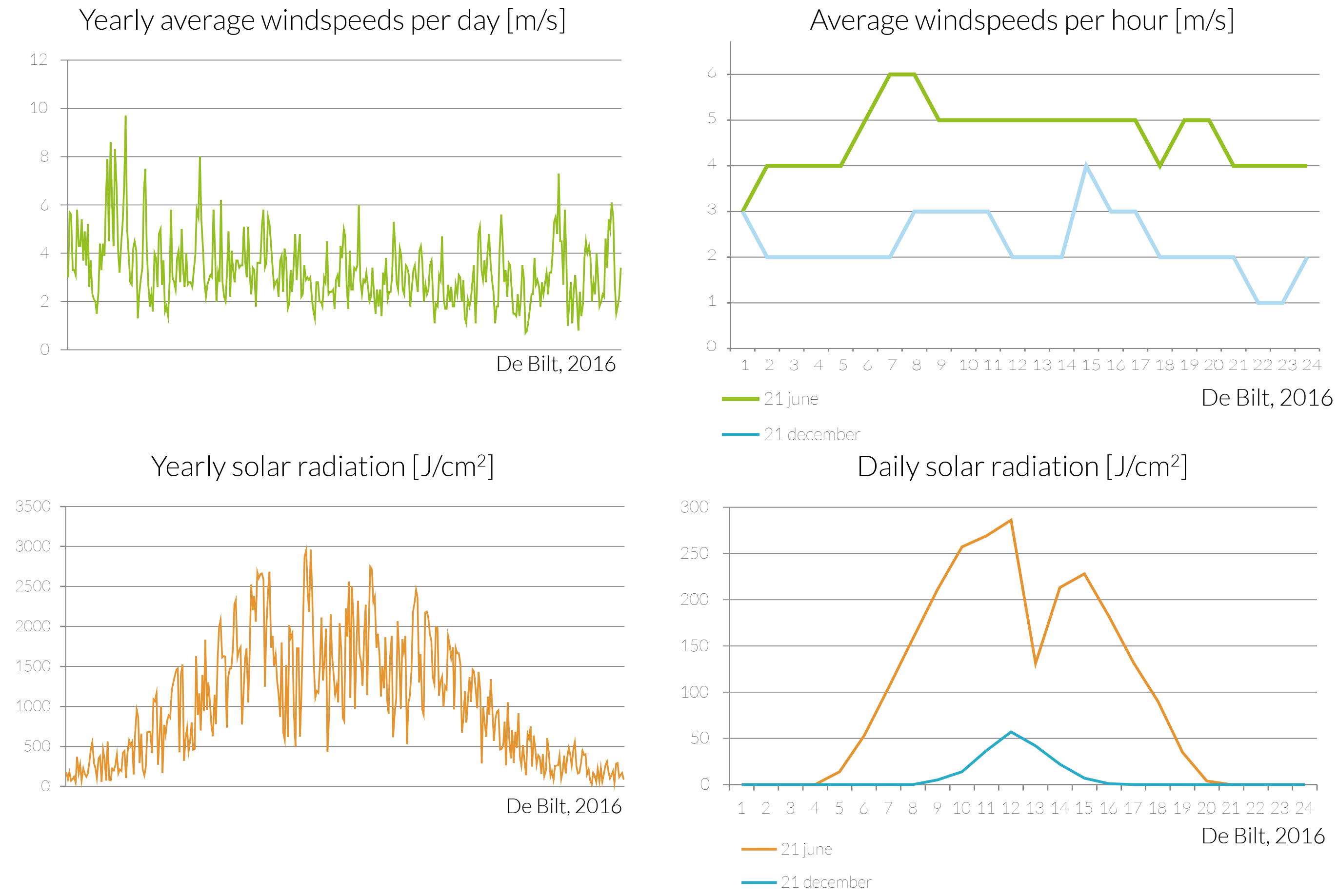


Figure 3.6 Graphs showing the daiy and seasonal fluctuations in supplies by solar radiation and wind (by Author, based on: KNMI data).

pipes in the earth. Cold water is pumped down in one pipe and again sucked up from the other. However after a while the heat will be sucked out of the earth and the earth's temperature is reduced. The earth will need time to recover to his original temperature (MacKay, 2009). In order to prevent this heat should be sucked out at such a rate that the earth doesn't get colder. This means sucking at the natural rate at which the heat is already flowing out of the earth.

The expectation is that geothermal energy can supply heat until about 30 year from now. It takes around 100 years for a geothermal source to heat up again. The estimation is that in the Netherlands there is about 90.000PJ thermal heat available. Which means that we can use 90.000/(100 +30) = 692PJ per year (Gommans, 2012). This means that when geothermal energy is used with its natural rate, it is a sustainable energy source with a lot of potential for the Netherlands.

3.2. Fluctuations in supplies

The energy transition will lead to an energy system based on renewables; a large share will be supplied by wind and solar energy. However an energy system based on these two renewables will lead to an unreliable energy supply. Both energy sources do depend on weather and climate conditions: resulting in daily and seasonal fluctuations in supplies. Overall solar energy can mainly be generated in the warmer seasons and during daytime. The day rhythm of solar energy supply does match the demand fluctuations during the day. At the same time the seasonal rhythm of wind energy, which is mainly generated during the colder seasons, matches the seasonal fluctuations of solar energy. However still periods with shortage and abundance will occur. Abundances will result in extreme low energy prices. This situation occurred in Denmark and Germany; on a certain days with a lot of sun and strong wind the electricity production became higher than the electricity demands. Power plants had to be stopped and the price of electricity was about negative (de Jong, 2016).

How to deal with these fluctuations?
At the moment these fluctuations are tackled by gas stations and the importation of electricity. But in the future other solutions should be found. This can be done by demand-driven energy use; certain activities will only take place when enough energy is available (Gommans, 2012). Another way is to work with fast modulating biogas stations which can quickly respond to the fluctuations. The third solution is seasonal electricity storage. Thereby the generated electricity can be storage in periods with an abundance of energy and can be used again in periods with a shortage. However the storage of electricity is complex, expensive and almost impossible in the Netherlands due to its flat topography (Gommans, 2012). A combination of these three solutions should be used to be able to deal with the fluctuations and to create a reliable energy system based on renewables.

3.3. Energy savings

Before the studied primary energy sources can be implemented the current energy demands should be limited first. This should be done at two scales levels: on building and collective scale. Savings on building scale are mainly focused on thermal energy, because these demands depend on the energetic state of the building. While electricity demands at building scale do mostly depend on the behaviour of the user; how often and what kind of devices are used. At collective scale energy savings can be made by optimal use of energy flows.

3.3.1. Energy savings on building scale

Energy saving measures on building scale do mainly focus on thermal energy savings by insulating the building envelope; for example with double glazing or additional insulation. In some cases these renovations lead to large energy savings, but in other cases these measures won't be cost-efficient. The better the energy performance of an existing building the less cost-efficient the energy saving measures will be. Looking at energy labels the transition from a lower energy label to label B is efficient, but the transition from label B to A will be disproportional expensive (Vermeulen & Willemse, 2016).

There are three main ways to decrease the thermal energy consumption of a building; by reducing the temperature demands, reducing the leakiness (building heat-loss coefficient) or increasing the efficiency of the heating installation. The first two do decrease the total energy losses of the building. This energy can be lost by conduction-heat flow directly through walls, windows, doors, etc. and ventilation. The energy losses by conduction can be found by multiplying the area with the thermal transmittance vale (U in W/m2/K) and with the temperature difference times the duration. This gives the following formulae (MacKay, 2009):

$$\text{Energy loss} = A * U * (\Delta T * \text{duration})$$

In the Netherlands the U-values are restricted by a minimum value for new residences, these restrictions are stated in the Bouwbesluit and NEN 1068 and are expected to become stricter in the future. The higher the U-value, the higher the energy losses. The current requirements can be found in the figure 4.1 (Bouwbesluit, 2012).
In figure 4.2 can be seen that the U-values in the Netherlands are less strict then the restricted values in Sweden. This means that stricter restrictions are achievable with the current building techniques. At the same time the U-values of the existing buildings can be increases by renovations of the building envelope.

Another way to decrease the thermal energy consumption is by increasing the efficiency of the heating installation. A standard condensing boiler has for example an efficiency of 90 percent. This efficiency is quite high. However with installations like a heat pump much higher efficiencies can be reached.

3.3.2 Energy savings on collective scale

Beside energy savings on building scale, energy can be saved on a bigger, collective scale. These savings are based on increasing the used quality of the energy; for example with energy cascading and the use of waste heat. Also higher efficiencies of conversion and transportation processes and seasonal thermal energy savings can contribute to a more efficient energy-use. These last principles will be addressed later in this chapter.

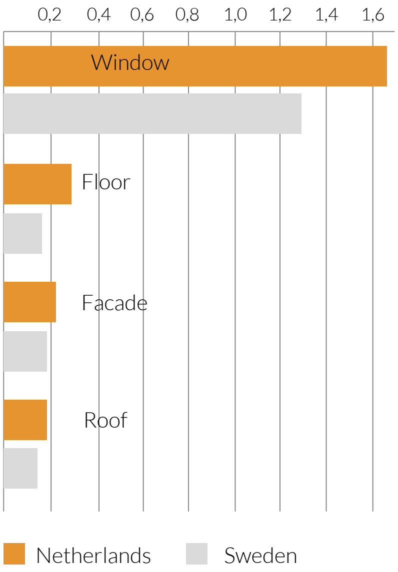
Energy cascading & Residual heat

Energy has special characteristics that are described in the first and second law of thermal dynamics. The first law states that energy cannot be produced nor be lost. Energy can be converted in another type of energy but will not disappear. This is also supported in the second law of thermal dynamics: the quality of energy (exergy) decreases naturally, until equilibrium is reached. In other words: every function that uses energy also has a stream of residual energy, foremost heat or wastewater. The re-use of these residues does give opportunities to decrease the energy demands (Broersma et al., 2011).

Table 3.7. Restricted U-values and Rc-values in the Netherlands according to NEN1068 and Bouwbesluit 2012 article 5.3 for buildings with a residential function.

	U-value (W/m2/K)	**Rc-value** (m2K/W)
Windows		1,65
Floor	0,29	3,5
Façade	0,22	4,5
Roof	0,17	6,0

Figure 3.8. Restricted U-values and Rc-values in the Netherlands according to NEN1068 and Bouwbesluit 2012 article 5.3 for buildings with a residential function.



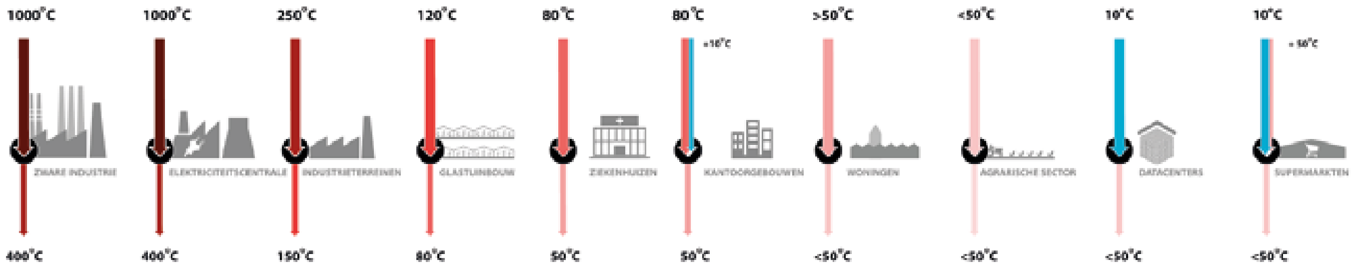


Figure 3.9. Temperature heat demands per sector (Vermeulen, et al., 2016, p16).

Because each building sector requires a different heating temperature, see figure 3.9, the residual heat of one function can be used as heat supply for another function. For example when a hospital is heated with 80°C, the water that is running through the heating systems is finally decreased to 50°C. This temperature can be heated up again to 80°C, but can also be used for low temperature heating purposes. In this way the energy is used multiple times, while the quality of the energy decreases in each step. This principle is called heat cascading.

Heat cascade doesn't always lead to collective energy savings. If the heat cascade network is connected to a power plant energy use of this power plant is not decreased. For example a power plant delivers a temperature of 100°C which normally returns at 50°C, but with the cascading at 20°C, more energy is needed to heat up the thermal energy to 100°C again.

Industrial waste heat

A lot of waste heat from production processes is discharged into the air or water. While at the same time households are burning natural gas for space heating. When this residual heat is re-used to heat these buildings a lot of energy can be saved.

Industrial waste heat is mostly released while burning fossil fuels. This makes the sustainability questionable. However the use of this available heat can be useful to start-up the transition to a sustainable energy system. A collective thermal grid is required to transport the heat. Finally in the last phase of the transition the residual heat source should be replaced by a sustainable heat source (Vermeulen & Willemse 2016).

3.4. Conversion of energy

The described primary energy sources are converted into the secondary sources; electricity, thermal heat, oil products and synthetic fuels. A part of these secondary energy sources will be transported immediately to the end-user. The other part of this energy will be converted again to another secondary energy type with different installations.

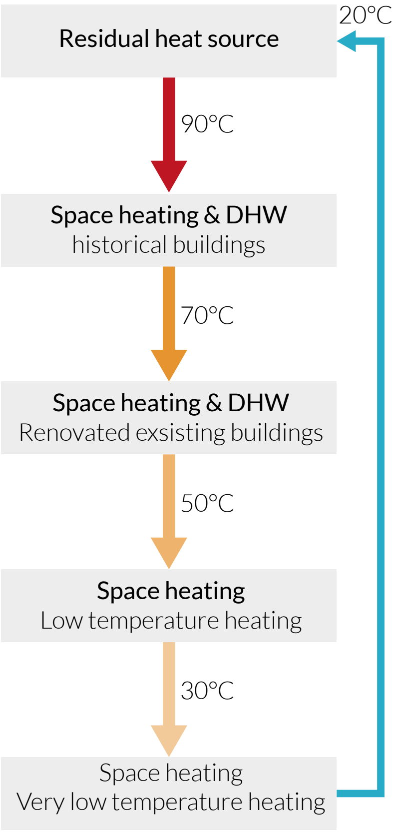


Figure 3.10. Example thermal energy cascading (Gommans, 2012, p247).

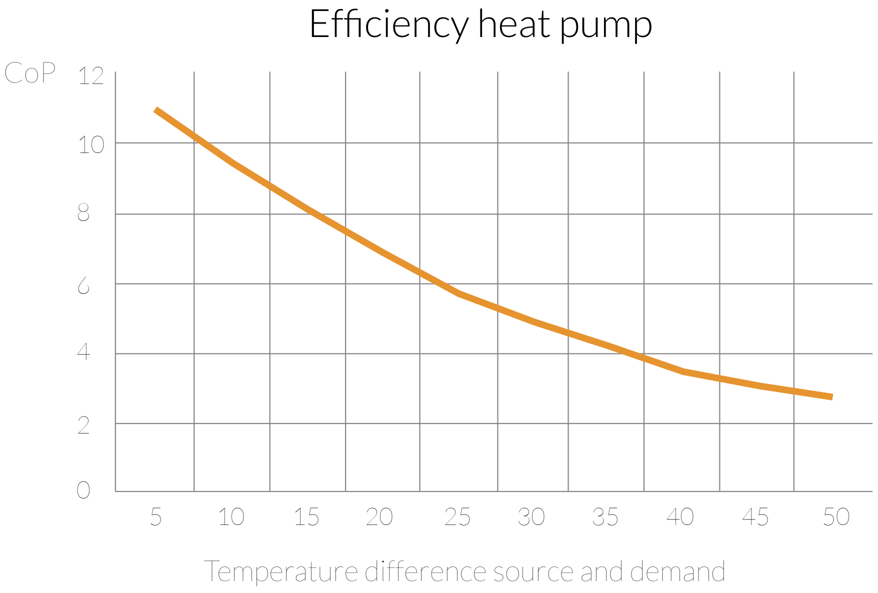
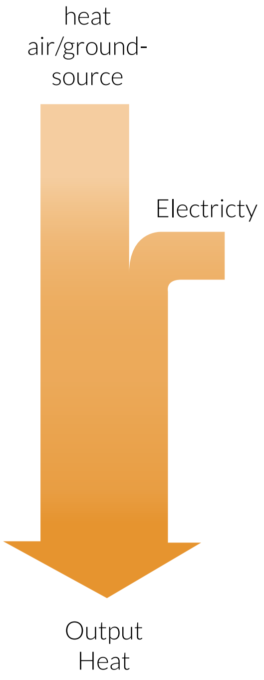


Figure 3.11. CoP value heat pump with the temperature difference between the source and inside temperature (Gommans, 2012, p131).

3.4.1. Heat pumps

A heat pump upgrades the heat from the air or ground to a higher temperature by using electricity. This electricity is used on a high efficiency, expressed in CoP: Coefficient of performance. A CoP of four is common for a heat pump. With a performance of 4, four times more thermal energy will be generated then the consumed amount of electricity that is used. For the efficiency of the heat pump applies: the closer temperature of the source to the required heating temperature, the higher the efficiency. Thereby the heat pump works the most efficient when the building is heated with low temperature heating.

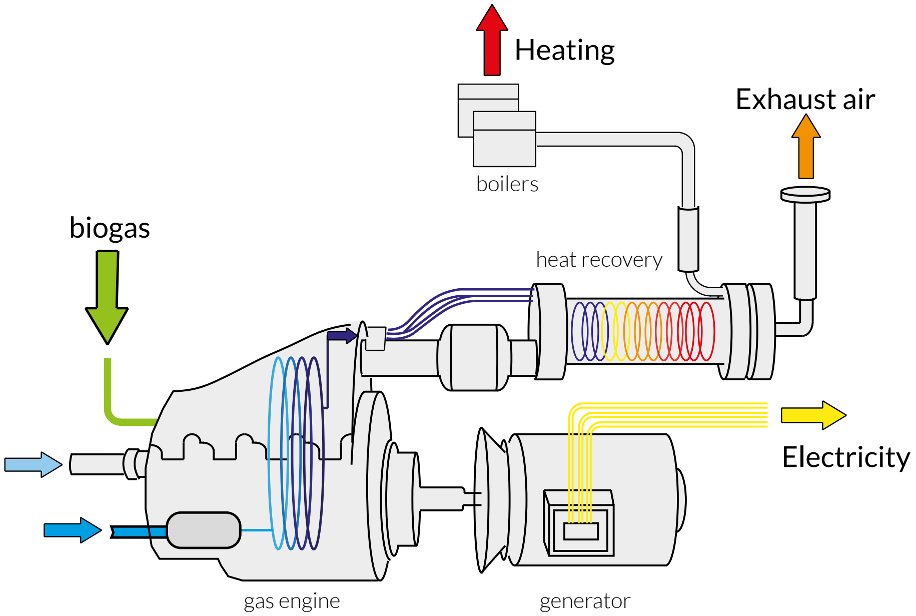
A heat pump can use the air- or ground-source as thermal energy source. The temperature of the ground is on average 11°C. The outside air temperature can drop below 0°C during the winter raise up to 30°C in the summer. Thereby the temperature of the ground is on average closer to the required temperature for heating than the outside temperature. This makes the ground theoretically a more suitable source than the outside air. A straightforward conclusion would thereby be to encourage the choice for a ground-source heat pump. However the ground is a limited heat source; if the heat will be sucked out to fast the source will be exhausted and cool down, as with the geothermal energy generation. This means that the flux that is sucked out of the ground in the winter cannot be bigger than the natural flux of energy in and out of the ground in the summer and winter (MacKay, 2009).



$$\text{CoP} = \frac{\text{Output}}{\text{Electricity input}}$$

Figure 3.12. CoP heat pump (de Vree, n.d.).

Figure 3.13. Diagram of the combined heat and power system (by Author).



3.4.2. Combined heat and power

In conventional power plants the produced heat that is released during electricity production is dumped into a cold place like cooling towers or water. Combined heat power or cogeneration installations do re-use this heat for heating purposes. This increases the total efficiency of the system to about 90 percent (Israëls et al., 2017). The cogeneration plant is sustainable when it is using biogas instead of natural gas. Cogeneration can be applied on different scales; a collective installation can generate energy for a whole neighbourhood, while micro-CHP systems can be applied for heating of bigger buildings or building blocks.

3.4.3. Power-to-Heat

In Denmark and Germany the enormous growth of the amount of wind parks and PV panels did lead to a new problem. On days with a lot of sun and strong wind the electricity production became more than the electricity demands. The Danish came with a solution that pays itself back in 200 operating hours a year. Electrical boiler where placed that can produce heat in a few seconds (de Jong, 2016). These electrical boilers use low cost electricity to generate heat, using the opportunity to benefit from the low and declining energy prices caused by a short surplus of electricity from wind and solar energy. By these relatively low costs and the flexibility by the fast response of the boiler on a surplus of electricity the potential for Power-to-Heat installations is large (Hers, Afman, Cherif, & Rooijers, 2015).

3.5. Energy storage

In order to rely on a renewable energy system two problems do need to be solved: lulls and slews. Lulls are long periods with a low renewable energy generation and slews are short-term changes in the demands and supplies. Storage can give a solution: energy will be stored in times with plenty energy supplies and will be released during periods with energy shortage (Gommans, 2012).

3.5.1. Electricity storage

Electricity storage is requested by the fluctuations in supplies by the renewable electricity sources; sun and wind. Daily storage can be done with batteries and flywheels. Seasonal storage can mainly be done with pumped electricity storage. Thereby water from a downhill lake will be pumped up to a higher situated lake during a period with plenty of electricity; then during a period with electricity shortage the energy is regenerated with turbines by dropping the water of the higher reservoir into the lower lake (MacKay, 2009).

However with the current technologies seasonal storage of electricity in the Netherlands is almost impossible; the country is to flat. To be able to store electricity we should use the facilities of other countries. This supports the initiative of the government towards an international, and thereby more reliable, electricity network.

3.5.2. Thermal energy storage

While electricity storage responds on the fluctuation in the supplies of wind and solar energy, thermal energy storage not necessarily responds to the changes in the thermal energy supplies, but does mainly decrease the thermal energy demands.

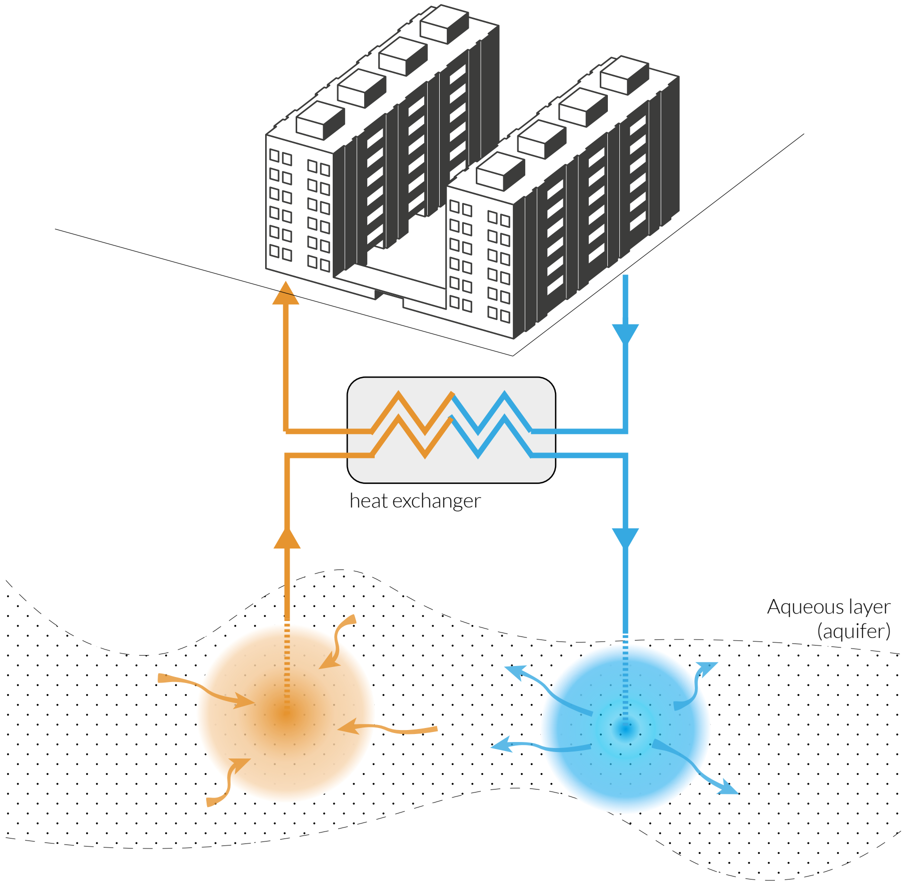
Thermal energy storage should not be confused with geothermal. While geothermal makes use of the heat inside the earth, thermal energy storage uses the insulating character of the top earth layers and takes place on a depth of 50-250 meter (van der Krogt, 2011).

ATES (Aquifer Thermal Energy Storge)

At 50-250 meters depth the aqueous layers of the earth (aquifers) are found. In these aquifers heat and cold can be stored seasonally. The most common type of thermal energy storage is the doublet system (ATES), which consists out of two open sources in the aquifer through which water will be pumped.

During the winter ground water from the heat source will be used to heat the building with a heat exchanger. Leaving the heat exchanger, the cooled water is pumped into the cold source. In the summer the principle works the other way around; cold water is pumped up to cool the building and the heat is pumped back into the heat source. In the winter a heat pump is

Figure 3.14. ATES principle Summer (by Author).



used to upgrade the temperature of the heat source to the required space heating temperature (van der Krogt, 2011).

When the amount of energy taken from the heat and cold source are in balance the ATES system can be used as heat source for the building. This balance can also be achieved by regenerating the overused source. For example a residence demands more heat that cold, thereby more heat will be used from the aquifer in the winter, then cold during the summer. Therefor regeneration of the heat source will be required; this can for example be done with heat from solar collectors.

ATES has the potential to storage energy between 6°C and 25°C, with 30-40kWh per m^3. In the Netherlands generally about 300m^3 can be extracted each hour per well (Schmidt & Miedaner, 2012).

BTES (Borehole Thermal Energy Storge)
Beside this open system a closed system with heat exchangers in the ground can be used. This system consists of closed pipes (boreholes) which are placed vertically in the ground, till 50-200m depth. Heat is exchanged

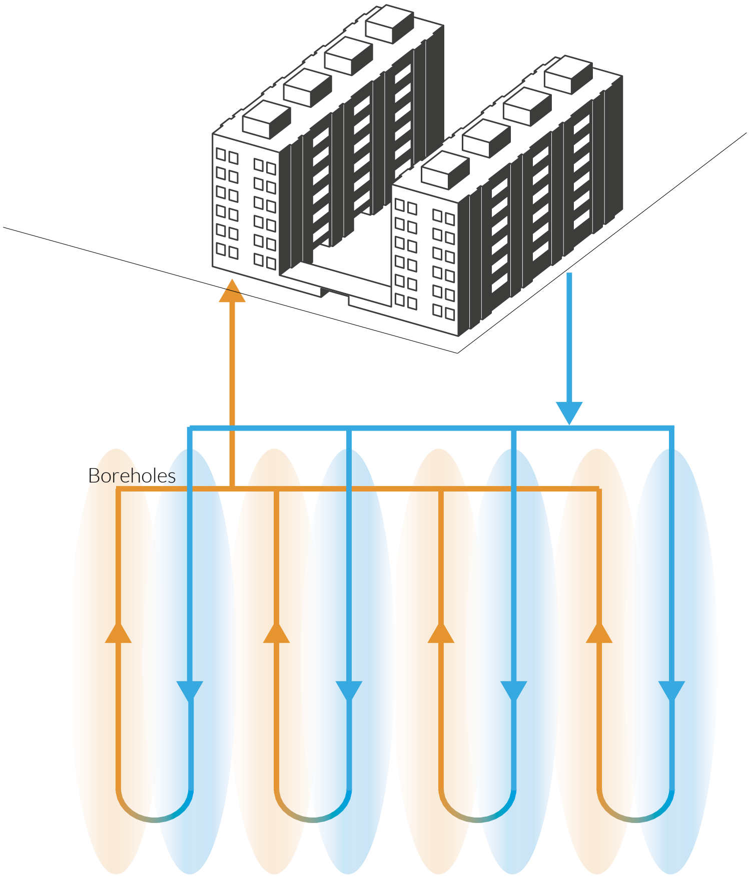


Figure 3.15. BTES principle Summer (by Author).

with the ground. With borehole storage the storage temperature is differs between 0°C and 11°C, with 15-30kWh per m^3 (Schmidt & Miedaner, 2012).

While BTES systems are easier to realize and operate, they have a lower heat transfer capacity than ATES and thereby ATES systems are a cheaper alternative, when an aquifer is available.

3.5.3. Storage biogas

The Netherlands is the owner of a high quality natural gas network throughout the whole country. Chancing to an energy system based on renewables doesn't mean we have to execute this network. The network can still be used to transport green gas. Beside that it can also store gas. At the same time the existing gas fields can also be used for biogas storage under high pressure (Gommans, 2012). By connecting the fields to the biogas producing installations, abundances of biogas during the summer can be stored and used during the winter when the gas demands for space heating are high (van der Krogt, 2011).

Figure 3.16. Gas infrastructure in the Netherlands (Gasunie, n.d.).

3.6. Energy transportation

When the energy demands on a certain location are bigger than the supplies energy should be transported towards this location. The transportation of energy will lead to energy losses, depending on the energy type, distance and transport medium (Gommans, 2012). The transportation of energy can take place before or after the conversion to secondary energy. However in most cases secondary energy is transported to the end user. Each of these energy types, like electricity, thermal energy and gas, do require their own network.

3.6.1. An international electricity grid

To respond to the fluctuations and to ensure the supplies of renewable electricity, the government is aiming for an international energy network. At the moment the Netherlands has three electricity network connections with Germany, two with Belgium, one with Norway and since 2010 also one with England. Currently the network owner Tennet is constructing the fourth connection to Germany, and a connection to Denmark (www.cbs.nl; TenneT, 2017).

3.6.2. Thermal energy networks

In order to provide the citizens with collective thermal heat, a thermal energy network is required. Collective thermal energy can origin from different renewable sources, like geothermal, residual energy and combined heat power systems. Each heat network will have its own temperature. The more connections are made to the network, the more cost-efficient the construction of the network will be. By their high density Dutch cities have a great potential for these thermal grids. For districts with a low population density it will be more cost-efficient to generate the heat individually.

Challenges

In the first years of the transition a large share of the thermal heat demands will be delivered by residual heat, which isn't considered as sustainable energy. This makes the realisation of the energy network an economical challenge. At the same time future demands and supplies are not guaranteed (Vermeulen & Willemse, 2016). However investors should be convinced that collective thermal heat networks will not only be used for waste heat, but will transform into a network of fed by geothermal and other sustainable heat sources in the future.

When a lot of individual measures are taken, less people will connect to the network. This makes the development of the thermal energy network less interesting for investors (Vermeulen & Willemse, 2016). The connection to a thermal grid should be stimulated by the municipality. A possibility can be to obligate households in certain neighbourhoods with a high density to connect to the thermal grid.

3.6.3. Gas network

The main energy source in the Netherlands is natural gas, this gas is transported in gas pipelines through the Netherlands. This network in the Netherlands is known for its reliability and efficiency (Gasunie, 2013) and has the potential to transport and store biogas in the future.

Currently every household and company in the Netherlands has the right to be connected to the gas network. This is incorporated into the gas law. At the moment the government wants to adapt this law to technique neutral right to of heat supply (Ministerie van economische zaken, 2016).

3.6.4. Biomass transportation

Biomass is often transported in his primary, solid appearance. This makes it possible to transport this primary energy source with vehicles, ships and trains. However this transportation method does require fuels and thereby leads to CO_2-emissions. However this type of transportation doesn't lead to energy losses. Thereby the location of the conversion of biomass into secundary energy should be considered.

3.7. Conclusions

This chapter aimed to answer the sub-research questions: ''***What are the potentials for renewable energy generation in Dutch cities and to what extent are they available?***'' and ***"Which technologies can a municipality use to match the demands with the supplies and what is their optimal implementation scale?"***. To answer these questions beside the literature study also case studies towards the implementation and combinations of these technologies is done. These case studies can be found in Attachment A. To finalize the conclusion an overview of the available renewable energy sources and the technologies that can be implemented in an energy system of Dutch cities is created on page 51.

For the energy transition of Dutch municipalities the current energy system should be transformed. Both electricity and heat demands of the built environment will be supplied by renewables. While the transition of the electricity network is the main responsibility of the national government the municipality should focus on the transition to a self-sufficient thermal energy system inside their boundaries. The electricity demands should be limited and the generation optimized.

Electricity

Electricity will mainly be generated with collective systems. Inside the municipality this can be done by using the primary energy sources wind, solar energy (photovoltaics/PVT) and water current of rivers. Another option is to convert biogas with cogeneration plants. Probably most of the electricity will be generated from solar or wind energy. Because these sources dependent on weather and climatic circumstances fluctuations will occur in the supplies. The international electricity network and fast modulating biogas stations can respond to these fluctuations. On national scale Power-to-Heat installations should be implemented to generate heat from the electricity supplies when these are in abundance.

Thermal energy

For the transition of thermal energy there are four main heating systems available, which should be integrated to supply the cities demands. These are the individual heat systems: all-electric, biomass and biogas and collective heat networks of different temperatures. High temperature demands can be fulfilled with biomass, biogas and high temperature heat networks. However high temperature heating should only be used if there is no other option. High temperature heating should never be used for low temperature heating purposes.

Biomass

Biomass can provide high temperature heat to an individual building or small neighbourhood. The energy supplies should not conflict with the local nature and agriculture. Thereby only waste products can be used: wood from garden waste or forest maintenance. This wood can be used for individual heating with a pellet boiler. The advantage of biomass as heat system is that no energy network is required for the heat supplies. This is especially an advantage for low density areas.

Biogas

Biomass can also be used to generate biogas; this is done by fermentation of food waste, sludge from water treatment plants or animal manure. The advantage is that biogas can be upgraded to the same properties as natural gas and thereby biogas can be transported and stored in the existing gas network. In the residences a high efficiency boiler will convert biogas into high temperature heat.

All-electric

Collective electricity sources can be used as energy supply for an air- or ground-source heat pump. These individual heat pumps will provide the building with both domestic hot water and space heating. The demanded heating temperature should be as low as possible to maximize the efficiency of the heat pump and thereby limit the electricity demands. On the roof of the building photovoltaic panels will be placed to decrease the final demands of the building. With the implementation of this heat system only electricity is used to supply the building with energy. The disadvantage of this system is the increased electricity peak demands. Those peak demands determine the capacity of the network and power plants (Gommans, 2012). The advantage is that only a connection to the electricitygrid is needed, no infrastructure for heating has to be constructed or maintained.

Thermal heat network

The construction of these networks requires large investments and thereby a lot of connections to the network are needed to make it cost-efficient. Therefor a thermal heat network should only be constructed in a high density area. These networks can be constructed for different heating temperature purposes. However the high temperature networks are less sustainable because the potential sources are limited. At the same time these networks are the most expensive due to the thick insulation layer that is required around the heat pipes. High temperature heat can be supplied with the primary sources collective biomass (wood) or geothermal. However geothermal should be used at his natural flow rate to avoid exhaustion of the heat-source. Other sources are industrial waste heat, which isn't sustainable and can thereby only be used to start-up the transition, and the conversion of biogas to heat with cogeneration.
Lower temperatures can be supplied by cascading these higher temperatures, solar energy (converted by PVT or solar collectors), small scale residual heat from for example datacentres and supermarkets or heat exchange with sewage pipelines, effluent or the ground. Thermal energy storage can also be connected to these low temperature heat networks to store heat that is generated in the summer. When the amount of heat and cold taken from the thermal energy storage are in balance this system can also be used as heat source for building (block). This balance can also be achieved by regenerating the overused source.

Heat pumps can be used to upgrade the heat from a low temperature network or source to a higher temperature, on collective or individual scale.

Concluding

In the first phase of the energy transition the municipality should decrease its energy demands; energy savings, increased efficiency and storage at local scale will lead to a minimized energy demand and thereby a smaller dimensioned network and less interventions at a higher scale level. All different renewable potentials and technologies should be combined to furfill the remaining demands whereby local potentials should be utilized maximally. Demands and supplies will be matched with conversion, transportation and storage.

Last but not least the constantly changing world should be taken into account and thereby the introduction of new technologies in the years to come should be allowed by flexibility in the energy system.

These finding are implemented in the in part II designed approach for the energy transition of Dutch cities.

Heating type	Required potential	Conversion	Transport	Scale
All-electric (Individual)	Wind	Wind-turbines	electricity grid	Regional, urban
	Solar energy	PV/PVT	electricity grid/directly to building	District, neighbourhood, building (block)
	Biogas	Cogeneration	electricity grid	Regional, urban, district
		micro-cogeneration	Directly to building block	neighbourhood, building (block)
Biomass (Individual)	Biomass: wood	Pellet boiler	Directly to heating system building	Building (block)
Biogas (Individual)	Fermentable biomass: animal manure, food waste, sludge	Fermentation	Existing gasnetwork	National, urban, district
Thermal heat (Collective)	Biomass	Pellet boiler	Heat grid	Urban, district, neighbourhood
	Solar energy	Thermal-collectors	Heat grid	District, neighbourh. building
		PVT	Heat grid	District, neighbourh. building (block)
		Asphalt collectors	Heat grid	District, neighbourhood
	Heat in the ground	Geothermal	Heat grid	District
		ATES (aquifer thermal energy storage)	Heat grid or directly to heat pump in building	Neighbourhood, building (block)
		BTES (borehole)	Heat grid or directly to heat pump in building	Neighbourhood, building (block)
	Industrial residual heat	x	Heat grid	District
	Small scale residual heat	x	Heat grid	district, neighbourhood, building (block)
	Electricty	Power-to-Heat	Heat grid	Urban, district, neighbourhood
	Biogas	Cogeneration	Heat grid	Regional, urban,district
	Water treatment plant	Effluent	Heat grid	District

Seasonal storage	Connection/ installation building	Temperature	Disadvantages/Risks
no potential for electricity storage in the Netherlands	Heatpump: *- Air-source (ventilation return air or outside air)* *- Ground source*	All temperatures *The higher the temperature difference with the source, the lower the efficiency (CoP)*	Increased peak-demands electricity Not suitable for high temperature heating (low CoP)
Storage as gas before conversion in existing gas network and fields			
Before conversion: energy stored in biomass	Pellet boiler directly connected to the radiators/convectors	All-temperatures, *HT most efficient use of material*	Generates high temperature heat, not suitable for low temperature demands
In existing gas network and fields	High-efficiency gas boiler	All-temperatures *Preffered use for HT heating demands*	
Before conversion: energy stored in biomass	Heat exchanger	All-temperatures *HT most efficient use of material*	
Heat cold storage (ATES/ BTES)	Heat exchanger	HT-MT Output: 70-40°C	Conflicts with electricity production
Heat cold storage (ATES/ BTES)	Heat exchanger	MT-LT-vLT Output: 50-15°C	Lower temp. output, but at the same time electricity production
Heat cold storage (ATES/ BTES)	Heat exchanger	LT-vLT Output: 40-15°C	Not often applied yet
Stored in ground, extracted when needed	Heat exchanger	HT-MT: +/- 75-60°C	Exhaustion source, use with natural flow rate
Stored in ground, extracted when needed	Heat exchanger or HP in building	6-25°C	The amount extracted and reinjected should be equal. ATES higher heat transfer capacity the BTES, but more diffult to operate and realize.
Stored in ground, extracted when needed	Heat exchanger or HP in building	0-11°C	
Heat cold storage (ATES/ BTES)	Heat exchanger	Depends on the source; mostly HT	Fossil fuels used for production process: non sustainable heat
Heat cold storage (ATES/ BTES)	Heat exchanger	MT-LT +/- 50-15°C	Delivery heat should be reliable (constant)
Heat cold storage (ATES/ BTES)	Heat exchanger	All temperatures possible, HT preffered	Only use when low-priced electricty available
Storage as gas before conversion in existing gas network and fields	Heat exchanger	HT preffered	Generates high temperature heat, not suitable for low temperature demands
Heat cold storage (ATES/ BTES)	Heat exchanger	+/- 20-10°C	x

PART II

THE URBAN ENERGY TRANSITION APPROACH

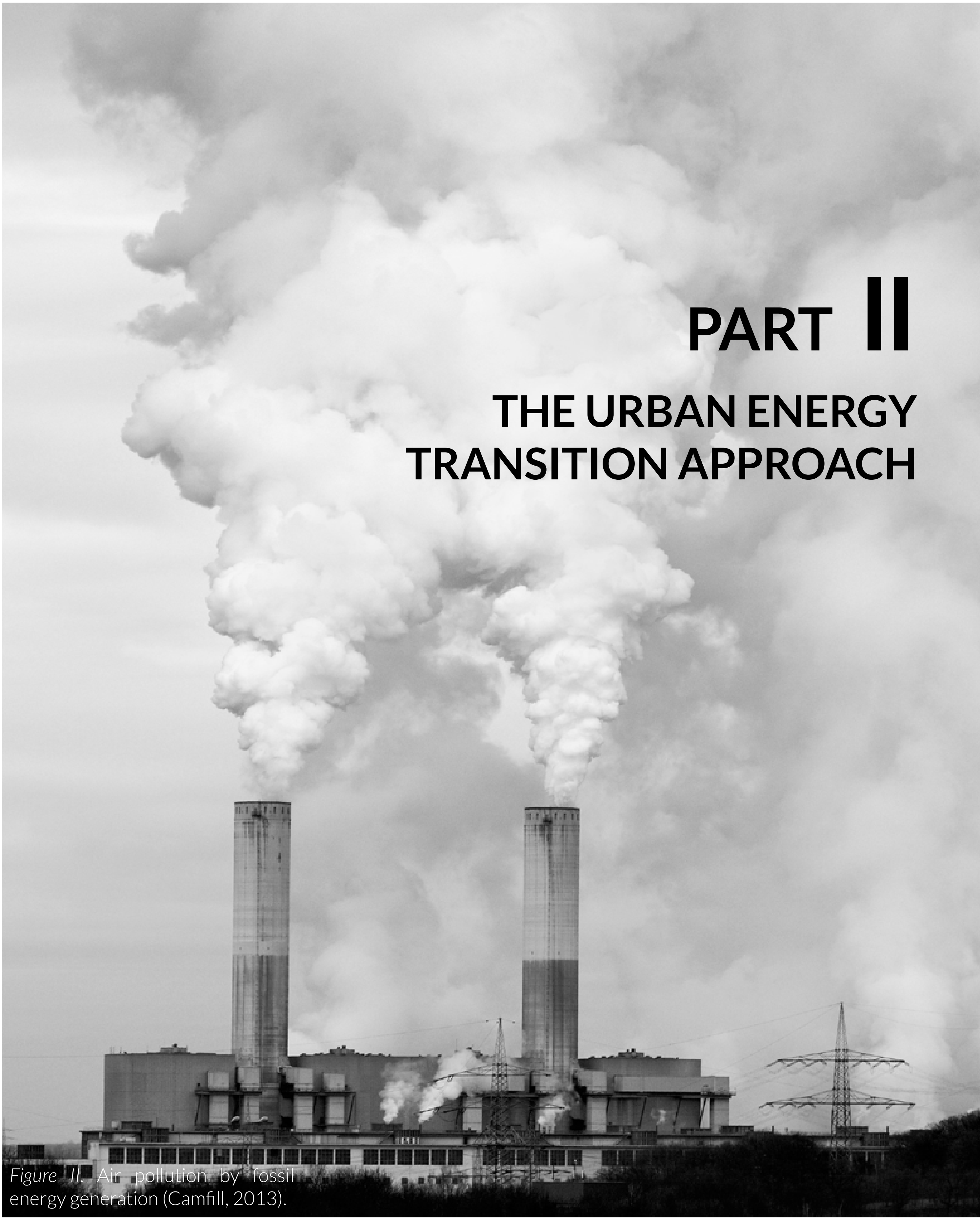


Figure II. Air pollution by fossil energy generation (Camfill, 2013).

The literature study in part I towards the basics of the energy transition resulted in an overview of all available energy potentials and technologies that can be used to match the demands with the supplies in Dutch municipalities. These results will form the basis for the approach and roadmap for Delft. In part II the second part of the main research question will be answered: '***How should the approach, for the energy transition of the built environment of Dutch municipalities that helps to create a roadmap that integrates technical interventions at different scales look like?***'. To generate this approach in the first chapter of part II existing approaches and methodologies will be analysed. After that the approach is developed simultaneously with the roadmap for the city Delft (part III), resulting in the final version of both roadmap and approach.

04

Exsisting methodologies & Approaches

To define the approach for the energy transition of Dutch cities the next step is to analyse how existing methodologies and approaches deal with the energy transition. This is results in the answer of the sub-research question: ''***How do existing methodologies and approaches deal with the energy transition?***''. The outcome will form the basis of the finally designed approach.

4.1. The road to an energy neutral municipality - CE Delft

CE Delft's approach starts with the analysation of the energy goals of the city, in this case the city Delft. How to furfill these goals depends on the climate policies of the municipality. These policies will be based on a strategy that matches the characteristics of the city. Those strategies are defined with the by the TU Delft developed Triple-P approach: stating that sustainable development will only occur when the three factors People, Planet, Profit are in balance.

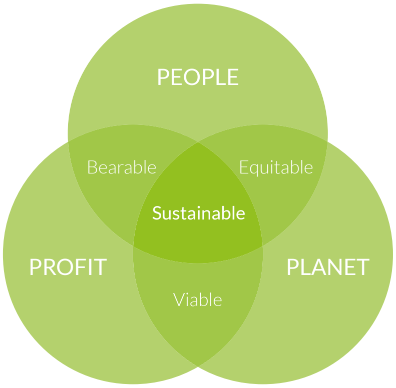


Figure 4.1. The Triple-P approach schematized (CSR Ambassadors, 2016).

This results into three possible strategies. Each based on a characteristic of the city and one of the three P's:
1. Coherent Delft [People]: Stimulating social cohesion in the city.
2. Green Delft [Planet]: Focussing on the environment, biodiversity and climate change.
3. Innovative Delft [Profit]: Technology is leading the transition with an important role for knowledge institutes (university) and companies.

While each of these strategies can lead to the achievement of the final transition goals, the most effective way should be chosen. The first step in the energy transition will be to limit the energy demands. After that the strategy or a combination of strategies that matches the identity of the city the best should be chosen (Leguijt, et al., 2011).

4.2. REAP – Rotterdam Energy Approach and Planning

The REAP approach is based on the new stepped strategy. This strategy is an adaptation of the Trias Energetica: a three step strategy towards sustainable design (figure 4.2). In the new stepped strategy one important step is added between the energy reduction and the use of renewables. This step focusses on the re-use of waste energy.

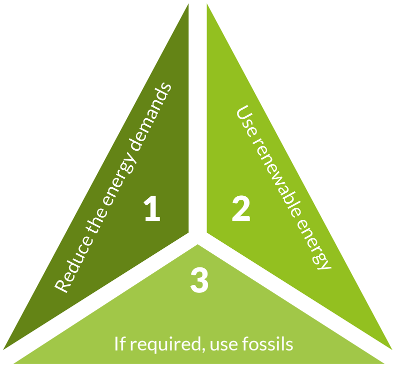


Figure 4.2. Trias Energetica (Schrooten, et al., n.d.).

0. Determine the current energy demands;
1. Reduce the energy demands;
2. Re-use of waste energy streams;
3. Use renewables to fulfill the remaining demands.

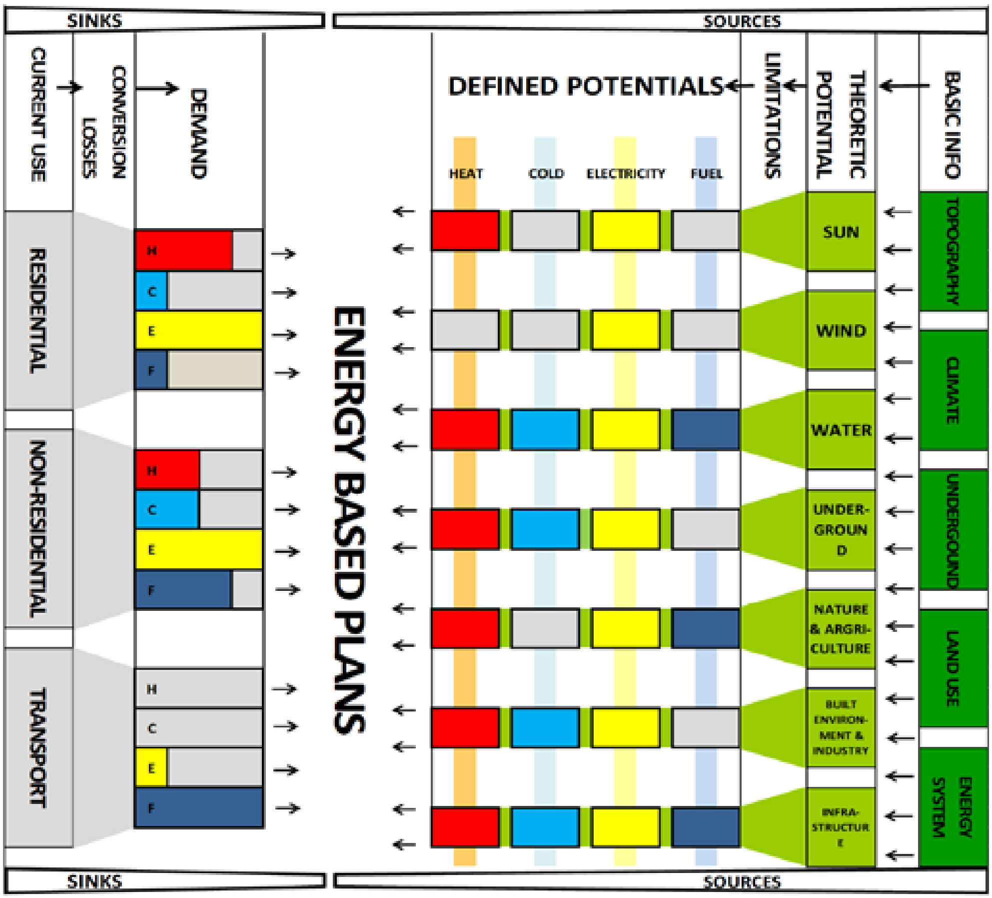
The REAP approach includes different scale levels: building, neighbourhood, district and urban scale. Because the impact on the urban planning by the interventions at the neighbourhood scale is limited, the approach aims to match the demands and supplies at this level first. Interventions on a bigger scale can improve or backup the energy system of the neighbourhood (Tillie, van den Dobbelsteen, Doepel, de Jager, Joubert & Mayenburg, 2009).

4.3. Energy potential mapping

The Energy Potential Mapping (EPM) method is developed to visualize the energy potentials and demands. The quantity, quality and location of the demands and (potential) supplies will be mapped. Quality applies to heat and cold, mapping this heat and cold is the main focus of EPM. The EPM will together with the Heat Mapping (HM) define an energy catalogue. This catalogue provides an overview of the local energy potentials, sinks, storage options and infrastructure.

In figure 4.3 the EPM method is schematised. On the left the current energy demands for different sectors are shown, divided in heat, cold, electricity and fuels. The final demands are found by limiting the energy use by the conversion losses. On the right the potentials for renewable energy sources are shown. Financial, political, social or technical limitations should be taken into account when determining the final potentials.

Figure 4.3. Diagram of the Energy Potential Mapping approach. (Broersma, et al., 2013, p496).



