The Hague's heat initiative: towards a smart thermal grid

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The Hague’s Heat Initiative
Towards a Smart Thermal Grid

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January 2016
The Hague’s Heat Initiative – Towards a smart thermal grid

By
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A dissertation submitted in partial fulfillment of
the requirements for the degree of
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Executive Summary

Over 90% of the heating in The Hague is currently provided by gas. With the gas reserves decreasing and the seismic risk is increasing, The Netherlands might soon become a net-importer of gas. The challenge is therefore to develop a more local and sustainable heating system for all. District Heating (DH) can transport heat from different –fossil and renewable- sources and is therefore very suitable for the energy transition. However, current market failure has caused the cities’ existing DH market to be in impasse.

The Hague’s Heat Initiative is founded by the municipality of The Hague and functions as a network of the municipality, residents, entrepreneurs, housing corporations, other real estate owners and energy companies. The Heat Initiative acts as a facilitator and accelerator for heat projects and connects suitable partners for this purpose, while keeping the overall goal of the city in mind. The aim is to achieve affordable and sustainable heating and to create a DH market in which the customer is the focus point. Because the market model will presumably change within the coming period, a small and flexible managing organization has been set up. Projects are developed based on the enthusiasm of residents; no one can, or will be forced to connect to DH. The aim is to create small projects now, which can combine all together in a smart thermal grid later on.

Heating in the built environment currently accounts for 22% of the city’s CO₂ emissions. Insulation measures and demolition will cause a drop in energy demand of around 37%. The Hague’s Heat Initiative will actively stimulate this improvement of energy performance of the built environment by proposing a sustainable renovation plan for all houses connecting to district heating. An interactive Heat and Cold map helps pointing out the most profitable areas for retrofitting and DH. From this map, it is estimated that DH is the best heating solution for around 100,000 households. Retrofitting and connecting to DH could lead to a combined decrease in CO₂ emissions of The Hague of around 10%.

The most important, local heat sources for The Hague are geothermal and biomass. There are also many regional opportunities for residual and geothermal heat. The aim is to create an independent network which can be used by different energy companies to transport and deliver heat. The environmental impact of sources could be used to divide the capacity of the grid, giving priority to cleaner sources.

The sources which currently are in planning / being researched would offer enough room for DH expansion up to 2023. After that year, more (renewable) heat sources should be deployed. Options for new heat sources include also the transformation of excess electricity (wind power) to heat.

In order for the thermal grid to be smart, it should include features like heat storage, cold supply, demand side management and smart control and dispatch. Some of these features can already be found in best practice projects in Europe, however no large scale fully smart thermal grids are found yet. Innovation in DH consists also of more energy efficient piping and lowering the supply temperature to the end-users, making the system more energy efficient.

Apart from technical features that should help optimize and balance the urban energy system, the desire for a DH grid which allows participation of many heat generation parties asks for certain functional requirements with should be secured during the development of DH. This includes the need for an independent network operator and the possibility of opening up the DH grid to all available energy producers, including prosumers.

This study has been performed specifically for the city of The Hague. Although the exact implementation of the smart thermal grid is highly sight specific, the general approach can be applied to any other city that wants to facilitate and accelerate the development of DH.
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1. Introduction

1.1 Ambition
The Municipality of The Hague aims at being an energy-neutral city by 2040. The ambition to be at the forefront of the energy transition also shows from the city’s policy programme, in which sustainability is one of the key elements. More specifically, the policy programme mentions the city’s existing building stock as the focus for the energy transition. The city comprises around 250,000 households, which together account for 35% of the city’s CO₂ emissions (Leguijt C., 2014). The largest energy demand of the existing building stock is related to space heating and hot water purposes. The municipality sees the expansion of the current District Heating (DH) grid (almost 18,000 connections) as the solution to meet its sustainability targets. The municipality has therefore set up The Hague’s Heat Initiative (Haags Warmte Initiatief) to promote DH as alternative to gas-heating and accelerate renewable and energy efficient heat generation projects. The aim is to develop a smart thermal grid in which various local heat producers can participate. The system shall be based on the common carrier principle in which third parties can take heat from, or deliver heat to the grid. At the same time, The Heat Initiative promotes energy conservation, which decreases the demand and makes it possible to work with lower temperature heating. The final, long-term ambition of The Heat Initiative is to achieve 100,000 extra connections to DH by 2