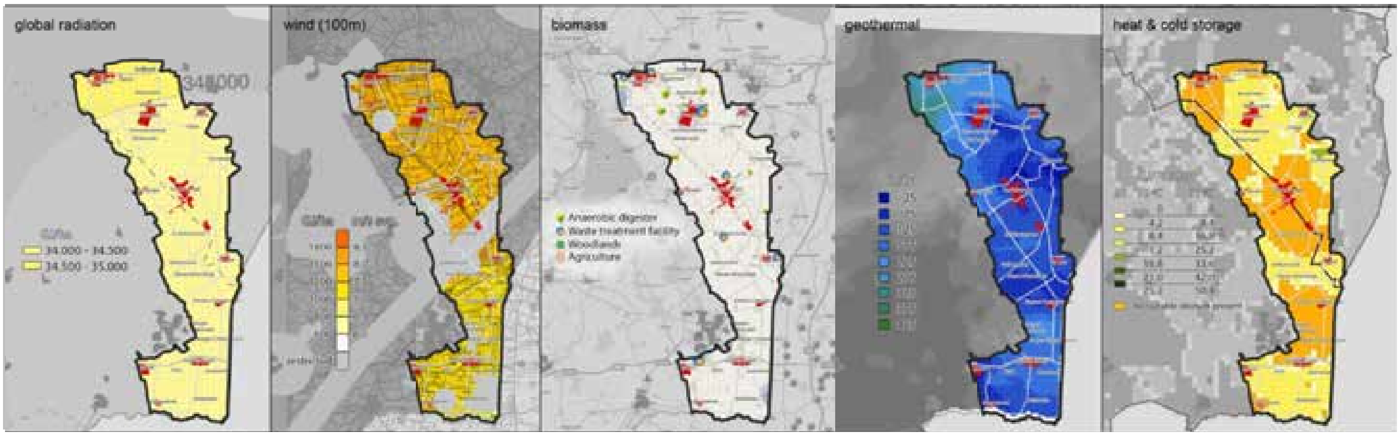


Figure 4.4. Example of energy potential mapping of 'De Veenkoloniën (Broersma, et al., 2013, p501).

As final result of the EPM the demands and potentials, including infrastructure and storage, will be mapped. In the middle of diagram 4.3 the sources and sinks (potentials and demands) will meet each other. The created energy catalogue will simplify the design of the final energy plans in a roadmap. Since not all of the data for the EPM study is available some values need to be calculated or estimated. The EPM study will give an overview of the best available data at that moment (Broersma, Fremouw, & van den Dobbelsteen, 2013).
In the following methodologies the EPM approach is applied.

4.4. The city-zen approach

The city-zen approach aims to involve different stakeholders in the transition process. Above that the approach intends too contribute to the achievement of the energy targets by defining interventions at technical and strategic levels on a roadmap. Therefor a 6 step methodology is created:

1. Map the present and near future
    1.1. Geographical-physical data collection: Including existing energy system, energy demands, infrastructure and the city's climate. This can be seen as the (energetic) context.
    1.2. Map and analyse the technical energy potentials; with the use of the EPM-method.
    1.3. Analyse and map the economic system with the financial barriers and opportunities.
    1.4. Analyse the social environment: the involved stakeholders.
    1.5. Analyse the political and legal environment.
    1.6. Map the near future.
2. Determine far-future scenarios for the city.
3. Select suitable interventions.
4. Create a vision: set targets and milestones in a future vision.
5. Define the roadmap: define suitable interventions on strategic and technical level and their optimal implementation moment.
6. Re-calibrate and adapt.

(Broersma, & Fremouw, 2011)

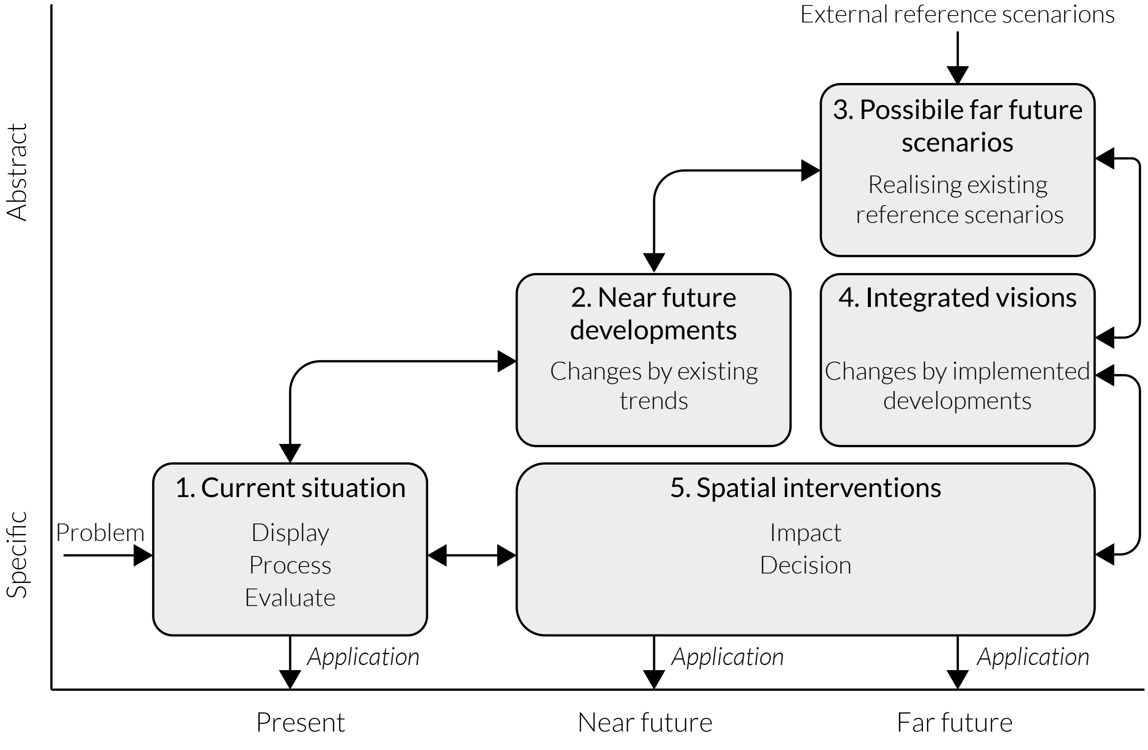
4.5. SREX methodology

This five step methodology helps to develop long-term future visions for different regions. The series of five steps should at least be repeated twice. In the first series the context and scope of the study will be defined, in the second series the future visions and interventions.

The five steps:
1. Analyse the current situation: current energy system, energy potential mapping (EPM) and historical developments.
2. Map the expected developments in the near future: analyse trends and political developments.
3. Design possible far-future visions
4. Compose integrated visions: transform a possible future into a desired future in different ways.
5. Determine spatial interventions.

The interventions that can be implemented in most of the created visions are seen as robust. The SREX methodology also includes a calculation method. This calculation method helps to choose the energy systems that use the energy potentials optimally. First the energy demands and CO_2-emissions of the reference situation are determined. Where after the effect of the interventions on the CO_2-emmisions compared to the reference situation and the payback time of the intervention are calculated (Broersma et al., 2011).

Figure 4.5. Framework of the SREX methodology (Broersma, et al., 2011, p111).



4.6. Conclusion

In the studied approaches the characteristics of the city are analysed as first step. Based on these characteristics a concept is created that helps to justify the chosen strategy for the energy transition. This concept also includes long term visions for the city. By defining a certain strategy or concept based on the characteristics and future visions choices during the transition process will be simplified. In line with this concept the transition targets of the city should be determined, including short, mid and long-term goals. According to most methodologies the following step is to analyse the current energetic context: the demands, energy system, infrastructure and climate. In this step also the status of the transition targets is defined. Beside the energetic context also studies towards the involved stakeholders should be done.

After that it is time to apply the Energy Potential Mapping. The EPM will result in an energy catalogue that gives an overview of the available energy sources, sinks, storage options and infrastructure of a particular area. One of these maps will show the energy reduction potential. This energy reduction will be the first step of the transition process. According to the new stepped strategy the re-use of waste streams and the use of renewables will follow. The roadmap should be evaluated and adapted through the time. Above that it is important to keep space for future innovations in the roadmap.

Except for the REAP methodology the scale of the final interventions isn't mentioned. While the energy potential mapping will be done from big to small scale, the final interventions should start on neighbourhood scale and use the bigger, urban scale as back-up and improvement of its energy system. The integration of the interventions at different scales in the city will be an important addition to the existing approaches. In the following chapter the designed approach for the energy transition of Dutch cities will be explained.

05

The approach

Based on the outcomes of part I and the analysation of the existing methodologies and approaches in the previous chapter a first concept of the transition approach was designed. This approach was at the same time implemented in the design process for the roadmap of Delft (part III). Findings during this application in the roadmap leaded to adaptations in the methodology. This process of testing and adapting resulted into the final and current version of the approach.

The designed approach consists out of 8 steps and finally results in a roadmap for a city in the Netherlands. Beside these steps also tools are added that help the municipalities to define the most suitable energy systems based on the local characteristic and potentials. Thereby this chapter will give answer to the main research question of this part "***How should an approach, for the energy transition of the built environment of Dutch municipalities that decreases the complexity and helps to create a roadmap that integrates technical interventions at different scales look like?***".

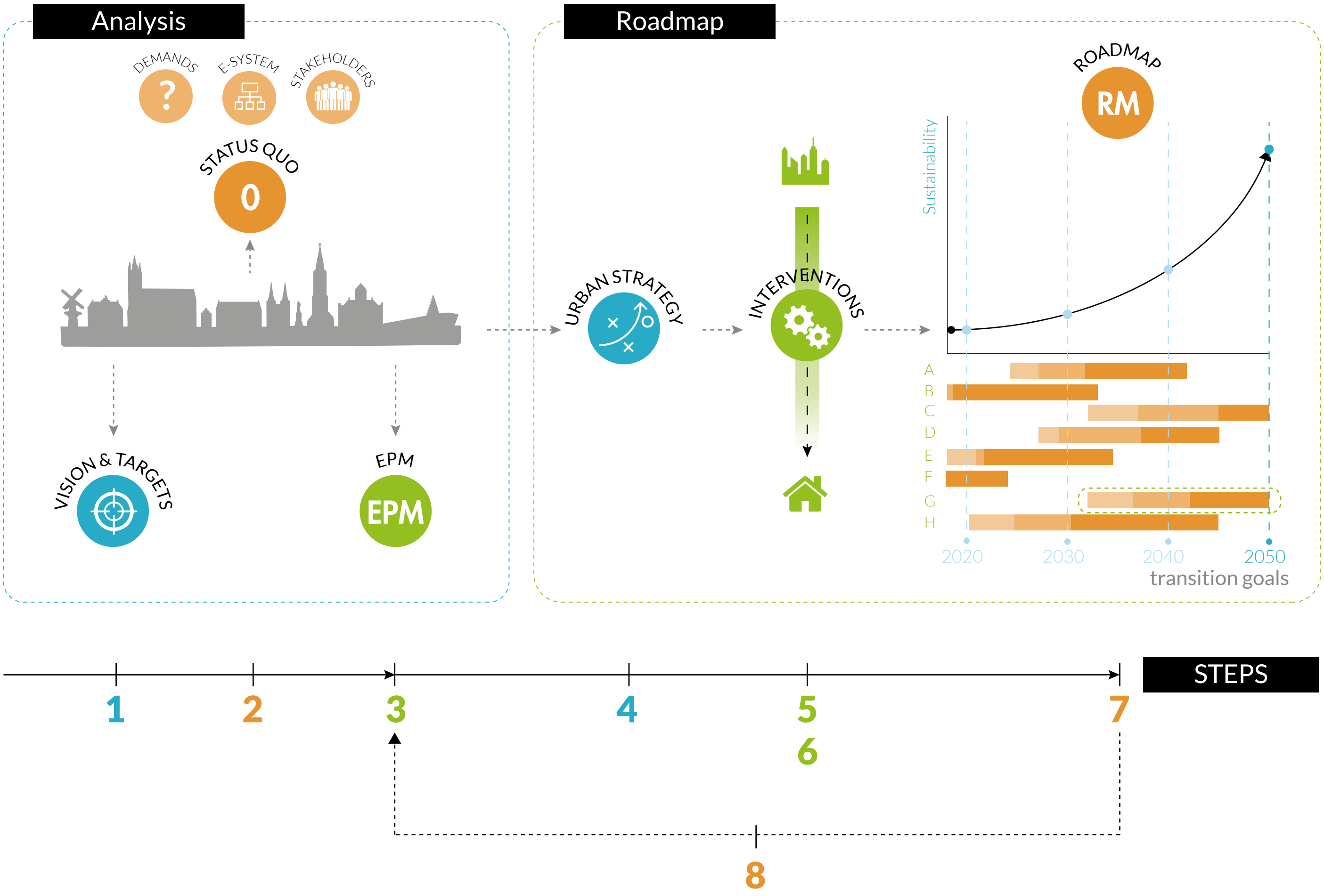


Figure 5.1: The methodology

5.1 The 8 step approach

The designed approach for the energy transition of Dutch cities exists out of 8 steps. In the first 3 steps the city will be analysed according to its characteristics, (transition) targets, energy system, demands, stakeholders and energy potentials. This will be the input for the Roadmap that will be created with steps 4-7. In these steps a scenario will be created that result in a strategy for the energy transition of the city. Also the resulting interventions at neighbourhoods and building scale will be determined. Finally these interventions at these different scales should be integrated into one roadmap including when, where and which interventions are applied. The last step is to keep evaluating and adapting the roadmap during the transition process.

1 Vision & Targets

1.1 Context & Vision

The first step towards the roadmap design starts with the analysis of the context, the main characteristics of the city. The typical characteristics of a city include history, building typologies, urban structure, functions, inhabitants and so on. This context analysis will help to formulate the vision for the energy transition of the city.

Each municipality has a vision on what kind of city they want to become in the future. The vision for the energy transition should include those goals that can affect the course of the transition. The vision should at least include the financial situation of the municipality; to what extent are they able to make a change? But even more important is their will to make a change. Therefor it's also important to analyse their relationship with important businesses and institutions inside the municipality. They should actively participate to succeed this transition. Beside that the connection between the city and its citizens is an important factor. To what extent are citizens willing to participate? But also to what extent they are able to participate? Finally the types of ownership of the buildings in the city is important because they will each require a different approach.

1.2 Targets & Milestones

Now the vision is created the final transition targets need to be defined. The achievement of these goal(s) should be assigned to a certain year. To simplify the road towards these goals the municipality should create milestones at short-, mid- and long-term. For example: with the final goals of energy neutrality in 2050 and the percentages of sustainable energy generation for 2020 and 2030 can be the milestones during the transition

2 Status Quo

To determine the interventions that should be taken to achieve the transition goals the current status of the targets and the existing energy-system should be analysed. This analysis consists out of 3 main parts:

2.1 Current demands & Status targets

To define the status of the targets the current demands should be calculated. These demands should be separated in demands of the households and the businesses, institutions and organisations: divided in thermal energy and electricity. Out of the calculated demands the current CO_2-emissions of the built environment will be calculated.

2.2. Current energy system & Initiatives

The current energy system will have a large influence on the final roadmap design. Therefor it is important to map the existing system. Especially the locations of heat networks and large heat cold storage projects are crucial. And if applicable also other sustainable energy systems and generation locations should be mapped. Beside that also the initiatives towards the energy transition should be analysed, because these will also influence the course of the transition.

2.3. Stakeholder analysis
An overview of the involved stakeholders and their influence towards the transition can be created with a Power-Interest matrix. This matrix will help to determine how to approach different stakeholders. In Attachment B different stakeholder groups are described and assigned to their position in the Power-Interest matrix.

3 Energy Potential mapping (EPM)

The last step of the analysis is to map the energy potentials inside the boundaries of the municipality. This will be the theoretical potential in the area. This means that limiting factors like finances and social resistance are excluded. Besides mapping the available energy potentials there should also be calculated to what extend the potentials are available and in case of thermal energy the temperature of the source needs to be determined too. The most important energy potentials that should be mapped are:
- Energy reduction potential: decreasing the energy demands of the buildings with energy retrofitting measures.
- Solar energy: available surfaces for PV, PVT and solar collectors.
- Wind energy: potential locations for wind-turbines.
- Biomass and fermentation to biogas: amount of wood from forest maintenance, animal manure, food and garden waste and sludge.
- Geothermal energy: the amount of heat (and temperature) in the aquifer at 2km depth and the potential output without exhausting the source.
- Thermal energy storage: the heat potential per hectares and presence of aquifers at 250m depth.
- Residual heat: the waste heat potential of the industries located in the municipality and the potential from small scale residual heat suppliers like supermarkets and datacentres.

4 Scenario & Urban scale strategy

4.1 Scenario
Based on the created vision and analysis a scenario for the transition of the city can be defined. This scenario is a set of assumptions that delimits the possibilities for the roadmap design and that finally results into a strategy which includes all the scales of the city. These assumptions should include to what extent energy savings will be achieved (for different real estate types) and the local renewables that can be implemented in the energy system. This also consists the scale on which the heat and electricity demands will be fulfilled. In Dutch cities the potential for sustainable electricity generation is small and above that the government is taking the responsibility for the electricity network by the realisation of an international electricity network and wind parks. The municipality should generate as much electricity

as possible and limit their peak demands. The thermal energy demands should be fulfilled self-sufficient with renewables generated inside the municipality. All the assumptions defined in the scenario will result in an energy balance between the current demands with the expected savings and the sustainable energy potentials.

4.2. Urban scale strategy
The created scenario will now be translated into an urban strategy for the city. For different building typologies the extent of the energy retrofitting should be defined; divided in moderate and deep retrofitting. Each of these will result in a different heat temperature demand, and they will thereby have their own specific energy system potentials. These can be derived from the **sustainable heating system tool**, see paragraph 5.2. The options for the heat system and sources are delimited by the created scenario in this step.

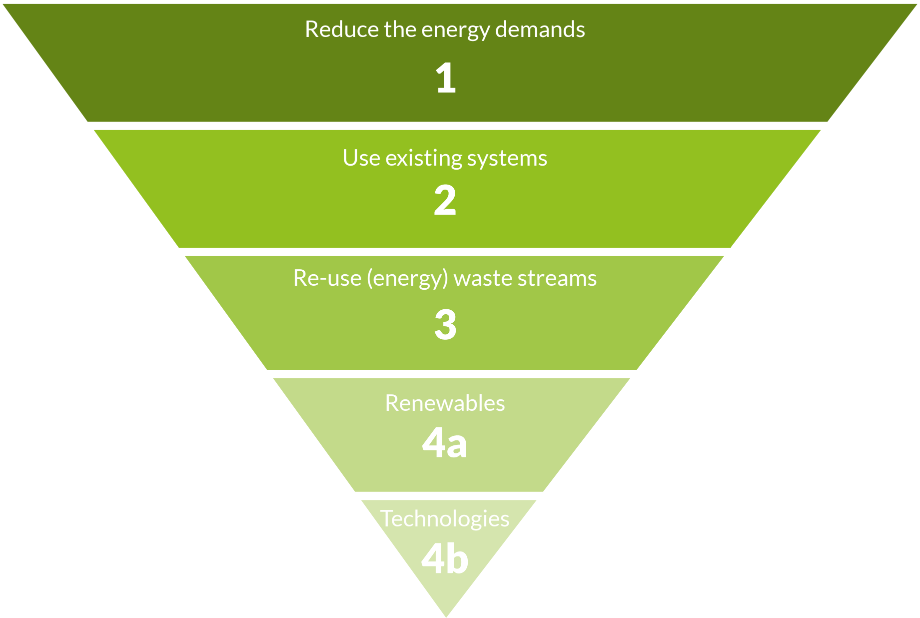
5

Interventions district scale

With this urban strategy the energy systems on district scale can be determined. This can be called the energy system potential mapping (ESPM). To simplify the final roadmap design this ESPM is divided in a few steps that prioritize the different interventions. These steps are based on the new stepped strategy, explained in chapter 4:

0. Determine the energy demands
1. Reduce the energy demands
2. Use the existing sustainable energy systems and potentials
3. Re-use of waste (energy) streams
4. Use renewable energy
    a. Energy that is already there, only has to be extracted
    Energy that is stored in the ground
    b. Energy that should be generated with added technologies
    PV(T) panels, solar collectors, wind turbines, etc.

For each step an energy potential map can be created showing the implementation locations for each of the available energy sources. Out of this catalogue a proposal for the energy systems per district/neighbourhood can be created, that will be implemented into the final roadmap.



6 Interventions neighbourhoods & Building blocks scale

The proposal for the heating systems in the city, requires interventions at neighbourhood scale. These interventions can be defined with the help of the **technology toolbox** of paragraph 5.3. After that consequences of the interventions towards the building blocks should be determined. What measures should be taken to heat the building with the proposed system? What are the energy savings that can and should be achieved and what interventions are required for these savings?

7 Final Roadmap

Finally the different interventions at urban, district, neighbourhood and buildings scale will be integrated in one roadmap. This roadmap will show which measures should be taken when to achieve the final transition goals. The required interventions are and their scale are already determined in steps 4-6. In the roadmap they will be integrated at a timeline: which interventions should implemented first, which the latest and why?

8 Evaluate & Adapt

The last step of the methodology is the keep evaluating and adapting the roadmap during the transition process. Thereby new technologies can be implemented in the energy system. The evaluation process restarts at step 3 and repeats all steps again until the final roadmap.

5.2. The sustainable energy system tools

In step 4 a strategy is developed for the energy transition of the city as a whole. This strategy describes the energy savings per building type in the city, resulting in a certain minimally required heating temperature for that building. This heat can be supplied with different heating systems. The sustainable heat systems tool schematized the potential heat systems for each required heat temperature group, divided in high, mid, low and very-low temperature heating.

5.2.1. Sustainable heat system tool

This tool (visualized on the next page) gives an overview of the possible heat systems that can be applied in the built environment on two scales: individual systems for buildings (blocks) and collective networks for districts or neighbourhoods. For each heat temperature group the potential heat systems are shown (horizontally). In total four main heating systems can be distinguished (concluded out of part I):

1. Biomass (I)
2. Biogas (I)
3. All-electric (II)
4. Heat networks at different temperature levels (III-VI)

In the black circles the possible heat sources per system (I-VI) are shown. Beside that the diagram shows for each heating temperature the required energy retrofitting level and the heating installations that should be implemented in the building to be heated with a certain heat system (I-VI).

Application

This tool can together with the energy potential mapping outcomes be used to map the heat system potentials for each district/neighbourhood. These maps give an overview of the potential heat systems that are applicable in a certain area.

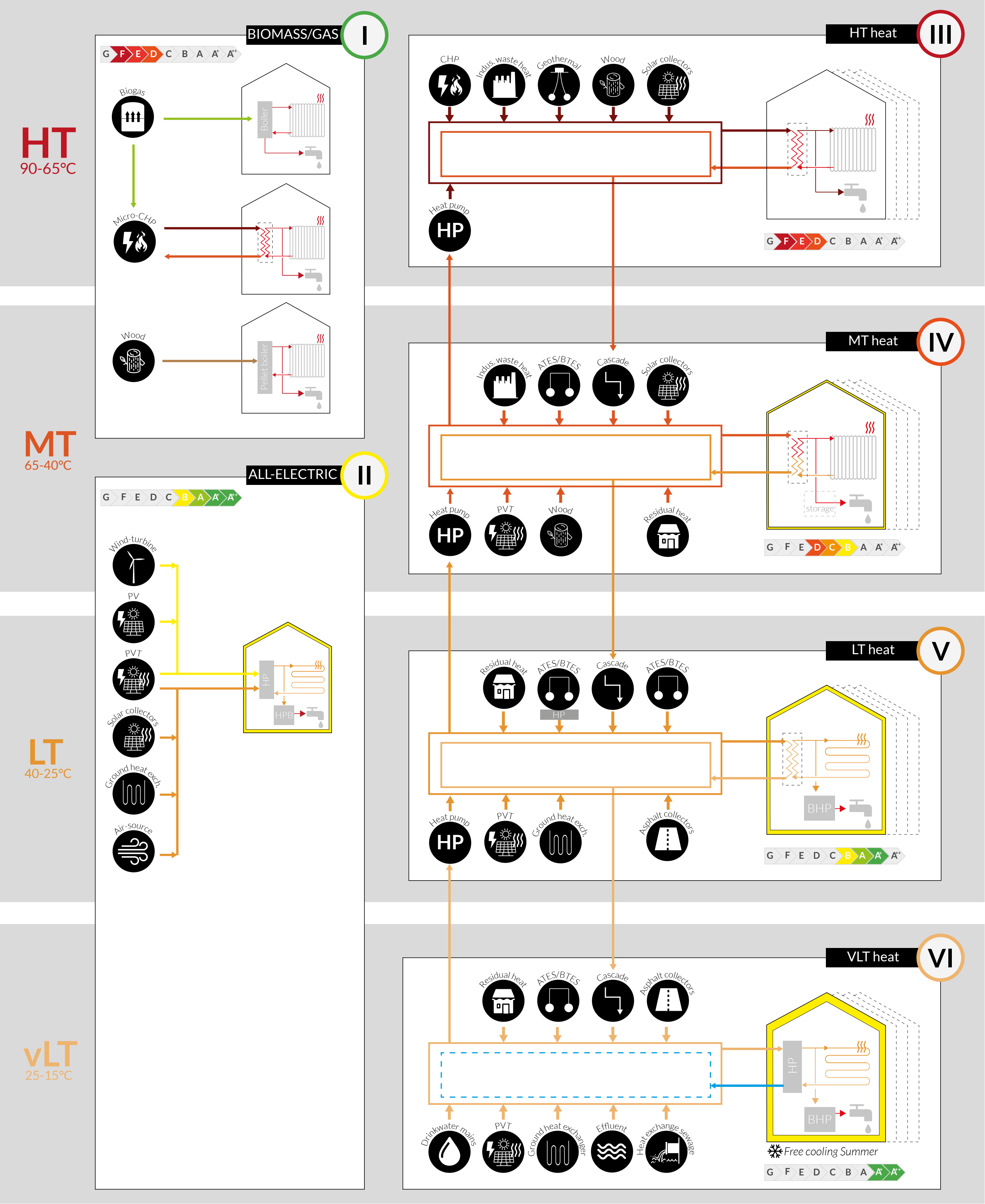
The following guidelines should be used next to the heat system tool:

- High temperature heating (high-energetic energy) should only be used when there is no other option. High temperature heat should never be used for low temperature heating purposes.
- If a sustainable infrastructure is already present this infrastructure should be used, only the current heat source has to be replaced with a renewable heat source.
- A heat network should only be expanded or constructed to provide a high density area (lot of costumers) with heat. Thereby low-density areas demands can only be fulfilled with individual heating systems (column 1).
- High temperature heat networks are very expensive (insulation) and have smaller energy potentials than low-temperature heat networks.
- When a few buildings with a higher temperature demand are connected to a lower temperature heat grid the temperature can be upgraded with an individual heat pump in these buildings.

SUSTAINABLE HEAT SYSTEMS

Individual systems
Building (block)

Collective systems
Urban-district-neighbourhood scale



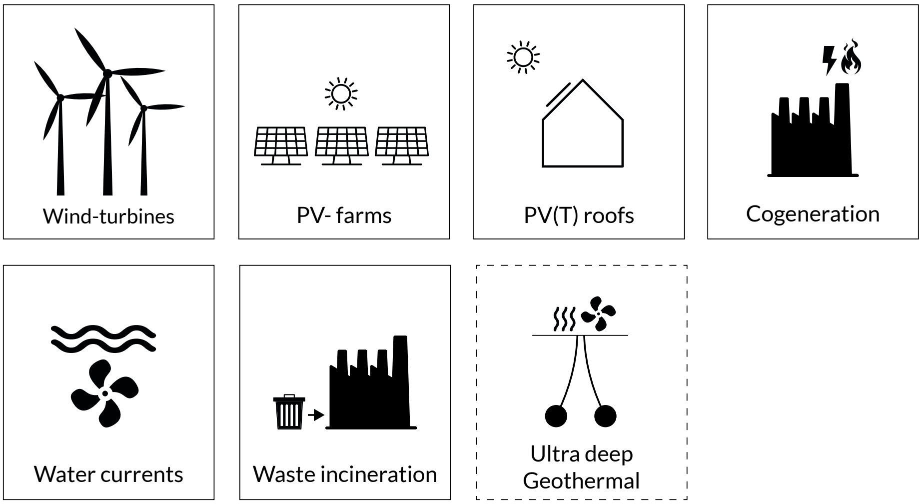


Figure 5.3: Diagram with possible centralized electricity potentials.

5.2.2. Electricity systems tool

Electricity generation in a city will mostly be done with centralized systems:
- Wind-turbines;
- PV-farms on empty plots or along high-ways/train tracks;
- PV(T) on building roofs;
- Cogeneration with biogas;
- Water currents in rivers;
- Waste incineration;
- Ultra deep geothermal (generator): not applicable in the Netherlands yet.

The potentials for these sources will be mapped with the Energy Potential Mapping (step 3). While mapping the potentials the choice for PV, PVT and solar collectors on available roof surfaces should be well considered. For Dutch cities at least about 70% of the suitable roof surfaces should be reserved for PV panels, to minimize the requested demands from the national grid. At the same time all-electric systems should mazimally heat 10-15% of the buildings to limit the peak demands.

5.3. The technology-toolbox

After a proposal is made for the energy systems per district the next step is to define the therefore required interventions on neighbourhood and district scale. In Attachment C for each heat system and heat source the interventions are schematized in sections and diagrams.

5.4. Conclusion

This chapter intended to give answer to the second part of the main research question: '***How should the approach, for the energy transition of the built environment of Dutch municipalities that helps to create a roadmap that integrates technical interventions at different scales look like?***'.

The complexity of the energy transition will be decreased by creating clear steps that should be followed in order to come to a final roadmap for a certain city. These steps are divided in two main parts. The first part focusses on the analysis of the energetic context and vision of the city. This forms the basis for the next part; the design of the roadmap.

By defining a clear vision in step 1 the optional outcomes of the roadmap are delimited. An overview of the potential energy system and sources is provided by the sustainable energy system tool. Together with the energy potential mapping and the scenario the municipality can now define the energy systems that can be implemented. Finally the chosen energy systems can be translated into required interventions on both neighbourhood and building scale. This results in an integrated roadmap on all scales.

Thereby there can be concluded that a methodology that to decrease the complexity of the energy transition of the built environment and to help creating a roadmap that integrates technical interventions at different scales clear steps should be defined. This approach will start with the analysis of the current situation, leading to a scenario for the energy transition of the city that finally results in a proposal for the energy systems and interventions that are required to succeed the energy transition.

In the next part this approach is applied to the city Delft to design a roadmap for the energy transition towards energy neutrality.

PART III

THE ROADMAP FOR DELFT

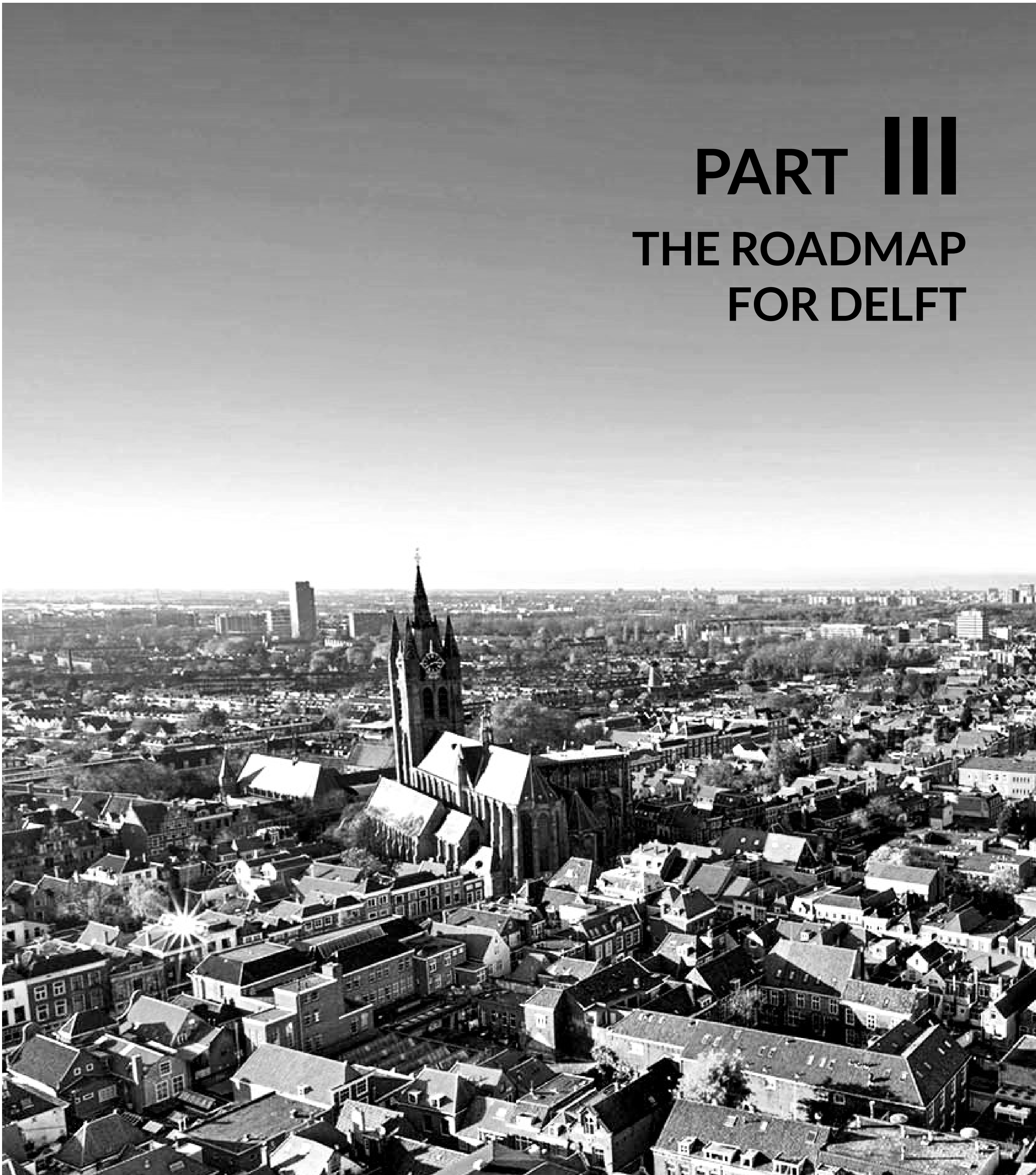
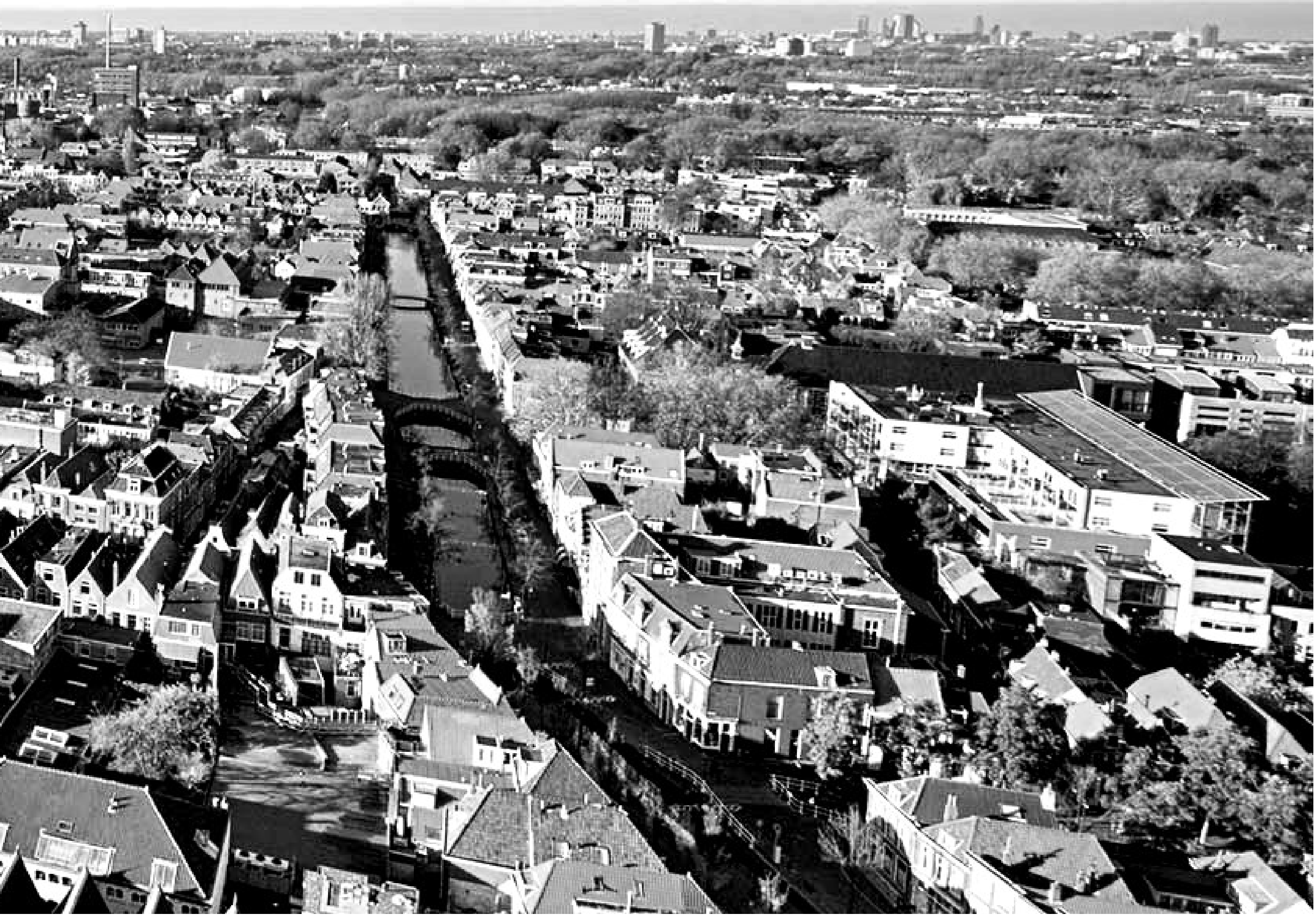


Figure III. Air photo of the city Delft (Delft Solar City, 2015)

In the previous part the approach for the energy transition of Dutch municipalities towards an energy neutral built environment is defined. This approach is based on the analysed existing energy transition methodologies but does also include the outcomes of the roadmap for the city Delft, as determined in this part, III. The roadmap and approach were design simultaneously after analysing the existing methodologies.

In these chapters the roadmap is designed by following the steps of the approach and by using the sustainable heat systems tool and the technology toolbox. Resulting in a roadmap that will integrate the interventions that use local energy potentials and that will be integrated on all scales of the city: urban, district, neighbourhood and buildings scale. Thereby this chapter will give answer to the first part of the main research question: '***How should the roadmap for the energy transition of the built environment towards energy neutrality for the city Delft look like, with technical interventions based on local sustainable energy potentials integrated at different scales?***'.



06

Vision & Targets

The first step of the approach towards a roadmap for the energy transition of Delft is to generate a vision for the energy transition, based on the characteristics of the city and the themes that the municipality includes in its future vision for the cities developments. During the design of the roadmap this vision will be translated into a scenario for the energy transition of the city, resulting in the final proposal for the roadmap. After the vision is defined the energy transition targets will be set. Thereby this chapter gives answer to the sub-question: ''***What are the energy transition goals of the city Delft?***''.

Figure 6.1. TU Delft campus (Mecanoo, 2014).

6.1. Context Delft

Before a roadmap can be developed its important to achieve some knowledge about the background of the city dealing with. Therefor the roadmap design first starts with the analysis of the context, the main characteristics of the city. Above that this context will help to formulate the vision in the following sub-step.

6.1.1. Characteristics

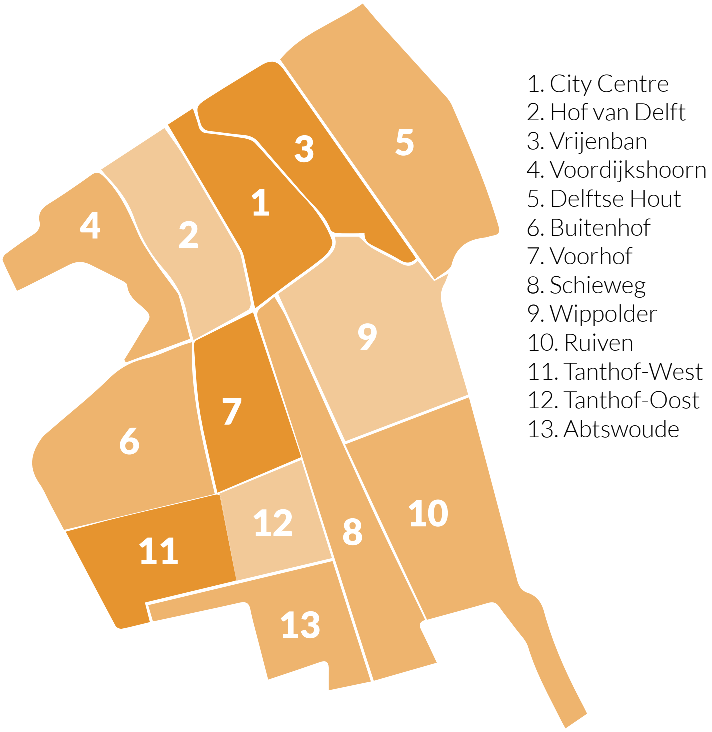
The city Delft is famous is two major ways: Delft as knowledge city and as Historical city. The historical city centre of Delft annually attracts many tourists. Most buildings are constructed before 1900 and thereby the city centre locates a lot of protected monuments.

While Delft is a city with a great history the slogan of the municipality currently is ''making history''. In 2017 the technical university, TU Delft did exists for 175 years and thereby the municipality gave this year the theme: City of Technology (Delft.nl, 2017). Beside the TU Delft other research institutes are located in the city, like TNO and Deltares. Both university and these institutions are well known for their technical knowledge and innovative inventions. Above that Delft is currently seen as one of the leaders of the Dutch energy transition (Leguijt et al., 2011).

Figure 6.2. Monuments in Delft (Rijksmonumenten, n.d.).

6.1.2. City structure

Around the city centre the districts Hof van Delft, Vrijenban and Wippolder can be found. These districts are the first expansion areas of Delft and are mainly constructed between 1900 and 1945. Between the sixties and the eighties the city started expanding more quickly with new neighbourhoods in the adjacent districts. The northern districts of Delft still have a very low density with a lot of green and recreational areas. However even by including these green areas the city has a very high density and has spatial a little potential for expansion (Leguijt et al., 2011).



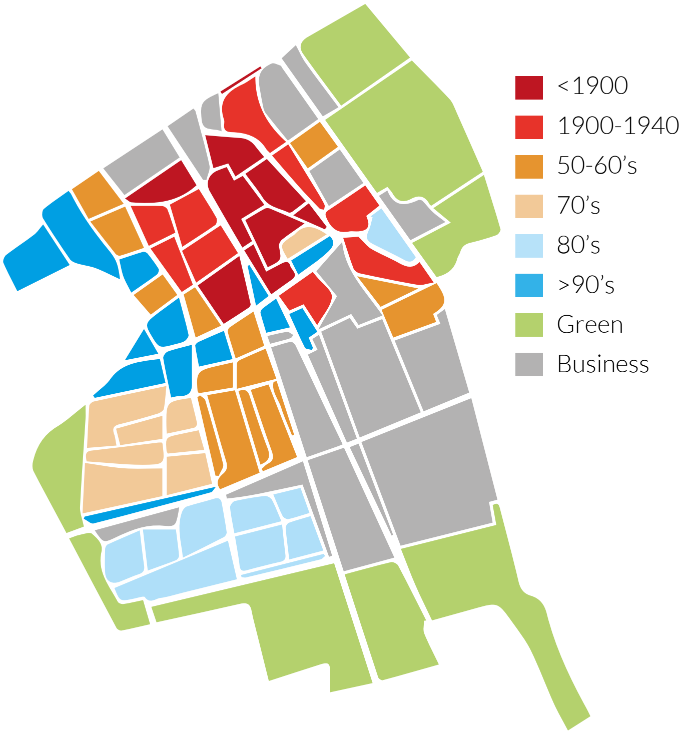


Figure 6.3. Districts of Delft (by Author).

Figure 6.4. Construction date neighbourhoods in Delft (by Author).

6.2. Vision

In the "Woonvisie 2016-2023" the municipality of Delft is focussing on two main themes that can affect the course of the energy transition. The first theme is becoming the city of technology by profiling as an international knowledge city. Instead of being a historical city they want to become a city that is "Making history". The other theme is creating a coherent city (Gemeente Delft, 2016). Another important factor that affects the energy transition is the problematic financial position of the municipality.

City of technology

The municipality wants to collaborate with the TU Delft and the companies at the TIC (Technological Innovation Campus). These companies and knowledge institutes have the required knowledge and expertise at the field of the energy transition. The municipality wants to mobilize and apply their knowledge into the energy transition (Gemeente Delft, 2016). Being an energy neutral city and leader in the transition can positively boost the status of the city as city of technology.

Coherent city

The municipality wants to increase the solidarity in the city. The citizens should feel connected to their city and thereby contribute to a better living environment in the city. The municipality wants to stimulate their involvement in the developments of the city (Gemeente Delft, 2016). This should increase their will to contribute to the energy transition of the city. These initiatives will also be stimulated with subsidies from the national government and by programs that have the intention to increase the awareness of climate change and the importance of the energy transition. The municipality aims to provide clear outlines of measures that individual households can take to make a contribution.

Finally a relatively large share of Delft's citizens will find the climate change such an important topic that they will contribute by energy retrofitting of their residences. This assumption is based on both the aim of the municipality to create a more coherent city and the results of the last national election of 2017. In this election the citizens of Delft did vote in large amounts for Groen Links, a political party with the largest program in climate change and sustainability. Groen Links became the third biggest party in Delft, with 14,3% of the votes compared to 9,1% in the whole Netherlands. The biggest party in Delft D66, with about 1/5 of the votes, also has a relative large focus on those topics (Reedijk, 2017).

However besides being willing to contribute to the transition citizens should also be financially able to contribute. In Delft 12,7% of the households lives from a low income and even 10,5% has an income around or below the social minimum, which is higher than the national average (www.cbs.nl). Thereby a large share of the households is living in energy poverty. This increases the importance of lowering the energy bills. These energy bills can be decreased by energy retrofitting of the buildings; more efficient heating installations and less energy losses through the building envelope. This doesn't only result in a lower energy bill, but also increases the indoor climate and liveability of the residences. These renovations cannot be paid by these low income households. However these citizens are mostly renting their residence from a housing corporation. In total in Delft 47% of the residences is property of housing corporations. This is an advantage for the transition because both municipality and corporations are aiming to upgrade all these residences to minimally label B by 2020. For the private rental sector the municipality aims to upgrade 80% of the residences to label B by 2020 (Gemeente Delft, 2016).

Financial situation & transition goals

The financial situation of the municipality is a problem for the development of the transition. The costs for the transformation of the Spoorzone (area of the train station) were much higher than expected, resulting in large financial problems (Huiskamp & Verlaan, 2016). Thereby they will probably not be able to do large investments. For construction of geothermal, energy networks or subsidies the money should mainly be coming from investors and higher governmental institutions. For example the new sustainable innovation fund of the province of South-Holland.

Figure 6.5. Vision on the energy transition of Delft 3 themes (by Author).

6.3. Targets & Milestones

The municipality of Delft is opting for energy neutrality; thereby CO2-emissions coming from fossil fuels won't be released anymore. With this transition the municipality wants to guarantee the energy supplies, make sure energy stays affordable and keep a clean environment for the citizens (Gemeente Delft, 2013).

CE Delft uses the following definition for an energy neutral city in the report 'De weg naar een energieneutrale gemeente' (Leguijt, 2011): ''Only energy of renewable sources (sun, wind, biomass, geothermal heat) will be used for heating, cooling, illumination and other processes (ICT, industrial processes, etc.) of all buildings (residences, offices, business premises) and for all the traffic and transport in between the city boundaries of Delft.''

In this thesis energy used for traffic and transportation is excluded. An energy neutral municipality doesn't only focus on CO2-emmisions, but tackles the issues at the basis by transforming the energy system. Not all energy has to be generated in the boundaries of the municipality. The generation of renewable energy at other locations is allowed, like electricity generation with offshore windmills (Leguijt, 2011). However this should be limited as much as possible because of a self-sufficiency ambition.

The energy goals of Delft are divided in short, medium and long-term goals (Gemeente Delft, 2013):

2020

- Out of the total energy consumption in Delft 15% will be generated with renewables;
- The energy demands are decreased with 35%.

2030

- 25% of the total energy consumption is generated sustainable;
- The energy demands are decreased with 50%.

2050

- Delft will be energy neutral.

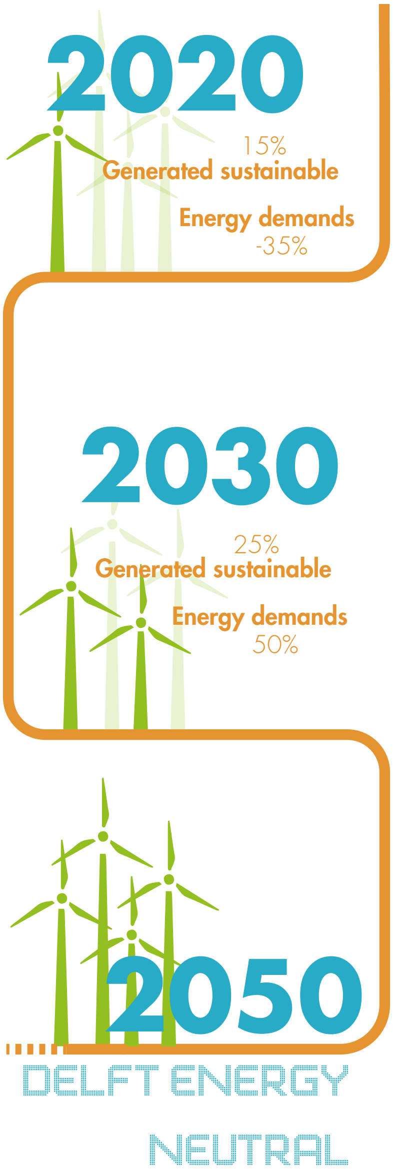


Figure 6.6. Energy goals of the city Delft divided in 2020, 2030 and 2050 (by Author, based on: Gemeente Delft, 2013).

In the original goals of 2013 also the CO2 reduction goals compared to 1990 were included. However these are now excluded from the transition goals because the CO2 reduction is compared to the situation of 1990, whereof the demands and CO2-emissions are unknown. Above that the CO2-emission are for most of the citizens a little known concept (R. Dijkgraaf & NAME, Gemeente Delft, personal communication, November 20, 2017).

In figure 5.6 the final energy transition goals for Delft are summarized, thereby an answer is given to the sub-research question: ''What are the energy transition goals of the city Delft?''.

07

Status Quo

Now the vision and transition targets are determined the starting point should be defined. This second step of the approach aims to determine the 'Status Quo' of the transition: ***"How does the current energy system of the city Delft work, concerning its demands and supplies and which initiatives are already taken towards a sustainable energy-system?"***. Therefor the current energy demands and the current energy system should be analysed together with the planned or already introduced initiatives concerning the development of the energy network. These findings will have a significant influence on the course of the transition and thereby on the final design outcome of the roadmap.

7.1 Energy demands

The energy demands of the city Delft are calculated with data from two databases: data of CBS (Dutch statistics) and Klimaatmonitor (maintained by the Ministry of Infrastructure and Environment).

To determine the energy demands the primary energy consumption (measured with the energy meter) should be multiplied with the efficiency of the heating installation. For electricity the energy demands are equal to the energy consumption because no conversion takes place between the grid and the building.

7.1.1. Energy demands residences

The CBS database contains the average electricity and gas consumption per residence for each district in Delft. Also the amount of residences per district can be found here. Thereby the electricity demands could be calculated easily. For the gas demands some more steps had to be taken, because not all residences are heated with a gas installation. According to figure 7.2 the heating systems in Dutch households are as followed (Gerbus, Marbus et al., 2016):

- 2% heat pump
- 3% local heating
- 12% heat network; in this calculation city-specific data of CBS is used.
- The remaining residences are heated with a gas installation, whereof:
    - o 89% a high efficiency boiler with an efficiency of 90%.
    - o 10% improved efficiency installation with n=80%.
    - o 1% conventional installation with efficiency of 75%.

With this data the total heat demands of residences heated with gas can be found. Dividing the heat demands by the amount of residences heated with gas gives the average primary gas consumption. These are multiplied with the average Dutch efficiency of heating installations (88,9%) and give the final heat demands. Because these final demands are independent form the heating installation this average can be taken for all residences. Finally this average per residence is multiplied with 98 percent of the residences. Because the two percent heated with a heat pump don't use thermal energy but electricity for heating. The calculation can be found in attachment D.

Table 7.1 a/b: Electricity and heating demands Residences Delft (by Author).

Electricity	[GWh]	[GJ;el]	per hectare [GJ;el/ha]	Average per household [GJ]
Total Delft	124,1	446.649,8	185,6	9,1

Thermal energy	Gas demands				Heat demands	
	[m3, primair]	[GJ;th, primair]	[GJ;th]	per hectare [GJ;th/ha]	Average [GJ] per household	Total [GJ] per district
Total Delft	44.895.931,3	1.420.956,2	1.262.519,6	590,6	27,9	1.345.883,5

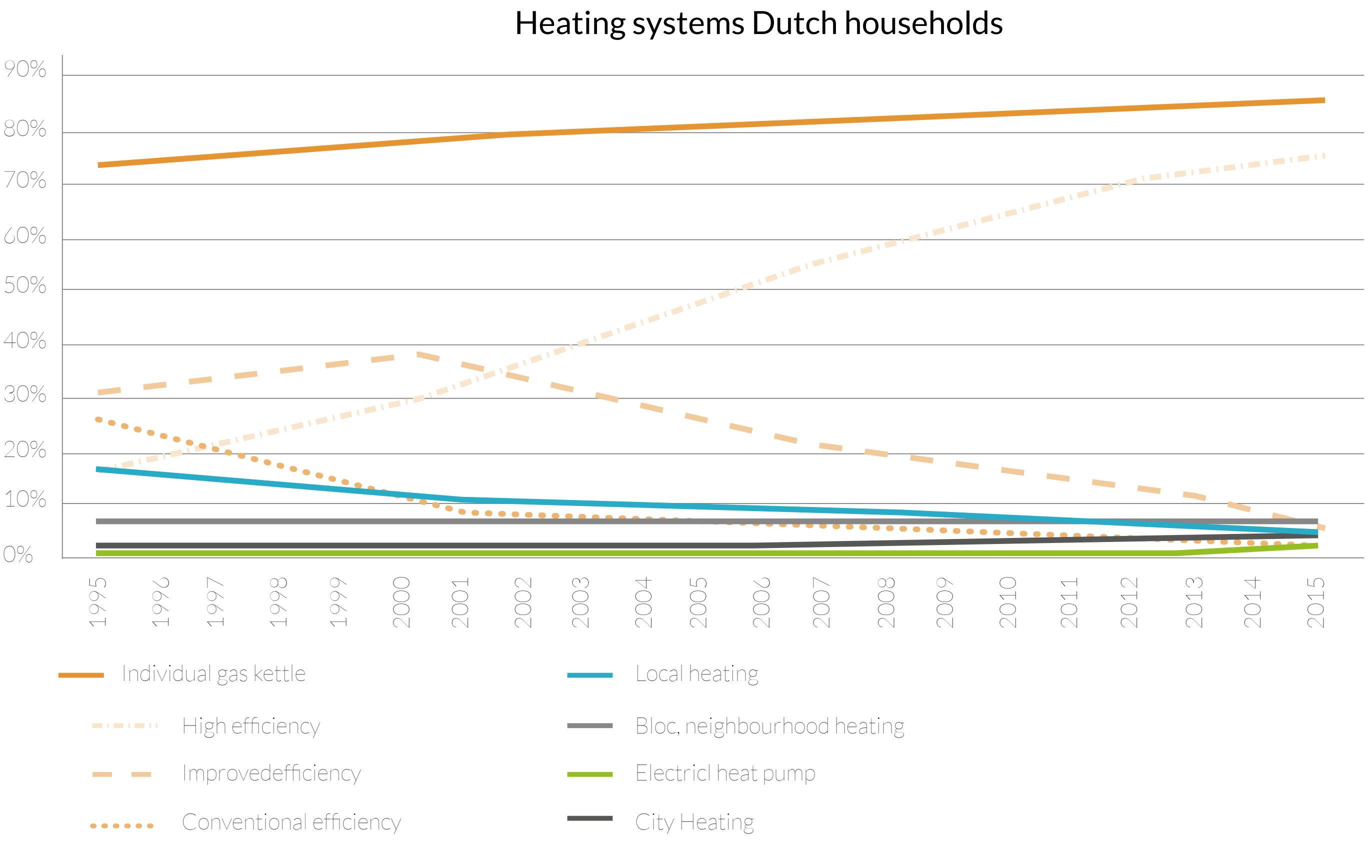


Figure 7.2. Different types of heating systems used in Dutch households between 1995 and 2015 (Gerdes, et al. 2016, p12).

7.1.2. Energy demands businesses

The energy demands for the businesses are harder to define. CBS doesn't give information about the energy demands of businesses in Delft. CBS does give information about the amount of businesses in the city and their division over the neighbourhoods according to SBI2008. SBI2008 assigns each business to a certain group. To find the energy demands the data of klimaatmonitor is used. This database gives insight in the total energy demands per SBI sector in Delft. Combining the data of Klimaatmonitor and CBS the average demands per sector and the demands per sector per district could be found, see attachment D3.

However the CBS data excluded SBI groups with governmental institutions, education and health care. Thereby the amount of businesses in this sector where unknown. Of all SBI group the demands of education were far-out the biggest according to Klimaatmonitor. This is mainly caused by the large demands of the TU Delft; found on energymonitor.tudelft.nl. In the attachment the TU Delft demands are subtracted from the total demands of the education sector and placed in a separate group.

The total amount of public services in the governmental institutions, education and health care groups are taken from energieinbeeld.nl and equally divided over 9 districts (all districts except the low density areas: Delftse hout, Abtswoude, Ruiven and Schieweg).

Figure 7.3 Energy demands in TJ per SBI sector in Delft (Rijkswaterstaat, 2017).

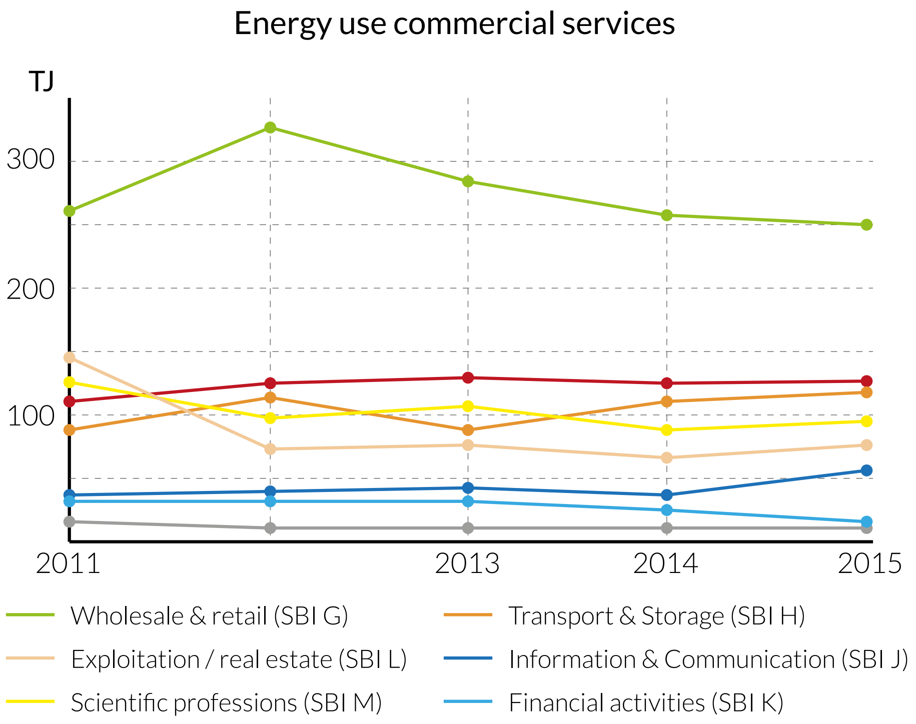


Table 7.4 a/b. Gas and electricity demands Business sector Delft (by Author).

Electricty	[kWh]	[GWh]	[GJ;el]	[GJ;el, per business]
Total Delft	231333736,2	231,3	832801,5	115,5

Thermal energy	[m3]	[GJ;th, primair]	[GJ;th, total]	[GJ;th, per business]
Total Delft	31171656,4	986582,9	876578,9	121,5

Table 7.5. Energy demands of the municipality of Delft in 2015 (by Author).

		Total demands [PJ]	Total CO_2 emissions [kton/year]
Residential	Electricity	0,45	73,2
	Thermal energy	1,35 (1,26 gas)	79,9
Businesses	Electricity	0,83	136,3
	Thermal energy	0,87	55,5
Total	Electricity	1,28	209,5
	Thermal energy	2,22	135,4
	Total	3,48	344,9

7.1.3 Total energy demands Delft

To validate the outcomes the calculated demands are compared with the CO_2-emission in the built environment of Delft according to the Klimaatmonitor for 2015: 338,4 kilotons CO_2 (www.klimaatmonitor.databank.nl). According to the calculation the final CO_2-emissions of the built environment are 344,9 kilotons CO_2. The deviation is relatively very small. Thereby the calculation can be assumed as right.

Figure 7.6. Water Treatment plant Harnaschpolder (Zoethout, 2015).

7.2. Current energy system & Initiatives

To be able to make a strategy for the transition to energy neutrality in Delft the existing energy system and the taken initiatives should be analysed first. Therefor it's mainly important to map the heat networks and if applicable other sustainable heating systems like large thermal energy storage projects. Beside that the current amount of electricity generation with photovoltaics will be determined.

7.2.1. Existing heat network

Delft locates three main heat networks. A network in the North-West that delivers heat from a water treatment plant, a network fed by boiler on natural gas at the Poptahof and the third network that feeds the university campus. In Voorhof-East a non-active heat network is found.

Figure 7.7. Heat station Harnasch polder (Harnasch foto, 2012).

Harnaschpolder

Just outside of Delft the water treatment plant Harnaschpolder is located. This is the biggest water treatment plant of the Netherlands and purifies about 250.000m3 water a day; originating from about a million citizens and 40.000 companies located in and around The Hague and Delft. The effluent with a temperature between 12°C and 20°C is pumped to a heat station. With three boilers, a CHP installation and a heat pump this station has a total output of 12,5MWth (394200GJ). The heat pump upgrades this heat to 70°C and delivers it to the heat network in Delfts neighbourhood Den Hoorn (Gemeente Delft, 2011; Stowa, 2013).

Poptahof

The Poptahof neighbourhood is currently undergoing large renovations. Beside these renovations some buildings are destructed and replaced by 1000 new residences and a park (the Arkropolishof). At the same time the existing district heat network on natural gas is upgraded and expanded with the connection of 88 new student houses and a sport centre in the adjacent district in Buitenhof to the network (Gemeente Delft, 2011).

Figure 7.8. New buildings in the Poptahof (RVO, n.d.).

Voorhof-East

This neighbourhood locates an inactive heat network with outdated combined heat power installations. However the network has the potential to be upgraded and re-used again with a renewable heat source. In figure 7.9 the heat network is visualized (R. Dijkgraaf & M. Kaiser, Gemeente Delft personal communication, November 20, 2017).

Figure 7.9. The existing inactive heat network in Voorhof-Oost (based on: Schild, et al. 2017).

Thermal network TU Delft

The heat system of the campus can be divided in two parts: the heat network above the Kruithuisweg and the Technopolis complex below, which is heated with thermal energy storage on low temperature. The aerospace university building, below the kruithuisweg, is the only exception and is also connected to the heat network. The thermal network of the campus is since 2012 in transformation to a Smart Thermal Grid. This as part of the aim of the university to in 2020 decrease the CO_2-emissions of the campus with 50 percent compared to 2012. Before the transformation the campus buildings were heated with a high temperature network of 100-130°C. The network is currently fed by a combined heat power plant on natural gas that delivers about 20-25 percent of the universities energy demands.

To achieve a CO_2-reduction of 50 percent energy retrofitting of the buildings won't be enough; sustainable energy sources should be used. To be able to use these energy sources the heat network should be transformed from a high to a mid-temperature network of 70-80°C. Therefore the buildings with the highest CO_2-emissions per square meter need to be renovated or even closed.

The network exists out of four heating tracks. Currently these tracks are separated and do now each have a different temperature level. Thereby the highest requested temperature doesn't determine the temperature of the full network anymore, but only the temperature of one track. In the next phase the requested temperatures by the buildings will be decreased with energy savings measures. In one of the tracks the temperature is already brought down with a return temperature of 50-55°C. This lowered return temperature will be needed to maximize the utilisation of the future geothermal source (Hellinga, 2014; C. Hellinga, personal communication, November 3, 2017).

Figure 7.10. Heat network TU Delft (Schmidt, et al., 2013, p19).

Geothermal energy
To increase the share of energy generated with renewables a geothermal well is planned. Around spring 2018 there will be decided if this geothermal source will be constructed or not. The Delft Sandstone Aquifer at 2km depth will deliver about 0,2PJ of heat per year with a temperature of 73°C. The capacity of the source will be sufficient to supply the heating demands of the campus, even during extreme cold weather conditions. However during most of the heating periods the capacity of this geothermal well will exceed the demands of the campus. The remaining heat is planned to be supplied to 1.500 residential units in Voorhof-East. To use the geothermal energy the return temperature of the building heat should be decreased to 40°C. This should be achieved with building renovations in the Voorhof and optionally with further cascades to for example the New Delft area or the greenhouses around Delft. Another option is to bring the temperature down with a heat pump.

Beside heat the production well will also extracts gas (for each m3 water, 1m3 natural gas is released). Thereby 20 percent of the extracted energy is fossil energy. Because this energy cannot be pumped back into the injection well and at the same time cannot be used in the natural gas network, the gas will be used locally in the existing cogeneration plant.

(Hellinga, 2017; C. Hellinga, personal communication, November 3, 2017)

The heat roundabout of South-Holland

In 2020 the province of South-Holland wants to realize a regional heat network: ‘the heat roundabout’ (de warmterotonde). This network of will connect industrial waste heat from the Rotterdam harbour (of 110°C) with the greenhouses and households in South-Holland. This system will not be sufficient anymore when the energy transition is finished, but will be a useful source during the transition process. Finally the network will be fed with sustainable heat sources, mainly geothermal energy (Bothof & Pijpers, 2015; Vermeulen & Willemse, 2016). In recent plans of Gasunie and HBR the heat roundabout will also pass through the city. This creates a great opportunity for the municipality to supply a large share of the households with collective heat during the energy transition process (C. Hellinga, personal communication, November 3, 2017).

7.2.2. Large thermal energy storage projects

Beside thermal network there are also sustainable thermal energy storage projects in Delft. The biggest projects are summed up in table 7.12.

Figure 7.11. Heat roundabout South-Holland (Green Deal 2015).

7.2.3. Solar energy Delft

In 2016 the TU Delft realised as part of their ambition 1000m2 of PV panels on their roofs, delivering about 1GWh electricity per year (RVO, n.d.). To further increase the amount of PV panels the initiative Delft Solar City is founded. In this project people can rent solar panels on roofs of other buildings or they can make their own roof available for solar panels (www.delftsolarcity.nl). Currently solar panels are already placed on the roofs of schools and DUWO buildings (student Housing Corporation).

7.3 Conclusion

This chapter aimed to answer the question: "How does the current energy system of the city Delft work, concerning its demands and supplies and which initiatives are already taken towards a sustainable energy-system?". Therefor the current situation, the status quo, was analysed.

Delft currently has a total energy demand 3,5PJ of which 2,2PJ is thermal energy. While the thermal energy demands are mainly determined by the households, the electricity demands are mostly originating in the business sector. At the moment these demands are mainly supplied by the natural gas network. Delft only has three thermal heat networks, of which one with a quite sustainable source: the effluent of a water treatment plant. The heat network at the TU Delft campus is undergoing large transformations towards a sustainable heat network by energy retrofitting of the buildings and adding a geothermal source. Furthermore the planned heat roundabout will have potential for the deliver industrial waste heat to buildings in the city, which will help to start-up the energy transition. In figure 7.13 an overview of these heat networks and initiatives is created. In the following chapter the analysis of the city will be finalized with the Energy Potential Mapping.

Table 7.12. Large heat cold storage systems in Delft. Based on: WKO tool

Location	System	Description
Zuidpoort	Vertical heat exchanger with collective heatpump	Heats up to 14.000m2 of shops and hospitality functions, 20.000m2 residences, 5.000m2 culture/other functions
5 TU Delft buildings	Individual vertical heat exchangers with heat pumps	5 individual buildings, like the University library
Hospital	Vertical heat exchanger with heat pump	In 2015 opened Reinier de Graaf hospital is one of the most sustainable buildings in Delft. The heat demands are furfilled with a heat pump and heat cold storage.
Bomenwijk	Open heat cold storage with individual heat pumps	101 residences (row)
Delftechpark	Open heat cold storage	2 Open heat cold storages for two collective business buildings
TNO Zuidpolder	2 Vertical heat exchangers	TNO complex heated with two vertical heat exchangers and heatpumps
New Delft	Multiple vertical heat exchangers and individual heat pumps	Coendersbuurt (residences), high school Delftland and the combined municipality and trainstation.
IKEA	Open heat cold storage	IKEA Delft heated with heat cold storage.

EXISTING SUSTAINABLE ENERGY SYSTEMS & INITIATIVES

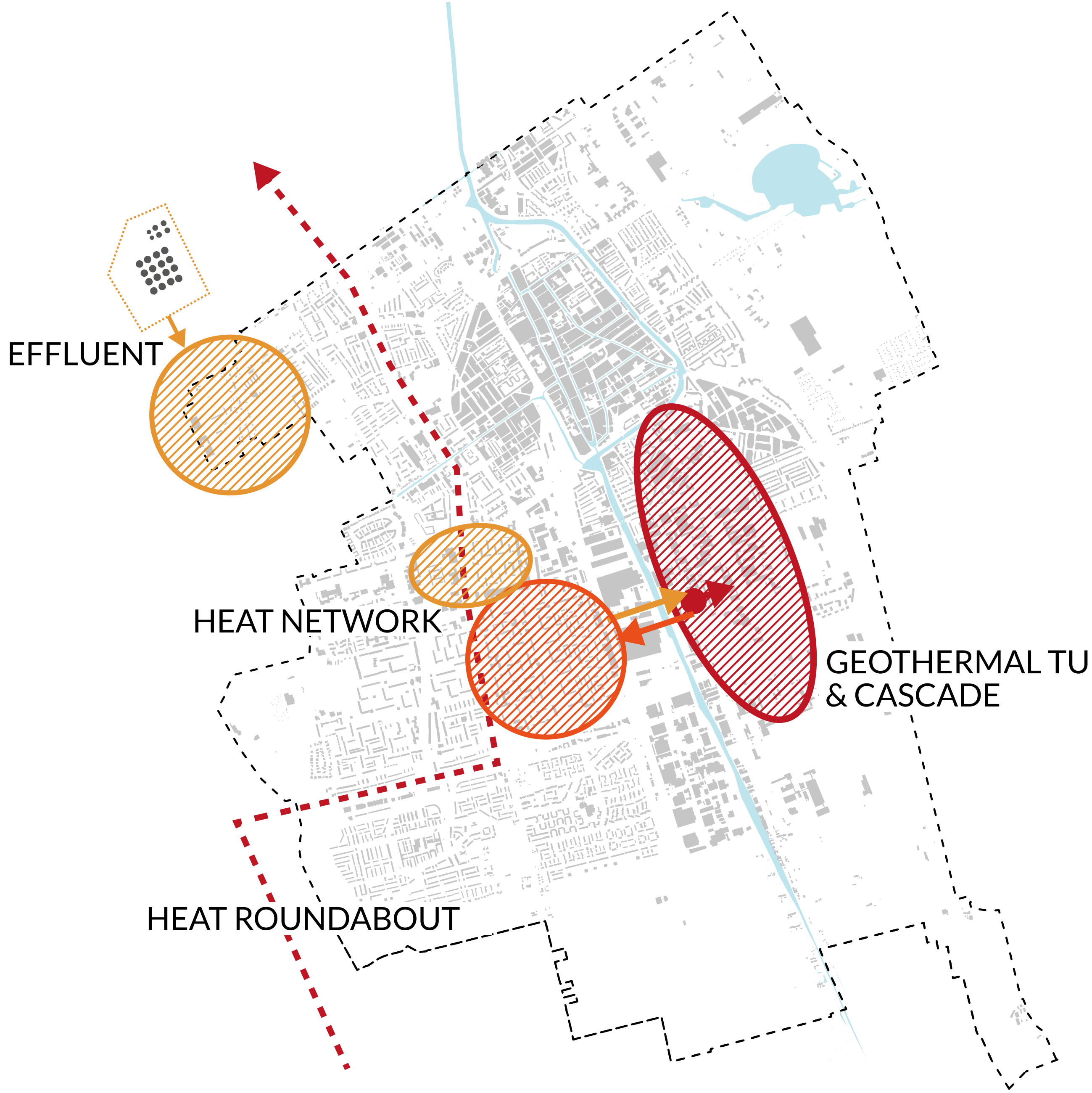


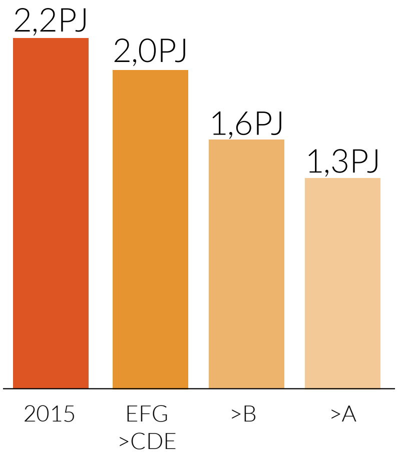
Figure 7.12. Map of the current Heat networks, including new planned initiatives (by Author).

08

Energy Potential Mapping

In the last step of the analysis part of the approach the energy potentials inside the municipality will be mapped. Thereby this chapter will discuss the question: "***What are the sustainable energy potentials of the city Delft and to what extent can they be applied?***". First the energy reduction potential needs to be calculated after that the potentials that can fulfill the remaining demands can be defined. These potentials are generated from the sun, wind and soil. Another potential is found in making optimal use of the energy demands, by re-using waste energy streams. In this chapter these potentials for the city Delft will be discussed and calculated one by one.

Figure 8.1. Energy savings potential residences compared to the current energy demands(by Author).



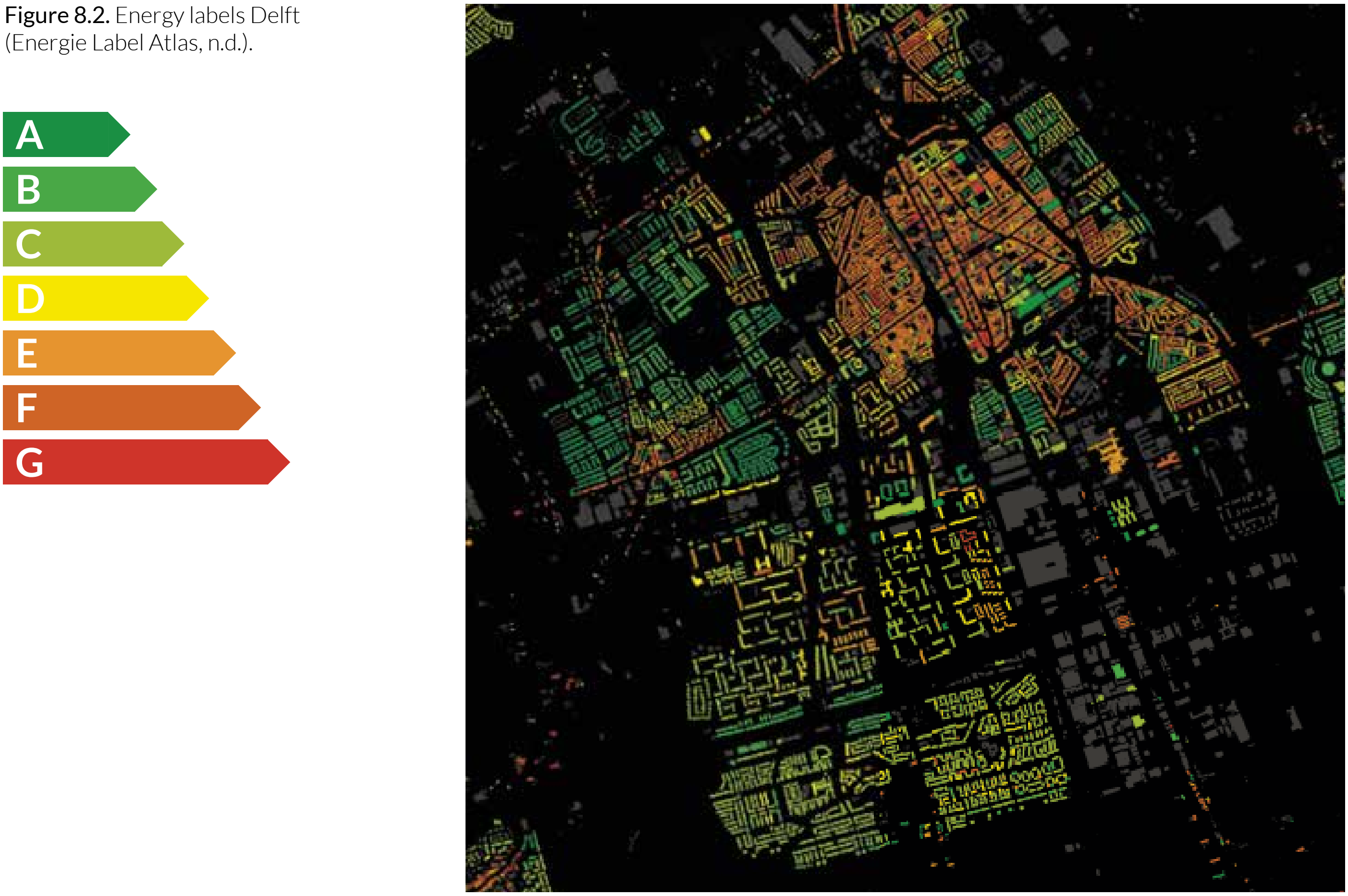
8.1. Energy reduction potential

The first step of the energy transition is to reduce the energy demands with energy retrofitting of the buildings. Part I stated that the better the energy performance of a building, the less cost-efficient energy retrofitting measures will be: the transition from a lower energy label to label B will be efficient, but the transition from label B to A will be disproportional expensive. However to succeed the energy transition demands should be limited as much as possible.

Web tool PICO gives insight in the energy savings that can be achieved when making a certain label step. Also the payback time of the investments is shown. Three different saving steps can be derived from PICO:
- Label EFG to a 2 steps higher label;
- Label CDEFG to label B;
- All labels to label A.

PICOs calculations are based on the report ''Voorbeeldwoningen 2011'' of Agentschap NL. In this report for 30 buildings that present the Dutch housing stock the energy savings for the 3 label steps are determined. In table 8.3 the thermal energy savings in GJ are shown for each neighbourhood.

Figure 8.2. Energy labels Delft (Energie Label Atlas, n.d.).



Neighbourhood	Thermal energy savings [GJ;th]		
	EFG > 2 higher	CDEFG > B	> A+
City Centre	20.698	57.955	70.375
Vrijenban	17.884	45.305	56.035
Hof van Delft	37.323	91.442	108.237
Voordijkshoorn	6.825	19.338	28.439
Delfste Hout	0	0	0
Tanthof West	0	20.938	39.021
Tanthof East	0	14.262	23.175
Voorhof	17.211	63.547	90.024
Buitenhof	6.393	49.012	80.977
Abtswoude	0	0	0
Schieweg	0	149	597
Wippolder	11.739	33.539	43.601
Ruiven	258	567	619
Total % reduction	9%	29%	40%

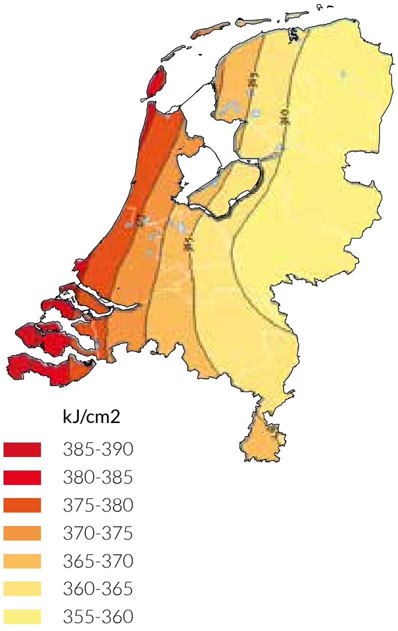
Table 8.3. Energy savings in GJ potential residences Delft for certain label steps (Based on: pico geodan, 2017).

8.2. Solar energy

Solar energy can be generated in different ways. In a compact city like Delft the most important potentials for solar-energy generation are PV, PVT and solar collectors on the building roofs. This total potential depends on the available roof surface in the municipality. Because no data about the roof surface in Delft was available the surface is based on data of the Netherlands. According NLExtract the total roof surface in the Netherlands was 1.241.776.878m2 in 2015 (Tooms, 2015). This gives an average roof surface of about 73,3m^2 per citizen (including roofs of offices, schools, etc.). With 101.030 citizens the total roof surface in Delft will be around 740,5ha. However not all roofs are available and suitable for solar energy generation. When limiting factors like orientation, exclusion and public acceptation are taken into account, about 29 percent of the roofs will be available (Broersma et al,. 2013). For Delft this results in a total available roof surface of 214,8ha.

With a global radiation of 3,75GJ/m^2 (www.klimaatatlas.nl) and an efficiency of 19 percent for the photovoltaics (Gommans, 2012) 1,53PJ electricity can be generated on the buildings roofs. When all available roof surface is filled with solar collectors with an efficiency of 35% 2,82PJ;th can be generated (Broersma et al., 2013). In the future the efficiencies and thereby the output of these panels are expected to increase.

Figure 8.4. Solar radiation in the Netherlands (Koninklijk Nederlands Meteorologisch Instituut, n.d.).



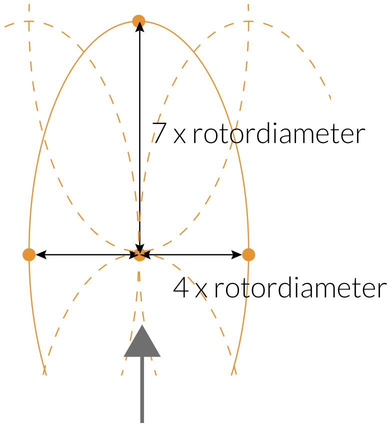


Figure 8.5. Minimal distance between windmills. Related to the common wind direction of the area (Broersma, et al., 2013, p40).

8.2.1. Asphalt thermal generation

The total length of the roads in Delft is currently 298km, whereof 275km is property of the municipality (www.cbs.nl). It won't be sustainable to remove the asphalt layers of roads that don't need maintenance. A road has a lifespan between 5 and 15 years. This means that it will be possible to transform all suitable roads into asphalt collectors, before 2035. However about 75% percent of the roads will probably not be suitable for these thermal collectors, because of their position. If the average width of roads in Delft is about 3m the final potential will be: 20,6ha of asphalt collectors that generate 0,165 PJ;th; 0,8GJ/m^2 (Broersma et al., 2013).

There should be kept in mind that asphalt thermal generation isn't applied a lot in practice. Currently they are mostly applied to keep bridges ice-free.

8.3. Wind energy

To determine the wind-energy potentials for the municipality Delft, height restriction by the Rotterdam-The Hague airport needed to be taken into account first. These restrictions are made visible in figure 8.7. In yellow the landing strip is shown; around this strip a few ellipses with the building height limitations between the 45 and 145m. Nowadays most common wind turbines have a rotor diameter of 93m centred at 80m height. Thereby a large area of Delft isn't suitable for these wind-turbines. This results in a lacking potential for wind energy in Delft.

Still three potential locations for windmills were found as described in table 8.6. The locations are determined based on the availability of space, the height restrictions and the minimal required distances between the wind turbines. As explained in figure 8.5. the distance between to turbines should be minimal 7 times the rotor diameter (in the common wind direction) and 4 times the diameter transverse to this wind direction (Broersma et al., 2013).

The final output of the wind turbines is determined with the typical load factor for the Netherlands of 22%. This means that 22% of the time the wind conditions are optimal (MacKay, 2009). Thereby the total potential will be 0,09PJ. However the smaller windmills in Technopolis will cause ground vibrations and thereby they will not be constructed (R. Dijkgraaf & M. Kaiser, Gemeente Delft, personal communication, November 20, 2017).

Tabel 8.6. Total potential wind energy generation in Delft (by Author).

Area	Windturbine height [m]	Rotor diameter [m]	Amount	maximal Power [MW]	Loadfactor NL	Output per turbine [GJ]	Total output [GJ]
Voorhof	93	80	2	2,3	0,22	15.957	31.914
Delftse hout	93	80	3	2,3	0,22	15.957	47.872
Technopolis	70	70	1	1,5	0,22	10.407	10.407
	50	50	1	0,75	0,22	5.203	5.203
Total							95.396

Figure 8.7. Height restrictions in Delft by Airport Rotterdam-The Hague (yellow). Vliegfunnel dotted and IHCS elips with an ray of 4km the area has a height restriction of 45m and after that another 2km increasing to 145m (by Author).

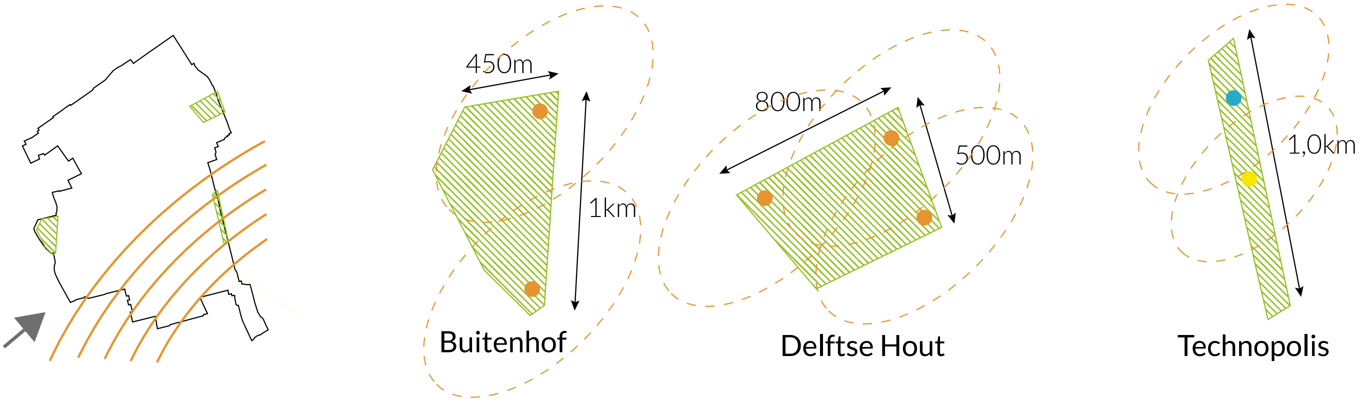


Figure 8.8. Potential locations for wind turbines. Positions wind turbines showns with the dots (by Author).

8.4. Biomass

As explained in part I only biomass originating from food waste, garden waste, animal manure, wood from forest maintenance and sludge is seen as sustainable and thereby considered as potential energy source. Wood can with a pellet boiler be converted into thermal heat. The other biomass potentials will be fermented to biogas.

8.4.1. Wood

Delft has in total 94ha of forest. According to the report energy potential study Oostland the harvestable part of the forest by maintenance is 8m3 per hectare with the dry matter content of 50%. At the same time only 60 percent of the forest area can be seen as harvestable (Broersma et al., 2013). Beside this wood from forest maintenance also wood particles in household waste can be used to generate heat with a pellet boiler. In Delft the separated amount of wood in household waste is 14,8kg per citizen a year (www.cbs.nl). Thereby in total 1.494.800kg wood is collected each year.

For each ton of wood that is burned 19GJ heat is released (Broersma et al., 2013), resulting in a total potential of about 32.687GJ;th.

8.4.2. Biogas

The energy potential for biogas is found in food waste, animal manure and sludge. However in Delft the amount of barn animals is so small that the biogas potential by manure is negligible.

Food waste

In Delft each citizen produces 410kg waste a year, whereof only 162kg is separated: existing for 29 percent out of food waste (www.cbs.nl). In the future the separation of food waste should be stimulated and also the food waste of businesses should be collected.

To calculate the energy potential in gigajoules the following data is used (Broersma et al., 2013). Fermentation of green, fruit and garden waste:
1 ton biomass = 100m3 biogas
1m3 biogas = 0,023GJ

This results in a total biogas potential of 10.756GJ fermented (separated) household waste.

Fermentation Sludge (black water)

Beside food waste also sludge from the water treatment Harnaschpolder can be fermented to biogas. When the sludge is fully fermented the remaining sludge is transported with trucks to the sludge combustion plant in Dordrecht (www.delfluent.nl). The heat of the remaining effluent is currently upgraded with a heat pump and feeds the heat network of the Harnaschpolder in Voordijkshoorn.

The amount of produced biogas can be increased when grey and black water are collected separately. Black water consist organic matter that can be fermented to biogas. This fermentation is the most effective when black water is collected in a high concentration. Therefore a vacuum toilets and vacuum sewage pipelines should be placed. The black water can now be fermented to biogas while at the same time a lot of drinking water is saved (Waternet, 2017). Per person about 13 litres of methane is produced per day. When this matter is fermented at 20°C about 189MJ can yearly be produced per person. In total about 140MJ is needed for the water treatment process (Blom, Telkamp, Sukkar & de Wit, 2010), thereby about 25% of the produced biogas can be used for the energy supplies of the city. This means that with a population of 101.030 there is a potential for 4774GJ biogas.

The water treatment plant in the Harnaschpolder is purifying black water from about 1 million citizens in the Delft-The Hague region. Thereby the potential for the whole treatment plant is about 47.000GJ biogas.

8.5. Potentials earth

While the soil is known for delivering fossil fuels, it also has sustainable potentials by using the inner heat of the earth. There are two main potentials: geothermal at 2km depth and thermal energy storage in aquifers or closed boreholes until around 250m.

8.5.1. Geothermal

Geothermal energy has the positive characteristic that the energy is stored and can be extracted when required. To determine the potential for geothermal energy, the first step is to define the amount of Heat in Place (HIP); the amount of heat that is present in the aquifer (Willemsen et al., 2016). In Delft at about 2000 meters depth the aquifer Delft Sandstone Member is found (Hellinga, 2017), with a temperature of 63-76°C (TNO, 2013).

With the ThermoGIS Expert tool of TNO the Heat in Place in the aquifer can be found, see figure 8.9. The average HIP is about 15GJ/m2 whereof between 30-50 percent can be extracted. To prevent exhaustion this should be done in a period of 30 years. Thereby the final potential is about: 150.000GJ/ha * 2406ha * 30-50% / 30 years = 3,61 – 6,02PJ of thermal energy for Delft.

Potential per system

To calculate the potential per geothermal system the following formulae will be used (van Adrichem et al., 2014; Willemsen et al., 2016):

$$P_{th}\ [MW_{th}] = q\ {*}\Delta T\ (Tpr - Tin)\ {*}y\ /\ 3600$$

$$y\ [MJ/m3\ C] = \phi {*}\ Cw\ + (1-\phi)\ {*}Cr$$

q	Flow rate [m3/h]	300
Tpr	Temperature production well [°C]	70
Tin	Temperature injection [°C]	40
y	Total heat capacity reservoir [MJ/m3°C]	2,0
ϕ	Porosity [%]	0,15
Cw	Heat capacity water [MJ/m3°C]	4,2
Cr	Heat capacity Delft Sandstone Member [MJ/m3°C]	1,6

In the report ‘Potentieel geothermie gemeente den Haag’ a quickscan for the geothermal potential in The Hague is done. The Hague gas the same aquifer: Delft Sandstone Member. Thereby there is assumed that the flowrate and heat capacity of the aquifer layer for Delft are the same as for The Hague (Willemsen et al., 2016).

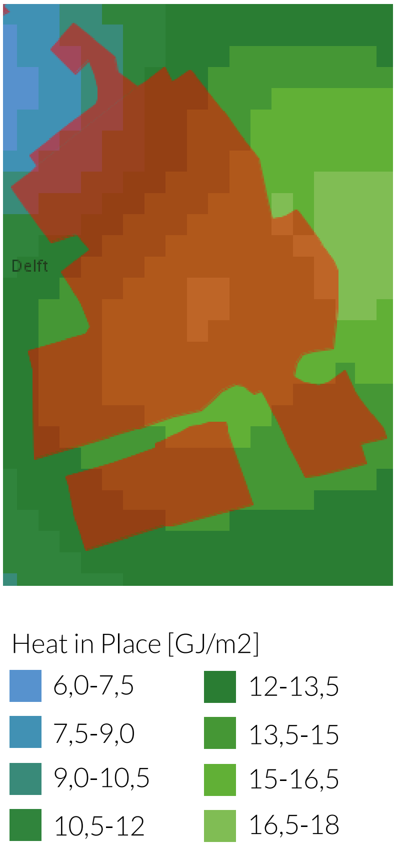


Figure 8.9. Heat in Place in the aquifer Delft Sandstone Member at ca. 2000m depth in Delft (TNO ThermoGIS Expert, 2013).

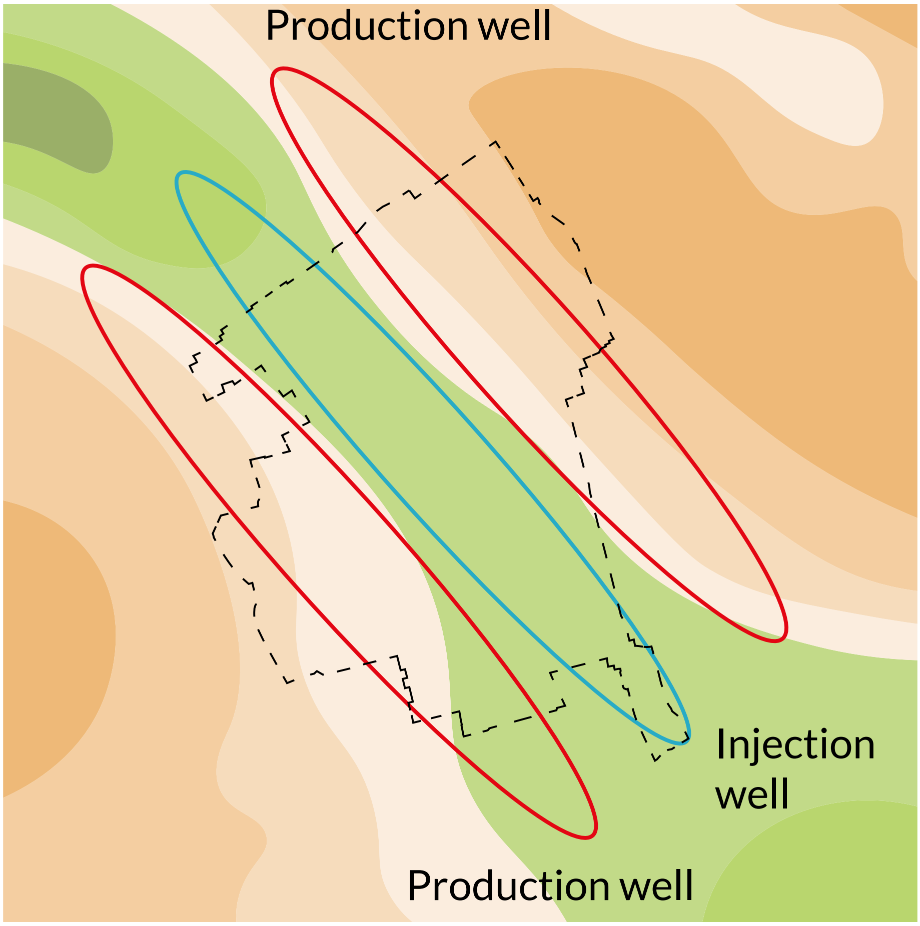


Figure 8.10. Temperature of the aquifer Delft Sandstone Member at ca. 2000m depth (TNO ThermoGIS Expert, 2013).

🟩 60-63°C
🟩 63-66°C
🟩 66-69°C
⬜ 69-72°C
🟧 72-75°C
🟧 75-78°C
🟧 78-81°C

This results in:
$y = 0{,}155 * 4{,}2 + (1- 0{,}155) * 1{,}6 = 2{,}0$ MJ/m^3°C
Pth = 300 * (70 – 40) * 2,0 / 3600 = 5,0 MWth

Thereby the heat production will be 5,0MWth per geothermal system. The production of geothermal energy will be active for about 5.958hours a year (Willemse et al., 2016). This means that in total the system has a potential to deliver about 107.244GJ per year. This geothermal generation will be a doublet system. The production well will be located in the higher temperature zones of the aquifer, the injection well in the lower temperature zones (figure 8.10). With a total potential of 3,6PJ a year maximally 32 geothermal systems of 5MW can be realized.

8.5.2. Thermal energy storage

The energy potential for thermal energy storage can easily be found with the heat atlas of RVO (warmteatlas.nl). Figure 8.11 shows that the yearly potential for aquifer thermal energy storage (ATES) is 2000-3000GJ/ha for the biggest part of the city. According to RVO the heat potential of BTES (borehole thermal energy storage) is about 1550-1700GJ/ha per year.

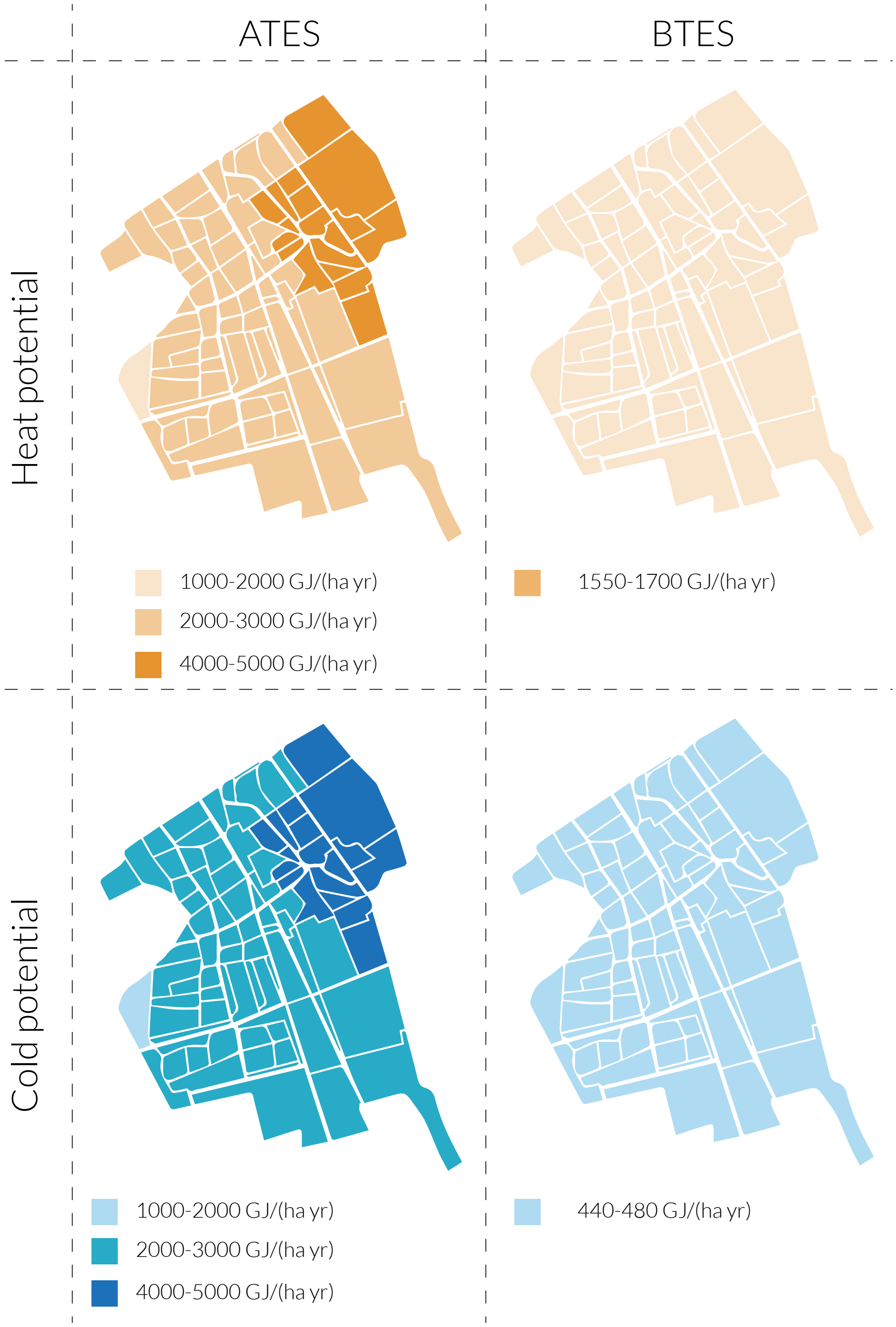


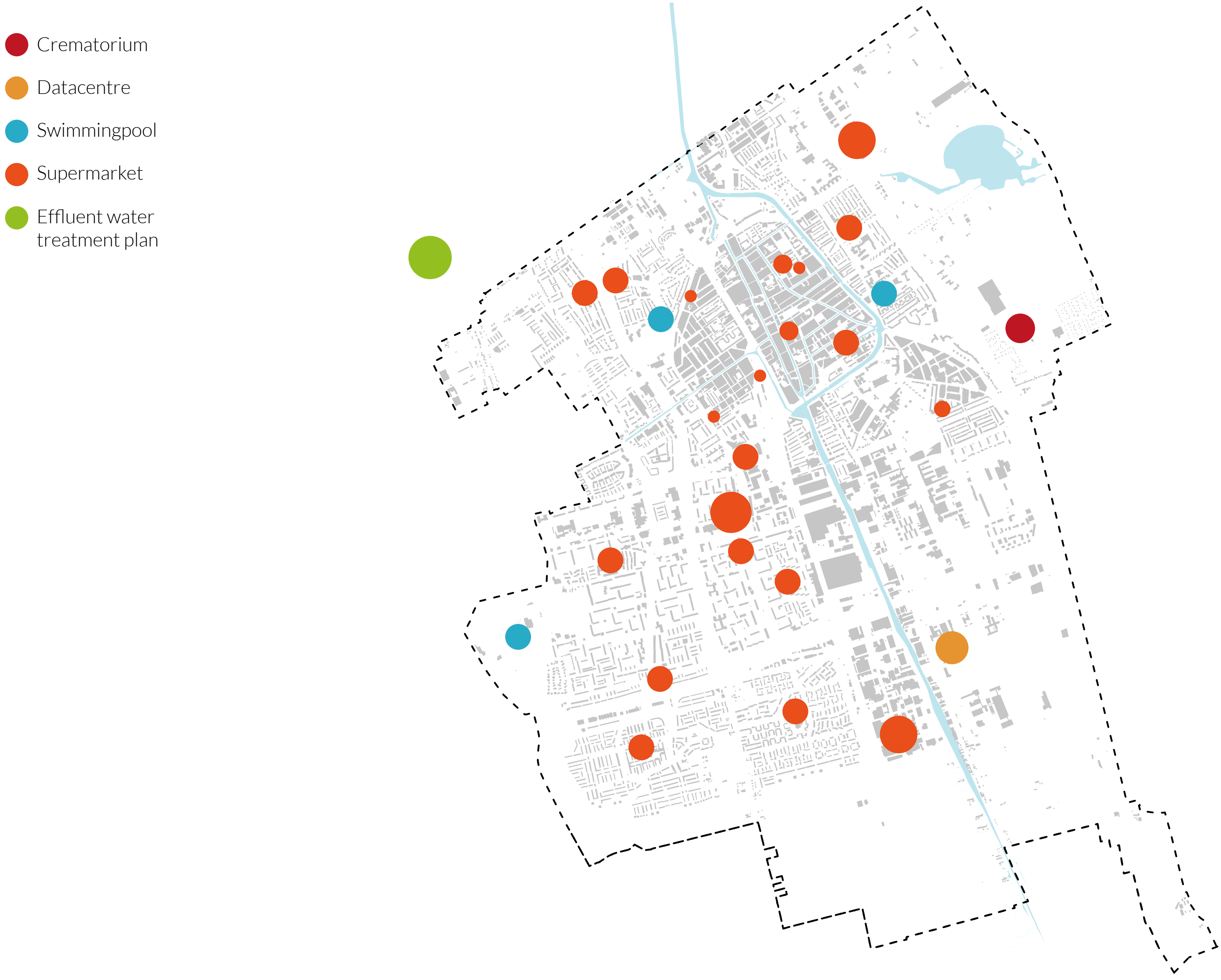
Figure 8.11. Potential for heat cold storage and heat exchange in Delft (RVO, 2017).

8.6. Residual thermal energy

Residual energy can be distinguished by non-sustainable and sustainable sources. Non-sustainable sources are waste heat from production processes based on fossil fuels. In this case the residual heat delivered should be replaced with a sustainable source during the transition. Inside the municipality in Delft there is no potential for this industrial waste heat. Delft did consist two industrial companies: DSM and the Cable factory. However the cable factory is not in function anymore and after research by the municipality there was concluded that DSM factory lacks potential as residual heat source (Broersma et al., 2013).

Sustainable residual energy is a waste product of functions that require almost only heating or cooling. These functions are now heated with a fossil energy but this will change during the transition. In this paragraph the sustainable waste heat potentials for Delft are described.

Table 8.12. Residual energy potential locations (by Author).



Sector	Total energy demands [PJ]	Total electricity demands [PJ]	Electricity demands for cooling [PJ]	% electricity used for cooling	Average CoP	Released condensor heat [PJ;th/year]
Supermarket	6,3	3,1	2,69	87	3	10,7
University	3,4	2,0	0,33	16	4	1,6
Office-building	34,5	10,8	1,8	17	4	9,0

Table 8.13. Energy demands and released condensor heat of different functions. (Pennartz, et al. 2016).

The table above shows for different sectors the percentage of the total electricity demands that used for cooling. Together with the average CoP this gives the released heat by the condenser; the residual heat potential (Pennartz & van den Bovenkamp, 2016). The released condenser heat is calculated by (SenterNovem, 2008):

*(CoP * electricity demands for cooling) + electricity demands for cooling*

8.6.1. Supermarkets

Supermarkets do all year require a lot of cooling. Thereby a large amount of heat is released into the air. Capturing this heat and re-use it as heat source will be a sustainable and reliable energy potential. Delft has about 20 supermarkets and 2 large wholesale markets (Makro and HANOS). Out of table 8.13 there can be concluded that with a regular cooling installation about 87% of the electricity demands are used for cooling. The average supermarket in the Netherlands is 875m^2 (DTZ Zadelhoff, n.d.) and has an electricity demand of 401kWh/m^2 (Meijer & Verweij, 2009). Thereby the total potential for residual heat from supermarkets in Delft is 96.303GJ a year, with a temperature of 20°C.

8.6.2. University & Offices

University buildings and offices do have the potential to deliver heat during summer, spring and autumn. The university used about 58.429.000kWh electricity a year (www.energymonitor.tudelft.nl), whereof 16 percent is used for cooling. With a CoP of 4 this results in a heat potential of 171.108GJ.

The average electricity demand of an office is 85kWh/m^2 per year (Meijer & Verweij, 2009) of which 17% is used for cooling. According to DTZ Zadelhoff Delft has about 419000m^2 office space (DTZ Zadelhoff, 2015), this gives a heat potential of 3.181GJ.

8.6.3. Datacentres

The Delft Datacentre Group has a surface of 2500m2. According to CE Delft the yearly electricity demands of a datacentre in the Netherlands is 3,45MWh/m^2. This means Delft Datacentre Group is using about 8625MWh electricity per year (Afman, 2014). This amount is equal to the amount of heat that is produced (Arts & Ning, 2016). Thereby heat potential of the datacentre is about 31.050GJ (40°C).

8.6.4. Other potentials

Other residual energy potentials is Delft are found by the crematorium and swimming pools. Crematoria do release a lot of heat into the air, when a heat recovery system is integrated this heat can be delivered to a heat network at about 40°C. The three swimming pools in Delft have a high heat demand and are thereby a potential cooling supplier.

8.7. Total potential

In this chapter an answer is given to the question: ''What are the sustainable energy potentials of the city Delft and to what extent can they be applied?''. The total demands of Delft are 3,5PJ; 2,2PJ thermal energy and 1,3PJ electricity. In theory the maximal potentials of all the analysed sources will sufficient to supply the demands. The thermal energy demand should in the first step of the transition be decreased to 2,0-1,3PJ by energy retrofitting of the residences with two labels steps or more. The remaining demands should be supplied by renewables.

However the potentials for electricity generation in Delft are limited. The placement of wind-turbines in Delft is minimal by the height-restrictions of Rotterdam Airport. 84% percent of the available roof surface should be covered with PV the supply the electricity demands of 1,28PJ. This means not a lot of roof surface will be left for the placement of solar collectors.
The thermal demands can be fulfilled with a combination of differ potentials: thermal collectors, biomass, biogas, geothermal, heat-cold storage and residual heat supplies. This means different heat systems will be used. Because of the limited potential for electricity generation in Delft all-electric heating systems should be minimized and balanced with the final electricity supplies.

09

The Roadmap

This chapter includes multiple steps of the approach towards the final design of the roadmap for the energy transition of Delft. In the previous steps a vision was created and transition targets were set. Also the 'Status Quo' of the transition and energy potentials was analysed. This analysis forms the basis of the steps to take in order to design the roadmap.

The first step (step 4) towards the roadmap is to define a scenario that delimits the outcomes of the roadmap. This scenario is based on the vision created in chapter 6 and determines the expected energy savings and the feasible energy potentials. This scenario will be translated into an urban strategy. In step 5 this urban strategy will be applied to the districts and neighbourhoods of the city and will result into a proposal for the energy systems (interventions including their scale and location) of the city. In step 6 the consequences of the intervention on neighbourhood and building scale will be determined (chapter 10). In the final step the interventions of the roadmap will be placed on a timeline. Thereby this chapter will finally have given answer to the question ''***Which energy systems and source are available for the energy transition of Delft and when and where should they be implemented?***''.

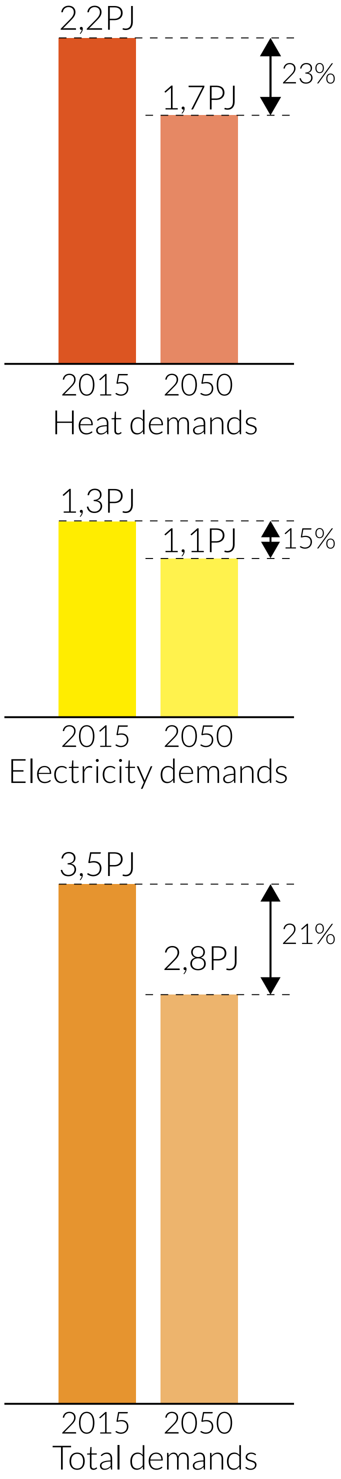


Figure 9.1 Energy savings for the scenario (by Author).

9.1. Scenario

The in step 1 defined vision will in this step be translated into a scenario for the roadmap of the energy transition of Delft. This scenario delimits the outcomes of this roadmap and determined the expected amount of energy savings and the available potentials to fulfill the remaining demands.

9.1.1. Thermal energy savings

To determine the thermal energy savings the same label steps are used as in paragraph 8.1:

- Lower energy labels EFG 2 labels steps higher;
- Energy labels CDEFG to label B;
- All energy labels to A+.

Thereby the achieved energy savings per neighbourhood could be taken from the PICO webtool.

The following assumptions were made (based on the vision) to determine the final energy savings:

- The municipality and housing corporations agreed by E-deals to upgrade all corporations housing to label B or higher. 47% of all residences in Delft are property of corporations.
- By becoming a coherent city the citizens will more actively participate in the transition; by energy retrofitting of their residences (or the residences they are renting to other citizens):
  - Private rental sector 80% renovated to label B or higher (stimulated with policies);
  - Private owned residences: 30% to label B or higher.
- These energy savings are supported by subsidies from the national government.
- Because each residence will require at least some maintenance before 2050, they will at least make the label step from EFG to a 2 steps higher label.
- Households will decrease their electricity demands with on average 15% by more efficient installations and change of behaviour. This 15% doesn't include the increased demands by required heat pumps.
- In the old city cente the options for energy retrofitting will be limited to 2 label steps. Due to the restrictions by the monumental status.
- Because offices and other non-industrial companies have comparable building typologies and ownerships as residences the energy savings will be similar.
- The municipality will make E-deals with industrial companies to decrease their energy demands however these energy saving will be limited and on average about 15% for both electricity and heat demands.

Total energy savings

By following this scenario the total energy demands are finally decreased with 23%, which means that the municipality's demands are decreased from 3,5PJ to 2,8PJ. The calculation is found in the table below. The energy savings for the different label steps are based on data of PICO and CBS, this data can be found in attachment D, table 7 and 8.

Thermal energy savings households based on PICO [GJ;th]:

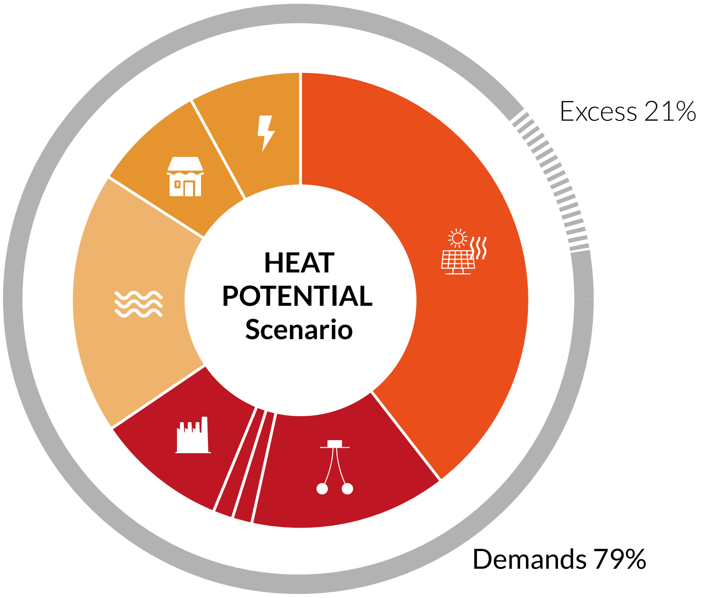
Corporations	181.143
Rental other	49.516
Privatly owned	87.787
Total savings	318.446 (=24%)

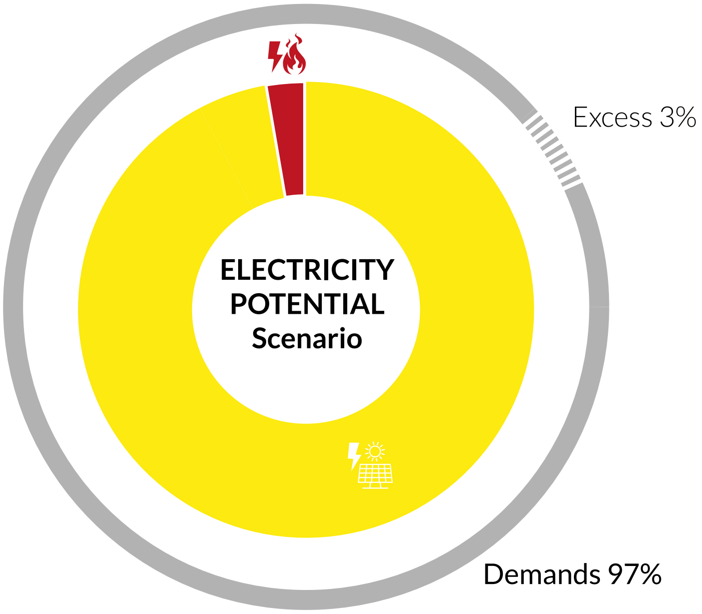
Demands	2015	2050	Savings(%)
Total heat demands	2,22	1,71	23
Households	1,35	1,03	24
industrial	0,20	0,17	15
Offices	0,67	0,51	24
Total electricity demands	1,32	1,06	15
Households	0,45	0,38	15
industrial	0,20	0,17	15
Offices	0,67	0,51	15
Total demands	**3,5**	**2,77**	**21**

9.1.2. Energy potentials

The following step is to determine the energy potentials of which it is realistic that they can be implemented into the roadmap. This is based on the created vision and the outcomes of the energy potential mapping. These potentials will fulfill the remaining demands when the energy savings are achieved. The following potentials are available to supply these demands:

- The placement of wind turbines won't be realistic by the height restrictions of Rotterdam Airport and Delfts high density, therefor electricity inside the municipality should be generated with CHP plants and PV(T)-panels.
- The TU Delft is already active with the energy transition of the campus. Even more participation in the transition of Delft is expected because the municipality want to increase the collaboration with the TIC and TU Delft to become the city of technology. Thereby there can assumed be that planned geothermal source and its connection to Voorhof-Oost will be realized.
- By the limited retrofitting potentials in the old centre, high temperature heating remains necessary. Biogas or geothermal energy will be possible sources to supply these demands.





Electricity potentials

	PJ;el	%	notes:
Demands	1,06		*15% reduction, excluding the increase by heat pumps systems*
PV	1,07	101	*70% available roof surface , 19% eff*
CHP	0,02	2	*Biogas > CHP (35% el.)*
Total	1,09	103	

Thermal energy potentials

	PJ;th	%	
Demands	1,71		*19% reduction of demands*
Solar coll.	0,85	50	*30% available roof surface, 35% eff - MT*
Geothermal	0,30	18	*2 geothermal wells (TU and 1 other) - HT*
CHP	0,03	2	*Biogas > CHP (50 % heat)*
Biomass	0,03	2	*Wood maintenance forest & wood houshold waste - HT*
Residual heat	0,20	12	*LT and MT heat from supermarkets, datacentre, crematorium*
Effluent	0,40	23	*vLT heat upgrade with heat pump*
All-electric	0,17	10	*max 15 % of all buildings*
H. Roundabout	0,17	10	*The heat roundabout will feed10-15% of the demands*
Total	2,15	126%	

Figures 9.2 & 9.3. Energy balans for heat and electricity. Potentials for this scenario do furfill all the demands (by Author).

Table 9.4. Total energy potentials according to scenario (by Author).

- The effluent of the water treatment plant just outside Delft is already used to feed a heat network in Delft. Another energy potential that can be added is the fermentation of the remaining sludge.
- Other sustainable energy sources that have the potential in Delft are residual heat from small scale businesses, biomass, solar collectors and thermal energy storage.
- According to the municipality Delft and Chris Hellinga the realisation of the heat roundabout of South-Holland is a realistic scenario. However this industrial waste heat isn't sustainable and should thereby only be used to start-up the transition (R. Dijkgraaf & M. Kaiser, Gemeente Delft, personal communication, November 20, 2017; C. Helinga, personal communication, November 03, 2017).

9.1.3. Energy balance scenario

On the left the energy balance is created between the remaining demands after the energy retrofitting and the energy potentials according to the scenario. The aim of the municipality is to become energy neutral and thereby the demands should as much as possible be be generated with sources from inside the municipality. However for the electricity demands this won't be completely possible and needed, because the transition of the electricity network will mainly be the responsibility of the national government. To limit the electricity demands at least 70% percent of the building roofs should be used by PV or PVT panels (this doesn't include the roofs of all-electric heated buildings). To limit the peak demands maximally 10% will be heated all-electric.

9.2 Urban strategy

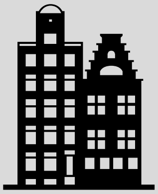
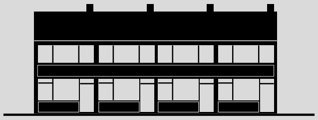
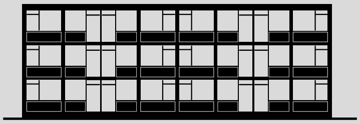
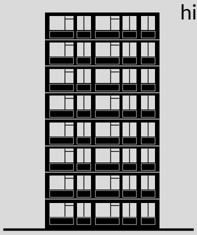
The created strategy is translated into an urban scale approach. This approach is visualized in diagram 9.5 at the next spread. This diagram shows the energy retrofitting for different housing typologies divided in moderate (2labels steps) and deep renovations (upgrade to label B or higher). Each of these retrofitting measures results in a certain heat demands (temperature). That can be fulfilled by different heat systems and sources; visualized in the last column of the designed strategy.

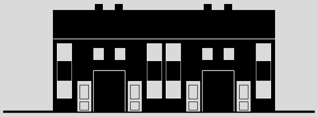
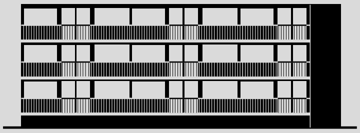
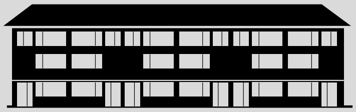
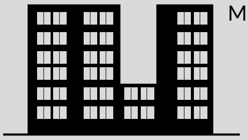
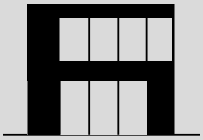
Energy-retrofitting

As described in the scenario the taken energy retrofitting measures by households do depend on the ownership type. The first column in the diagram shows the degree of retrofitting per housing type: in white the current energy label (source: www.energielabelatlas.nl) and coloured the label after moderate (2 labels steps) or deep energy retrofitting (>label B).

Heating temperature after energy retrofitting

In the next column the demanded heating temperature is shown for the different renovations. Very low temperature heating is only an option for buildings constructed after 2010, for the other buildings the upgrade to vLT heating will be too expensive.

Typology	Retrofitting	°C	Energy potentails
 **>1900** Residences & offices	Small or no renovations limited possibilities due to monumental status G F **E** D C B A A^+ A^{++} *by 100% of the Private house-owners*	HT	I: Biogas III: CHP, Geothermal, Solar collectors, Indus. waste heat
1900-1945 Single-family housing 	Moderate renovations G F E **D** **C** B A A^+ A^{++} *by 55% of the Private house-owners*	MT	IV: Cascade, Residual heat, Solar collectors, Indus. waste heat, Heat Pump HP
	Deep renovations G F E D C **B** **A** **A^+** A^{++} *by 45% of the Private house-owners*	LT	II: PV, PVT, Ground heat exch., Air-source V: Cascade, Residual heat, PVT, ATES/BTES, Heat Pump HP
50-60's Single-family housing 	Moderate renovations G F E D **C** **B** A A^+ A^{++} *by 55% of the Private house-owners* *by 50% of the Corporation*	MT	IV: Cascade, Residual heat, Solar collectors, Indus. waste heat, Heat Pump HP
	Deep renovations G F E D C **B** **A** **A^+** A^{++} *by 45% of the Private house-owners* *by 50% of the Corporation*	LT	II: PV, PVT, Ground heat exch., Air-source V: Cascade, Residual heat, PVT, ATES/BTES, Heat Pump HP
50-60's Multi-family 3-6layers 	Moderate renovations G F E D **C** **B** A A^+ A^{++} *by 55% of the Private house-owners* *by 50% of the Corporation*	MT	IV: Cascade, Residual heat, Solar collectors, Indus. waste heat, Heat Pump HP
	Deep renovations G F E D C **B** **A** **A^+** A^{++} *by 45% of the Private house-owners* *by 50% of the Corporation*	LT	V: Cascade, Residual heat, PVT, ATES/BTES, Heat Pump HP
50-60's Multi-family high-rise 	Small/Moderate renovations G F E D **C** B A A^+ A^{++} *by 20% of the Private house-owners*	MT	IV: Cascade, Residual heat, Solar collectors, Indus. waste heat, Heat Pump HP
	Deep renovations G F E D C **B** **A** **A^+** A^{++} *by 80% of the Private house-owners* *by 100% of the Corporation*	LT	V: Cascade, Residual heat, PVT, ATES/BTES, Heat Pump HP

Typology	Retrofitting	°C	Energy potentails
70-80's Single-family housing 	Renovations G F E D C B A A^+ A^{++} *by 100% of the Private house-owners* *by 100% of the Corporation*	LT	II PV PVT Ground heat exch. Air-source
			V Cascade Residual heat PVT ATES/BTES Heat pump HP
70-80's Multi-family 3-6layers 	Small/Moderate renovations G F E D C B A A^+ A^{++} *by 55% of the Private house-owners*	MT	IV Cascade Residual heat Solar collectors Indus. waste heat Heat pump HP
	Moderate/Deep renovations G F E D C B A A^+ A^{++} *by 45% of the Private house-owners* *by 100% of the Corporation*	LT	V Cascade Residual heat PVT ATES/BTES Heat pump HP
90-00's Single-family housing 	Small/Moderate renovations G F E D C B A A^+ A^{++} *by 100% of the Private house-owners*	LT	II PV PVT Ground heat exch. Air-source
			V Cascade Residual heat PVT ATES/BTES Heat pump HP
90-00's Multi-family 3-6layers 	Small/Moderate renovations G F E D C B A A^+ A^{++} *by 100% of the Private house-owners* *by 100% of the Corporation*	LT	V Cascade Residual heat PVT ATES/BTES
>2010 	Moderate renovations G F E D C B A A^+ A^{++} *by 100% of the Private house-owners*	vLT	II PV PVT Ground heat exch. Air-source
			VI Cascade Residual heat PVT ATES/BTES Effluent
Farm & low density 	Little renovations G F E D C B A A^+ A^{++} *by 50% of the Private house-owners*	HT	I Biogas Wood
	Deep renovations G F E D C B A A^+ A^{++} *by 50% of the Private house-owners*	LT	II PV PVT Ground heat exch. Air-source

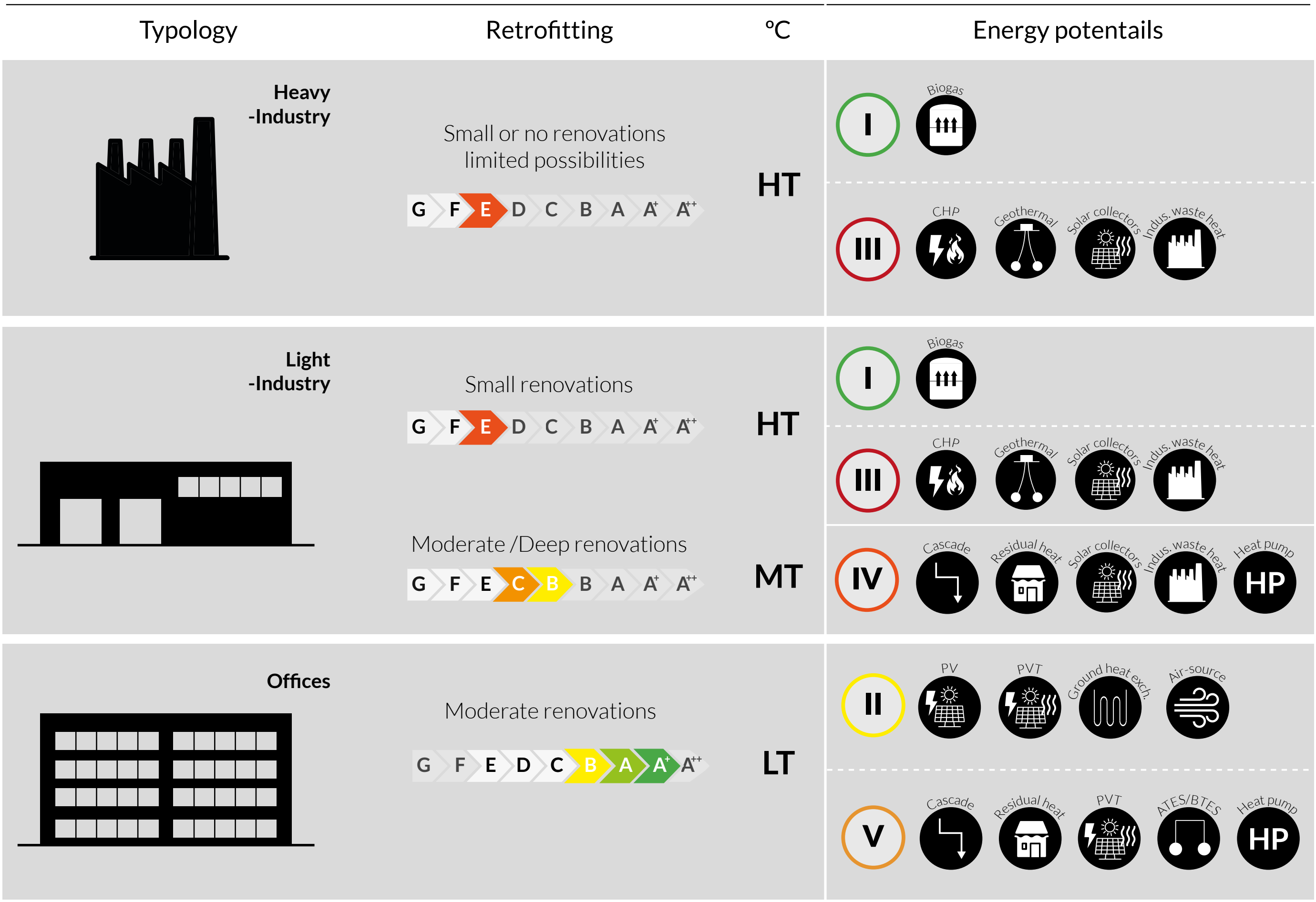


Figure 9.5. Strategy for the energy transition of Delft on Urban scale for different building typologies (by Author).

Heat systems & sources
Finally in the last column the optional heat systems (I-VI) and sources to supply the demands are given. These are determined with the sustainable heat systems tool. The roman number shows which heating system can be applied:
I. Biogas/biomass (individual)
II. All-electric (individual)
III-VI. High, mid, low and very-low temperature heat networks (collective)

The black icons present the available sources. The options are limited by the created scenario and the following statements:
- Because max. 15% of the buildings should be heated with all-electric heating this system will only be applied for low/very low temperature heating of single-family housing.
- Because heat networks require a high density to be cost-effective, low-density areas can only be heat with individual systems.
- Because the biogas potentials in Delft are limited this potential will only be used to heat functions with a high temperature heat demand.

9.3 Strategy District scale

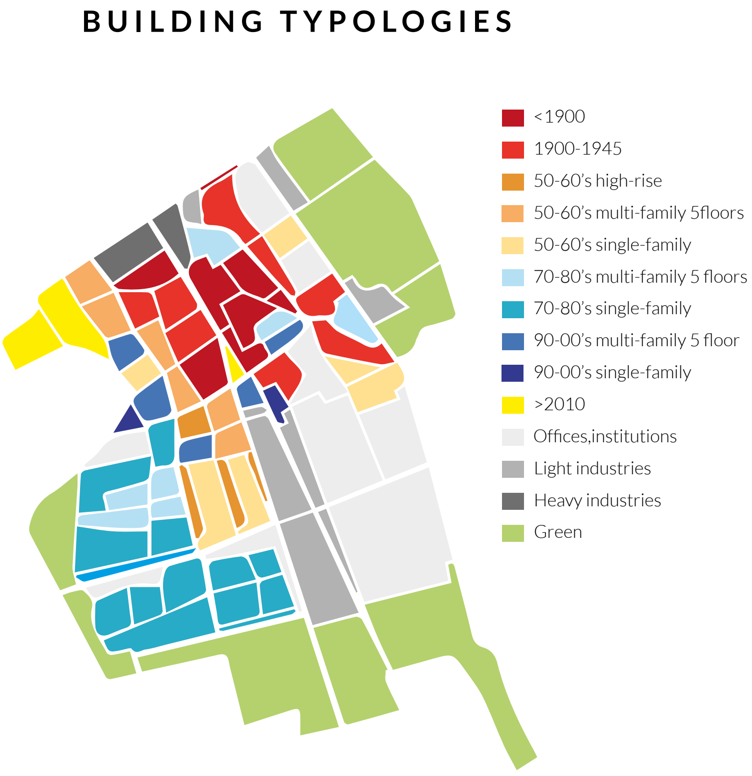
To define an approach for the energy systems and sources per district in Delft a variant of the new stepped strategy is used. This strategy helps to prioritize which energy systems and sources should be implemented with their full potential and which only to fulfill the remaining demands. Thereby the strategy helps to simplify the final choice for a certain energy system.

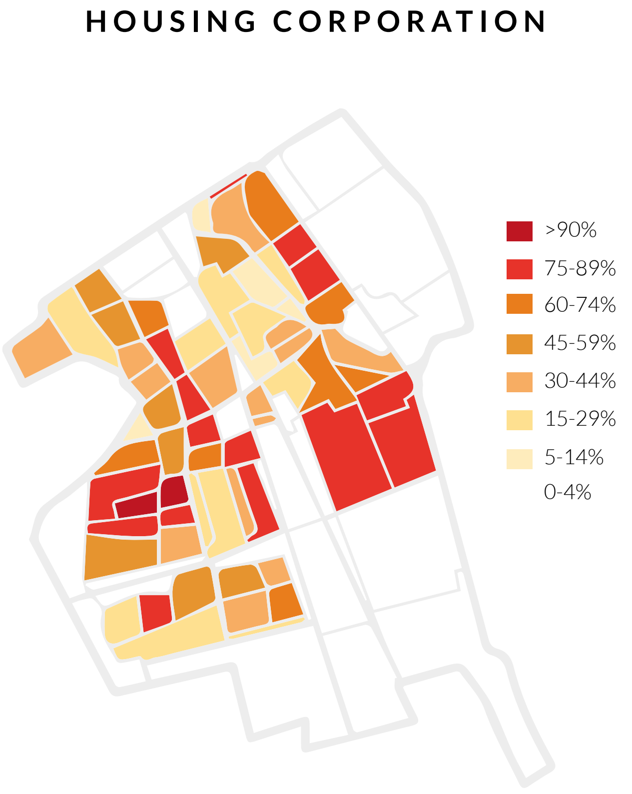
0. Determine the energy demands
1. Reduce the energy demands

<u>The remaing demands will be fulfilled by:</u>
2. Use the existing sustainable energy systems and potentials
3. Re-use of waste (energy) streams
Residual heat, fermentable organic matter, biomass
4. Use renewable energy
    a. Energy that is already there, only has to be extracted
    Energy that is stored in the ground
    b. Energy that should be generated with added technologies
    PV(T) panels, solar collectors

Figure 9.6 (Left). Building types and construction periods Delft (by Author, based on: code.waag.org).

Figure 9.7 (Right). Percentage of residences that is property of housing corporations (by Author, based on: www.cbs.nl).



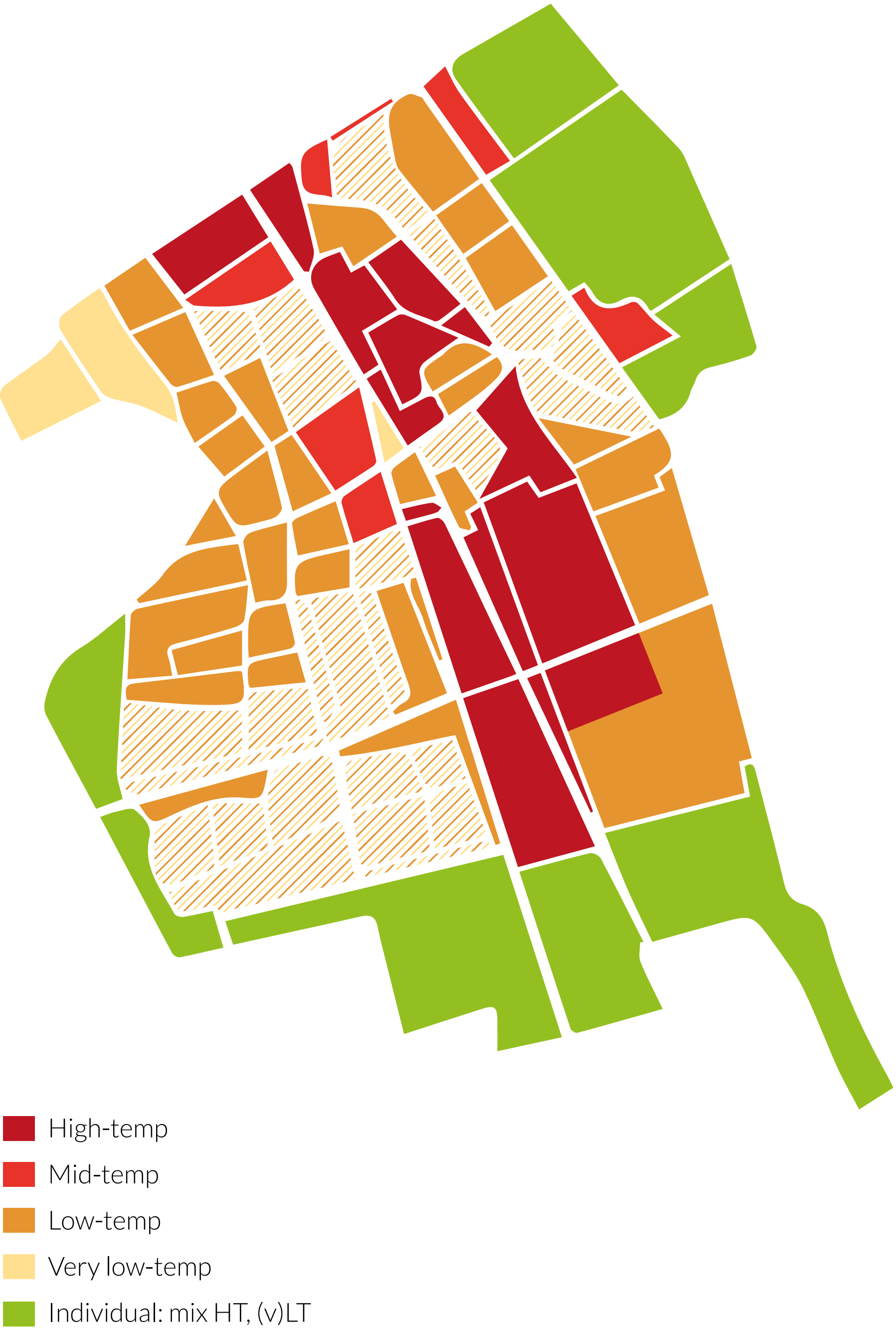


1

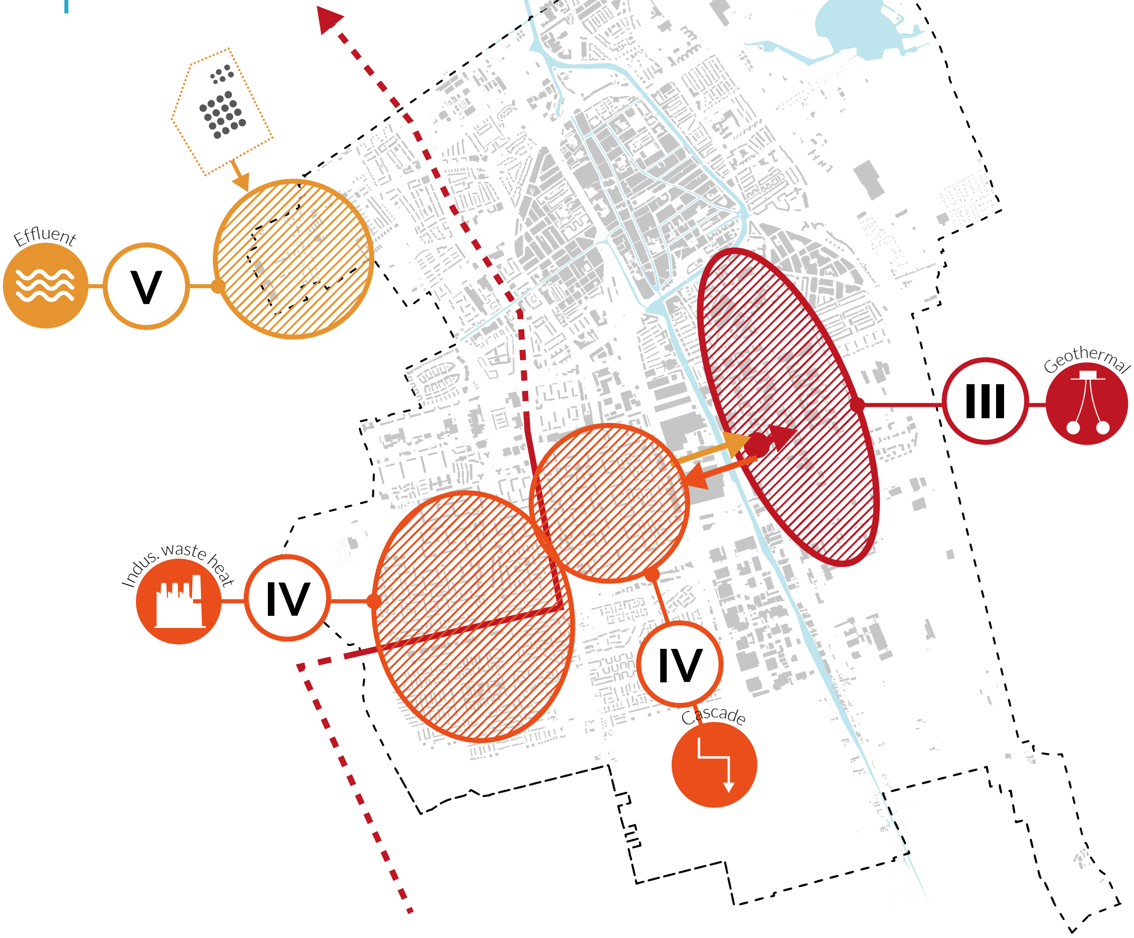
Reduce the energy demands

In the energy balance the energy savings of the scenario are determined resulting in a total thermal energy saving of 22%. To determine the potential heating temperatures for each neighbourhood the urban strategy diagram is combined with the data of maps 9.6 and 9.7; that show the building typologies and housing corporations per neighbourhood.

In the figure on the right the heating temperatures are given for each neighbourhood. The striped mid/ low temperature neighbourhoods can be heated with low temperature but this requires large effort. The south-east districts of the 60-80's require small renovations but the realisation is difficult because the inhabitants aren't very wealthy and at the same time not living in corporation housing.



2 Existing sustainable systems & Initiatives



A. Geothermal TU Campus. In 2020 the geothermal source at the TU campus will be realized that will supply the existing heat network with 73°C. After heating the buildings the heat will return to the heat network at 50°C. A lower return temperature to the injection well is desired; therefore the return heat will be cascaded to Voorhof-East. Thereby moderate renovations to the buildings and the existing (non-active) heat network is needed. The return heat will be pumped back into the injection well

B. Heat roundabout of South Holland. The municipality has great faith in the realisation of the heat roundabout which will supply the neighbourhood in Buitenhof-South and Tanthof-West with mid-temperature heat. With as advantage that only limited renovations are needed. The heat will be used to start up the transition. Because the heat is originating from a non-sustainable source it should be replaced by renewables during the transition, like solar collectors, ATES/BTES.

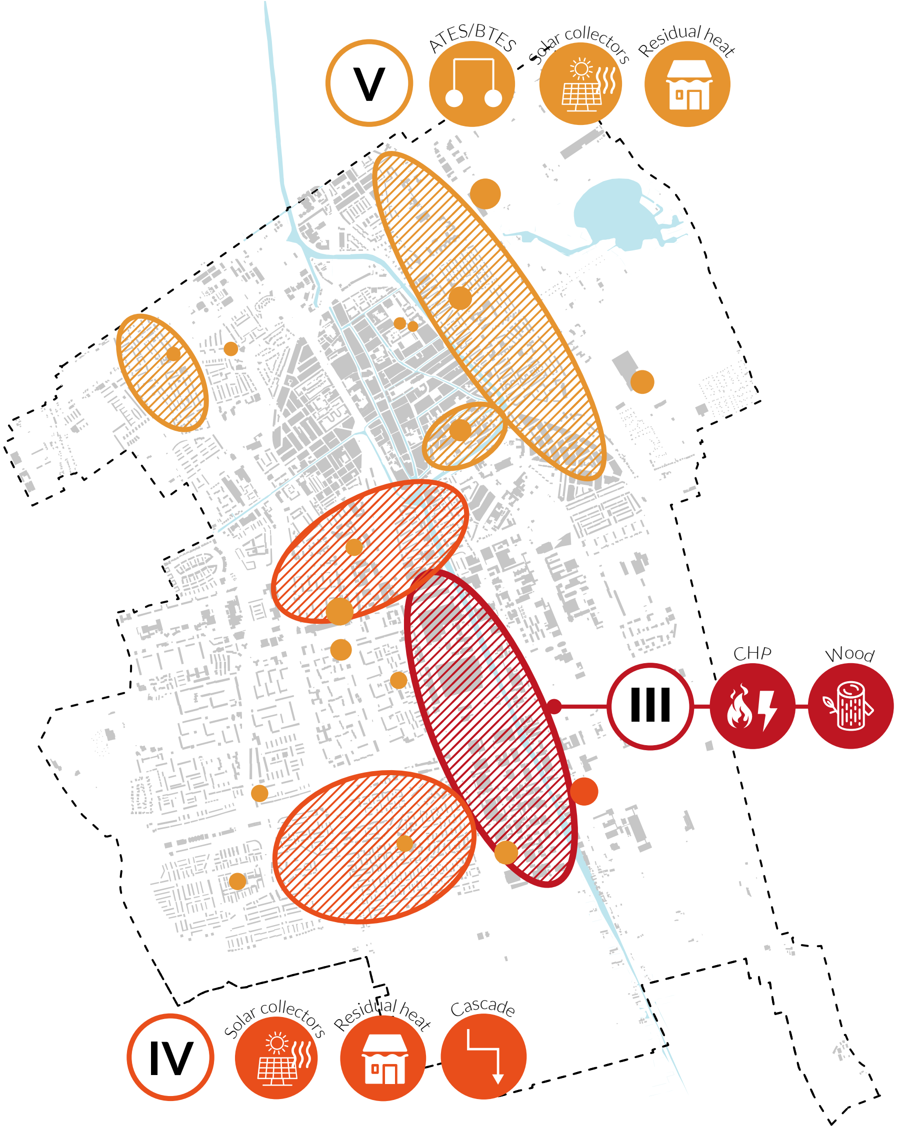
C. Effluent Water treatment plant Harnaschpolder. This effluent of 12-20°C is currently upgraded with a heat pump to 70°C and heating the neighbourhood Den Hoorn. However with limited energy retrofitting measures this neighbourhood can be heated with low-temperature heat of about 30-40°C this results a lot of electricity savings (higher CoP).

3/4
Re-use waste streams
Implement Renwables

D. Small scale low temperature heat networks. Small scale residual heat sources can in combination with thermal energy storage and solar collectors/PVT provide heat to the Vrijenban and Kuyperwijk. Heat pump will be placed to, where needed, upgrade the heat to the desired temperature. This system is further explained in chapter 10.

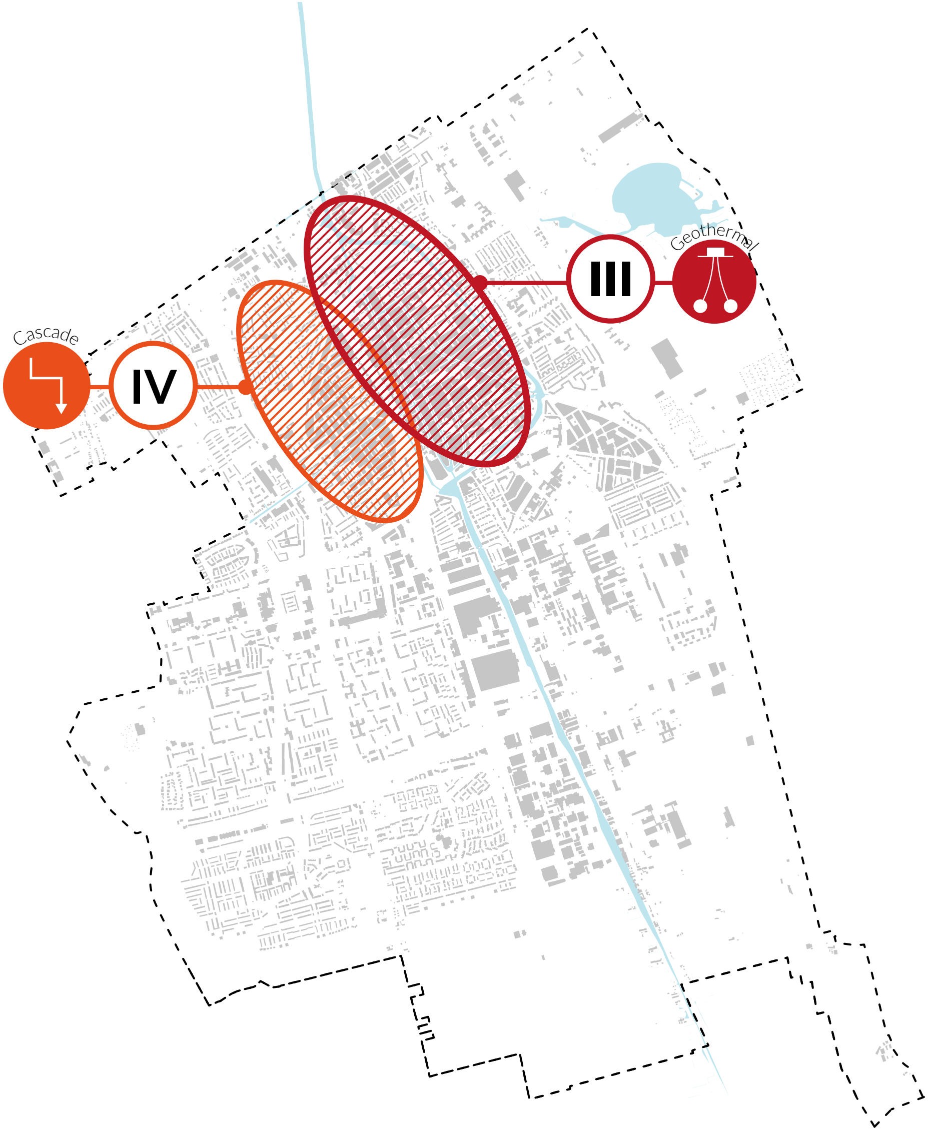
E. Thermal heat network MT CHP and cascade to LT network. The industrial companies at the Schieweg require high and mid temperature heating. A high temperature heat network fed by cogeneration plants on biogas and pellet boilers (wood household waste) will be a reliable and cost-efficient way to do so. This food (fermentation to biogas) and garden waste is currently already collected in the Schie district by Avalex. After use the remaining heat will be cascaded to adjacent neighbourhoods (see the diagram). This network will also be fed by small scale residual heat sources (datacentre and supermarkets) and a solar collector farm. That will be constructed at the roofs of the Schieweg businesses.

F. Low density areas: Pellet boilers. Delft has a few districts with a very low density and thereby also very small energy demands. The buildings with a high or mid temperature demands can thereby be supplied with individual pellet boilers (wood).



4 A. Available renewable energy

G. Historic city centre & Old Hof van Delft. The historical centre and old areas of Hof van Delft are a difficult but important factor in the transition of Delft, because the potentials for energy retrofitting are limited or very expensive. Currently the most suitable energy potential for the historic centre will be a high temperature thermal energy network fed geothermal heat. This heat can be cascaded to the Hof van Delft. However this is not preferred due to the large required interventions. Therefor this option will only be implemented when no other potential becomes available. The Centre and hof van delft will be heated the longest with fossil heat. When in the future new, more suitable, technologies are available this would be the implemented instead of the geothermal network. Hydrogen for example can supply high temperature heat and only requires small adaptations to both the existing gas network and the heating and cooking installations inside the buildings.



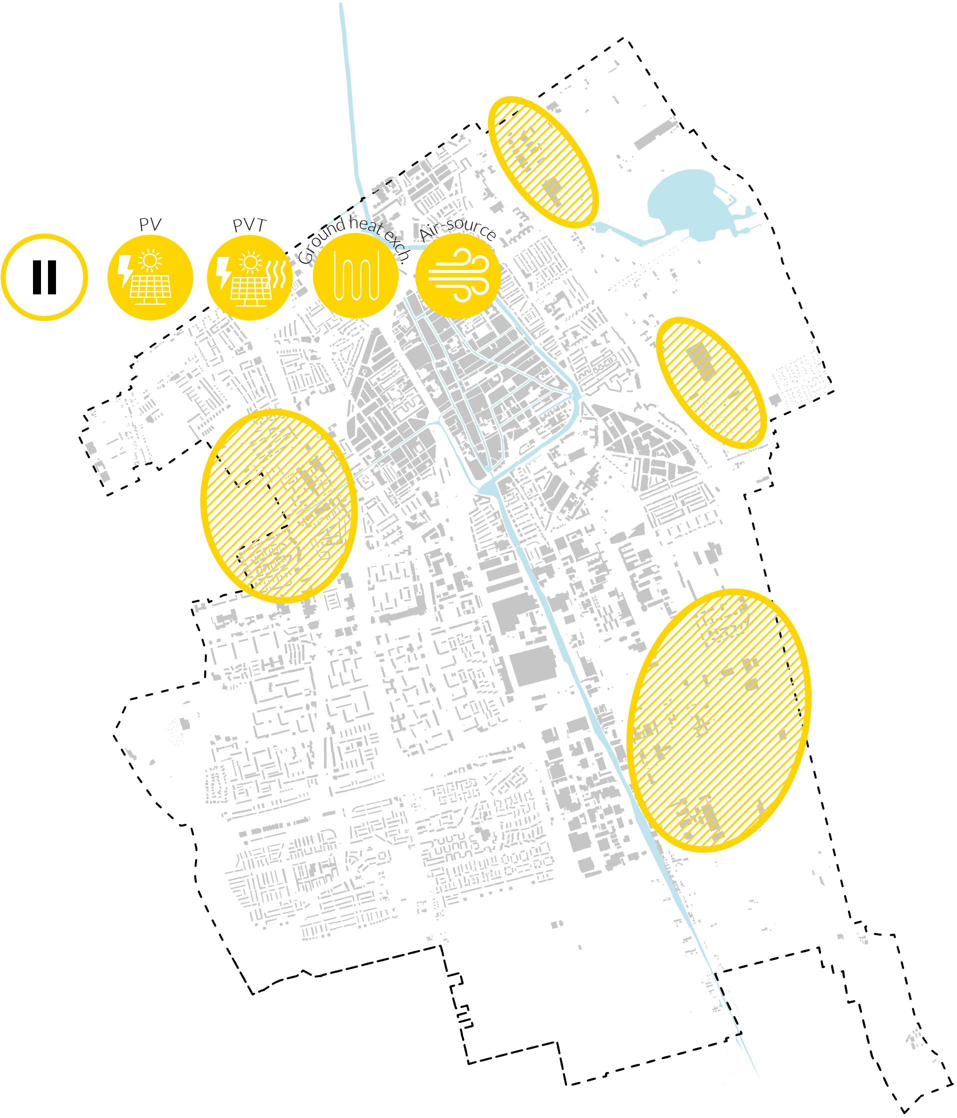
4

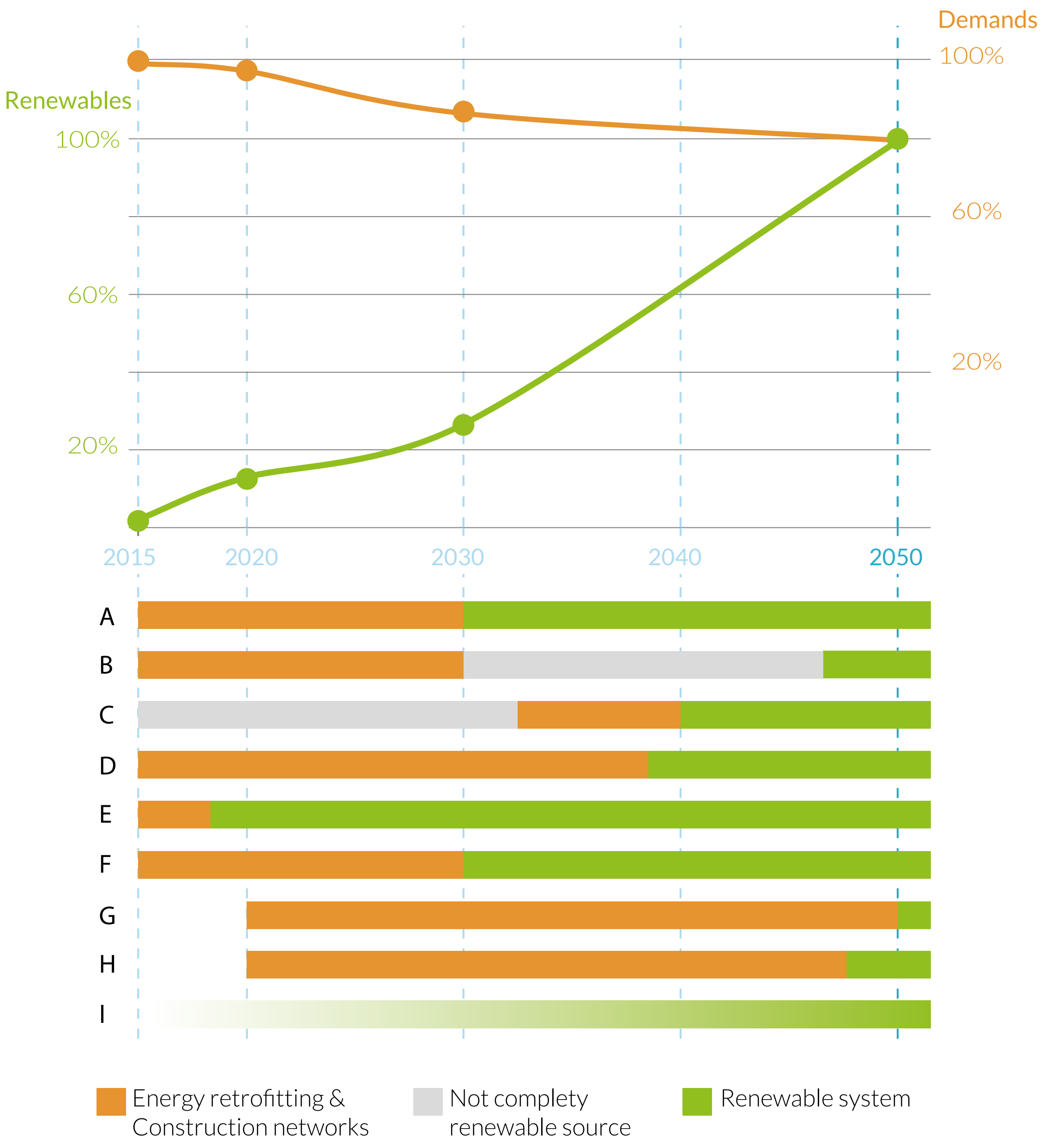
B. Implement generating technologies

F. Low density areas: All-electric. The low temperature demands in these areas will be supplied with all-electric systems: heat pumps with a ground or air-source and PV panels.

H. All-electric. The TIC companies around the campus are not connected to the heat network and can be heated at low temperature. Often they are already heated by using thermal energy storage as a heat source and can relatively easy be retrofitted to all-electric. Also some other businesses and residential areas with LT heat demands and lacking potential for other types of heating will be all-electric.

I. Photovoltaics. The available roofs that aren't used by solar collectors and PV panels of all-electric heated buildings will be covered with photovoltaics to lower the electricity demands of the city (about 70% of the available roof surface).





9.4. Roadmap

In the previous steps the energy systems and interventions with their scale and location for the energy transition of Delft are determined. However to finalize the roadmap also the moment of implementation needs to be defined. Therefor the interventions A-J, described in the previous paragraph, will be placed on a timeline.

Figure 9.14. Roadmap of the final proposal for the energy transition in Delft. Showing which intervention should be implemented at which moment in the total transition (by Author).

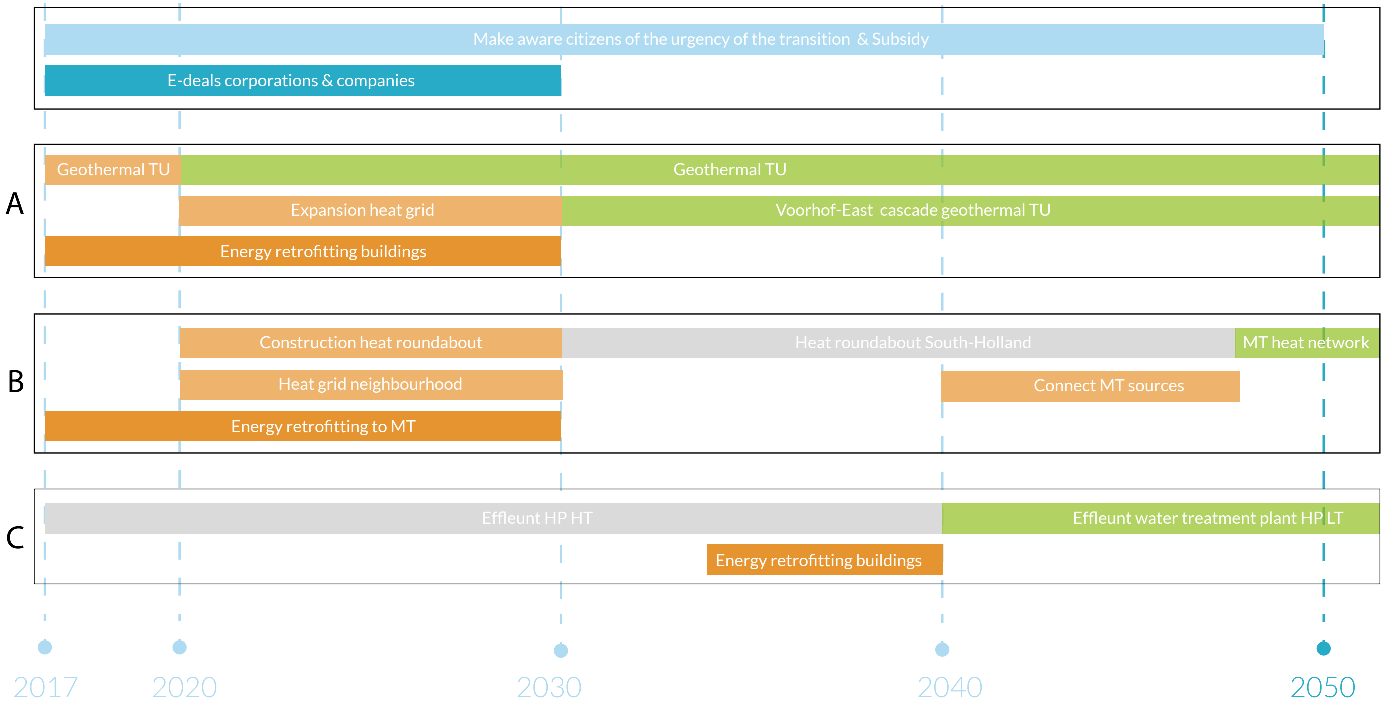


Figure 9.15a. More detailed roadmap for intervention I-III (by Author).

A. The geothermal source of the TU is expected to be active in June 2020 (Hellinga, 2017). Thereby the highest priority is to make the Voorhof-East neighbourhood ready for the around 50°C cascade heat. The expansion of the existing heat network in Voorhof-East to the other buildings and to the campus will start as soon as the geothermal source is working.

B. The heat roundabout will be completed around 2030. This heat network passes Delft and will be a temporary source for the Buitenhof district and a large part of Tanthof-West. Therefor a heat network needs to be constructed. The heat will be supplied at mid temperature with as result that the required renovations are relatively simple. More to the end of the transition the heat source will be slowly be replaced with sustainable mid temperature heat sources like solar collectors.

C. The existing heat network in the neighbourhoods Den Hoorn and Hoornse Hof will be brought down to a low temperature heat network. However this first requires energy retrofitting of the residences. Because these buildings are constructed after 2010 their building state is good, at the same time the heat source is already relatively sustainable. Therefor this step has a low priority and will take place in the last phase of the transition.

D. The realisation of a low temperature heat network requires large renovations of the existing buildings. These buildings are partly owned by corporations but also a large share is private property and thereby the retrofitting is the responsibility of the owner. This makes the timespan till the level of LT heating is achieved long. At the end of the transition these neighbourhoods will be fed by sustainable LT heat sources.

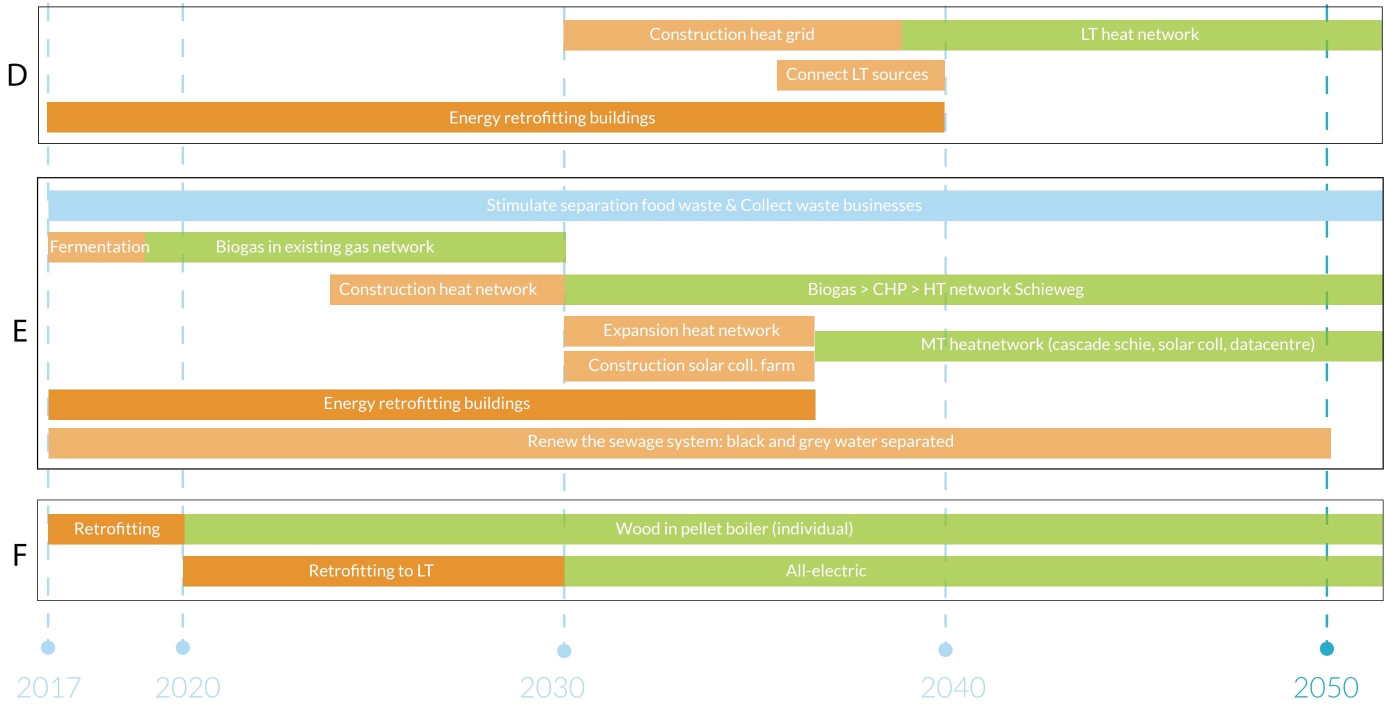


Figure 9.15b. More detailed roadmap for intervention IV and V (by Author).

E. The fermentation of food waste can start immediately; only a bio-digester should be placed that supplies to the existing gas network. This will instantly increase the amount of sustainable energy in the municipality. During the transition the separation of food waste by citizens and companies should be stimulated. At the same time the existing sewage system needs to be replaced by a system in which grey and black water are separated. When this process is finished in 2050 also the sludge from the water treatment can be fermentated.

The businesses in the Schieweg district have to be retrofitting and at the same time the heat network will be constructed. A CHP installation will be connected to the bio-digester which generates the heat for the network.
After that the expansion of the heat network to surrounding neighbourhoods can start, to facilitate the heat cascade. The buildings in these neighbourhoods have been retrofitted from the start of the transition. The heat network will also be fed by the solar collector farm at the roofs of the Schieweg companies that is constructed simultaneously with the heat grid. The other sources will be connected as soon as the heat network is realized.

F. The individual interventions are easy to implement. Buildings with a high temperature demand will be heated with a pellet boiler. This supplies high temperature heat and thereby it doesn't require much renovation. Thereby this intervention will already be realized in the first years of the transition.
The other buildings will be heated all-electric. To optimize the efficiency of the heat pump low temperature heating is required. Therefor these buildings need to be renovated. Because all of these residences have a

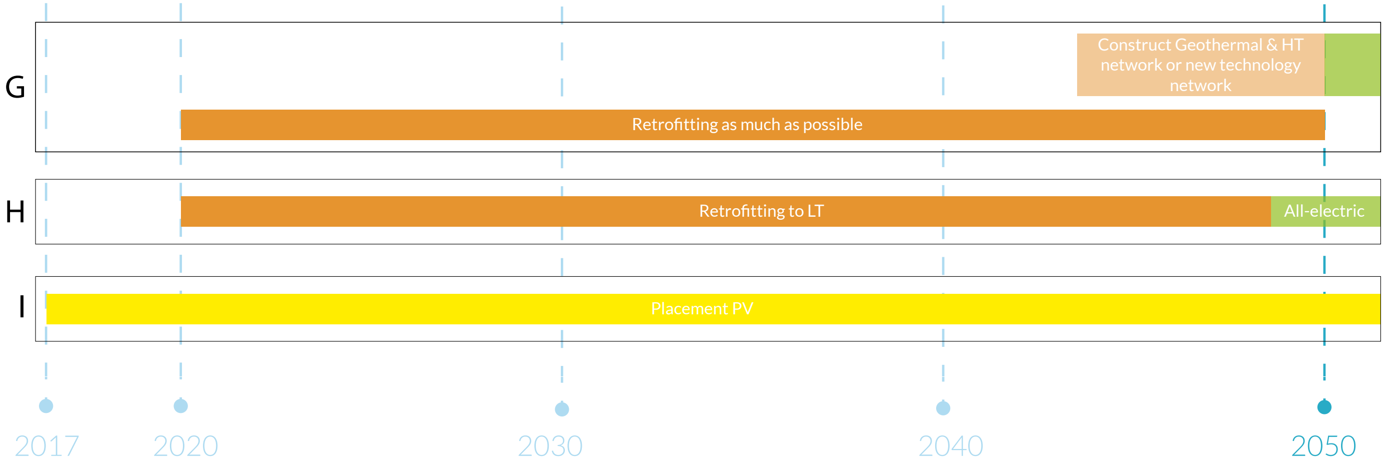


Figure 9.15c. More detailed roadmap for intervention VI-IX (by Author).

private owner the energy retrofitting of these 200-300 buildings will take relatively long.

G. The transition of the historical city centre and the Hof van Delft will be done in the final phase of the transition, to be able to implement new, more, suitable technologies when possible. During the transition the buildings will be renovated as much as possible, taking into account their protected historical status. When no new more suitable technologies become available the last option is to construct a high temperature heat network supplied with geothermal energy and cascaded to the Hof van Delft district.

H. A few neighbourhoods will be heated all-electric. This requires a lot of transformations to the building and thereby the timespan of the retrofitting is long.

I. During the transition PV panels will be placed on the available building roofs (that are not used for all-electric or solar thermal generation). In total 150ha PV will be placed (about 4,7ha/year).

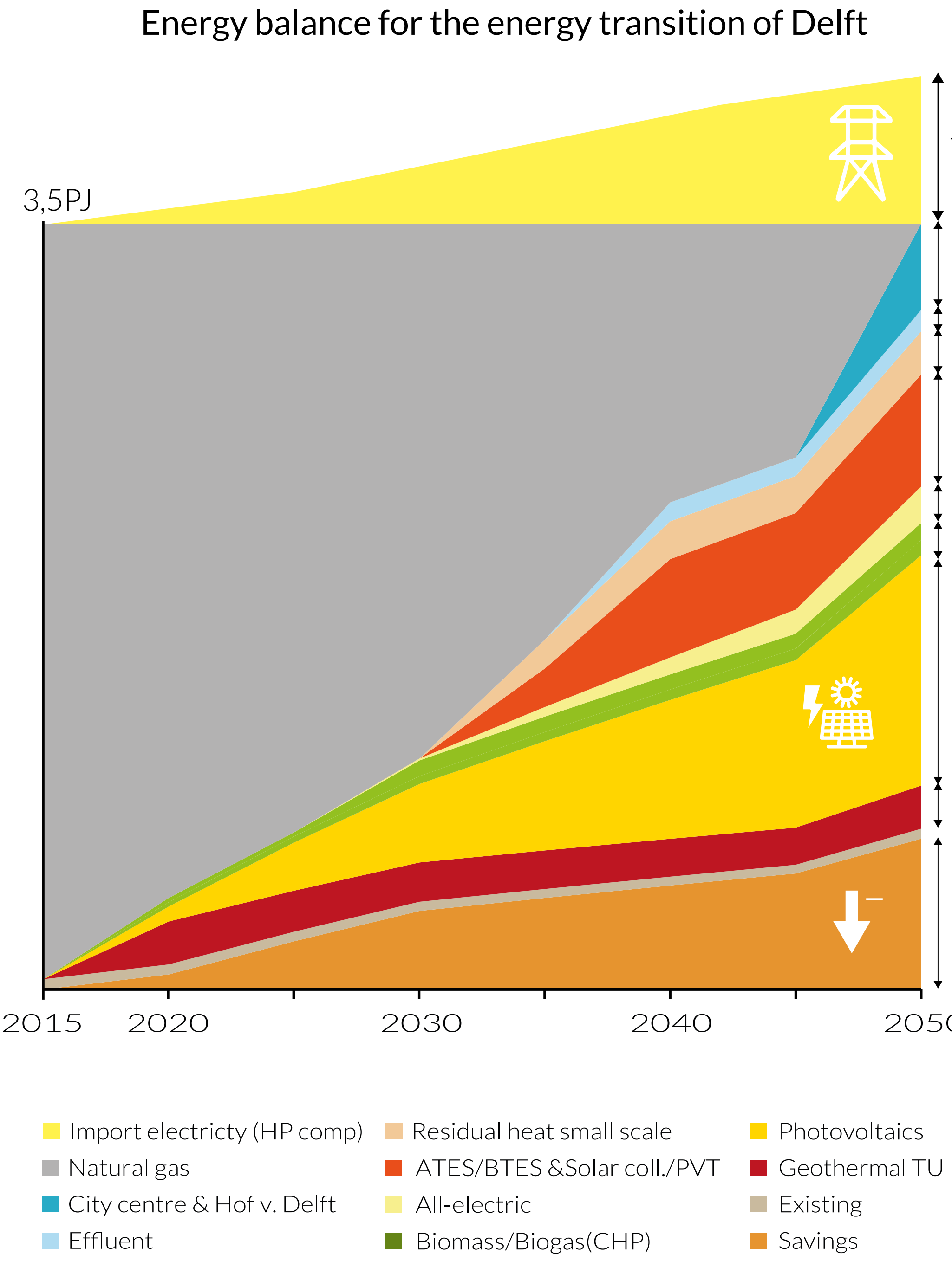
9.5. Final energy balance

The proposed strategy for Delft shows where and what type of interventions should be taken to succeed in the energy transition.Thereby an answer is given to the question: "Which energy systems and source are available for the energy transition of Delft and when and where should they be implemented?". In the roadmap of the previous paragraph these interventions (A-I) are placed on a timeline. Finally the energy balance is created, showing the development of the share of renewables towards energy neutrality in 2050.

The original demands were 3,5PJ in 2015. In 2050 these will be decreased with 21%. Therefor about 1.500 residences, 70 industrial companies and 155 offices should be retrofitted per year (see attachement E). To fulfill the remaining 80% of the original demands renewables are added. By the use of heat pumps the electricity demands will in the future be higher than the amount that will be supplied with the renewables. This remaining amount of electricity will be imported from other sustainable sources.

Thereby in 2050 energy neutrality is achieved. By realizing an energy system that is for 100% based on renewable energy, generated inside the municipality as much as possible. The calculations behind this energy balance can be found in attachment E.

Figure 13.16. Energy balance (by Author).



10

Interventions neighbourhoods & Building scale

This last chapter the roadmap will be completed by determining the consequences of the defined interventions at neighbourhood and building scale. For two of the proposed energy systems neighbourhoods are chosen for which the interventions at this small scale are determined. Intervention D will be analysed in the Kuyperwijk neighbourhood and intervention E will be implemented to the neighbourhoods in Voorhof-North. At building scale the renovations will be defined that will be required to be able to heat the building with the proposed energy system. This includes the insulation of the building envelope and the required installations concerning heating, ventilation and domestic hot water. Thereby this chapter responds to the sub-research queston: '***What interventions need to be implemented into the two neighbourhoods according to the defined interventions on bigger scale?***'.

Figure 10.1. Air picture of the Kuyperwijk (googlemaps.nl)

10.1. Kuyperwijk

The Kuyperwijk is located in the district Voordijkshoorn in the North of Delft. This area neighbourhood is almost fully constructed in the sixties. The most common housing typology is the 3-5 layer apartment block, mostly "portiekflats". Of the 3285 inhabitants 92 percent lives in multi-family housing that for 55% is property of corporations (www.cbs.nl).

10.1.1. Energy demands & Savings

Most of the buildings have a poor energy performance with a D or E energy label. However there is a lot of potential for energy retrofitting. With the BEAM-Up program a few of the residences in the neighbourhood where upgraded to label A and B (image: the red roof tiles in the North). According to the urban scale strategy the other buildings will be upgraded to label A, B or with 2 label steps.

Currently the buildings are heated with natural gas and have an average gas demand of 26,7GJ per year (www.cbs.nl). After the energy retrofitting these demands will be decreased with 25%, the non-industrial businesses in with a similar percentage. The electricity demands are decreased with 15%. Resulting in a final total heat demand of 46.762GJ (-25%) of about 40°C, see table 10.3 (the calculation can be found in attachment F.1).

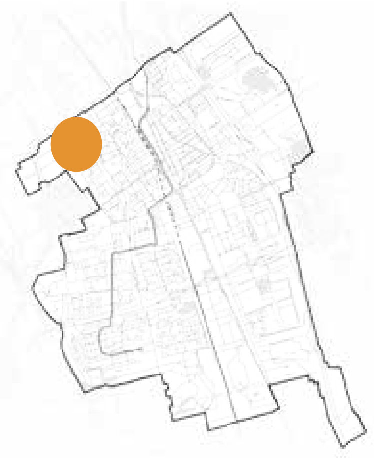


Figure 10.2. Location of the neighbourhood in Delft (by Author).

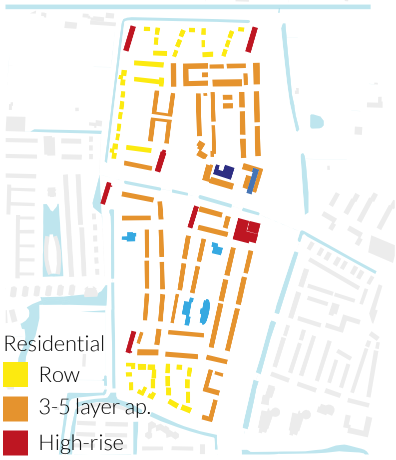
Table 10.3. Energy demands of the Kuyperwijk before en after the renovations (by Author).

Energy demands	Residences [GJ]	Savings	Businesses [GJ]	Savings	Total [GJ]	Savings
Heat demands	34.230	29%	12.532	29%	46.762	29%
Electricity demands	11.312	15%	10.673	15%	21.985	15%
Total demands	45.542	26%	23.205	23%	68.747	25%

CONSTRUCTION PERIOD

ENERGY LABELS

TYPOLOGIES



10.1.2. Energy system neighbourhood

In the previous chapter a small scale low temperature heat network (intervention D) is proposed for this neighbourhood. This network will be supplied with heat from 2 large supermarkets and solar collectors combined with thermal energy storage. This energy system is schematized in figure 10.5.

Supermarkets

The residual heat of two supermarkets will supply the network: the PLUS ($^{+}/_{-}$ 1150m^2) and AH ($^{+}/_{-}$ 2000m^2). The potential residual heat is calculated at 15.825GJ of 20°C (based on data EPM §8.6.1). The amount of heat that can be used during the heating season (215days/year) will be 9.179GJ. The remaining can be used to regenerate the ATES source.

To upgrade this heat to 40°C collective heat pumps will be installed in the building blocks (CoP 6). With an heat supply of 9.180GJ the heat pump finally generates 10.700GJ with an electricity input of 1.530GJ.

Solar collectors or PVT

Another source that can regenerate the aquifer during the summer are solar collectors. With googlemaps and zonneatlas.nl there is determined that easily 1ha of solar collectors can be placed on the building roofs. With an efficiency of 35% and solar radiation of 3,75GJ/m^2 this results in 13.100GJ;th at about 50°C.

Another option will be to place PVT panels on the building roofs instead of solar collectors. With these panels both electricity and thermal energy can be generated. Thereby the demands of the heat pump will be slightly compensated. The generated heat will have a lower temperature, similar to the heat grid.

Aquifer thermal energy storage (ATES)

The aquifer can be used as a heat source when the extraction from both aquifers is equal. However the heat demands are higher than the cooling demands in this area. Therefor the heat source should be regenerated in the summer by the solar-collectors and summer heat of the supermarkets.

While small part of the heat demand is be supplied by the supermarkets still about 0,031PJ is demanded. This can be supplied by the ATES source in combination with the collective heat pumps. For this process the heat pump will have a CoP of 4. This means that to generate 0,031PJ;th, 0,023PJ;th of the aquifer and 0,008PJ;el is needed.

The aquifer can supply about 2.500GJ/ha/year. This means one or multiple wells should be constructed with a total area of 9,2ha.

Figure 10.4 - Different charateristics of the Kuyperwijk: construction period , energy labels and typologies residences (by Author, based on: code.waag.org, www.energielabelatlas.nl).

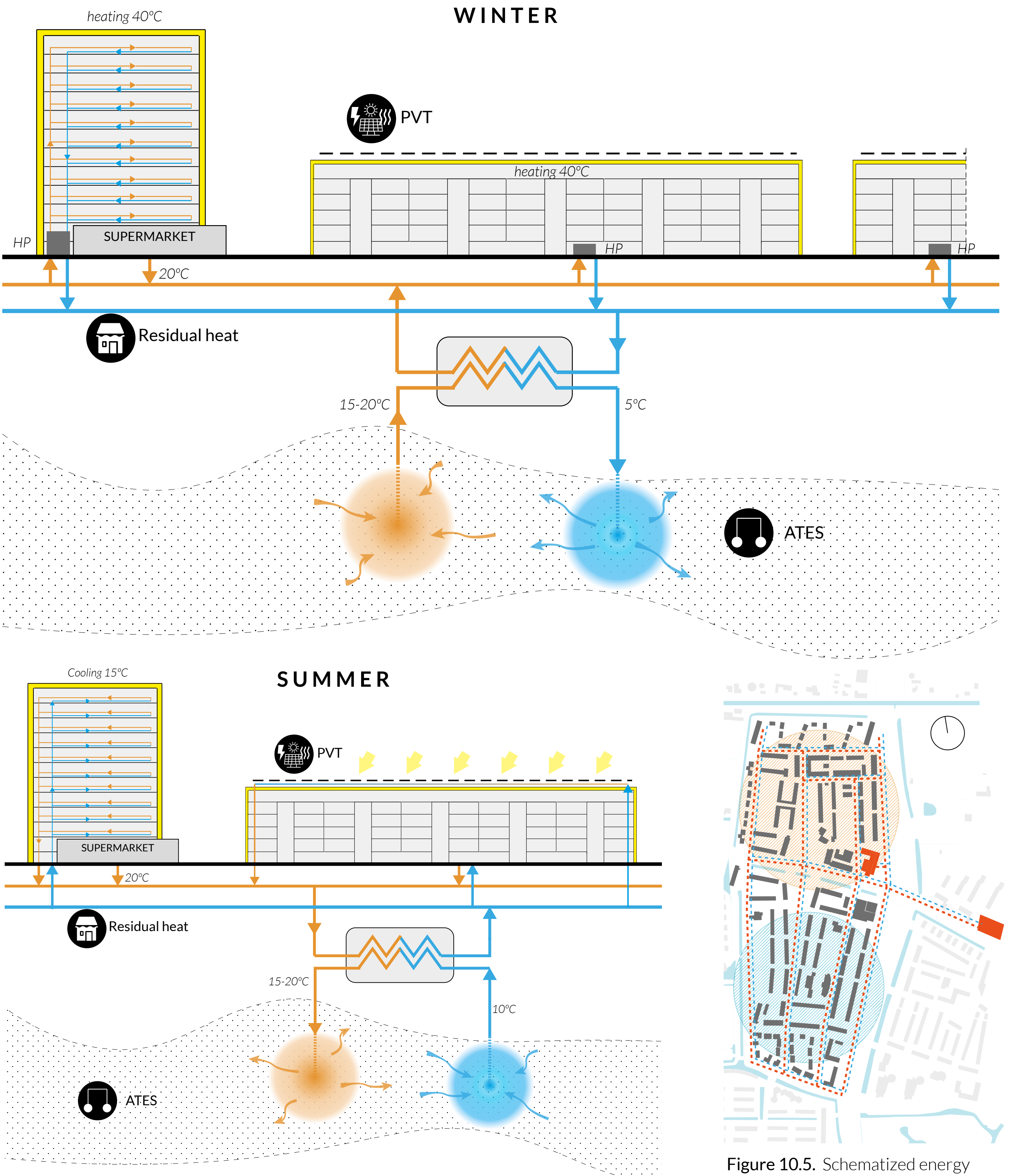


Figure 10.5. Schematized energy system (intervention D) Kuyperwijk (by Author).

Figure 10.6. Residences van Almondestraat (Taco Verbeek Makelaardij, 2017).

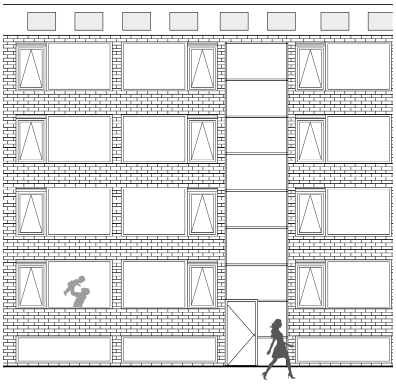


Figure 10.7. Impression new facade (by Author).

14.1.3. Interventions building block

The building block at the van Almondestraat is a typical Dutch Portiekflat built in 1959. The building does exists out of 24 residential units of 66m2. The current energetic quality is low with energy label E, with single-pane glazing in a plastic window frame and an uninsulated building envelope. The current R_c/U-values of the building are based on the "portiek" residence (1946-1964) of the example residences from Agentschap NL 2011. Heating is done locally with gas heaters in the dining room/ kitchen, geysers are used for domestic hot water (www.funda.nl). Ventilation is done naturally through the windows.

After Retrofitting

I. Building insulation

To make sure energy losses are limited and the residences can be heated with low temperature heating insulation has be added exteriorly to the building envelope. Therefor the existing corrugated steel cladding has to be removed. This cladding is connected with steel battens to the inner brick walls and can thereby easily be removed. On top of the insulation the brick slips will be attached, this improves the architectural value of the façade (currently corrugated steel plates). At the same time the windows will be replaced by triple HR++ glazing in aluminium window frames. In figure attachment F details of the façade before and after the renovation are shown.

Also the roof can be exteriorly insulated with a thick layer. The walls adjacent to the cold staircases and the first floor should be insulated from inside the staircases and basement. This results in the insulation values as shown in table 10.9, based on the achieved values of the BEEM-UP residences in the neighbourhood (BEEM-UP, 2013).

II. Ventilation, heating and cooling

A collective heat pump that upgrades the heat from the grid to 40°C will be placed in the basement. The living room and kitchen will be heated with floor heating, in the bedrooms LT-convectors will be placed (quicker adaptable temperature). Individual heat pump boosters (in each residence) will upgrade the collective heat to the desired temperature for the domestic hot water supplies. Above that at least once in 1/2 weeks the temperature will be brought above 60°C for salmonella prevention.

The self-regulating ventilation louvres in the new windows will provide fresh air. The ventilation exhaust will now be done mechanically in the bathroom, toilet and kitchen. The ceiling of the entrance, toilet and kitchen will be lowered to integrate the ventilation ducts. The installation principle for the ventilation and heating is shown in figure 10.8 and on floor plans in attachment F.

Finally 100m2 PVT will be placed on the building roof. The heat will be used to regenerate the aquifer during the summer.

Results
Finally the energy demands are decreased with 40% after the renovations. This results in the energy label step label E to around energy label A+ (de Jong et al., 2012). The electricity demands are increased with 51% because heating is now provided by the collective heat pump. The user-related electricity demands are expected to be decreased with 15% after the renovations by changes in behaviour. In reality the demands can be higher or lower than the calculations because the software Uniec calculates with a standard household. However in both the situations before and after the renovations this same data is used and thereby the final energy savings in percentage is reliable.

For the amount of heat taken from the network there is calculated with an CoP of 4. This means that of the final heat demands $^1/_4$ is provided by the heat pump and $^3/_4$ by the heat source, which is 18,6GJ per residence. The final heat demands are decreased with 56%, this is more than the 25%

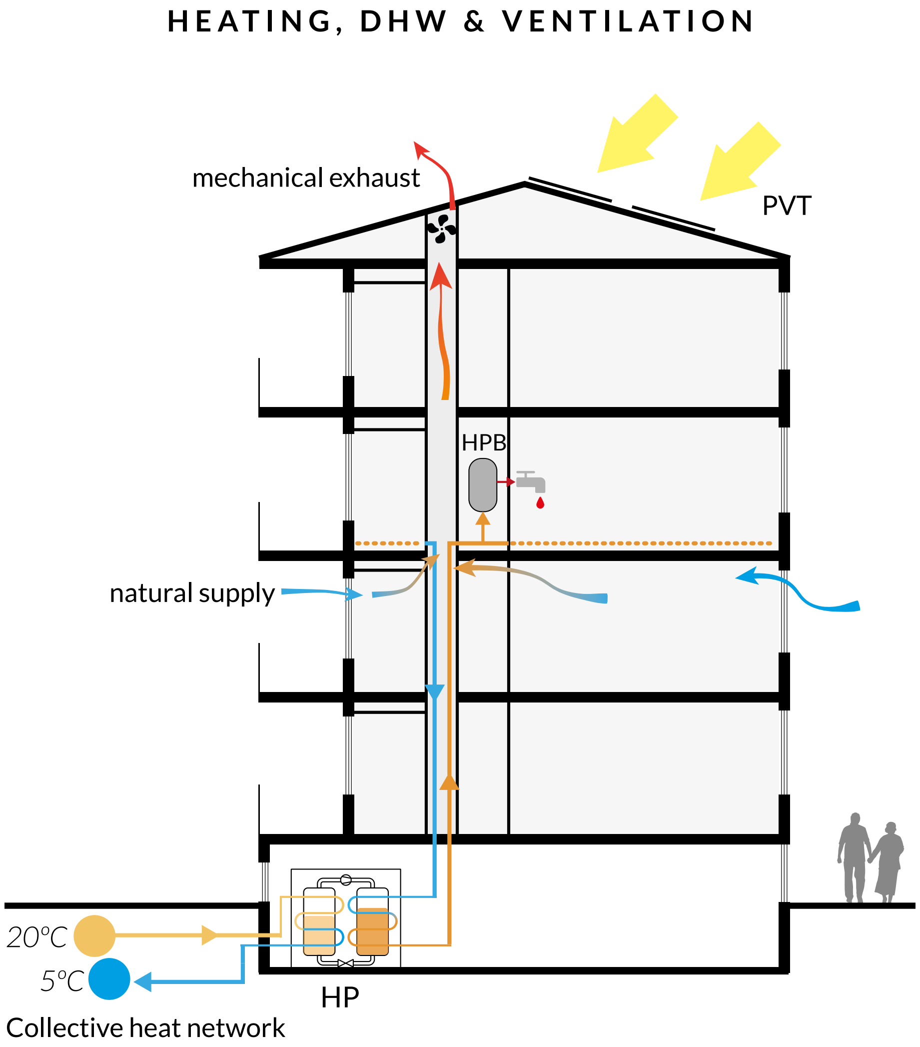


Figure 10.8. Diagram of the heating and ventilation principle of the building after the renovations (by Author).

savings assumed for the neighbourhood. This suggests that even more savings are achievable and that the energy taken from the aquifers can be smaller. The required m2 of aquifer should be calculated when the savings for all residences are known.

Table 10.9. Insulation values of the building envelope and installations before and after the renovation. And the results of the renovation in terms of energetic performance (by Author; based on calculations with Uniec2.2.See attachment F for the calculation).

INSULATION

	Rc facade	Rc roof	Rc floor	Rc wall staircase	Glazing type	U glazing	ZTA glazing	U doors
Before	0,36	0,39	0,32	0,36	Single glazing	5,2	0,8	1,65
After	4,5	6,0	3,5	3,5	HR++	1,1	0,5	1,65

INSTALLATIONS

	Heating system				Domestic hot water	Ventilation	PV/PVT/ solar collectors
	Installation	Heater (afgifte)	HT/LT heating	Cooling	Installation	System	
Before	Local gas heater	Local gas heater	HT	x	Geyser (gas heater)	Natural ventilation	x
After	Collective HP. Source: heat network	Floor heating/ convectors (bedrooms)	LT 40°C	HP ATES	Individual heat pump booster (CoP 3) - heat from heat grid	Natural inlet (self-regulating louvres) mechanical outlet	100m2 PVT 150WP/m2.

RESULTS

	EPC	Electricity demands				Heat demands			Total
		Building-related	User-related	Total per residence	Per residence [GJ;el]	Total	per residence	Per residence [GJ;th]	Per residence GJ
Before	1,658	5.835 kWh	44.403* kWh	2.093 kWh	7,5 GJ;el	32.182 m3	1.341m3	42,4GJ;th	49,9
After	0,328	50.574 kWh 80% heat	37.743 kWh	3.152 kWh (=-PVT 12.655 kWh)	11,3GJ;el 55% heat			18,6GJ;th (by heat network)	29,9GJ
Savings			-15%		+51%			-56%	-40%

**Higher than the outcome of the Uniec calculation, the value of the after scenario is taken because the before sitaution calculates with a smaller residential area than in reality, because the heated zone in this case is smaller (only heating applied in the kitchen/dining room.*

Figure 10.10. Air picture of Voorhof-North (googlemaps.nl).

10.2. Voorhof-North

The post-war expansion district Voorhof is almost fully constructed in the in the sixties. The northern part consist 2.530 residences of which 99% is multi-family housing. In total 80 percent of the residences is property of housing corporations (www.cbs.nl). In the northern part of the Voorhof four neighbourhoods are located: Poptahof-North, Poptahof-South, Voorhof and Mythologiebuurt, each with different characteristics. The Poptahof exist out of ensembles of high, mid and low-rise residences. There are also a lot of shops in this part, like the De Hoven shopping centre. In 2009-2012 old residences in Poptahof-South were demolished and replaced.

The Voorhof neighbourhood locates light industries and shopping facilities, but will be transformed into a new residential area as part of the Spoorzone. The mythologiebuurt also has some light industries, but mainly exists out of apartment blocks of the sixties.

10.2.1. Energy demands & Savings

The energy performance in the neighbourhoods differs a lot with energy labels vary between A and E. For the lower labels there is a large potential for energy retrofitting to minimally label B, because most of these residences are property of housing corporations. By the energy retrofitting the whole area will become suitable for low temperature heating. Currently

Figure 10.11. - Location of Voorhof-North in Delft (by Author).

Table 10.12. Energy demands and potential savings of Voorhof-North according to the scenario (by Author).

Energy demands	Residences [GJ]	Savings	Businesses [GJ]	Savings	Total [GJ]	Savings
Heat demands	28.719	38%	29.102	27%	57.821	33%
Electricity demands	16.516	15%	30.582	15%	47.098	15%
Total demands	45.235	32%	59.684	21%	104.919	26%

most buildings are heated with natural gas and have a yearly gas demand of 18,5GJ per residence (www.cbs.nl). Poptahof-South is partly heated with a heat network (300 residences).

The energy retrofitting will result in a final energy saving of 26%. The heat demands will be decreased with 33%, resulting in a demand of 0,058PJ;th. See table 10.12, the complete table is found in attachment F.2.

10.2.2. Total Energy system

Voorhof-North will be heated with a heat network of about 50°C. This heat will be supplied by different sources, see figure 10.15. With the same principle also Delftzicht/Koningsveld (North of the Schieweg) and Tanthof-East will be heated. In figure 10.14 the energy balance between heat supplies and demands of this energy network is found. On the building roofs (excl. the roofs at the Schieweg) PV panels will be placed. If in Voorhof-North 5.000m2 panels about 3.500GJ; per year will be generated.

In Tanthof-South already a heat network is constructed that is also connected to two buildings in the district Buitenhof. With the expansion of the heat network through Voorhof-North also the neighbourhood Juniusbuurt will be connected to this network.

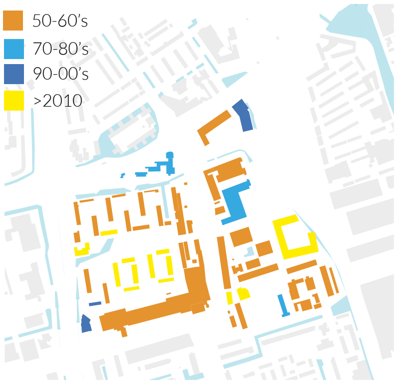
Cascade HT heat Schieweg

In the schie district Delfts waste is collected at Avalex. This waste will partly locally be converted into renewable energy. This can be done with the fermentation of local separated food waste and burning garden waste from households. Also the sludge of the water treatment plant will be fermented in the bio-digester. The thereby produced biogas will be used as source of a CHP installation that together with the pellet boiler supplies the Schieweg district, the Rotterdamseweg and Voltaweg with HT heat. The return heat of about 50°C will be cascaded to the surrounded mid temperature heat networks.

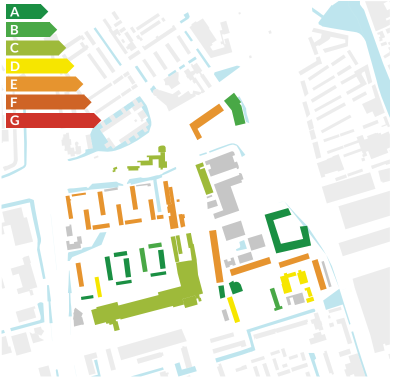
Solar collector Farm the Schieweg

Also solar collectors will feed the low-temperature heat network. These solar collectors will be placed on the large flat roofs of the industries. In total about 1ha can be covered with solar collectors. Which results in a total potential of 0,013PJ;th of 50°C.

CONSTRUCTION PERIOD



ENERGY LABELS



TYPOLOGIES

Figure 10.13. Different charateristics of Voorhof-North (by Author, based on: www.code.waag.org, www.energielabelatlas.nl).

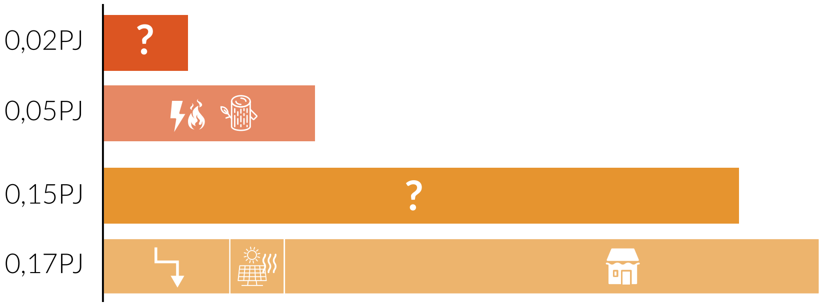


Figure 10.14. Energy balance of the energy system (by Author).

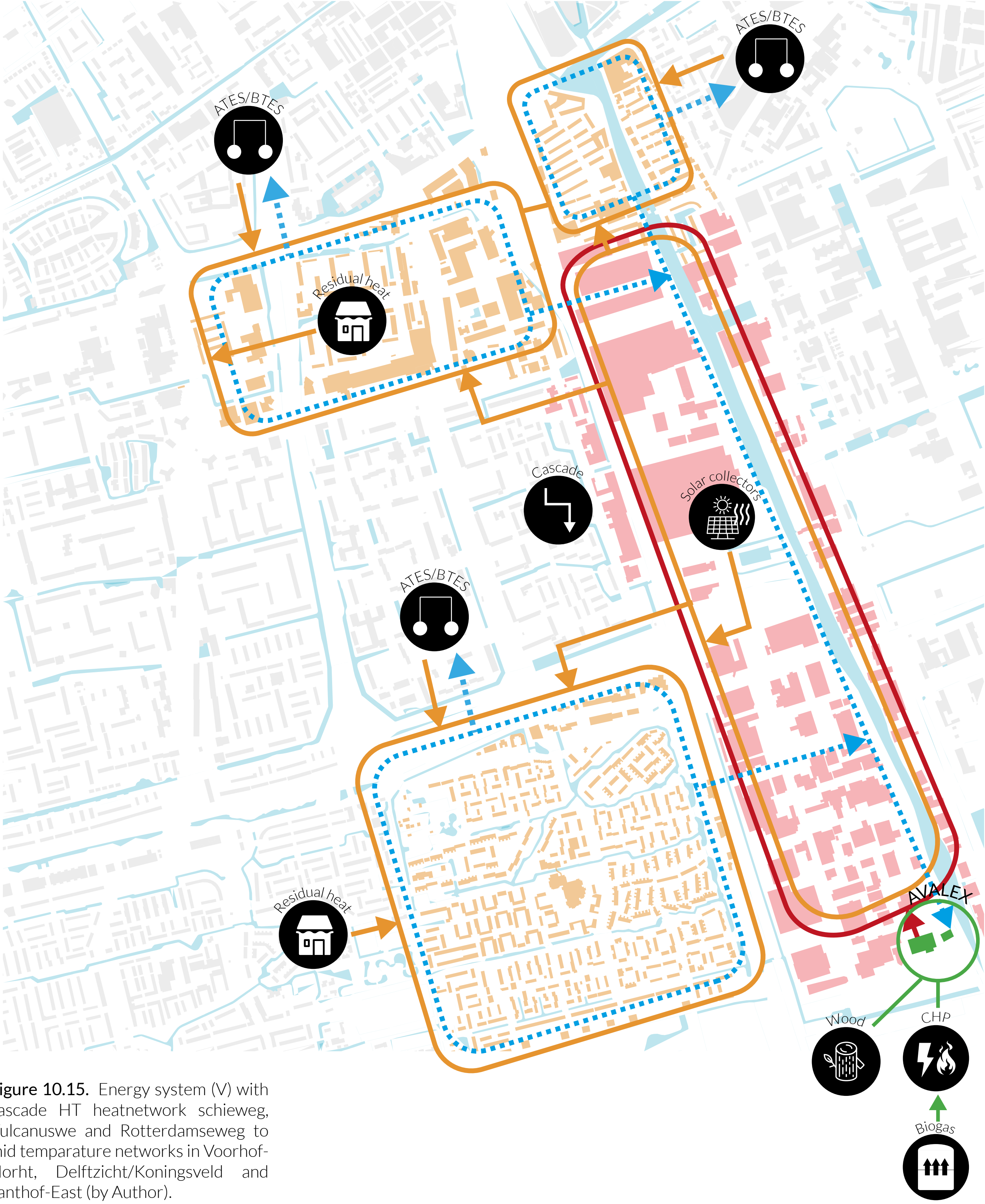


Figure 10.15. Energy system (V) with cascade HT heatnetwork schieweg, Vulcanuswe and Rotterdamseweg to mid temparature networks in Voorhof-Norht, Delftzicht/Koningsveld and Tanthof-East (by Author).

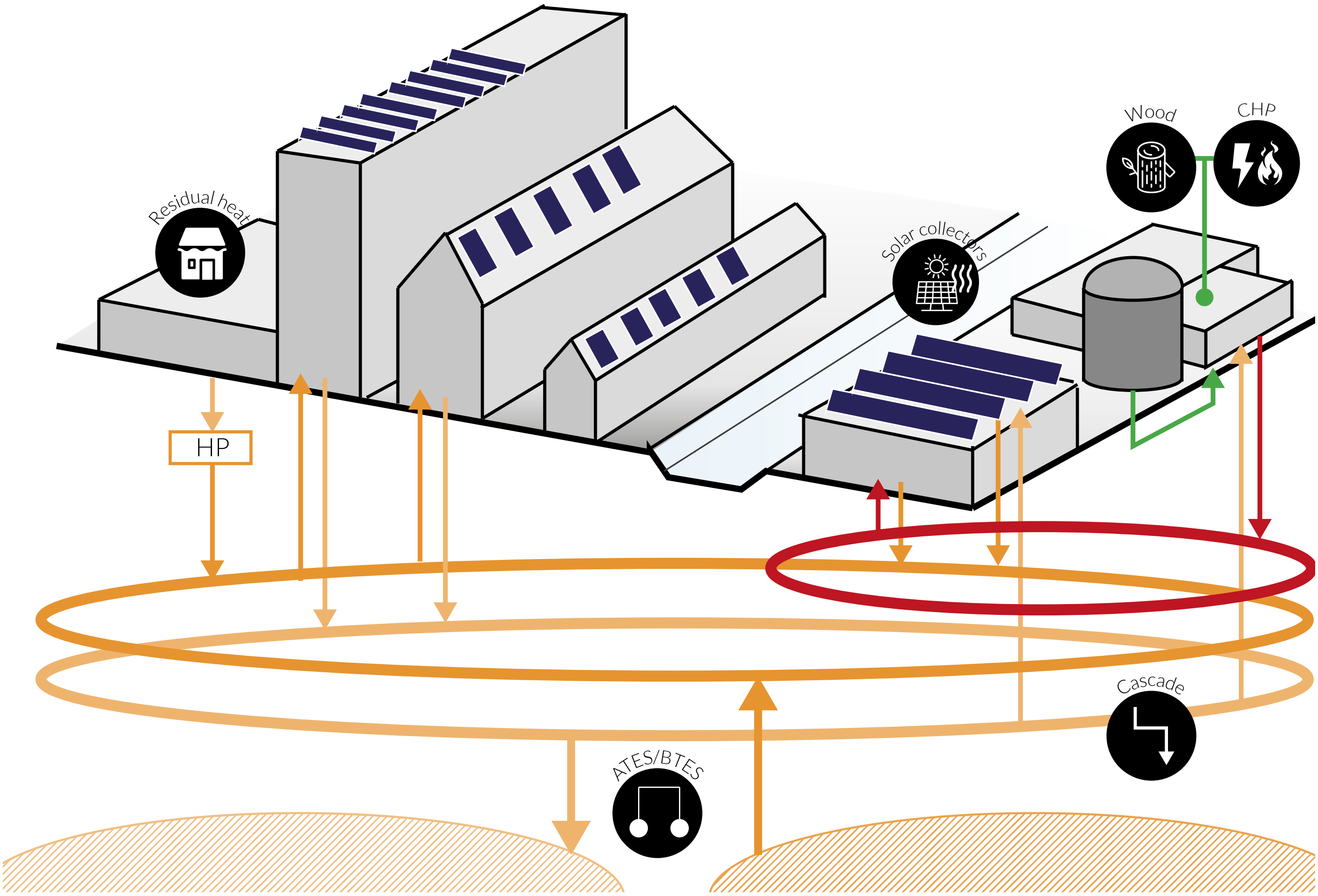


Figure 10.15. - Energy system in 3D (V) with cascade HT heatnetwork to mid temparature networks (by Author).

Residual heat Datacentre & Supermarkets

The Delft Datacentre in Ruiven will supply 0,03PJ of 40°C heat to the network. Also 8 large supermarkets and the Makro will supply heat to the network. Their 20°C residual heat will be upgraded by a heat pump to 40-50°C and supply about 0,1PJ. Thermal energy storage will be used to store the generated heat during the summer.

10.2.3. Intervention building block

The building block at the Papouwselaan is a typical Dutch 'galerijflat' built in 1968. The building does exists out of 36 residential units of 91m2. At the ground floor 14 shops are located.

The energy performance of this building isn't optimal yet with energy label E. Currently the building is heated with collective block heating. Individual electric boilers supply warm water for the bathroom and kitchen. Ventilation is supplied naturally and the exhaust is done mechanically in the kitchen, toilet and bathroom (www.funda.nl).

The current insulation values are based on the gallerij-residence 1965-1974 of the example residence of Agentschap NL 2011 (Agentschap NL, 2011). The facades, ground floors and roofs are uninsulated. The windows have double glazing. In this construction period the buildings where constructed with concrete or sand-lime brick load bearing structure, a 60mm air-cavity and often brick facade cladding.

After Retrofitting

The residences are mainly private property (rental or privately owned). Thereby the renovation to a higher energy label should be done with limited measures. Moderate retrofitting measures are required to make the building suitable for the 50°C heating.

Figure 10.16. Building block Papouwselaan (Bjornd Makelaardij, 2017).

Figure 10.17. Insulation method of the cavity-wall. Source:

I. Building insulation

Insulation should be added to the building to limit the heat losses. The facade will be insulated by adding insulation into the 60mm deep air-cavity, see figure 10.17. With this type of insulation energy savings can be achieved easily, for a small amount of money and without nuisance for the residents. By injecting the EPS insulation in the cavity an insulation value of 1,7m2K/W can be reached.The windows with double glazing will be kept.

The ground floors applied in the sixties mostly had rounded edges at the bottom side. This makes it more complicated to add insulation. However still high insulation values with an Rc of 5,0 can be reached by spraying multiple layers of HR-insulation foam to the bottom of the floor (de Jong et al., 2012). The roofing will be removed and a thick package of insulation will be added.

II. Heating, cooling & Ventilation

Because the building is currently heated with collective block heating the transformation to the collective heat network heating is relatively easy. The collective heating installation has to be replaced by a heat exchanger. The existing radiators will require all lot of energy to be heated; it will take a long time to heat up the residence with these radiators and 50°C heat. Therefor the existing radiators will be replaced by floor heating and convectors. The existing electrical boilers won't be used on regular basis anymore, but only once in 1-2 week to prevent salmonella. Finally on the building roof in total 100PV panels will be placed, that generate 107.000kWh electricity per year. The principle for heating, cooling and ventilation is visualized in figure 10.19.

Results

In the calculation the shops on the ground floor are not included. The renovation of the residences does result in a 27% energy saving. The electricity demands are decreased with 53% mainly because the boiler will now only be used once in 1/2 week to prevent salmonella. Also the generation of electricity with PV results in large electricity savings.

The heat demands are only decreased with 10%, this is less than expected. However when the insulation of the building is also done with insulation from inside the building much more savings can be achieved.

Table 10.18. Insulation values of the building envelope and installations before and after the renovation. And the results of the renovation in terms of energetic performance (by Author, based on calculations with Uniec2.2.See attachment F.2 for the calculation).

INSULATION

	Rc facade	Rc roof	Rc floor	Glazing type	U glazing	ZTA glazing	U doors
Before	0,43	0,86	0,32	Double glazing	2,9	0,7	1,65
After	1,7	5,0	5,0	Double glazing	2,9	0,7	1,65

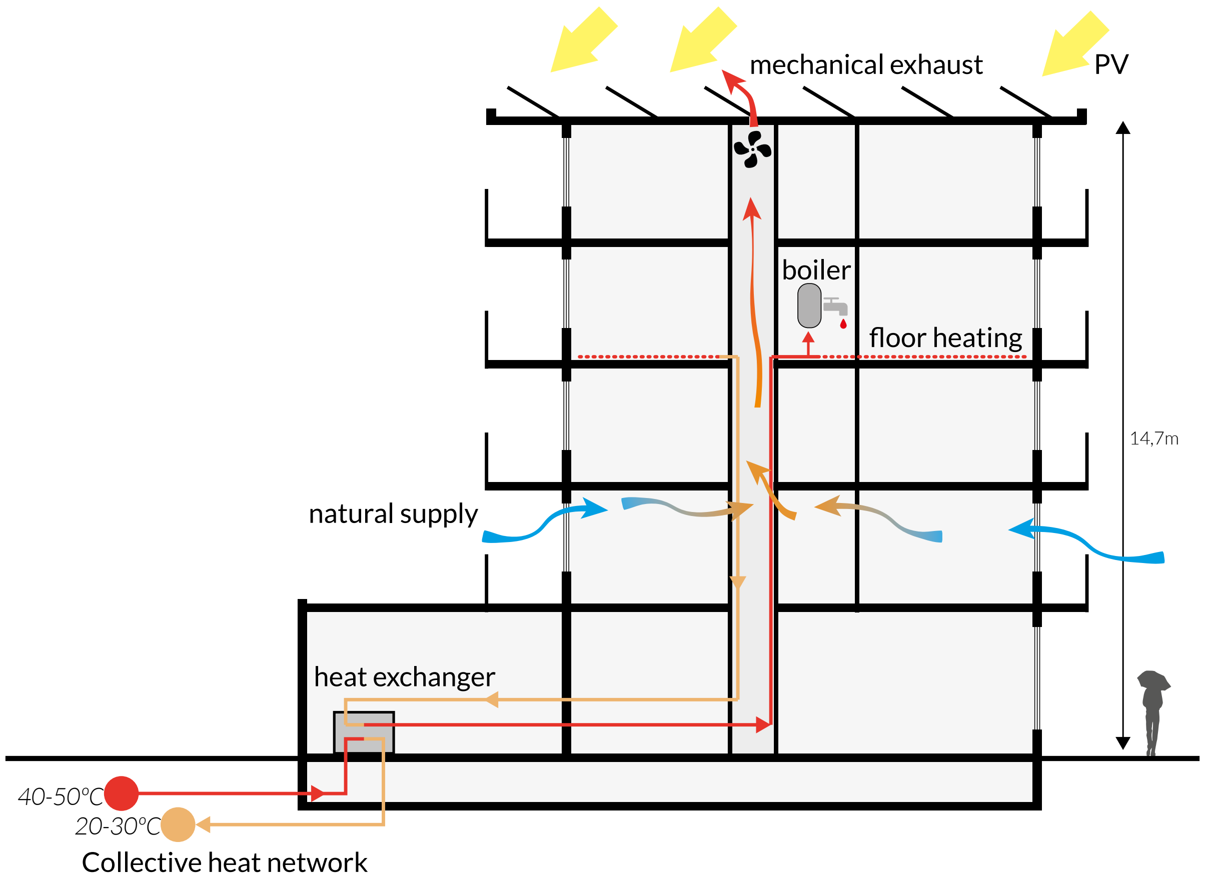
INSTALLATIONS

	Heating system				Domestic hot water	Ventilation	PV/PVT/ solar collectors
	Installation	Heater (afgifte)	HT/LT heating	Cooling	Installation	System	
Before	Collective block heating on natural gas	Radiator	HT	x	Electrical boiler	Natural supply (louvres), mechanical exhaust	x
After	Heat network with 50°C	Floor heating living rooms, Convectors bedroom	MT (50°C)	Supplied by heatnetwork	H eat grid + Electrical boiler: samonella prevention	Natural supply (louvres) Mechanical exhaust	100 PV panels 270WP South-West 30°

RESULTS

	EPC	Electricity demands				Heat demands			Total
		Building-related	User-related	Total per residence	Per residence [GJ;el]	Total heating	Per residence m3	Per residence [GJ;th]	Per residence GJ
Before	1,534	135.688 kWh	91.945 kWh	6.323kWh	22,8GJ;el	40.493 m3	1.125m3	35,6 GJ;th	58,4GJ
After	0,686	39.316 kWh	78.153 kWh	2.989kWh (= - PV: 107.617 kWh)	10,8GJ;el	1.154GJ	x	32,0GJ;th	42,8GJ
Savings			15%	53%	53%			-10%	-27%

HEATING, DHW & VENTILATION



10.3. Conclusion

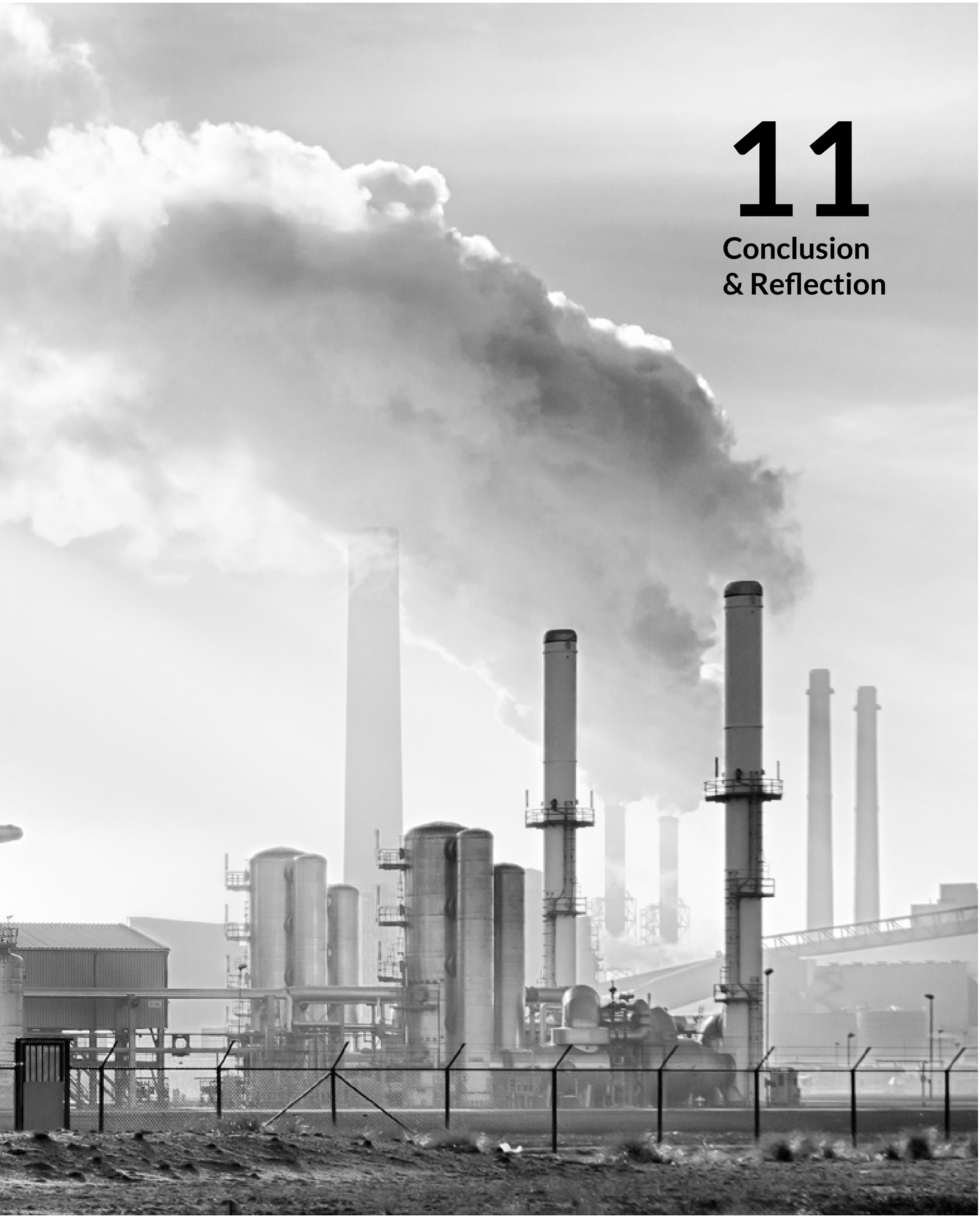
In this chapter gives answer to the question: What interventions need to be implemented into the two neighbourhoods according to the defined interventions on bigger scale? The Kuyperwijk will be heated according to intervention D: a small scale heat network of 40°C feed with residual heat from two supermarkets, solar collectors/PVT and balanced thermal energy storage. The Voorhof-North district energy system will be a mid-temperature heat network (intervention E), supplied with cascade heat from the Schie district, solar collectors and residual heat. Therefor heat networks needs to be constructed that connect the buildings with the energy sources. On building scale this means that the buildings have to be renovated so that they become suitable for the temperature heat of the heat network. Because of the current poor energy performance this takes a lot of interventions. A collective heat pump will supply the heat to the residences. Domestic hot water can directly be taken from the mid temperature network in Voorhof, but in the Kuyperwijk it should be upgraded to a higher temperature first with individual heat pump boosters. The extent of renovation depends on the current state of the building, the temperature of the heat network and the ownership type of the building.

Figure 10.19. Heating and ventilation princple schematized for the residence (by Author).

Figure 11. Energy generation fossils.
(Te Connectivity, n.d.).

11

Conclusion & Reflection



11.1 Conclusion

The global temperature is increasing, resulting in a decline of biodiversity and more extreme weather conditions like floods and draughts. This is partly caused by carbon emissions that are released by burning fossils. At the same time the fossil energy reserves are running out; the energy supply will become unsure and dependent on other countries.

In order to regulate this exhaustion and climate change the transition to an energy system based on renewables in mandatory. While the Netherlands signed the Climate Agreements towards carbon neutrality in 2050 the energy transition by the national government is still far from reaching these goals. This lagging transition can partly be blamed by the opposite interest of the government in the transition: as being an energy trading country the fossil industry is highly interwoven with our economy. However to be able to succeed the energy transition this transition process should be speeded up.

By the importance of local potentials and the local variable housing stock the municipality should take an active role in the transition of the thermal energy supplies. The transition of the electricity network will remain the main responsibility of the government. The municipality should limit their demands and should try to maximize the generation of sustainable electricity. However for most municipalities the energy transition process is too complex to make a difference. The same applies to the city Delft: while the transition targets are defined the starting point and road towards this ambition is undefined. Therefor a roadmap should be created that shows the required interventions at all scales and that makes use of the local energy potentials.

Given these points this thesis aimed to give answer to the research question '***How should the roadmap for the energy transition of the built environment towards energy neutrality for the city Delft look like, with technical interventions based on local sustainable energy potentials integrated at different scales and what is the general approach for the energy transition of Dutch municipalities?***'

Before the roadmap was designed the vision and targets of the municipality Delft were defined first. Followed by the status quo of the transition. Now the starting and end point where defined the path between these points could be designed: the roadmap. To start with this design the energy potentials needed to be mapped; including the energy savings and generation potentials.

These potentials can be assigned to the four main heat systems; the individual systems biomass, biogas and all-electric and the collective heat networks. Two important rules that should be kept in mind are: high temperature heating only should be used when low temperature heating is no option (like in historic city centres) and low density areas should always be heated by individual heat systems, because a collective heat network requires a lot of connections to be cost-efficient.

To determine the interventions initially the energy systems that can use the present heat networks or that are based on existing initiatives will be implemented. Followed by potentials based on waste (energy) streams. The remaining demands will be supplied by renewables that can be extracted from the ground or generated with man-made objects, like photovoltaics. A variant of the new stepped strategy can help to determine the energy systems for each district according to this order of priority.

By following these steps and guidelines the interventions were determined. As being part of a design process the outcomes of the roadmap according to the chosen energy systems and interventions can differ per designer. Multiple options can lead to the same outcome: energy neutrality in 2050. The outcome depends on how the available energy potentials are implemented. While some of the interventions can be excluded easily for a certain location, other locations have multiple potentials. It is important to match the potentials for both generation and energy savings with the characteristics of the neighbourhood as much as possible to propose a realistic intervention.

While there are multiple outcomes possible for the roadmap of Delft this research includes a broad analysis that offers a good basis to do a realistic proposal for the energy systems in Delft. These interventions are integrated by going through the different scales of the roadmap for each of the proposed energy systems. The consequences of the chosen intervention for a certain area were analysed on both the scale of the neighbourhood and the buildings. Finally the interventions were placed on a timeline to finalize the roadmap.

Above all the roadmap of Delft demonstrated that the energy transition of Dutch municipalities towards energy neutrality in 2050 is achievable. Although it requires active participation by the citizens, companies, corporations, etc. that are located in the city to achieve the desired energy savings. They should become aware of the urgency of the transition and their role in this process. The municipality should stimulate this involvement and provide clear guidelines of the measures that they can take. To succeed the transition the participation of both citizens and companies is one of the most important factors.

Furthermore not only the citizens but the municipality itself should become aware of the urgency of the transition and of the large scale of this assignment. Thereby they should no longer wait for the national government to take action but they should act now. With as result that a bottom up movement will occur that finally also stimulates the transition of other municipalities and the participation of the government. The municipalities can immediately start with awareness programs and energy retrofitting of buildings while at the same time designing the roadmap. In the roadmap they should take into account a constantly changing world by regularly adapting and updating the roadmap during the transition. This thesis can help Dutch municipalities to make a roadmap for their energy transition by using the created approach and by the case study of Delft. Above that the thesis can help more local initiatives to define the most suitable heat system for their neighbourhood.

On basis of the results of this design and research process there can be concluded that *by working through all scales while defining the energy systems and interventions according to the local characteristics and energy potentials an integrated and realistic roadmap towards an energy neutral built environment in 2050 is designed for the city Delft; at the same time the designed approach can also help other municipalities to achieve their energy transition goals.*

11.2. Recommendations

This thesis approached the energy transition from a technical point of view. The main focus was to design a roadmap for the energy transition of Delft that integrates the required technical measures on all scales. As part of the generated approach step 2 included the analysis of the involved stakeholders. However this step isn't performed for the city Delft, as stated in the boundary conditions. In further research towards the energy transition the involved stakeholders and the way they should be approached should be analysed more deeply. For each of the defined interventions the involved stakeholders that should participate need be mapped. The same applies to the financial aspect of the transition; how to finance the required measures and how to subsidies and stimulate the retrofitting measures should be determined in financial models.

A Recommendation for the roadmap of Delft is to rephrase the described scenario after the stakeholder and financial analysis is performed; resulting into some adaptations to the defined interventions. After that an action plan for the period to come should be created in order to achieve the planned savings and to realize the proposed energy systems.

Beside that to finalize the proposal more deeply should be looked into the cooling demands and the potentials to supply this type of thermal energy.

Furthermore I realize that by the fast development of new technologies and improvement of the existing technologies regarding this topic the proposed strategy will get outdated relatively fast. Thereby it's important that these kinds of studies and roadmaps created by municipalities will be evaluated and adapted on a regular basis. When designing a roadmap space should be left for these kinds of developments. This means that when using the approach to define the roadmap, step 3 (EPM) till step 7 need to be repeated on regular basis during the transition process.

For the final energy transition strategy also energy demands that are not related to the built environment should be included. In this thesis the emissions and energy demands by transportation and traffic are not taken into account. Transportation for example is expected to be fully electric in 2030. This will increase the electricity demands extremely, but at the same time it gives the opportunity to store electricity by using the batteries of the cars. However it is difficult to appoint these demands to a specific city: while the commuters travel between two cities, they will maybe charge their vehicle at another location.

11.3. Reflection

Position topic in the graduation studio

The master building technology combines design and engineering with a focus on sustainable façade, climate and structural design in the built environment. In this thesis a roadmap for the energy transition of the city Delft is developed together with an approach for the transition of Dutch municipalities. Both roadmap and approach focussed on the technical aspects of the energy transition. The roadmap integrates the required interventions on different scales: urban, district, neighbourhood and building scale. The interventions at the building scale will show the consequences of the chosen energy system for the district/neighbourhood towards the envelope and the installations of the building. Thereby the thesis is focussing on the climate and sustainability department.

Relation between the research approach and aimed results

This thesis is divided in 3 parts: I the basics of the energy transition (literature review), II the approach and III the roadmap of the city Delft. With the literature study the basic knowledge about the Dutch energy transition and the available technologies for generation, conversion, storage and transportation of energy was gained. This resulted in an overview of available technologies and in guidelines that helped to create the approach and the roadmap.

In the next phase the approach (II) and roadmap of Delft (III) were designed. As proposed in the research approach these steps where performed simultaneously. Finding during the design of both methodology and roadmap affected each other until the final methodology was created.

The first steps of the approach are the analysis of the context of the roadmap including characteristics of the city, energy demands, existing energy systems and energy potentials. In the next phase the roadmap was designed. The design process of the roadmap and the approach was a more complex process of trial and error. Finally, as aimed, the final roadmap integrated the defined interventions based on local potentials on all scales of the all scales of the city by going through all scales of the city during the design process.

Relation between research and design

The research focussed on the general background information of the energy transition: the current energy system in the Netherlands, sustainable energy sources and load matching technologies. This resulted in guidelines for the energy transition of Dutch cities. Together with the analysis of existing methodologies for the energy transition this formed the initial basis of both approach and roadmap (design-by-research). The literature study results can clearly be found in the created 'sustainable heating systems tool'.

While the research done resulted in the first version of the design, the remaining part of the roadmap and approach is defined with research-by-design. By designing the roadmap the last steps in the approach towards the roadmap were designed.

Application of results in practice

The defined approach should help municipalities to simplify the transition process by providing steps that result in a roadmap design that integrates the sustainable energy systems on all scales (based on local potentials). This approach is supported by tools that help to determine which energy system and energy sources can be implemented on which location.

The approach doesn't include how to involve the stakeholders to finally realise the by the roadmap proposed interventions. However it helps the municipality to define a roadmap and thereby they will have a concept/ idea about what can be done at which location and what the scale is of the transition task.

Achievement of projected innovation

The city Delft is aiming to become energy neutral in 2050. However the road towards this energy neutrality is unknown. The designed roadmap for the city Delft results in a proposed energy strategy for the transition, This proposal appoints which energy system and interventions have to be implemented in which district/neighbourhood to succeed in the transition towards energy neutrality.

Compared to existing methodologies the approach is not only focussing on a roadmap at urban scale, but it makes sure that the chosen interventions are integrated at all scales of the city (urban, district, neighbourhood and building block). The developed tools that are added to the approach can help the municipality with this integration.

Contribution to sustainable development

The designed roadmap results in an energy neutral Delft. Energy neutrality means that no energy originating from fossil fuels is used, so only renewables do supply the energy demands. Thereby no CO_2-emissions will be released.

The created approach for the energy transition of Dutch municipalities will help to define a roadmap for other cities. Beside that the thesis focusses on the urgency of the transition and the importance of an active role of the municipality in this transition process by the slow development of the energy transition by the national government.

Impact on sustainability (PPP)

<u>Planet</u> - Currently the global temperature is increasing: the climate is changing. An energy transition is required to limit this climate change and to be able to preserve the world we live in and thereby keep it liveable for our next generations. Therefor we should get rid of an energy system based on fossil fuels (results in CO_2-emissions) and change to a system based on

renewables.
People - The world is running out of his fossil fuel reserves; therefore the transition is required to be able to guarantee the energy supplies to furfill our demands. The approach will result in a roadmap in which the energy system is based on renewables. Thereby the energy supplies will be guaranteed. At the same time the use of renewables will not result in the release of CO_2-emissions, so that the air pollution cab be avoided.

Currently a lot of citizens in the Netherlands are living in energy-poverty. The first step of the energy transition to energy neutrality is energy retrofitting of buildings. These renovations will lead to a decrease of energy demands and thereby smaller energy bills. At the same time these renovations will increase the indoor climate and living conditions of citizens.

Profit - Because fossil fuels are running out not only the supply of energy should be guaranteed, but also energy supply should stay affordable. This is another reason for the transition. The transition is a complex and expensive process, but at the same time this will lead to new jobs in the knowledge, management and construction sectors.

Relation between the project and the wider social context

The energy transition asks for good management from the governmental institutions, but will also ask for participation and effort of companies and the citizens. Therefor the municipality should make the citizens aware of the urgency of the transition and at the same time they should provide information about the measures that the citizens and companies can take. Although quite some citizens are willing to contribute, the municipality should also expect resistance from their citizens. Not all citizens and companies will be able or willing to participate in the transition by energy retrofitting their buildings. At the same time citizens should chance their traditional view on the energy supplies, as being invisible. In this new sustainable world energy will be a visual factor; wind-turbines, roofs covered with PV and solar collectors will fill the skylines of the cities. To succeed the energy transition the participation of both citizens and companies is one of the most important factors.

Influence of project to architecture / the built environment

Currently architects are become more aware of sustainability, this leads to a trend of sustainable buildings, often heated with a heat pump. However this process of choosing a heating system should become more integrated with surrounded the built environment. The energy potentials in the surroundings should be well analysed in order to choose the best suitable heating option which won't be contradicted to the energy transition roadmap of the full city. For existing buildings intelligent energy systems/ technologies should be chosen that limit the required interventions in the area. The energy transition will only succeed if all scales of the built environment are integrated.

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Appendix

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A-F

Appendix

A

Case studies

A.1. Buiksloterham

(Jansen, Bokel, et al. 2016).

Buiksloterham is a former industrial area which will be transformed into a residential area with some small businesses. It is the ambition to achieve a complete sustainable and self-sustaining energy system for Buiksloterham. The existing buildings are mostly industrial buildings, constructed after 1960. After the transformation the area will mostly exist out of new buildings in a high density.

Existing buildings:

For the existing building stock no energetic refurbishment actions are taken, only the sustainable generation is enlarged with solar and wind energy.

New buildings:

A part of the electricity demands of the residences will be supplied by small turbines and PV-panels on their roofs. Beside local generation also regional options should be included, because it is impossible to generate all energy locally by the high density. In the Buiksloterham neighbourhood two third of the electricity demands will be covered by wind and solar energy. Thereby a large peak supply of electricity will occur in the summer.
Variants heating system:

1. Gas.

All space heating inside the buildings is generated with high efficiency boilers on biogas, electricity is taken from the electricity network and cooling is produced with air-conditioning. This option isn't feasible because of the area's high density. Regional generated biogas or green gas will be required to furfill the demands. This is contrary to the aim of self-sufficiency.

2. All-electric; heat pumps with heat cold storage in the ground.

Because the area exists mostly out of residences the heat demands are much higher than the cooling demands. This means a misbalance in the soil temperature when using a ground-source heat pump. With the combination of PVT panels or heat recovery the heat can be regenerated and the soil temperature will be balanced again. However this requires a lot of installations and results in a much higher electricity demand.

3. Expansion of the existing thermal heat network.

Both space heating and domestic hot water will be supplied by the thermal heat network of Westpoort heating. Therefor the existing thermal network should be expanded. This expansion of infrastructure results in the high investment costs (about 6 times higher than the construction of a gas or electricity network) and thereby leads to a low flexibility of the development of sustainable heating systems.

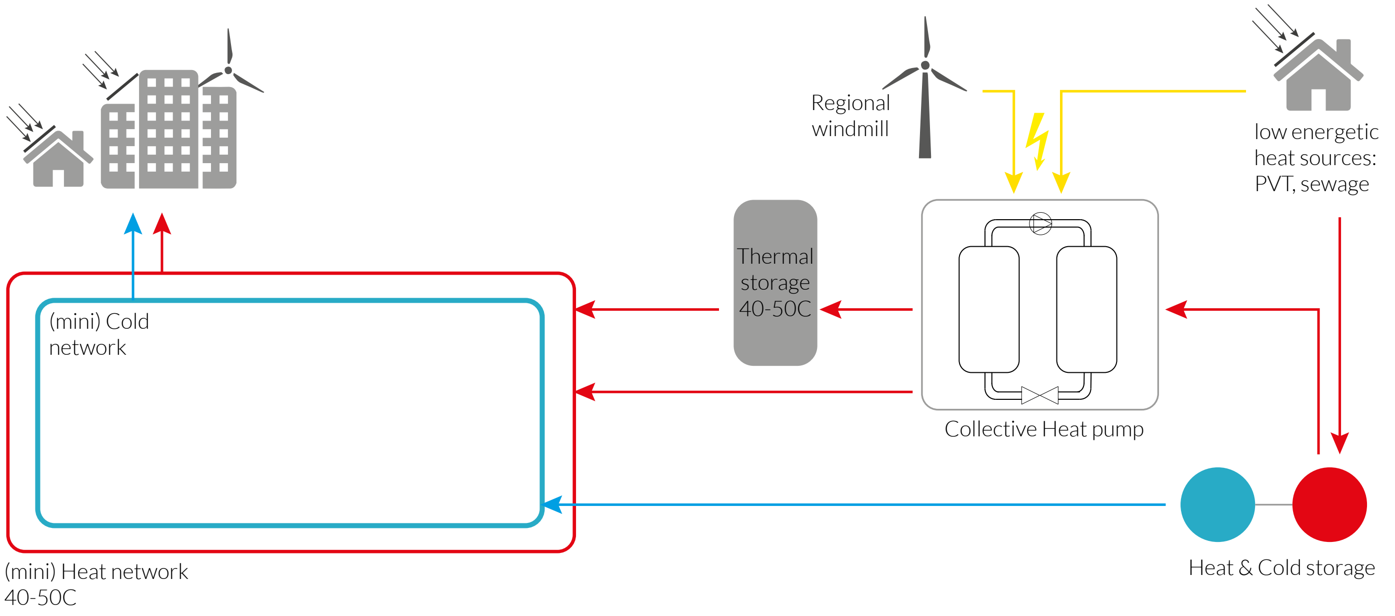


Figure A.1. Diagram of energy system of the chosen variant. (Jansen, et al. 2016, p69).

Chosen variant: Maximal local heat and system integration

The final energy system consists out of the following components:

- A mini thermal heat network with a temperature of 40-50°C, which can directly be used for space heating.
- A mini thermal cold network for cooling.
- A collective heat pump to upgrade the low energetic heat (from PVT, residual heat of the sewage, heat recovery buildings) to the level of the thermal heat network.
- Double heat storage
    - o Heat and cold storage in the ground: large capacity and delivery of cooling.
    - o Storage vessel for the a bit higher temperatures of 40-50°C. The heat for this storage is delivered by the heat pump. This will mainly occur during periods with cheap electricity.

For the existing building stock the required temperatures are 80-90°C. Because the amount of new building compared to the existing buildings is very high it wouldn't be efficient to construct a heat network on high temperatures, because only a few buildings will be connected to this network. In this case it will be more efficiency to locally increase the temperatures of the heat network with a heat pump. Beside that a heat network on high temperatures is not suitable for future sustainable energy supplies.

A.2. Duindorp

(Gommans, Broersma, et al. 2017)

The energy system of Duindorp is based on a very low temperature heating network, called the bronnet, which delivers heat and cold to 780 residences in Duindorp. The bronnet has a temperature of 11-20°C and uses seawater as source. With a central heat pump (the seawaterplant) the bronnet is heated up to the desired temperature. Inside the residences another heat pump is located that upgrades the temperature of the bronnet of 30-35°C to 55-60°C, which is used space heating with floor heating. In the summer the bronnet can also be used for cooling. However the seawater plant will be demolished because new residences will be constructed at this location. Research was done towards a new heating system for the 780 residences. The ambition of the municipality is to reduce as much of the CO_2-emissions as possible.

Potentials building scale

The residences do have a relatively good insulation quality. Thereby most of the energy reducing measures relatively gain only very small savings, especially compared to the required investment. To reduce the final energy demands residual heat should be re-used inside the building. Therefore heat recovery units can be added to the ventilation system and the shower. The residual cold of the heat pump should be used for cooling. Finally residual heat from the parking will be captured with heat recovery. This heat can be used as source heat pump.

At building scale the energy potentials will be found on the roofs, here PV-panels, solar collectors, PVT panels and windmills can be placed.

Variants heat source

1. Replacement of the seawaterplant

Relocation of the seawaterplant whereby the power plant has to be fully reconstructed. Which leads to high investment costs, but more efficiency because the energy use of the distribution pumps will decrease.

2. Effluent heat and cooling machine

This principles uses the effluent of the nearby located wastewater treatment plant Houtrust as heat source. The temperature of the effluent is about 15°C and has the potential to be heated up to required temperatures with a heat pump by using a relatively low amount of energy. Because the temperature of the effluent is too high for cooling a cooling machine should be added. Thereby extra energy will be used, which decreases the energy efficiency and the CO_2-reduction.

3. Thermal energy storage with regeneration of the source with dry coolers

Because residences require more heat than cold, the ground will cool down by the heat use in the winter. During the summer the heat source has to be regenerated. Therefore dry coolers are used in the summer to extract heat from the outside air.

4. Effluent heat and thermal energy storage
This principles uses the effluent of the nearby located wastewater treatment plant Houtrust as heat source of the bronnet of Duindorp in combination with heat-cold storage. The heat-cold storage is regenerated with the effluent heat in the summer and is used in the winter when the effluent temperature is low. This option has a high efficiency and also the investment costs for CO_2-reduction are low.

5. DSM
Currently ground water from the gist factory in Deft DSM is pumped up to keep the groundwater level in Delft stable. This effluent has a temperature of about 12°C, comparable to the temperature of heat cold storage. Because of this temperature it is an attractive source to heat and cool the residences. The energy use of the pumps is relatively low and also the investment costs are low which results in low costs per saved CO_2-emmision. However this option requires a lot of research.

6. Vertical heat exchangers
This option suggest heat pumps with vertical heat exchangers in the ground. These pumps do use a relatively low amount of energy and at teh same the time a distribution network isn't required anymore. However the investment costs are higher than the ATES option and also cooling is less effective.

7. Collective heat pump on air and electric boilers for DHW
Results in high energy use but low investments. The domestic hot water is supplied with electric boilers. Because air is used as source the efficiency of the heat pump is significantly lower than in other heat pump variants. However compared to the conventional heating system the efficiency is still high. It is also possible to combine this system with PVT panels.

8. Thermal energy storage with PVT panels
The heat that is generated by the PVT panels is directly used by the heat pump or stored to regenerate the aquifer. Because the PVT delivers a higher temperature the efficiency of the heat pumps is higher and thereby less electricity will be used to heat the building. This variant is based on maximal CO_2-reduction.

Conclusion
Looking at the energetic performance and CO_2-emissions variants 4,5 and 6 While 5 and 6 score a bit better they require more research. The PVT option (8) has the lowest CO2-emissions but a high price per reduced kg of CO_2-emissions. However when this option is applied with the existing heat pumps which will only be replaced when these don't work anymore the price per CO_2-emissions will be drastically decrease until about the level of variant 4, however with a lot more CO_2-emission. Transportation of heat and cold cost a lot of electricity for the pumps; so local potentials should be optimally used, like PVT.

A.3. Oostland

(Broersma, Steigenga, et al., 2013)

Oostland is an area in the province South-Holland, that includes multiple municipalities. In Oostland a lot of greenhouses are located. Innovation and sustainability is an important value for these local businesses.

Short-term

As first step the different energy potentials in the area where studied. Based on these studies sustainable interventions which could be implemented on short term (2013-2020) where proposed.

Geothermal energy cascade:
The energy demands of different functions, that request different temperatures, will be supplied in a cascade to use as much thermal energy of the geothermal source as possible.

Heat network:
Connecting different suppliers and customers to the network to create a reliable system. The residual heat of supermarkets can be used to feed the network for example.

Solar collectors and heat storage:
An aquifer will be used to replace the heat supply by fossil energy. To lengthen the lifespan of the source solar collectors will be added to the system to regenerate the heat source with heat from the solar collectors during the summer.

Sustainable heat network business park Bleizo:
In the north of Oostland the business park Bleizo is under construction. The heat demands of this area can be supplied with a heat network fed by different sources: solar collectors, heat cold storage, geothermal, residual heat sources and combined heat power systems.

Fermentation of green-waste:
Fermentation of biomass to biogas that will be used in combined heat power systems to generate both electricity and heat. This process is suggested to take place at the local green waste processing station.

Sewage treatment plants:
Currently the three sewage treatment plants in the area are inactive. The nutrients are leaving the area, while energy is imported. Closing cycles and being self-sufficient is an important goal of the transition of Oostland. Therefor the sewage treatment plants should reopen and fermentate the effluent. The generated biogas can be converted into heat and electricity with a combined heat power installation.

Heat supplying greenhouses:
A greenhouse receives five times as much solar heat as required. This heat is ventilated into the outside air during the summer months. When this heat is collected and stored into the ground this heat can be used as a sustainable energy source for residences.

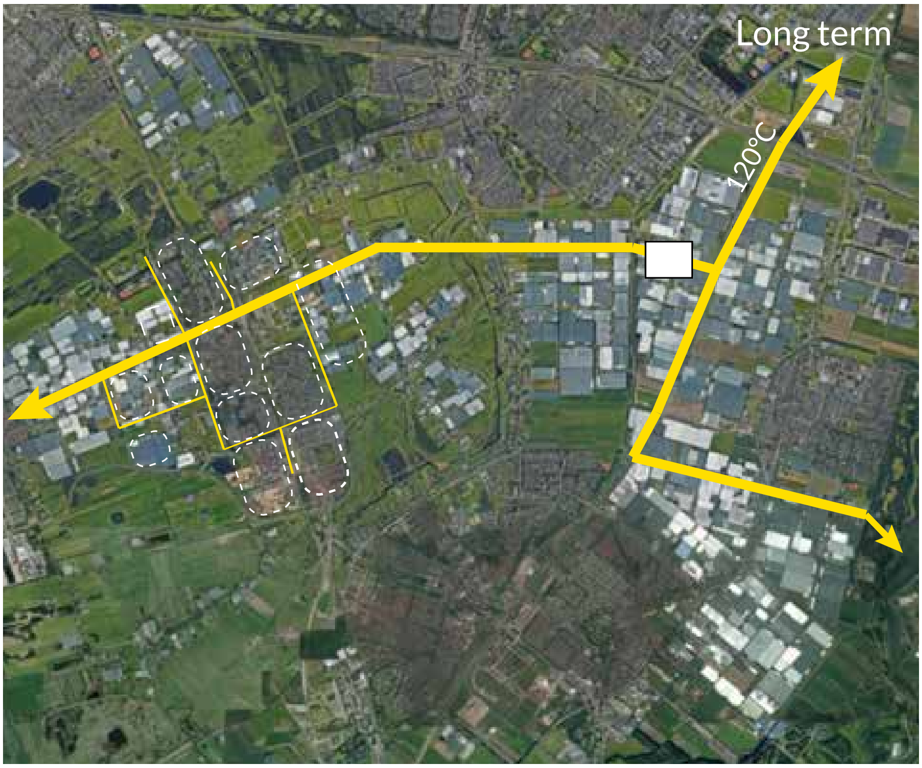
Wind energy:
In the area different locations for wind energy are appointed.

Long-term
At long-term these different small scale heat projects will be connected to create one reliable system in which the demands and supplies are better divided. Under the condition that the main network supplies are on the same temperature. This main network shouldn't have a to high temperature, because a lot of heat cold storage systems are used. Otherwise the efficiency (CoP) of the heat pumps will be too low. A temperature of 50°C would be sufficient. Local heat pumps will be placed to upgrade the heat of the network to 65-70°C for the domestic hot water supplies of the residences.

If the future demands are very high and the application of heat networks are common; the Oostland heat network can be connected to the existing ROCA-network. Currently this network works with high temperature (120°C). Thereby a direct connection isn't possible yet, a connection-station will be required between the two networks.

Figure A.2. Development heat grids. (Broersma, et al. 2013).

● Geothermal
⬚ Local heatnetwork
— Urban heat network
▬ Regional heat network
+ Heat demands
- Heat supplies
K Connecting station



B

Stakeholders

Each stakeholder has a specific interest in the energy transition. In this analysis the stakeholders are divided in six different groups: policy makers, energy sector, research & knowledge institutes and companies, users, financers and media.

B.1. Policy makers

This approach is generated for municipalities. The municipality itself belongs to the group policy makers, together with the national government and the provinces. This group is aiming to reach their energy transition targets. The government should achieve the Paris Climate Agreement goals for 2050 and the European goals for 2020. Therefor the government defines laws and policies and makes sure that the citizen and companies comply with these laws. However as appointed before the Dutch government has opposite interests in achieving these climate goals because of the positive influence of fossil fuels, mainly natural gas, on the Dutch economic position.

The provinces and municipalities mostly have set their own transition goals. The involvement of the municipality in the transition is important because of the impact of local potentials. However to achieve those goals they are to a certain extent dependent on the climate policies of the national government. While on the other hand the interest is higher because the municipalities want to reduce CO_2-emissions, increase the use of sustainable energy and obtain self-sufficiency. At the same time the energy transition should lead to more jobs and an increased economic position.

B.2. Energy sector

The energy sector is responsible for the generation, transportation and supply of energy to the customers. There overall interest is to make profit with these handlings. The stakeholders in the energy sector are:

- *The network administrator*: replacement, maintenance and expansion of the energy network. Which network administrator is involved in the transition of the municipality depends on the location. Mostly the network administrator for the gas and (low voltage) electricity network are the same. In figure B.1 the different network administrators for electricity (a) and gas (b) in the Netherlands are shown (Gerdes et al., 2016). The national high-voltage electricity network is controlled by TenneT.
- *Supervisor*: overviews the energy market and controls the energy tariff.
- *Producers*: generates energy (fossil or renewable). The largest producers in the Netherlands are Nuon, Eneco and Essent.
- *Supplier*: distributes the energy to the users (by using the network of the network administrator). Citizens are free to choose their own supplier. Suppliers can deliver sustainable energy or energy from fossil fuels. The biggest suppliers are Nuon, Eneco and Essent. Not all suppliers do generate energy as well.

B.3. Research and knowledge institutes/companies

These stakeholders do research towards sustainable environments and new ways of sustainable energy generation and technologies. Beside creating new knowledge they also share their knowledge. This stakeholder group includes:

- *Universities and other research and knowledge institutes*: educate, share and create knowledge about the energy transition.
- *Sustainability organisations*: increase awareness of the urgency of the transition and promote sustainable energy generation and use.
- *Technology and engineering companies*: develop new technologies to generate energy sustainable or other technologies concerning sustainable energy.
- *Consultants*: Assist and advise other stakeholders in the transition process.

B.4. Users

In the Netherlands customers do have influence on the transition because they can choose their own energy supplier. The choice for sustainable, or fossil energy depends on their preferences. Beside that they can also choose to generate electricity on their own property, with for example PV panels. The generated energy can be used to furfill their own demands. When the electricity supplies are bigger then the demands this electricity can be sold to the grid. Citizens, companies and public organisations (hospitals, schools, etc.) do belong to the user group.

B.5. Financers

Financers invest in energy with the objective to maximize profit (banks, private investors, corporations) or they invest to encourage a certain action, like sustainable energy generation (subsidy providers).

B.6. Media

This last group of stakeholders' interest is to inform, to create discussion and to create awareness of the energy transition.

B.7. Power-Interest Matrix

The final step of the stakeholder analysis is to map the actors according to their influence and interest in the energy transition of the municipality. This stakeholder map will provide a quick overview of the involved stakeholders, their position and how to deal with these actors. According to their amount of interest and the extent of their power the position in the matrix will be determined. There are four blocks in the matrix in which stakeholders can be placed.

- Crowd: low interest and low power, the municipality's effort in this group should be minimal.
- Context setters: low interest, but high power. The municipality should keep this group satisfied.
- Subjects: high interest, but low power. This group should be well informed by the municipality about the taken steps in the transition.
- Key players: high interest and high power. The municipality should involve this group actively in the transition.

(Enserink et al., 2010)

In the diagram the analysis is done for the described stakeholders, because this analysis isn't done for one specific city the location of the stakeholders cannot given very precisely, but they are assigned to a bigger area.

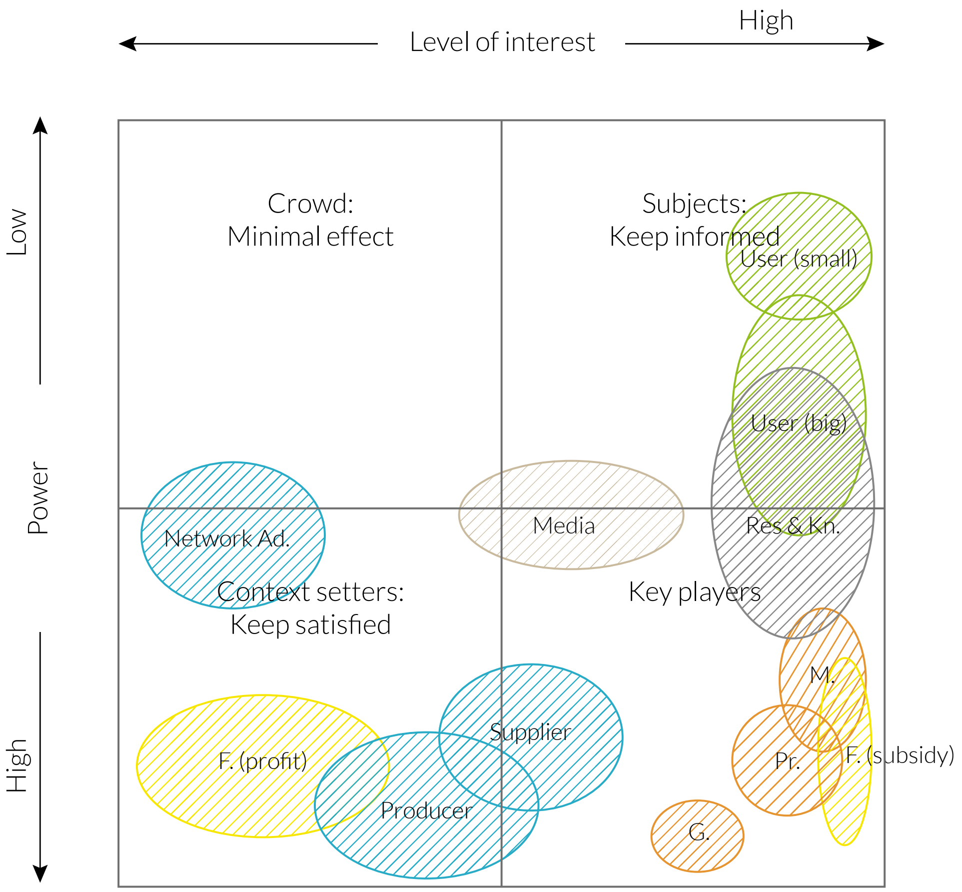


Figure B.1. – Power-Interest matrix for the energy transition of Dutch municipalities (Enserink, et al., 2010, p101).

C

Technology Toolbox

1. Individual systems

Biogas & Micro-CHP (I)

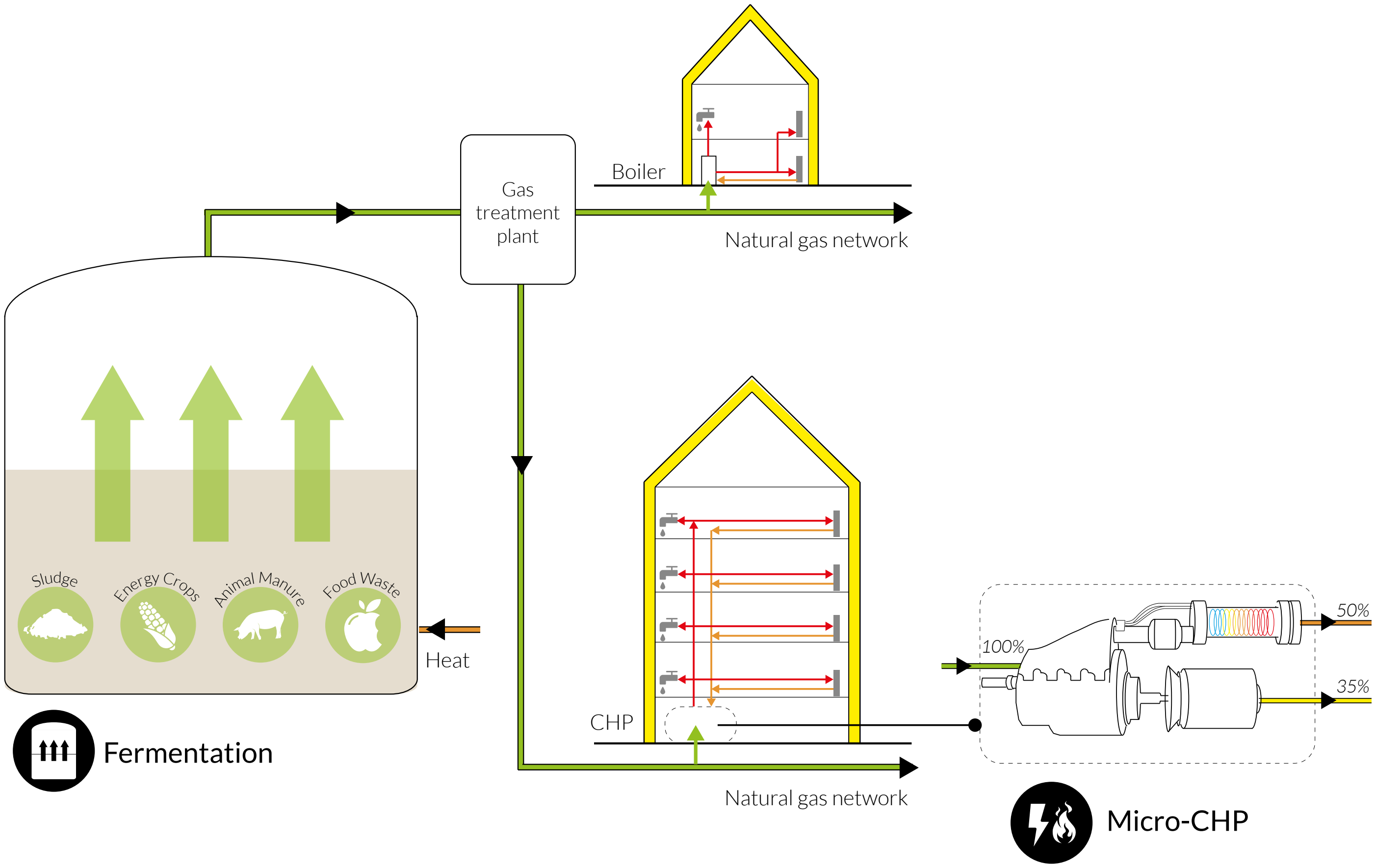
With the Fermentation of biomass (manure, food waste and sludge) in an anaerobic digester biogas is produced. When this gas is upgraded to the same quality as natural gas it can be transported in the existing gas network towards the boilers of the buildings.

Another option is to supply the biogas to a micro CHP (combined heat power) plant that generates both electricity and high temperature heat. A CHP installation can also be applied on collective scale to feed a heat network (see paragraph 5.4.2).

Application

The advantage of these systems is that the existing gas network can be used for the transportation. The conversion with a boiler or CHP results in high temperature heating. Thereby these systems should be applied in neighbourhoods where the energy retrofitting potentials are limited, like in historic city centres.

Figure C.1: Installation scheme individual system biogas. Fermentation to biogas used with boiler or with a micro-CHP (by Author).



Biomass (I)

A pellet boiler can be used to generate heat. The input is wood from forest maintenance and wood particles in household waste. The system requires a storage facility for the wood inside or near the building.

Application

When the heat demands of a building (block) are supplied with a pellet boiler no heating network is required, only the electricity network has to be maintained. This is an advantage for low density areas. A pellet boiler delivers high temperature heat and is thereby only suitable to furfill high temperature demands. Lower temperature demands in these sparsely populated neighbourhoods can better be supplied with all-electric heating.

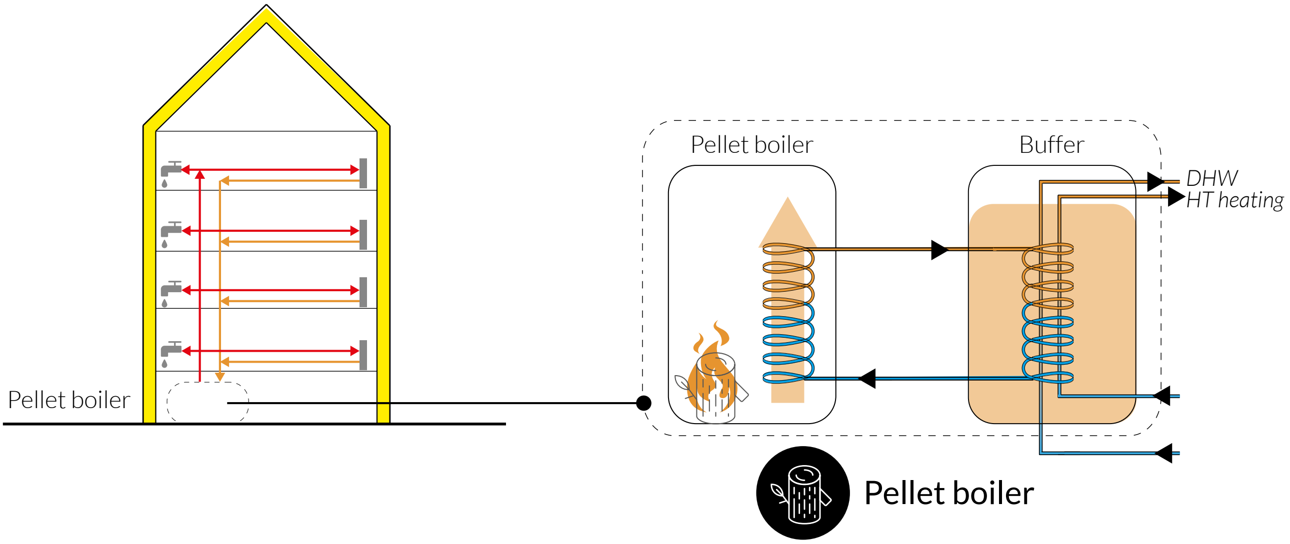


Figure C.2: Installation scheme individual system biomass. Pellet boiler used to generate heat from wood (by Author).

All-electric (II)

In all-electric buildings all of the demanded energy is supplied with electricity. For heating a heat pump is used. This heat pump upgrade low temperature heat to a higher temperature by using electricity very efficiently. The lower the temperature difference between the source and the demand the higher this efficiency. The electricity demands of the building will be generated with PV panels on the roof as much as possible. There are two main heat sources for the heat pump:
- Ground-source: vertical or horizontal heat exchangers in the ground
- Air source: outside or ventilation air.

Application

All-electric systems have the advantage that only an electricity network needs to be present in the area. Because the efficiency of the heat pump is the highest when temperature difference is small, this system is mostly suitable for low-temperature heating.

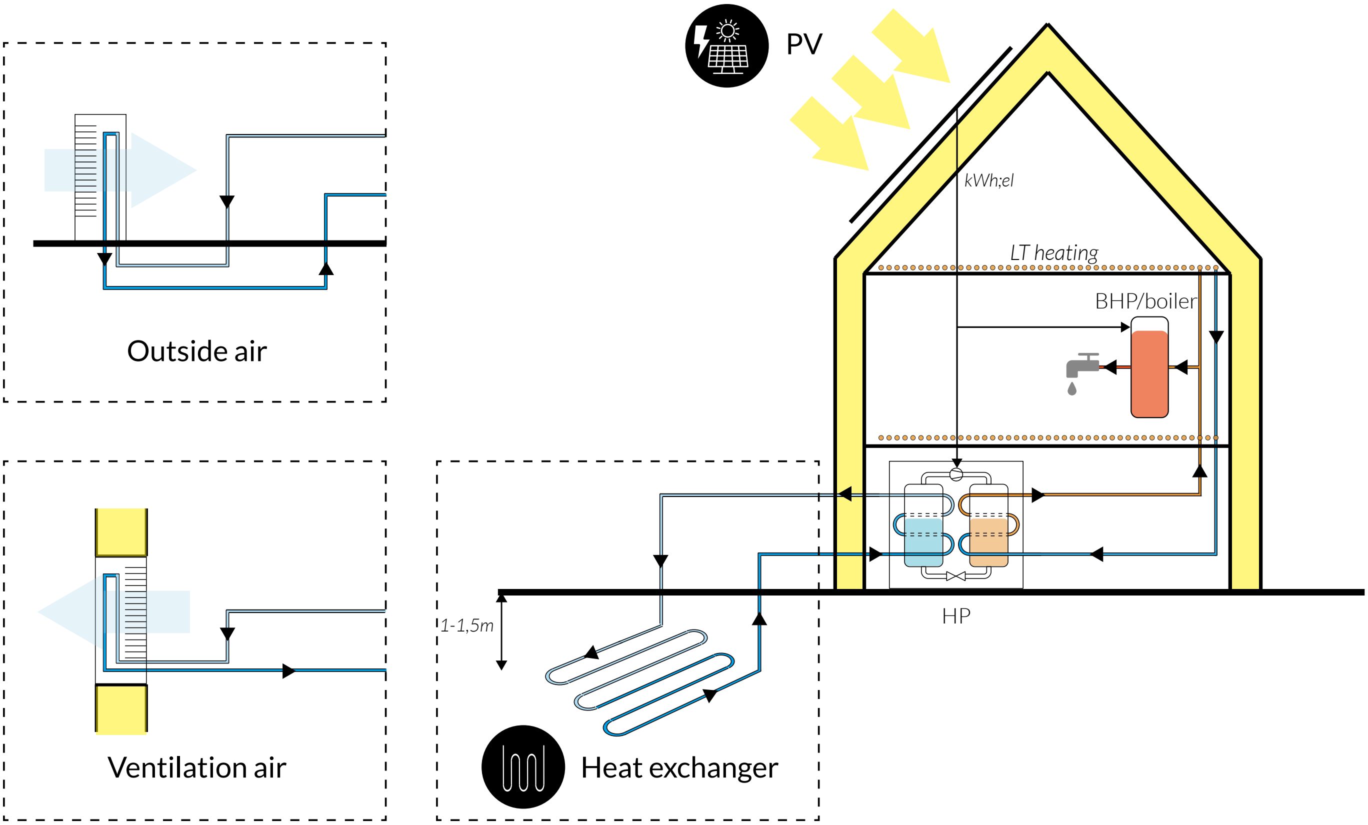


Figure C.3: Installation scheme all-electric with a heat pump and different heat sources (by Author).

5.4.2. Collective heat networks (III-VI)

Heat networks can be constructed for different heating purposes. In this thesis four heat classes are distinguished: high temperature (90-65°C), mid temperature (65-40°C), low temperature (40-25°C) and very-low temperature (25-15°C). High temperature heat networks do have a smaller potential than lower temperature networks by the limited availability of sustainable high temperature heat sources. At the same time these networks are more expensive due to the thick required insulation layer around the heat pipes. However when there is no other potential heat system available for a certain area this option can still be implemented.

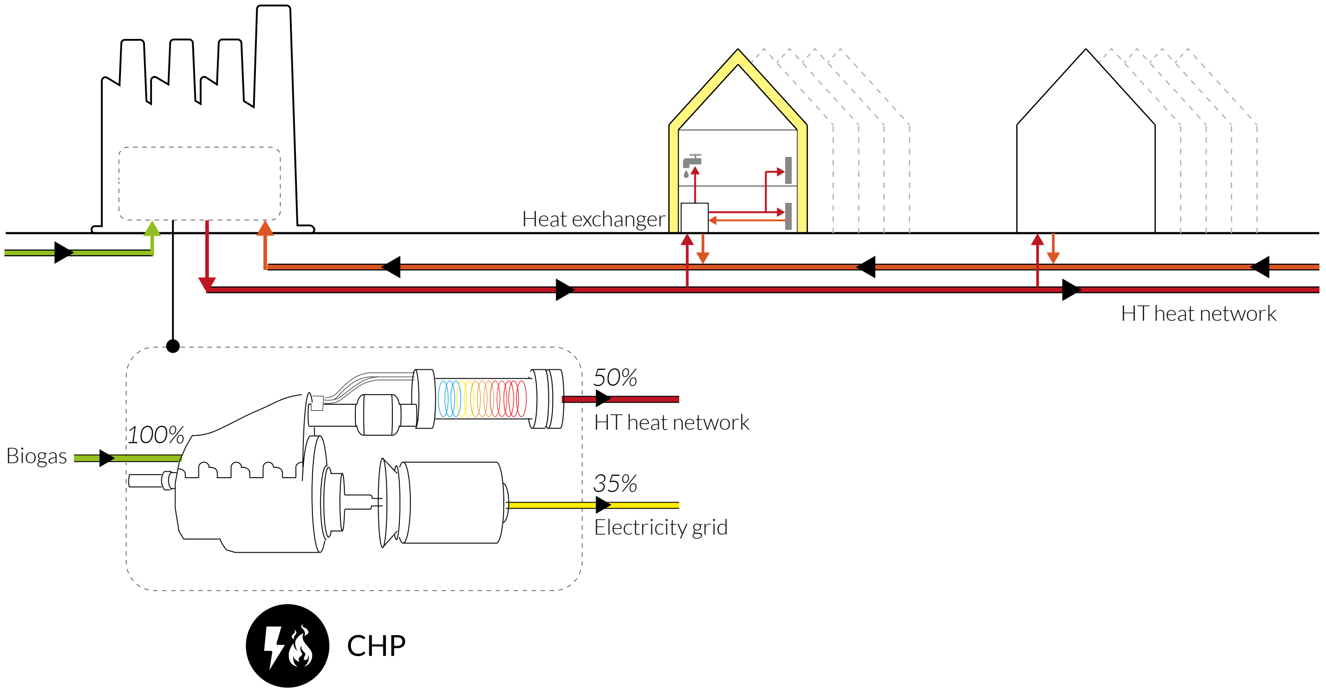
Combined heat power

This installation produces both electricity and heat, from biogas, with a total efficiency of about 90%. This heat can be supplied to a high temperature heat network.

Application

Combined heat power plants can supply heat at about 70-90°C. Thereby it can be used to supply high temperature heat network with heat.

Figure C.4. Installation scheme combined heat power plant connected to a HT heat network (by Author).



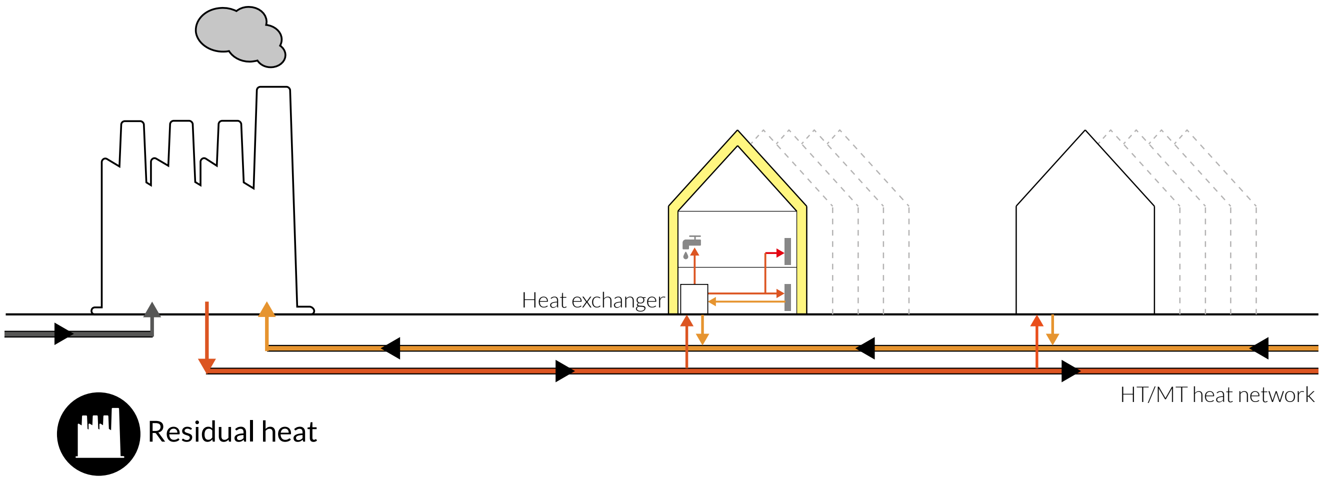
Industrial waste heat

This heat source can only be used to start-up the transition because the heat is released during industrial processes that require fossil fuels. During the transition a sustainable heat source should replace these supplies.

Application

Industrial waste heat has a high temperature between 60-130°C. Depending on the heat source it can feed high or mid temperature heat networks.

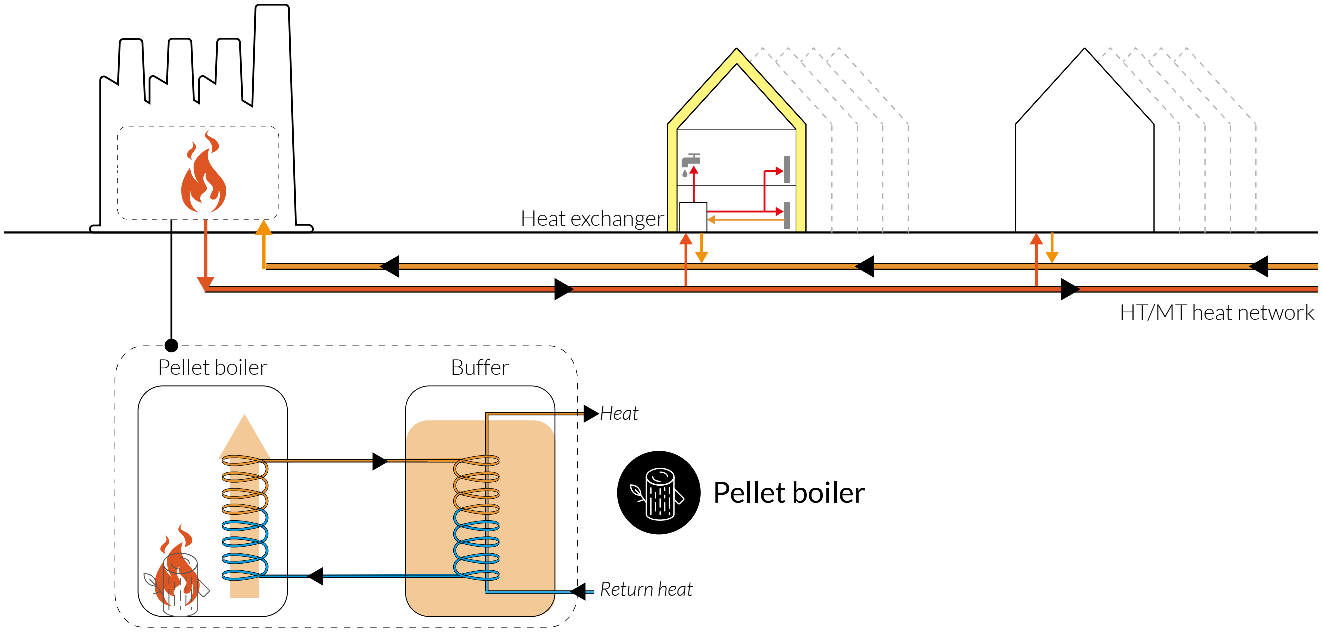
Figure C.5. Installation scheme of residual heat from industrial production processes supplied to a high or mid temperature network (by Author).



Pellet boiler

Supplies high temperature heat to a heat network by burning wood from forest maintenance and garden waste. In cities the potential will be lower than in more rural areas.

Figure C.6. Installation scheme pellet boiler connected to a high or mid temperature heat grid.



IV. Geothermal heat & Cascade

Geothermal heat needs to be extracted at its natural flow rate to prevent exhaustion. The temperature of the extraction is about 70°C and can thereby feed a high temperature heat network. Because the return temperature into the injection well needs to be decreased to 30-40°C a heat cascade is desirable. Cascades can also be applied in combination with other heat sources to maximize the used quality of this heat source.

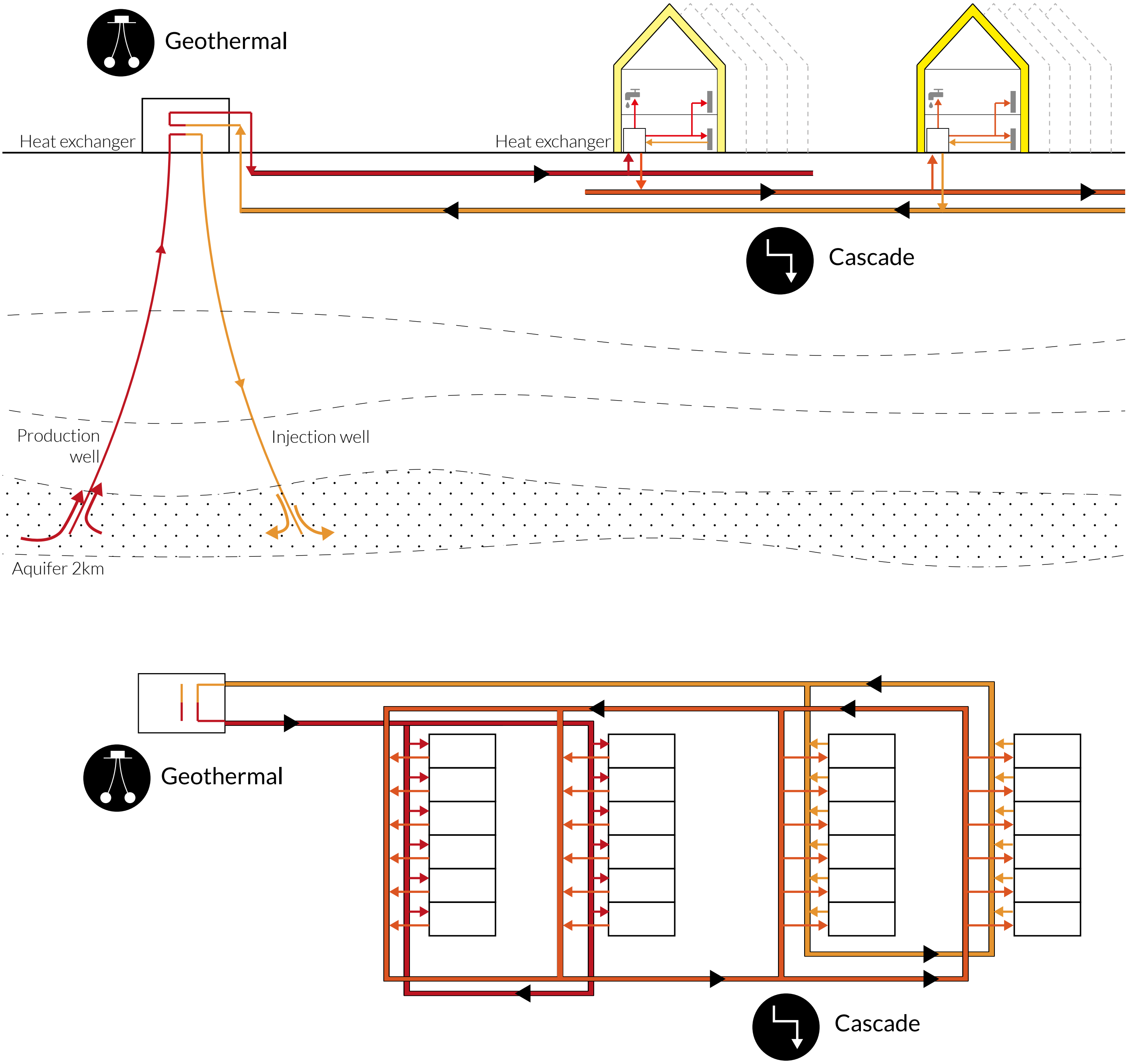


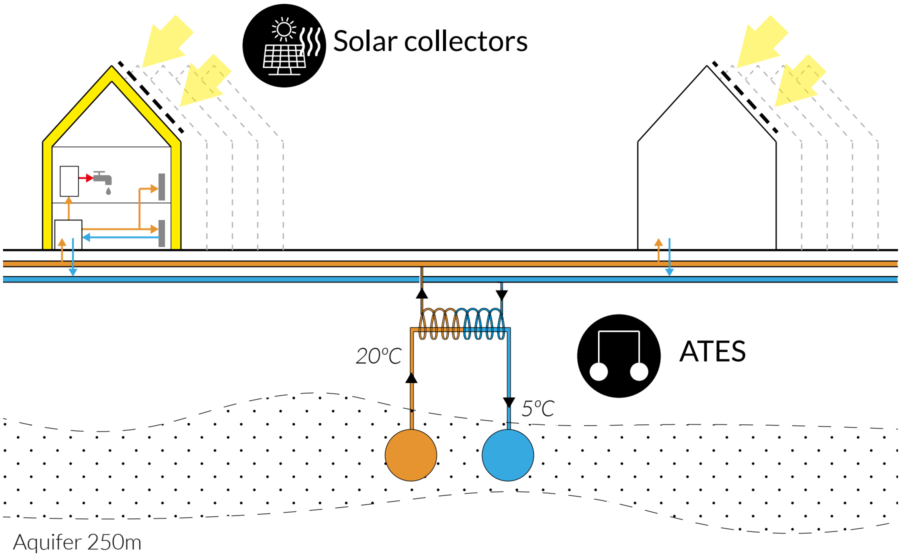
Figure C.7 a/b. Top - Section of geothermal source connected to a high temperature heat network, cascade to a mid-temperature to decrease the return temperature in the injection well (by Author).

Solar collectors & ATES

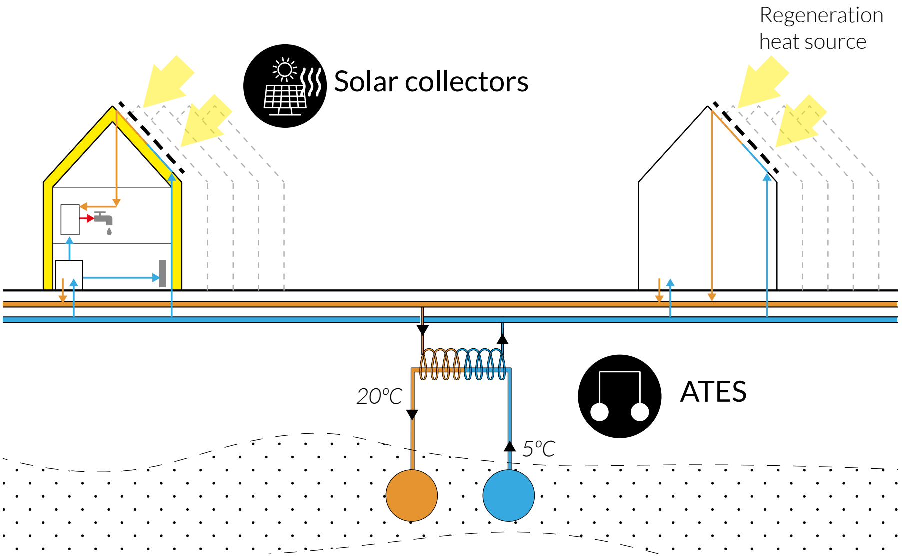
Solar collectors can deliver heat with a temperature between 40°C and 70°C. The output of the solar collectors does depend on the daily and seasonal weather circumstances and thereby have fluctuations in the supplies. A combination with aquifer thermal energy storage will increase the usable output of solar collectors because the summer heat can be stored and used during the winter.

Figure 5.8. Winter (top) & Summer (down) situation heating supplied by ATES combined with solar collectors. (by Author).

Winter



Summer

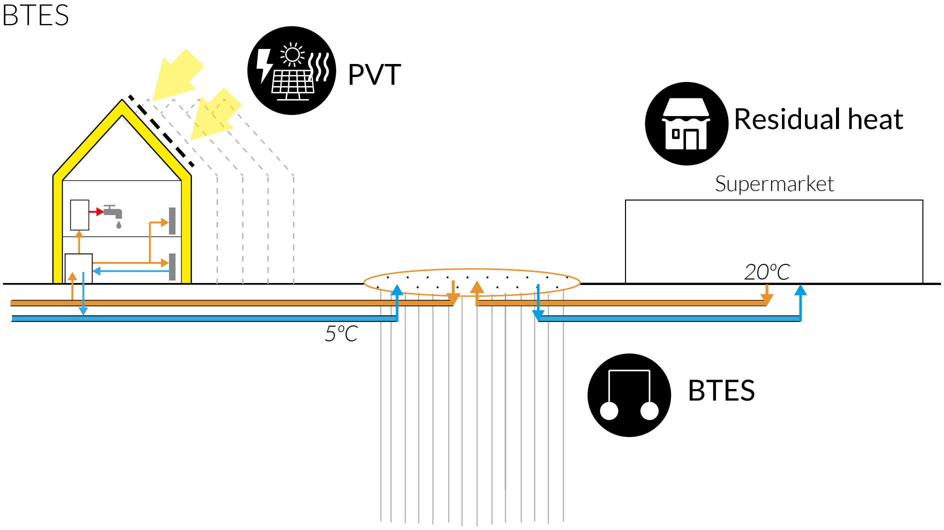


Small scale residual heat & ATES/BTES

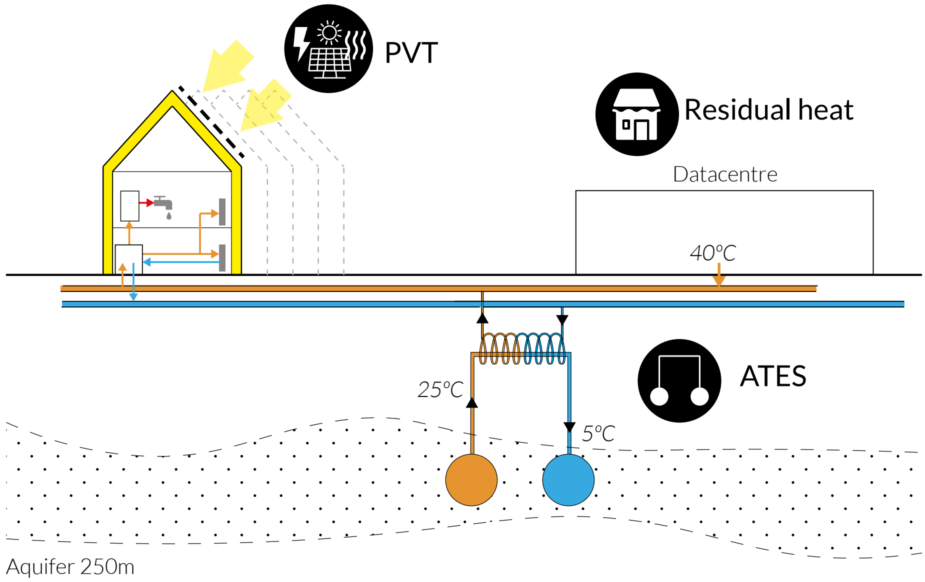
Small scale residual heat differs between 15°C and 40°C. Thereby it has the potential to feed low or very low temperature heat networks. The efficiency can be increased when the residual source is connected to thermal energy storage. This means that during the summer (when heating isn't demanded) the released heat can be stored. This stored heat can again be extracted during colder periods.

Figure 5.9. Principle of small scale residual heat used for heating purposes, connected to aquifer/ borehole thermal energy storage (by Author).

BTES



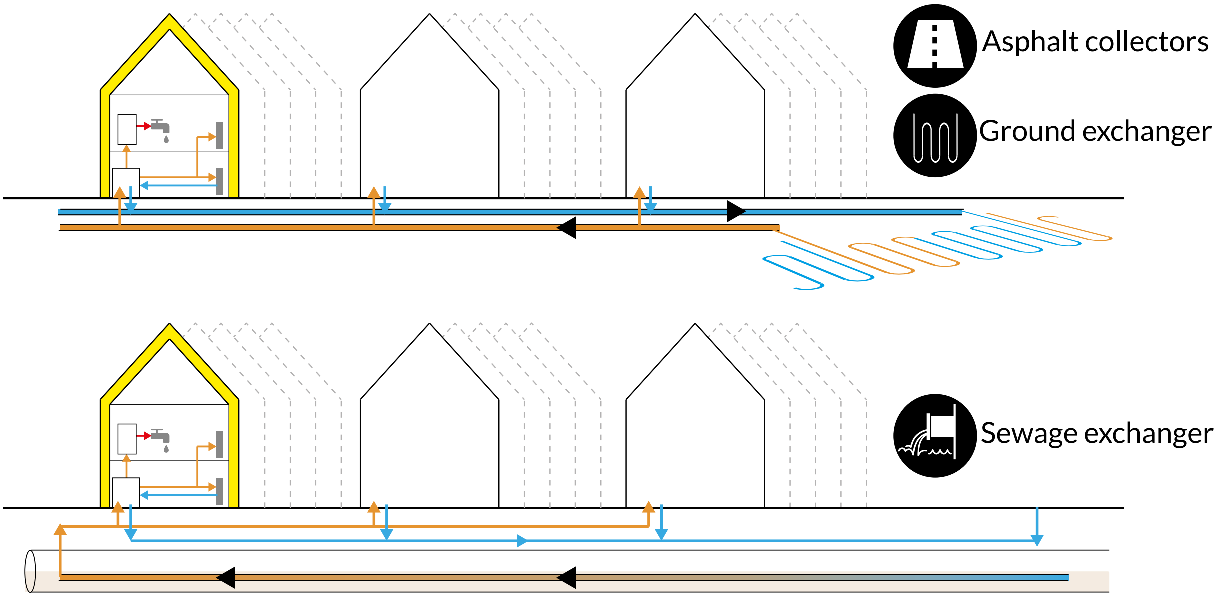
ATES



Asphalt collectors, ground heat exchanger & heat exchange with sewage pipelines

In all of these cases heat exchangers are used to generate low temperature heat of about 5-20°C. These heat exchangers are thin pipelines filled with water that are placed underneath the top layer of asphalt roads, the ground or inside sewage pipelines. Their output is the highest during the summer, however during the heating season the potential of these sources is low. Thereby thermal energy storage should be added to the heat system to optimize the output throughout the whole year.

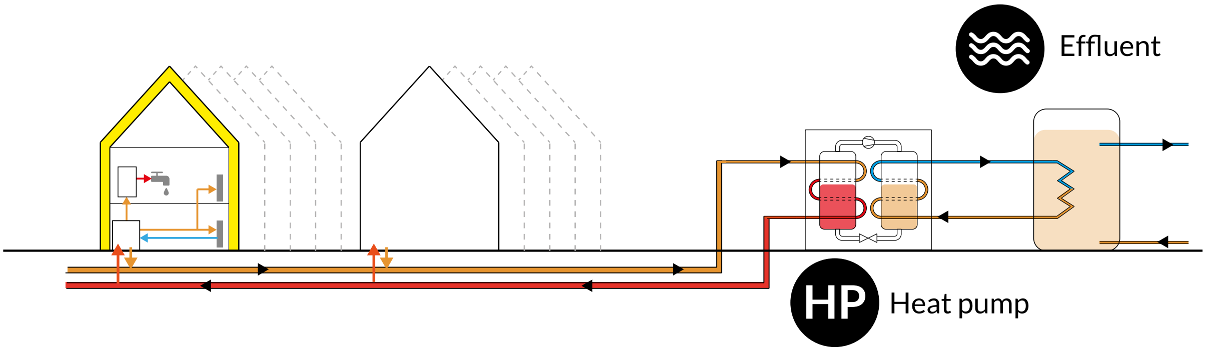
Figure C.10. Principle heat exchangers placed in asphalt roads, the top layer of the earth of sewage pipes (by Author).



Effluent water treatment plant

The effluent of water treatment plants has a temperature of 12-20°C. With the use of a heat exchanger the effluent can be used to feed a very-low temperature heat network. When a collective heat pump is used to upgrade the heat temperature the effluent can also be the source of low or mid temperature networks. A heat pump can also be used in combinations with the other heat source to upgrade the heating temperature.

Figure C.11. Installation scheme effluent water treatment plant upgraded to a higher temperature to feed a heat network (by Author).



D

Energy demands & Savings

D.1. Electricity demands - Residences

District	Amount of residences	Surface district [ha]	Average electricity demand [kWh] per household	electricity demands per district		
				[GWh]	[GJ;el]	Average per household [GJ]
City Centre	6057	145	2600	15,75	56693,5	9,4
Vrijenban	4460	152	2430	10,84	39016,1	8,7
Hof van Delft	5940	155	2310	13,72	49397,0	8,3
Voordijkshoorn	5096	161	2620	13,35	48065,5	9,4
Delfste Hout	24	300	3900	0,09	337,0	14,0
Tanthof West	3795	141	2840	10,78	38800,1	10,2
Tanthof East	3171	92	2670	8,47	30479,7	9,6
Voorhof	7170	129	2410	17,28	62206,9	8,7
Buitenhof	6904	226	2590	17,88	64372,9	9,3
Abtswoude	6	143	5460	0,03	117,9	19,7
Schieweg	608	202	2620	1,59	5734,7	9,4
Wippolder	5851	264	2370	13,87	49920,7	8,5
Ruiven	117	296	3580	0,42	1507,9	12,9
Total Delft	49199	2406	2520	124,1	446649,8	9,1

Table D.1.- Thermal energy demands for the residences of Delft and its district (by Author, based on: www.cbs.nl).

D.2. Thermal energy demands Residences

District	Amount of residences	Surface district [ha]	Heating systems^{*1}			
			% Heat network^{*2}	% Heat pump	% Local heating	% Gas connection
City Centre	6057	145	0,0%	2,0%	3,0%	95,0%
Vrijenban	4460	152	0,0%	2,0%	3,0%	95,0%
Hof van Delft	5940	155	0,0%	2,0%	3,0%	95,0%
Voordijkshoorn	5096	161	14,0%	2,0%	3,0%	81,0%
Delfste Hout	24	300	8,3%	2,0%	3,0%	86,7%
Tanthof West	3795	141	0,0%	2,0%	3,0%	95,0%
Tanthof East	3171	92	0,0%	2,0%	3,0%	95,0%
Voorhof	7170	129	19,1%	2,0%	3,0%	75,9%
Buitenhof	6904	226	0,0%	2,0%	3,0%	95,0%
Abtswoude	6	143	0,0%	2,0%	3,0%	95,0%
Schieweg	608	202	0,0%	2,0%	3,0%	95,0%
Wippolder	5851	264	0,0%	2,0%	3,0%	95,0%
Ruiven	117	296	0,0%	2,0%	3,0%	95,0%
Total Delft	49199	2406				

Table D.2 - Thermal energy demands for the residences of Delft its and districts (by Author, based on: www.cbs.nl).

D.3. Energy demands - Businesses in Built Environment

Total demands

	G+I	H+J	K-L	M-N	R-U	O	P	P;tu delft	Q
gas	4812000	2411000	1395000	1555000	1997000	1278000	8441192	4585808	4739000
electricity	63019000	27782000	14004000	15840000	9850000	14609000	4825000	58429000	23475000

Average demands

	G+I	H+J	K-L	M-N	R-U	O	P	P;tu delft	Q
gas	3461,9	2739,8	2513,5	630,8	2158,9	18000,0	27585,6	4585808	7381,6
electricity	45337,4	31570,5	25232,4	6426,0	10648,6	205760,6	15768,0	58429000	36565,4

Table D.3a/b - Gas and electricity demands per SBI2008 business sector in Delft in total and on average. (by Author, based on: www.cbs.nl & klimaatmonitor.nl).

Average gas demand [m3, primair] per household	Gas demands per district			Heat demands	
	[m3, primair]*3	[GJ;th, primair]*4	[GJ;th]*5	Average [GJ] per household	Total [GJ] per district*6
1240	7135146,0	225827,4	200647,6	34,9	206983,9
970	4109890,0	130078,0	115574,3	27,3	119224,0
1140	6433020,0	203605,1	180903,1	32,1	186615,8
810	3343485,6	105821,3	94022,2	22,8	113755,3
1970	40991,8	1297,4	1152,7	55,4	1303,0
910	3280777,5	103836,6	92258,8	25,6	95172,3
1020	3072699,0	97250,9	86407,4	28,7	89136,1
670	3646160,1	115401,0	102533,8	18,8	132388,8
1120	7345856,0	232496,3	206573,0	31,5	213096,4
2669	15213,3	481,5	427,8	75,1	441,3
890	514064,0	16270,1	14456,0	25,0	14912,5
1040	5780788,0	182961,9	162561,7	29,2	167695,2
1600	177840,0	5628,6	5001,0	45,0	5159,0
970	44895931,3	1420956,2	1262519,6	27,9	1345883,5

Total amound of businesses per SBI2008 sector

District	Amount of businesses and organisations									
	G+I	H+J	K-L	M-N	R-U	O	P	P;tu delft	Q	Total
City Centre	565	175	185	640	270	8	34	0	71	1948
Vrijenban	60	70	30	180	65	8	34	0	71	518
Hof van Delft	105	115	60	365	105	8	34	0	71	863
Voordijkshoorn	70	70	60	215	85	8	34	0	71	613
Delfste Hout	25	15	5	30	15	0	0	0	0	90
Tanthof West	65	50	30	120	60	8	34	0	71	438
Tanthof East	40	40	18	80	40	8	34	0	71	331
Voorhof	155	80	30	145	85	8	34	0	71	608
Buitenhof	75	65	35	170	70	8	34	0	71	528
Abtswoude	0	0	0	0	0	0	0	0	0	0
Schieweg	100	35	25	80	25	0	0	0	0	265
Wippolder	90	115	50	330	90	8	34	1	71	789
Ruiven	35	45	25	100	15	0	0	0	0	220
Total Delft	1385	875	553	2455	925	71	306	1	642	7213

Table D.4 - Amount of businesses in Delft and the districts divided in the SBI2008 sectors (by Author, based on: www.cbs.nl).

Thermal energy demands businesses in Delft

District	Total gas demands per sector [m3]					
	G+I	H+J	K-L	M-N	R-U	O
City Centre	1955956,8	479460,2	465000,0	403732,3	582908,1	142000,0
Vrijenban	207712,2	191784,1	75405,4	113549,7	140329,7	142000,0
Hof van Delft	363496,4	315073,9	150810,8	230253,5	226686,5	142000,0
Voordijkshoorn	242330,9	191784,1	150810,8	135628,8	183508,1	142000,0
Delfste Hout	86546,8	41096,6	12567,6	18924,9	32383,8	0,0
Tanthof West	225021,6	136988,6	75405,4	75699,8	129535,1	142000,0
Tanthof East	138474,8	109590,9	45243,2	50466,5	86356,8	142000,0
Voorhof	536589,9	219181,8	75405,4	91470,6	183508,1	142000,0
Buitenhof	259640,3	178085,2	87973,0	107241,4	151124,3	142000,0
Abtswoude	0	0	0	0	0	0,0
Schieweg	346187,1	95892,0	62837,8	50466,5	53973,0	0,0
Wippolder	311568,3	315073,9	125675,7	208174,4	194302,7	142000,0
Ruiven	121165,5	123289,8	62837,8	63083,2	32383,8	0,0
Total Delft	4794690,6	2397301,1	1389973,0	1548691,7	1997000,0	1278000,0

Table D..5 - Gas demands per sector and district in Delft for 2015. (by Author, based on: www.cbs.nl, klimaatmonitor.database.nl; www.energymonitor.tudelft.nl).

Electricity demands businesses in Delft

District	Total electricty per sector [kWh]					
	G+I	H+J	K-L	M-N	R-U	O
City Centre	25615636,7	5524829,5	4668000,0	4112616,6	2875135,1	1623222,2
Vrijenban	2720244,6	2209931,8	756973,0	1156673,4	692162,2	1623222,2
Hof van Delft	4760428,1	3630602,3	1513945,9	2345476,7	1118108,1	1623222,2
Voordijkshoorn	3173618,7	2209931,8	1513945,9	1381582,2	905135,1	1623222,2
Delfste Hout	1133435,3	473556,8	126162,2	192778,9	159729,7	0,0
Tanthof West	2946931,7	1578522,7	756973,0	771115,6	638918,9	1623222,2
Tanthof East	1813496,4	1262818,2	454183,8	514077,1	425945,9	1623222,2
Voorhof	7027298,6	2525636,4	756973,0	931764,7	905135,1	1623222,2
Buitenhof	3400305,8	2052079,5	883135,1	1092413,8	745405,4	1623222,2
Abtswoude	0	0	0	0	0	0
Schieweg	4533741,0	1104965,9	630810,8	514077,1	266216,2	0,0
Wippolder	4080366,9	3630602,3	1261621,6	2120568,0	958378,4	1623222,2
Ruiven	1586809,4	1420670,5	630810,8	642596,3	159729,7	0,0
Total Delft	62792312,9	27624147,7	13953535,1	15775740,4	9850000,0	14609000,0

Table D.6 - Electricty demands per sector and district in Delft for 2015 (by Author, based on: www.cbs.nl, klimaatmonitor.database.nl; www.energymonitor.tudelft.nl).

				[GJ;th, primair]	[GJ;th, total]	[GJ;th, per business]
P	P;tu delft	Q	Total			
937910,2	0,0	526555,6	5493523,2	173870,0	154483,5	79,3
937910,2	0,0	526555,6	2335246,9	73910,6	65669,5	126,7
937910,2	0,0	526555,6	2892786,9	91556,7	81348,1	94,2
937910,2	0,0	526555,6	2510528,5	79458,2	70598,6	115,1
0,0	0,0	0,0	191519,7	6061,6	5385,7	59,8
937910,2	0,0	526555,6	2249116,3	71184,5	63247,5	144,3
937910,2	0,0	526555,6	2036598,0	64458,3	57271,2	172,9
937910,2	0,0	526555,6	2712621,6	85854,5	76281,7	125,4
937910,2	0,0	526555,6	2390530,0	75660,3	67224,2	127,3
0,0	0	0	0	0	0	0
0,0	0,0	0,0	609356,4	19286,1	17135,7	64,7
937910,2	4585808,0	526555,6	7347068,8	232534,7	206607,1	261,8
0,0	0,0	0,0	402760,0	12747,4	11326,0	51,5
8441192,0	4585808,0	4739000,0	31171656,4	986582,9	876578,9	121,5

				[GWh]	[GJ;el] Total	[GJ;el, per business]
P	P;tu delft	Q	Total			
536111,1	0,0	2608333,3	47563884,7	47,6	171230,0	87,9
536111,1	0,0	2608333,3	12303651,7	12,3	44293,1	85,5
536111,1	0,0	2608333,3	18136227,7	18,1	65290,4	75,6
536111,1	0,0	2608333,3	13951880,4	14,0	50226,8	81,9
0,0	0,0	0,0	2085662,9	2,1	7508,4	83,4
536111,1	0,0	2608333,3	11460128,6	11,5	41256,5	94,1
536111,1	0,0	2608333,3	9238188,1	9,2	33257,5	100,4
536111,1	0,0	2608333,3	16914474,4	16,9	60892,1	100,1
536111,1	0,0	2608333,3	12941006,3	12,9	46587,6	88,2
0	0	0	0	0	0	0
0,0	0,0	0,0	7049811,0	7,0	25379,3	95,8
536111,1	58429000,0	2608333,3	75248203,8	75,2	270893,5	343,2
0,0	0,0	0,0	4440616,7	4,4	15986,2	72,7
4825000,0	58429000,0	23475000,0	231333736,2	231,3	832801,5	115,5

D.4. Thermal energy savings potential

Energy savings potential for different label steps

neighbourhood	Label EFG 2 better			Label CDEFG > B			> Label A+		
	% savings	GJ savings	payback time	% savings	GJ savings	payback time	% savings	GJ savings	payback time
City Centre	10%	20698	13	28%	57955	22	34%	70375	29
Vrijenban	15%	17884	10	38%	45305	22	47%	56035	29
Hof van Delft	20%	37323	11	49%	91442	22	58%	108237	27
Voordijkshoorn	6%	6825	11	17%	19338	26	25%	28439	35
Delfste Hout	0%	0	7	0%	0	23	0%	0	29
Tanthof West	0%	0	12	22%	20938	33	41%	39021	35
Tanthof East	0%	0	12	16%	14262	33	26%	23175	35
Voorhof	13%	17211	18	48%	63547	34	68%	90024	37
Buitenhof	3%	6393	15	23%	49012	39	38%	80977	43
Abtswoude	0%	0	0	0%	0	0	0%	0	0
Schieweg	0%	0	7	1%	149	38	4%	597	41
Wippolder	7%	11739	11	20%	33539	23	26%	43601	31
Ruiven	5%	258	9	11%	567	18	12%	619	26
total	9%	118331		29%	396055		40%	541099	

Table D.7. Theremal energy savings residences Delft for different label steps (www.pico.geodan.nl)

Energy savings potential per neighbourhood according to scenario

Neighbourhood	Total amount of residuences	Ownership			Heat demands per residence [m3/r]		Total savings		
		% corporation	% rental other	% private property	rent	private	corporation	rental other	Private property
City Centre									
Centrum-Noord	476,0	58,0	7,0	35,0	1070,0	1680,0	73260,6	8841,8	43102,8
Centrum-West	1054,0	14,0	40,0	44,0	1280,0	1390,0	0,0	0,0	0,0
Centrum-Oost	1151,0	18,0	21,0	59,0	1100,0	1270,0	0,0	0,0	0,0
Centrum	1193,0	25,0	49,0	23,0	1290,0	1600,0	0,0	0,0	0,0
Stationsbuurt	3,0						0,0	0,0	0,0
Centrum-Zuidwest	664,0	14,0	44,0	39,0	1230,0	1260,0	0,0	0,0w	0,0
In de Veste	585,0	33,0	29,0	36,0	1180,0	1300,0	70617,7	49646,4	42162,1
Centrum Zuidoost	374,0	4,0	29,0	62,0	1060,0	1330,0	0,0	0,0	0,0
Zuidpoort	557,0	36,0	13,0	51,0	1000,0	1120,0	62161,2	17957,7	48996,4

Neighbourhood	Total amount of residuences	Ownership			Heat demands per residence [m3/r]		Total savings		
		% corporation	% rental other	% private property	rent	private	corporation	rental other	Private property
Vrijenban									
Bedrijventerrein Haagweg	55,0	9,0	60,0	27,0	1360,0	1410,0	2861,1	15259,2	4585,5
Indische Buurt-Noord	265,0	86,0	2,0	12,0	950,0	900,0	92014,6	1711,9	6267,8
Indische Buurt-Zuid	1018,0	30,0	14,0	56,0	1030,0	1410,0	133688,9	49910,5	176035,0
Sint Joris	148,0	68,0	2,0	20,0	840,0	980,0	35928,5	845,4	6352,8
Koepoort	731,0	25,0	9,0	66,0	1210,0	1210,0	93979,2	27066,0	127847,1
Bomenwijk	526,0	79,0	1,0	20,0	630,0	620,0	111260,8	1126,7	14284,1
Biesland	575,0	86,0	4,0	10,0	700,0	950,0	147113,8	5474,0	11962,9
Heilige Land	1088,0	67,0	3,0	29,0	1030,0	910,0	319102,2	11430,5	62880,0
Bedrijventerrein Delftse Poort-West	54,0	0,0	11,0	89,0	1120,0	840,0	0,0	2262,0	8841,1
Hof van Delft									
Agnetaparkbuurt	553,0	0,0	42,0	57,0	1260,0	1280,0	0,0	125253,2	115795,5
Ministersbuurt-West	603,0	68,0	13,0	19,0	990,0	1390,0	217177,7	33215,4	45705,4
Ministersbuurt-Oost	974,0	1,0	20,0	78,0	1340,0	1530,0	6982,6	111721,7	333600,6
Westeindebuurt	274,0	78,0	3,0	19,0	880,0	880,0	100619,4	3096,0	13148,3
Olofsbuurt	1549,0	24,0	22,0	52,0	1150,0	1230,0	228725,3	167731,9	284342,5
Krakeelpolder	712,0	76,0	5,0	19,0	900,0	810,0	260549,3	13713,1	31448,5
Westerkwartier	1275,0	33,0	19,0	46,0	970,0	1020,0	218348,2	100572,5	171692,0
Voordijkshoorn									
Kuyperwijk Noord	893,0	53,0	16,0	31,0	880,0	1230,0	87464,0	21123,4	31666,6
Kuyperwijk Zuid	937,0	58,0	22,0	20,0	870,0	1210,0	99290,1	30129,4	21088,1
Ecodus	374,0	34,0	5,0	60,0	750,0	1190,0	20027,7	2356,2	24834,3
Marlot	210,0	42,0	6,0	52,0	1170,0	1790,0	21670,7	2476,7	18178,5
Westlandhof	763,0	55,0	20,0	25,0	600,0	1030,0	52875,9	15382,1	10020,1
Hoornse Hof	844,0	19,0	2,0	79,0	570,0	870,0	19195,1	1616,4	53947,6
Den Hoorn	514,0	33,0	8,0	59,0	50,0	430,0	1781,0	345,4	12127,4
Molenbuurt	561,0	14,0	7,0	74,0	750,0	940,0	12370,1	4948,0	36291,5

Neighbourhood	Total amount of residence	Ownership			Heat demands/res. [m3/r]		Total savings		
		% corporation	% rental other	% private property	rent	private	corporation	rental other	Private property
Delftse Hout	0						0	0	0
Tanthof West									
Tanthof West	24,0	0,0	21,0	75,0	.	1870,0	0,0	0,0	2221,6
Afrikabuurt-West	759,0	20,0	1,0	79,0	780,0	980,0	37297,3	1491,9	38782,8
Afrikabuurt-Oost	970,0	76,0	4,0	20,0	770,0	950,0	178807,9	7528,8	12163,8
Latijns Amerikabuurt	834,0	48,0	1,0	51,0	920,0	1090,0	116012,7	1933,5	30599,0
Aziëbuurt	1208,0	29,0	5,0	62,0	780,0	1020,0	86073,6	11872,2	50420,0
Tanthof Oost									
Boerderij buurt	586,0	49,0	9,0	42,0	1010,0	1190,0	60902,4	8948,9	14058,4
Dierenbuurt	428,0	39,0	8,0	53,0	970,0	1200,0	34001,6	5579,8	13066,0
Vogelbuurt West	1129,0	42,0	18,0	40,0	1090,0	1100,0	108539,8	42529,9	23844,5
Vogelbuurt Oost	692,0	60,0	6,0	34,0	920,0	1120,0	80216,6	6417,3	12648,7
Bosrand	335,0	19,0	2,0	79,0	700,0	900,0	9356,6	787,9	11432,9
Voorhof									
Poptahof Noord	693,0	80,0	20,0	0,0	.	.	0,0	0,0	0,0
Poptahof Zuid	539,0	64,0	6,0	30,0	10,0	40,0	2000,8	150,1	1520,0
Bedrijventerrein Voorhof	169,0	0,0	46,0	40,0	850,0	810,0	0,0	30660,7	12867,7
Mythologiebuurt	1129,0	82,0	3,0	15,0	1040,0	800,0	0,0	16344,3	31837,8
Aart van der Leeuwbuurt	627,0	29,0	32,0	39,0	.	.	0,0	0,0	0,0
Roland Holstbuurt	2034,0	26,0	37,0	37,0	1300,0	1420,0	398745,4	453956,3	251135,9
Voorhof-Hoogbouw	1313,0	32,0	28,0	40,0	180,0	520,0	43864,7	30705,3	64179,4
Multatulibuurt	660,0	83,0	1,0	16,0	680,0	1270,0	216052,3	2082,4	31516,3
Buitenhof									
Reinier de Graafbuurt	478,0	66,0	34,0	0,0	.	.	0,0	0,0	0,0
Buitenhof Noord	1772,0	83,0	1,0	16,0	1420,0	1160,0	636986,2	6139,6	29599,5
Juniusbuurt	372,0	55,0	26,0	20,0	460,0	220,0	28705,4	10855,9	1473,1
Gillisbuurt	655,0	99,0	0,0	1,0	1100,0	.	217555,0	0,0	0,0

Neighbourhood	Total amount of residence	Ownership			Heat demands/res. [m3/r]		Total savings		
		% corporation	% rental other	% private property	rent	private	corporation	rental other	Private property
Fledderusbuurt	494,0	87,0	0,0	13,0	940,0	740,0	123217,9	0,0	4277,1
Het Rode Dorp	488,0	97,0	0,0	2,0	990,0	980,0	142931,1	0,0	860,8
Pijperring	357,0	80,0	0,0	19,0	930,0	850,0	81010,4	0,0	5189,0
Verzetstrijdersbuurt	1285,0	46,0	13,0	41,0	0,0	1690,0	0,0	0,0	80133,9
Vrijheidsbuurt	731,0	32,0	6,0	61,0	1460,0	1320,0	104164,6	15624,7	52974,1
Buitenhof Zuid	269,0	0,0	3,0	97,0	1080,0	1040,0	0,0	2126,6	24423,0
Abtswoude	6,0						0,0	0,0	0,0
Schieweg									
Delftzicht	379,0	33,0	6,0	60,0	720,0	1020,0	2251,3	327,5	695,8
Zuideinde	159,0	37,0	7,0	52,0	690,0	860,0	1014,8	153,6	213,3
Schieweg Noord	51,0	0,0	16,0	84,0	910,0	780,0	0,0	148,5	100,2
Schieweg-Zuid	8,0						0,0	0,0	0,0
Schieweg Polder	11,0						0,0	0,0	0,0
Wippolder									
Zeeheldenbuurt	637,0	27,0	14,0	56,0	1240,0	1560,0	49051,5	20347,3	60656,7
TU-Noord	458,0	73,0	9,0	17,0	.	1560,0	0,0	0,0	13239,3
Wippolder Noord	929,0	37,0	18,0	43,0	1220,0	1330,0	96450,6	37537,5	57911,2
Wippolder Zuid	805,0	73,0	7,0	20,0	860,0	1030,0	116237,2	8916,8	18075,5
Rdamsweg Noord	20,0	0,0	50,0	50,0	.	1730,0	0,0	0,0	1885,7
TU Campus	1716,0	88,0	12,0	0,0	350,0	1310,0	121561,4	13261,2	0,0
Professorenbuurt	863,0	81,0	1,0	18,0	980,0	1140,0	157561,4	1556,2	19302,5
Delftech	72,0	78,0	7,0	15,0	.	.	0,0	0,0	0,0
Pauwmolen	44,0	9,0	0,0	91,0	.	2320,0	0,0	0,0	10125,3
Konings veldbuurt	307,0	0,0	3,0	94,0	860,0	1130,0	0,0	1457,4	35544,4
Ruiven									
Ackersdijk	19,0						0,0	0,0	0,0
Total [m3]							5739636,0	1568943,3	2781588,5
Total [GJ]							181142,9	49515,9	87786,9

E

Energy balance roadmap

	2015	2020	2030	2050	
Demands [PJ]	Total	Total	Total	Heat	Electricty
	3,50	3,43	3,1	1,7	1,1
Savings compared to 2015	100%	2%	10%	22%	15%
Generated with renewables [PJ]	0,047	0,38	0,78	1,72	1,23
Existing	0,047	0,047	0,047	0,039	0,008
Geothermal TU & Cascade		0,2	0,2	0,2	
Effluent water treatment plant				0,1	
ATES/BTES + Solar collectors/PVT				0,5	0,12
Residual heat (small scale)				0,20	
City centre & Hof van Delft				0,4	
Biogas /CHP		0,02	0,004	0,04	0,03
Biomass		0,02	0,08	0,08	
All-electric			0,01	0,17	
Photovoltaics		0,07	0,40		1,07
% Renewables	1%	10%	25%	100%	119%

Table E.1. Input for the energy balance.
(by Author).

	2020				
	Total renovations	% retrofitted	Savings Heating	Savings Electricity	Total savings
Corporations	3.092	13%	24.317	6.717	40.460
Private	1.780	7%	9.426		
Industrial	0	0%	0	0	0
Offices	555	11%	18.021	9.545	57.566
Total	4.872	10%	51.764	16.262	68.026
Total savings %			2%	1%	2%

	2030				
	Total renovations	% retrofitted	Savings Heating	Savings Electricity	Total savings
Corporations	15.694	68%	123.439	41.949	243.404
Private	14.732	57%	78.016		
Industrial	2.260	100%	30.000	38.863	38.863
Offices	1.688	34%	54.814	29.034	29.034
Total	34.374	61%	286.269	109.846	109.846
Total savings %			13%	8%	11%

	2050				
	Total renovations	% retrofitted	Savings Heating	Savings Electricity	Total savings
Corporations	23.030	100%	181.143	67.500	385.946
Private	25.927	100%	137.303		
Industrial	2.244	100%	30.000	124.500	315.300
Offices	4.996	100%	160.800		
Total	56.197	100%	509.246	192.000	701.246
Total savings %			22%	15%	20%

Figure E.2. Final energy demands and total renovations (by Author).

F

Interventions neighbourhood & building scale

I. Kuyperwijk

F.1. Energy demands & Savings - Neighbourhood

Heat demands residences	Residences	m3 / res	GJ;th /res.	GJ;th total	Savings
Before renovations	1.830	950	26,7	47.911	x
After renovations	1.830	x	18,7	34.230	29%
34% > A⁺	627	x	15,8	9.877	41%
34% > B	627	x	17,5	10.973	35%
32% > 2 steps	576	x	23,2	13.380	13%

Electricty demands residences	Residences	kWh / res.	GJ;el /res.	GJ;el total	Savings
Before renovations	1.830	2.020	7,3	13.308	x
After renovations (excl HP)	1.830	1.717	6,3	11.312	15%

Heat demands businesses	Businesses	GJ;th total	Savings
Before renovations	25% businesses of Voordijkshoorn	17.650	x
After renovations	25% businesses of Voordijkshoorn	12.532	29%

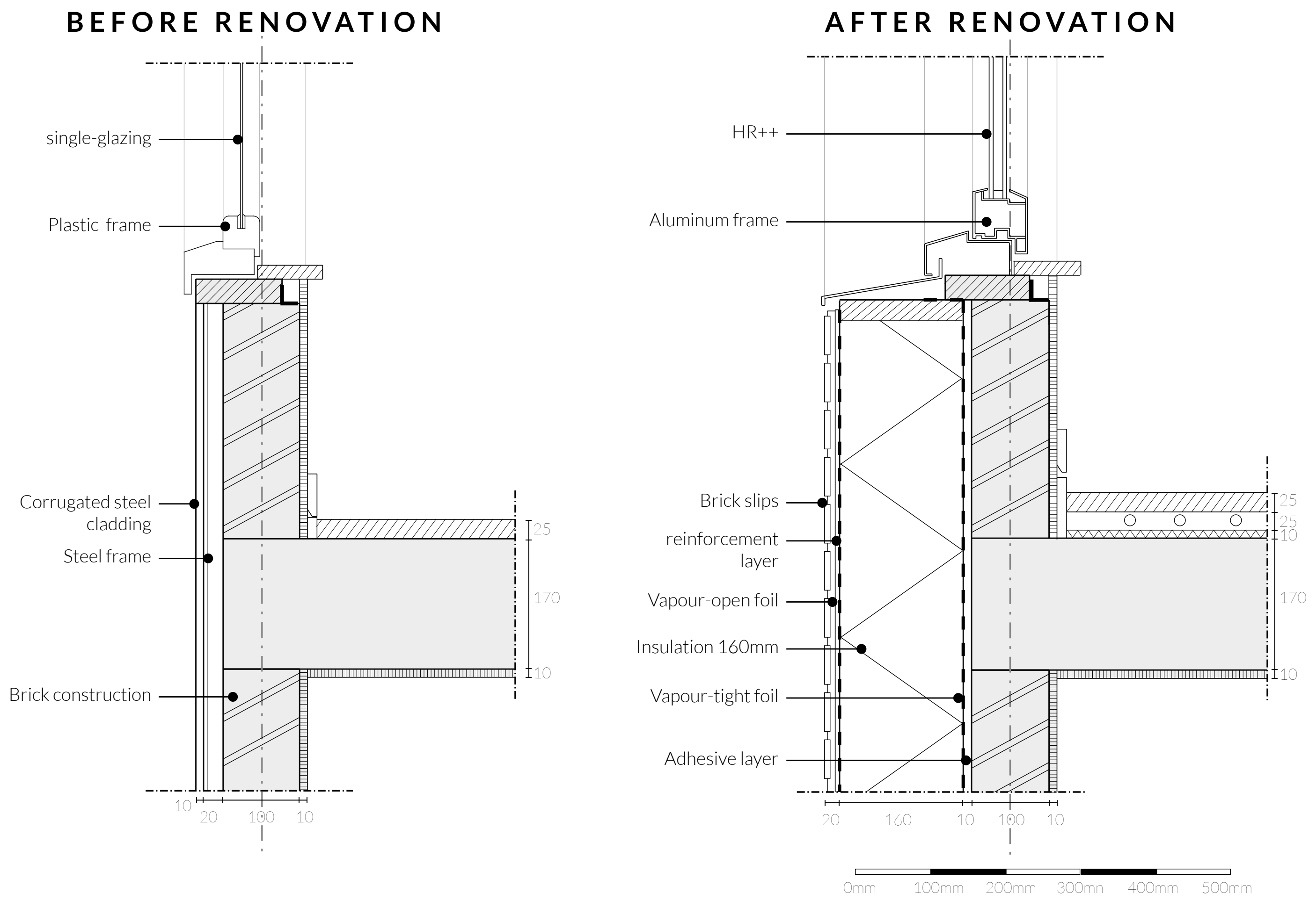
Electricty demands businesses	Businesses	GJ;el total	Savings
Before renovations	25% businesses of Voordijkshoorn	12.557	x
After renovations (excl HP)	25% businesses of Voordijkshoorn	10.673	15%

Energy demands	Residences [GJ]	Savings	Businesses [GJ]	Savings	Total [GJ]	Savings
Heat demands	34.230	29%	12.532	29%	46.762	29%
Electricity demands	11.312	15%	10.673	15%	21.985	15%
Total demands	45.542	26%	23.205	23%	68.747	25%

Table F.1. Energy demands of the Kuyperwijk before en after the renovations (by Author, based on www.cbs.nl; www.pico.geodan.org).

F.2. Interventions building scale

Figure F.2. Details of the facade before and after the renovations. (de Jong, et al., 2012)



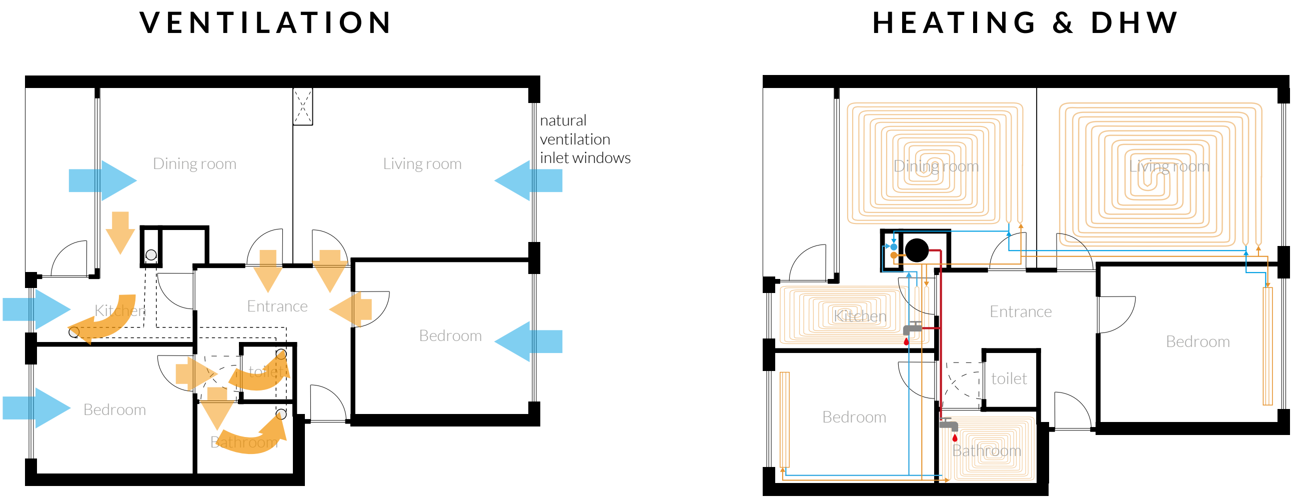
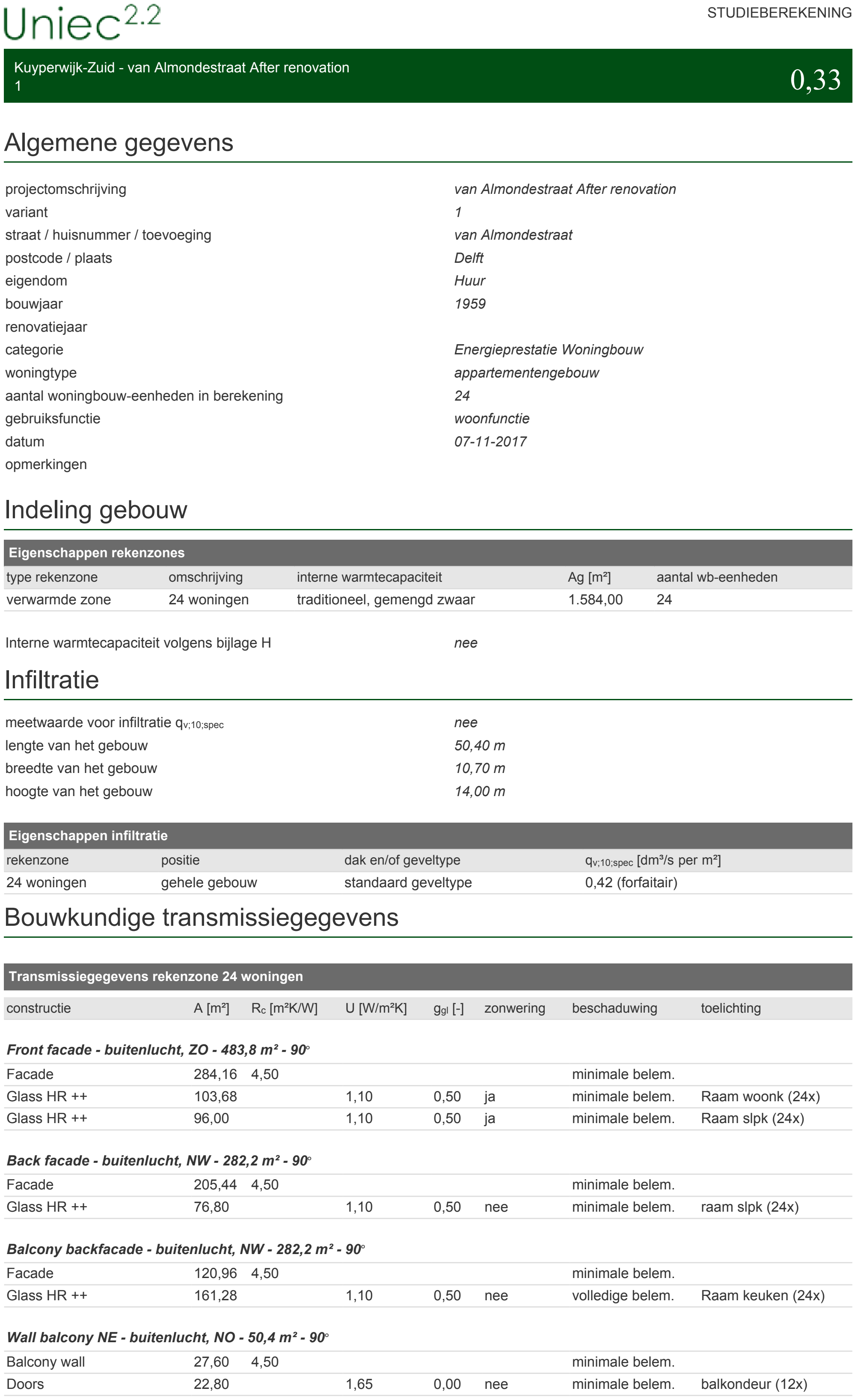


Figure F.3. - Ventilation, heating and DHW shown on floor plan.(by Author).

F.3. Uniec calculation



Uniec$^{2.2}$

STUDIEBEREKENING

Kuyperwijk-Zuid - van Almondestraat After renovation
1

0,33

Algemene gegevens

projectomschrijving	*van Almondestraat After renovation*
variant	*1*
straat / huisnummer / toevoeging	*van Almondestraat*
postcode / plaats	*Delft*
eigendom	*Huur*
bouwjaar	*1959*
renovatiejaar	
categorie	*Energieprestatie Woningbouw*
woningtype	*appartementengebouw*
aantal woningbouw-eenheden in berekening	*24*
gebruiksfunctie	*woonfunctie*
datum	*07-11-2017*
opmerkingen	

Indeling gebouw

Eigenschappen rekenzones

type rekenzone	omschrijving	interne warmtecapaciteit	Ag [m²]	aantal wb-eenheden
verwarmde zone	24 woningen	traditioneel, gemengd zwaar	1.584,00	24

Interne warmtecapaciteit volgens bijlage H	*nee*

Infiltratie

meetwaarde voor infiltratie $q_{v;10;spec}$	*nee*
lengte van het gebouw	*50,40 m*
breedte van het gebouw	*10,70 m*
hoogte van het gebouw	*14,00 m*

Eigenschappen infiltratie

rekenzone	positie	dak en/of geveltype	$q_{v;10;spec}$ [dm³/s per m²]
24 woningen	gehele gebouw	standaard geveltype	0,42 (forfaitair)

Bouwkundige transmissiegegevens

Transmissiegegevens rekenzone 24 woningen

constructie	A [m²]	R_c [m²K/W]	U [W/m²K]	g_{gl} [-]	zonwering	beschaduwing	toelichting
Front facade - buitenlucht, ZO - 483,8 m² - 90°							
Facade	284,16	4,50				minimale belem.	
Glass HR ++	103,68		1,10	0,50	ja	minimale belem.	Raam woonk (24x)
Glass HR ++	96,00		1,10	0,50	ja	minimale belem.	Raam slpk (24x)
Back facade - buitenlucht, NW - 282,2 m² - 90°							
Facade	205,44	4,50				minimale belem.	
Glass HR ++	76,80		1,10	0,50	nee	minimale belem.	raam slpk (24x)
Balcony backfacade - buitenlucht, NW - 282,2 m² - 90°							
Facade	120,96	4,50				minimale belem.	
Glass HR ++	161,28		1,10	0,50	nee	volledige belem.	Raam keuken (24x)
Wall balcony NE - buitenlucht, NO - 50,4 m² - 90°							
Balcony wall	27,60	4,50				minimale belem.	
Doors	22,80		1,65	0,00	nee	minimale belem.	balkondeur (12x)

Wall balcony SW - buitenlucht, ZW - 50,4 m² - 90°

Balcony wall	27,60	4,50				minimale belem.	
Doors	22,80		1,65	0,00	nee	minimale belem.	Balkondeur (12x)

Side facade NE - buitenlucht, NO - 132,1 m² - 90°

Facade	128,14	4,50				minimale belem.	
Glass HR ++	4,00		1,10	0,50	nee	minimale belem.	Zijraam (4x)

side facade SW - buitenlucht, ZW - 132,1 m² - 90°

Facade	128,14	4,50				minimale belem.	
Glass HR ++	4,00		1,10	0,50	nee	minimale belem.	Zijraam (4x)

Floor at storages - sterk geventileerd, HOR, vloer - 504,7 m²

Floor	504,72	3,50					

Walls non-heated zones - sterk geventileerd, wand - 403,2 m²

Walls non-heated zones	357,84	3,50					
Doors	45,36		1,65	0,00	nee		voordeur (24x)

Pitched roof front - buitenlucht, ZO - 293,3 m² - 23°

Roof	293,30	6,00				minimale belem.	

Pitched roof bakc - buitenlucht, NW - 293,3 m² - 23°

Roof	293,30	6,00				minimale belem.	

De lineaire warmteverliezen zijn berekend volgens de forfaitaire methode uit hoofdstuk 13 van NEN 1068.

Verwarmingsystemen

Opwekking

type opwekker	*elektrische warmtepomp, voldoet aan tabel 14.14*
bron warmtepomp	*bodem*
ontwerpaanvoertemperatuur	$35^\circ < \theta sup \leq 40^\circ$
vermogen warmtepomp	*70,00 kW*
β-factor warmtepomp	*24,28*
aantal opwekkers	*24*
type bijverwarming	*geen bijverwarming*
transmissieverlies verwarmingssysteem - januari (H_T)	*1.596 W/K*
warmtebehoefte verwarmingssysteem ($Q_{H;nd;an}$)	*268.428 MJ*
hoeveelheid energie t.b.v. verwarming per toestel ($Q_{H;dis;nren;an}$)	*11.530 MJ*
opwekkingsrendement - warmtepomp ($\eta_{H;gen}$)	*4,250*
opwekkingsrendement - bijverwarming ($\eta_{H;gen}$)	*0,000*

Regeneratie

zonne-energiesysteem voor regeneratie	*nee*

Kenmerken afgiftesysteem verwarming

Type warmteafgifte (in woonkamer)

type warmteafgifte	positie	hoogte	R_c	$\theta_{em;avg}$	$\eta_{H;em}$
vloer- en/of wandverwarming en/of betonkernactivering	buitenvloer of buitenwand	< 8 m	≥ 2,5 m²K/W	n.v.t.	1,00

regeling warmteafgifte aanwezig	*ja*
individuele bemetering	*ja*
afgifterendement ($\eta_{H;em}$)	*1,000*

Kenmerken distributiesysteem verwarming

buffervat buiten verwarmde ruimte aanwezig	*ja*
verwarmingsleidingen in onverwarmde ruimten en/of kruipruimte	*ja*
leidingen in onverwarmde ruimten en/of kruipruimte ongeïsoleerd	*nee*
distributieleidingen buiten gebouw op het perceel	*nee*
distributierendement ($\eta_{H;dis}$)	*0,970*

Hulpenergie verwarming

hoofdcirculatiepomp aanwezig	*ja*
hoofdcirculatiepomp voorzien van pompregeling	*ja*
werkelijk vermogen hoofdcirculatiepomp bekend	*nee*
aanvullende circulatiepomp aanwezig	*nee*
aantal toestellen met waakvlam	*0*

Warmtapwatersystemen

Opwekking

warmtapwaterbereidingssysteem	*zonder warmwatervoorraadvat(en)*
type opwekker	*kwaliteitsverklaring incl. hulpenergie - warmtepomp*
hoeveelheid energie t.b.v. warmtapwater per toestel ($Q_{W;dis;nren;an}$)	*168.766 MJ*
opwekkingsrendement	*3,500*
opwekkingstoestel tevens gebruikt voor verwarming	*nee*
opwekkingstoestel zonder hulpenergie	*nee*

Kenmerken tapwatersysteem

aantal woningbouw-eenheden aangesloten op systeem	*24*
warmtapwatersysteem ten behoeve van	*keuken en badruimte*
gemiddelde leidinglengte naar badruimte	*0-2 m*
gemiddelde leidinglengte naar aanrecht	*0-2 m*
inwendige diameter leiding naar aanrecht	≤ *10 mm*
afgifterendement warmtapwater ($\eta_{W;em}$)	*1,000*

Kenmerken distributiesysteem tapwater

individuele afleverset	*ja*
afleverset aangesloten op	*LT*
circulatieleiding	*nee*

Douchewarmteterugwinning

douchewarmteterugwinning	*nee*

Zonneboiler

zonneboiler	*nee*

Ventilatie

ventilatiesysteem	*C. natuurlijke toevoer en mechanische afvoer*
systeemvariant	*Zehnder ComfoFan S CO2 met uitbreidingssensoren + ZR-roosters ? 1 Pa*
luchtvolumestroomfactor voor warmte- en koudebehoefte (f_{sys})	*1,09*
correctiefactor regelsysteem voor warmte- en koudebehoefte (f_{reg})	*0,51*

Kenmerken ventilatiesysteem

werkelijk geïnstalleerde ventilatiecapaciteit bekend	*nee*
warmtepomp op ventilatieretourlucht in rekenzone(s)	*nee*
luchtdichtheidsklasse ventilatiekanalen	*LUKA C*

Passieve koeling

max. benutting geïnstal. ventilatiecapaciteit voor koudebehoefte	*ja*
max. benutting geïnstal. spuicapaciteit voor koudebehoefte	*ja*

Kenmerken ventilatoren

totaal nominaal vermogen (P_{nom}) centrale ventilatie-units	*280,00 W (24 units)*
reductiefactor luchtvolumestroomregeling centrale ventilatie-units (f_{regfan})	*0,364*
totaal effectief vermogen (P_{eff}) van alle ventilatie-units	*101,920 W*

Koeling

Kenmerken opwekker

type opwekker	*koudeopslag / bodemkoeling (zonder inzet koelmachine)*
koudebehoefte koelsysteem ($Q_{C;nd}$)	*24.579 MJ*

opwekkingsrendement ($\eta_{C;gen}$)	*10,000*

Kenmerken koelsysteem

koeltransport	*water*
distributierendement ($\eta_{C;dis}$)	*1,00*

Zonnestroom

PVT

PVT systeem	*onafgedekt PVT-systeem*
piekvermogen (Wp) per m²	*150 Wp/m² bepaald volgens NEN-EN-IEC 60904-1*

Zonnestroom eigenschappen				
ventilatie	A_{PV} [m²]	oriëntatie	helling [°]	beschaduwing
matig geventileerd - op dak/gevel, met spouw	100,00	ZO	32	minimale belemmering

Resultaten

Jaarlijkse hoeveelheid primaire energie voor de energiefunctie			
verwarming (excl. hulpenergie)	$E_{H;P}$	166.689	MJ
hulpenergie		87.191	MJ
warmtapwater (excl. hulpenergie)	$E_{W;P}$	123.440	MJ
hulpenergie		0	MJ
koeling (excl. hulpenergie)	$E_{C;P}$	7.551	MJ
hulpenergie		0	MJ
zomercomfort	$E_{SC;P}$	0	MJ
ventilatoren	$E_{V;P}$	8.228	MJ
verlichting	$E_{L;P}$	72.991	MJ
geëxporteerde elektriciteit	$E_{P;exp;el}$	0	MJ
op eigen perceel opgewekte & verbruikte elektriciteit	$E_{P;pr;us;el}$	116.631	MJ
in het gebied opgewekte elektriciteit	$E_{P;pr;dei;el}$	0	MJ

Oppervlakten			
totale gebruiksoppervlakte	$A_{g;tot}$	1.584,00	m²
totale verliesoppervlakte	A_{ls}	2.907,92	m²

Elektriciteitsgebruik		
gebouwgebonden installaties	50.574	kWh
niet-gebouwgebonden apparatuur (stelpost)	44.403	kWh
op eigen perceel opgewekte & verbruikte elektriciteit	12.655	kWh
geëxporteerde electriciteit	0	kWh
TOTAAL	82.321	kWh

CO_2-emissie			
CO_2-emissie	m_{co2}	21.418	kg

Energieprestatie			
specifieke energieprestatie	EP	221	MJ/m²
karakteristiek energiegebruik	E_{Ptot}	349.459	MJ
toelaatbaar karakteristiek energiegebruik	$E_{P;adm;tot;nb}$	426.190	MJ
energieprestatiecoëfficiënt	EPC	0,328	-
energieprestatiecoëfficiënt	EPC	0,33	-

BENG indicatoren		
energiebehoefte	51,4	kWh/m²
primair energiegebruik	48,5	kWh/m²
aandeel hernieuwbare energie	58	%

II. Voorhof-North

F.4. Energy demands & Savings - Neighbourhood

Heat demands residences	Residences	GJ;th /res.	GJ;th total	Savings
Before renovations	2.530	18,46	46.715	
After renovations	2.530	11,35	28.719	38%
50% > A⁺	1.265	10,15	12.840	45%
50% > B	1.265	12,55	15.879	32%

Electricty demands residences	Residences	GJ;el /res.	GJ;el total	Savings
Before renovations	2.530	7,68	19.430	
After renovations (excl HP)		6,53	16.516	15%

Heat demands businesses	Businesses	GJ;th total	Savings
Before renovations	290 (59% Voorhof	39.662	
After renovations	290 (59% Voorhof)	29.102	27%
Offices	151	18.444	32%
Industries	139	10.658	15%

Electricty demands businesses	Businesses	GJ;el total	Savings
Before renovations	290	35.978	
After renovations (excl HP)	290	30.582	15%

Energy demands	Residences [GJ]	Savings	Businesses [GJ]	Savings	Total [GJ]	Savings
Heat demands	28.719	38%	29.102	27%	57.821	33%
Electricity demands	16.516	15%	30.582	15%	47.098	15%
Total demands	45.235	32%	59.684	21%	104.919	26%

Table F.4.. - Energy demands and potential savings of Voorhof-North according to the scenario (by Author based on: Pico.geodan.nl and cbs.nl).

F.5. Interventions building scale

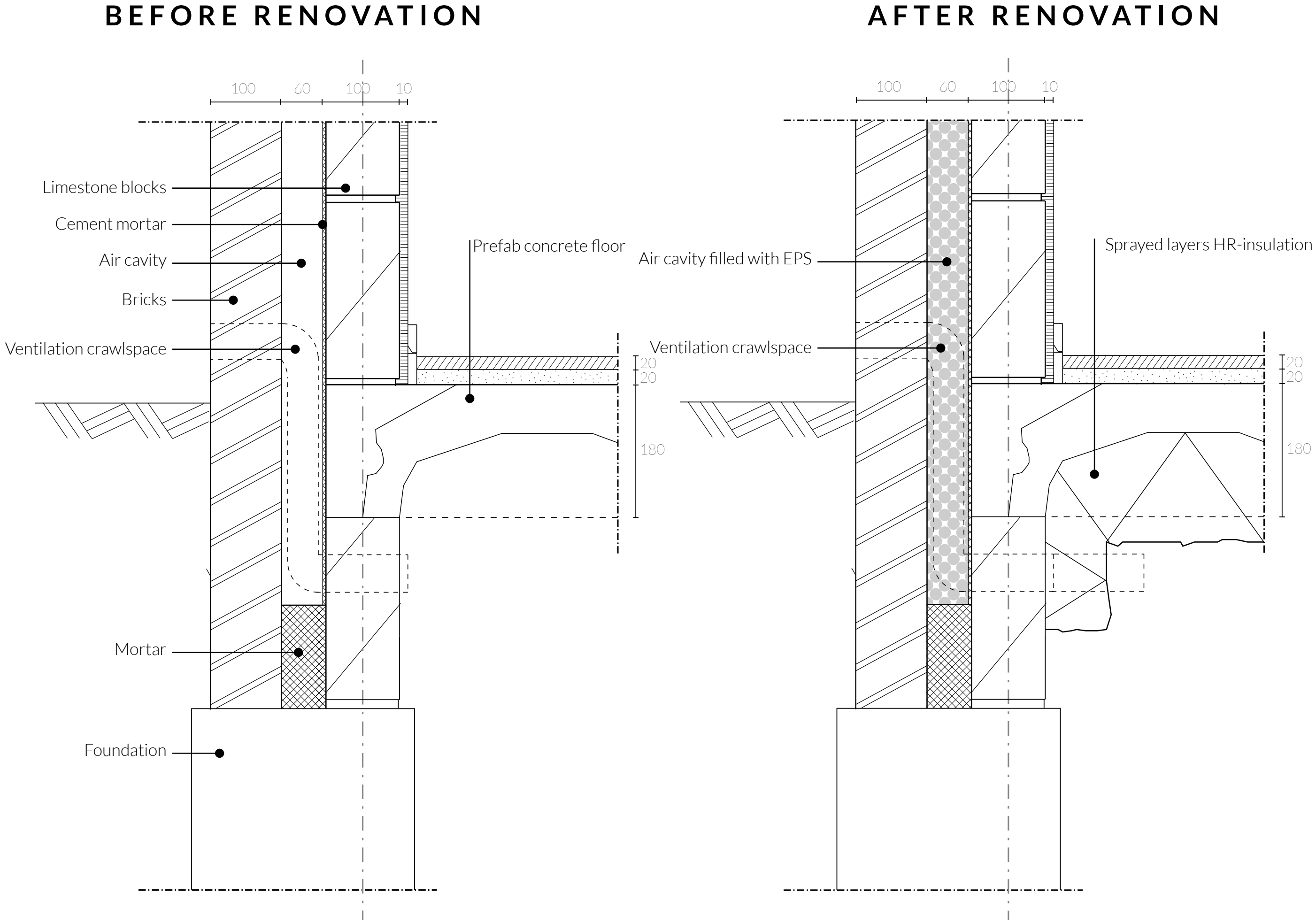
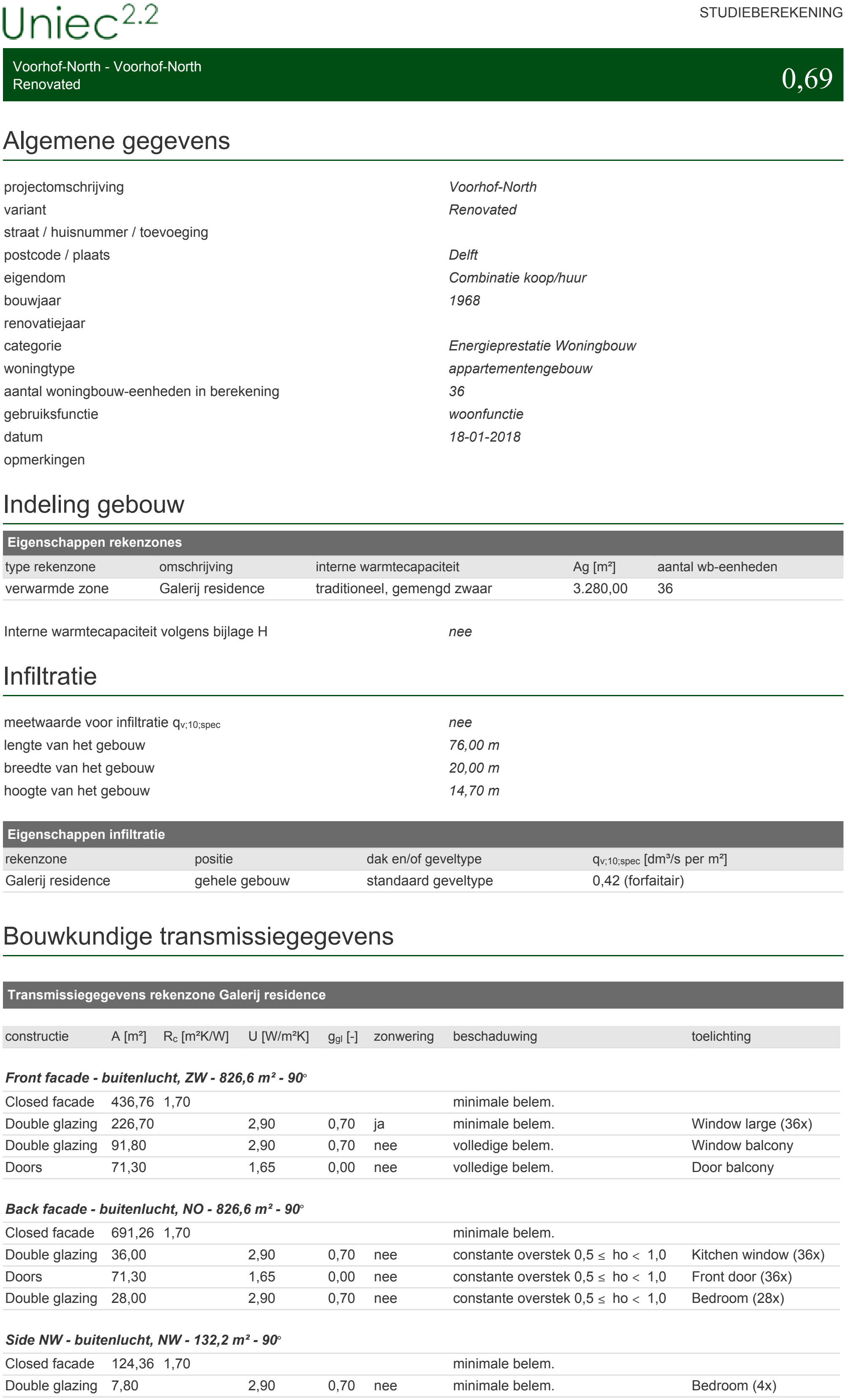


Figure F.5. Details of the facade before and after the renovations (de Jong, et al., 2012).

F.6. Uniec calculation



Uniec 2.2

STUDIEBEREKENING

Voorhof-North - Voorhof-North
Renovated

0,69

Algemene gegevens

projectomschrijving	*Voorhof-North*
variant	*Renovated*
straat / huisnummer / toevoeging	
postcode / plaats	*Delft*
eigendom	*Combinatie koop/huur*
bouwjaar	*1968*
renovatiejaar	
categorie	*Energieprestatie Woningbouw*
woningtype	*appartementengebouw*
aantal woningbouw-eenheden in berekening	*36*
gebruiksfunctie	*woonfunctie*
datum	*18-01-2018*
opmerkingen	

Indeling gebouw

Eigenschappen rekenzones

type rekenzone	omschrijving	interne warmtecapaciteit	Ag [m²]	aantal wb-eenheden
verwarmde zone	Galerij residence	traditioneel, gemengd zwaar	3.280,00	36

Interne warmtecapaciteit volgens bijlage H *nee*

Infiltratie

meetwaarde voor infiltratie $q_{v;10;spec}$	*nee*
lengte van het gebouw	*76,00 m*
breedte van het gebouw	*20,00 m*
hoogte van het gebouw	*14,70 m*

Eigenschappen infiltratie

rekenzone	positie	dak en/of geveltype	$q_{v;10;spec}$ [dm³/s per m²]
Galerij residence	gehele gebouw	standaard geveltype	0,42 (forfaitair)

Bouwkundige transmissiegegevens

Transmissiegegevens rekenzone Galerij residence

constructie	A [m²]	R_c [m²K/W]	U [W/m²K]	g_{gl} [-]	zonwering	beschaduwing	toelichting
Front facade - buitenlucht, ZW - 826,6 m² - 90°							
Closed facade	436,76	1,70				minimale belem.	
Double glazing	226,70		2,90	0,70	ja	minimale belem.	Window large (36x)
Double glazing	91,80		2,90	0,70	nee	volledige belem.	Window balcony
Doors	71,30		1,65	0,00	nee	volledige belem.	Door balcony
Back facade - buitenlucht, NO - 826,6 m² - 90°							
Closed facade	691,26	1,70				minimale belem.	
Double glazing	36,00		2,90	0,70	nee	constante overstek 0,5 ≤ ho < 1,0	Kitchen window (36x)
Doors	71,30		1,65	0,00	nee	constante overstek 0,5 ≤ ho < 1,0	Front door (36x)
Double glazing	28,00		2,90	0,70	nee	constante overstek 0,5 ≤ ho < 1,0	Bedroom (28x)
Side NW - buitenlucht, NW - 132,2 m² - 90°							
Closed facade	124,36	1,70				minimale belem.	
Double glazing	7,80		2,90	0,70	nee	minimale belem.	Bedroom (4x)

Side SO - buitenlucht, ZO - 132,2 m² - 90°

Closed facade	124,36	1,70				minimale belem.	
Double glazing	7,80		2,90	0,70	nee	minimale belem.	Bedroom (4x)

Roof - buitenlucht, HOR, dak - 870,8 m² - 0°

Flat roof	870,80	5,00	minimale belem.

Floor - AVR - 783,8 m²

Ground floor	783,80	5,00	

Floor cantilevered - buitenlucht, HOR, dak - 88,0 m² - 0°

Ground floor	88,00	5,00	minimale belem.

De lineaire warmteverliezen zijn berekend volgens de forfaitaire methode uit hoofdstuk 13 van NEN 1068.

Verwarmingsystemen

Opwekking

type opwekker	*externe warmtelevering*
regio	*- regio zonder NVN 7125 verklaring -*
warmteleveringssysteem	*externe warmtelevering - forfaitair (2e trap)*
aantal afleversets	*8*
transmissieverlies verwarmingssysteem - januari (H_T)	*2.612 W/K*
warmtebehoefte verwarmingssysteem ($Q_{H;nd;an}$)	*784.065 MJ*
opwekkingsrendement verwarming – ext. warmtelev. ($\eta_{H;gen}$)	*1,000*

Kenmerken afgiftesysteem verwarming

Type warmteafgifte (in woonkamer)

type warmteafgifte	positie	hoogte	R_c	$\theta_{em;avg}$	$\eta_{H;em}$
vloer- en/of wandverwarming en/of betonkernactivering	buitenvloer of buitenwand	< 8 m	≥ 2,5 m²K/W	n.v.t.	1,00

regeling warmteafgifte aanwezig	*ja*
individuele bemetering	*ja*
afgifterendement ($\eta_{H;em}$)	*1,000*

Kenmerken distributiesysteem verwarming

ongeïsoleerde verdeler / verzamelaar aanwezig	*nee*
buffervat buiten verwarmde ruimte aanwezig	*nee*
verwarmingsleidingen in onverwarmde ruimten en/of kruipruimte	*nee*
distributieleidingen buiten gebouw op het perceel	*nee*
distributierendement ($\eta_{H;dis}$)	*1,000*

Hulpenergie verwarming

hoofdcirculatiepomp aanwezig	*ja*
hoofdcirculatiepomp voorzien van pompregeling	*ja*
werkelijk vermogen hoofdcirculatiepomp bekend	*nee*
aanvullende circulatiepomp aanwezig	*nee*
aantal toestellen met waakvlam	*0*
afleverset met elektronica	*ja*

Warmtapwatersystemen

Opwekking

warmtapwaterbereidingsysteem	*zonder warmwatervoorraadvat(en)*
type opwekker	*externe warmtelevering*
regio	*- regio zonder NVN 7125 verklaring -*
warmteleveringssysteem	*externe warmtelevering - forfaitair (2e trap)*
hoeveelheid energie t.b.v. warmtapwater per toestel ($Q_{W;dis;nren;an}$)	*369.939 MJ*
opwekkingsrendement	*1,000*
opwekkingstoestel tevens gebruikt voor verwarming	*ja*
opwekkingstoestel zonder hulpenergie	*nee*

Kenmerken tapwatersysteem

aantal woningbouw-eenheden aangesloten op systeem	*36*
warmtapwatersysteem ten behoeve van	*keuken en badruimte*
gemiddelde leidinglengte naar badruimte	*6-8 m*
gemiddelde leidinglengte naar aanrecht	*6-8 m*
inwendige diameter leiding naar aanrecht	*≤ 10 mm*
afgifterendement warmtapwater ($\eta_{W;em}$)	*0,773*

Kenmerken distributiesysteem tapwater

individuele afleverset	*ja*
afleverset aangesloten op	*LT*
circulatieleiding	*nee*

Douchewarmteterugwinning

douchewarmteterugwinning	*nee*

Zonneboiler

zonneboiler	*nee*

Ventilatie

Ventilatiesysteem

ventilatiesysteem	*C. natuurlijke toevoer en mechanische afvoer*
systeemvariant	*C1 standaard*
luchtvolumestroomfactor voor warmte- en koudebehoefte (f_{sys})	*1,09*
correctiefactor regelsysteem voor warmte- en koudebehoefte (f_{reg})	*1,00*

Kenmerken ventilatiesysteem

werkelijk geïnstalleerde ventilatiecapaciteit bekend	*nee*
warmtepomp op ventilatieretourlucht in rekenzone(s)	*nee*
luchtdichtheidsklasse ventilatiekanalen	*onbekend*

Passieve koeling

max. benutting geïnstal. ventilatiecapaciteit voor koudebehoefte	*ja*
max. benutting geïnstal. spuicapaciteit voor koudebehoefte	*ja*

Kenmerken ventilatoren

nominaal vermogen ventilator(en) forfaitair	*ja*
type ventilatoren (vermogen forfaitair)	*gelijkstroom*
extra circulatie op ruimteniveau	*nee*

Aangesloten rekenzones

Galerij residence

Koeling

Kenmerken opwekker

type opwekker	*externe koudelevering*
koudebehoefte koelsysteem ($Q_{C;nd}$)	*13.154 MJ*
opwekkingsrendement ($\eta_{C;gen}$)	*1,000*

Kenmerken koelsysteem

koeltransport	*water*
distributierendement ($\eta_{C;dis}$)	*1,00*

Hulpenergie koeling

koude direct afgegeven aan binnenlucht of LBK	*nee*

Zonnestroom

piekvermogen (Wp) per paneel *270 Wp/paneel*

Zonnestroom eigenschappen				
ventilatie	$n_{panelen}$	oriëntatie	helling [°]	beschaduwing
sterk geventileerd - vrijstaand	100	ZW	30	minimale belemmering

Resultaten

Jaarlijkse hoeveelheid primaire energie voor de energiefunctie		
verwarming (excl. hulpenergie)	$E_{H;P}$	705.659 MJ
hulpenergie		39.559 MJ
warmtapwater (excl. hulpenergie)	$E_{W;P}$	332.945 MJ
hulpenergie		0 MJ
koeling (excl. hulpenergie)	$E_{C;P}$	13.149 MJ
hulpenergie		15.114 MJ
zomercomfort	$E_{SC;P}$	0 MJ
ventilatoren	$E_{V;P}$	162.050 MJ
verlichting	$E_{L;P}$	151.142 MJ
geëxporteerde elektriciteit	$E_{P;exp;el}$	0 MJ
op eigen perceel opgewekte & verbruikte elektriciteit	$E_{P;pr;us;el}$	223.434 MJ
in het gebied opgewekte elektriciteit	$E_{P;pr;dei;el}$	0 MJ

Oppervlakten		
totale gebruiksoppervlakte	$A_{g;tot}$	3.280,00 m²
totale verliesoppervlakte	A_{ls}	2.876,24 m²

Externe warmtelevering gebruik (n.v.t. bij 2e trap)	
gebouwgebonden installaties	1.154 GJ

Elektriciteitsgebruik	
gebouwgebonden installaties	39.916 kWh
niet-gebouwgebonden apparatuur (stelpost)	91.945 kWh
op eigen perceel opgewekte & verbruikte elektriciteit	24.244 kWh
geëxporteerde electriciteit	0 kWh
TOTAAL	107.617 kWh

CO_2-emissie		
CO_2-emissie	m_{co2}	111.443 kg

Energieprestatie		
specifieke energieprestatie	EP	365 MJ/m²
karakteristiek energiegebruik	E_{Ptot}	1.196.184 MJ
toelaatbaar karakteristiek energiegebruik	$E_{P;adm;tot;nb}$	697.523 MJ
energieprestatiecoëfficiënt	EPC	0,686 -
energieprestatiecoëfficiënt	EPC	0,69 -

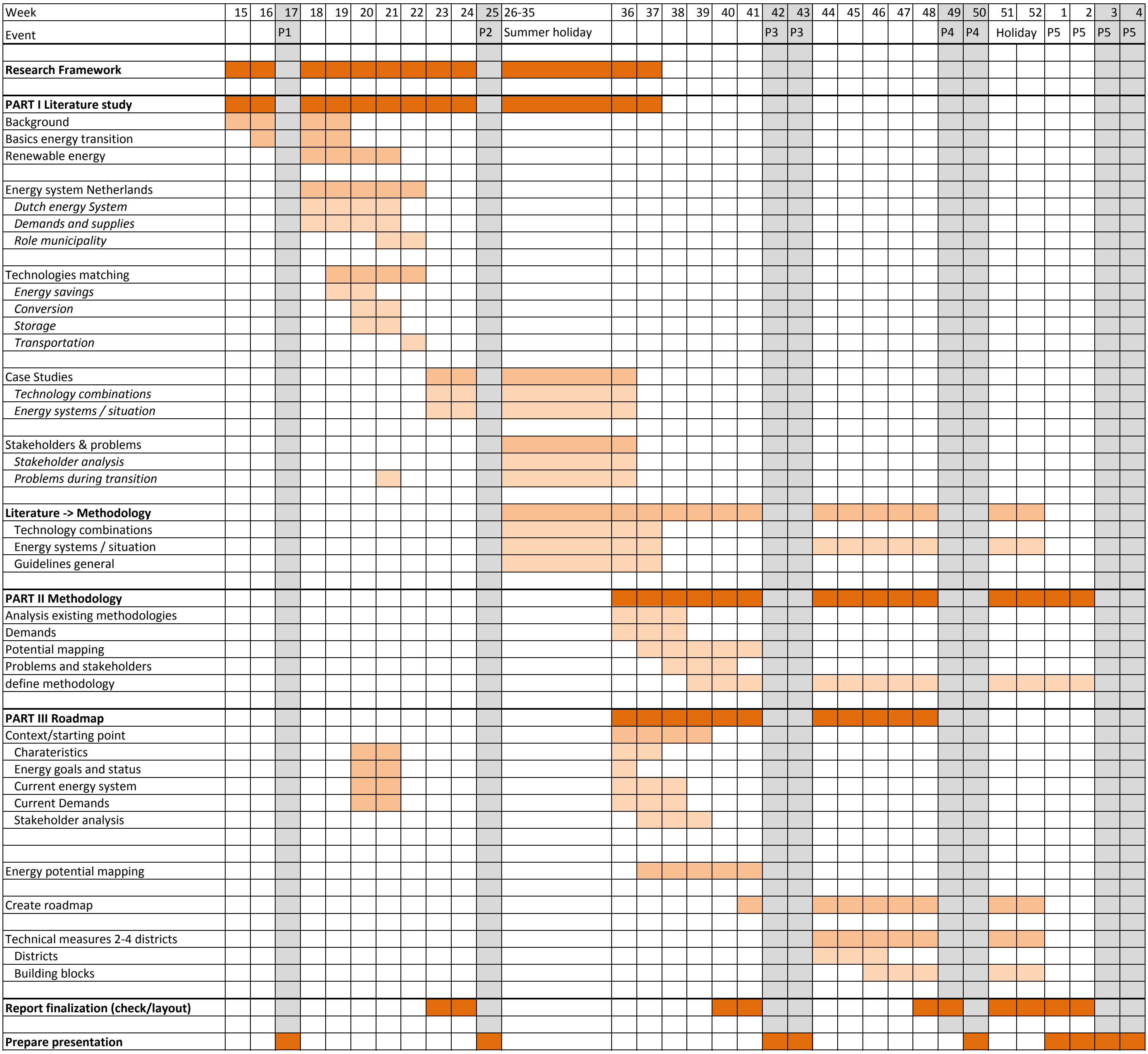
BENG indicatoren	
energiebehoefte	67,5 kWh/m²
primair energiegebruik	88,8 kWh/m²
aandeel hernieuwbare energie	8 %

G

Planning

Planning

The graduation period is divided into 5 reflection points: the P1-5 presentations. In the period until P2 the literature study was done (part I of the thesis). After the P2 the literature study results were implemented into the roadmap and approach design. At the same time the analysis of the context/starting point for the roadmap for Delft was performed. After the P3 the design of the roadmap resulted in resulted into a first version of the approach. Both roadmap and approach where optimized until the P4 presentation. Finally the complete thesis (including the literature study, approach and roadmap) was improved to the final version that is presented during the P5 presentation.



Week	15	16	17	18	19	20	21	22	23	24	25	26-35	36	37	38	39	40	41	42	43	44	45	46	47	48	49	50	51	52	1	2	3	4
Event			P1								P2	Summer holiday							P3	P3						P4	P4	Holiday		P5	P5	P5	P5
Research Framework	█	█		█	█	█	█	█	█	█		█	█	█																			
PART I Literature study	█	█		█	█	█	█	█	█	█		█	█	█																			
Background	▓	▓		▓	▓																												
Basics energy transition		▓		▓	▓																												
Renewable energy				▓	▓	▓	▓																										
Energy system Netherlands				▓	▓	▓	▓	▓																									
Dutch energy System				░	░	░	░																										
Demands and supplies				░	░	░	░																										
Role municipality							░	░																									
Technologies matching					▓	▓	▓	▓																									
Energy savings					░	░																											
Conversion						░	░																										
Storage						░	░																										
Transportation								░																									
Case Studies									▓	▓		▓	▓																				
Technology combinations									░	░		░	░																				
Energy systems / situation									░	░		░	░																				
Stakeholders & problems												▓	▓																				
Stakeholder analysis												░	░																				
Problems during transition							░					░	░																				
Literature -> Methodology												▓	▓	▓	▓	▓	▓	▓			▓	▓	▓	▓	▓			▓	▓				
Technology combinations												░	░	░																			
Energy systems / situation												░	░	░							░	░	░	░	░			░	░				
Guidelines general												░	░	░																			
PART II Methodology													█	█	█	█	█	█			█	█	█	█	█			█	█	█	█		
Analysis existing methodologies													░	░	░																		
Demands													░	░	░																		
Potential mapping														░	░	░	░	░															
Problems and stakeholders															░	░	░																
define methodology																░	░	░			░	░	░	░	░			░	░	░	░		
PART III Roadmap													█	█	█	█	█	█			█	█	█	█	█								
Context/starting point													▓	▓	▓	▓																	
Charateristics						▓	▓						░	░																			
Energy goals and status						▓	▓						░																				
Current energy system						▓	▓						░	░	░																		
Current Demands						▓	▓						░	░	░																		
Stakeholder analysis														░	░	░																	
Energy potential mapping														▓	▓	▓	▓	▓															
Create roadmap																		▓			▓	▓	▓	▓	▓			▓	▓				
Technical measures 2-4 districts																					▓	▓	▓	▓	▓			▓	▓				
Districts																					░	░	░										
Building blocks																							░	░	░			░	░				
Report finalization (check/layout)									█	█							█	█							█	█		█	█	█	█		
Prepare presentation			█								█								█	█							█			█	█	█	█

This research has two major purposes: (1) to design a roadmap for the energy transition towards energy neutrality of the built environment for the city Delft, with technical interventions, based on local potentials, integrated at all scales of the city and (2) to develop a general approach that can be applied to other Dutch municipalities. The final result is based on both design-by-research (literature study) and research-by-design.

The thesis exists out of three parts. The first part includes the literature study that forms the basis of the later designed approach and roadmap. This literature identifies the available energy sources and technologies that can be used to match the demands with the supplies and an analysis the existing methodologies. The approach for the energy transition of Dutch municipalities is defined in part II. This approach exists out of 8 steps; starting with the analysis of vision and targets. Followed by the status quo/the starting point. In the next step the local energy potentials are determined, resulting in a scenario for the energy transition of a certain city. Finally the roadmap is designed. In the last part of this thesis the approach is implemented to the roadmap towards energy neutral Delft.This results in an proposal for the energy systems and interventions.

On basis of the results there is concluded that by working through all scales while defining the energy systems and interventions according to the local characteristics and energy potentials an integrated and realistic roadmap towards an energy neutral built environment in 2050 is designed for the city Delft; at the same time the designed approach can also help other municipalities to achieve their energy transition goals.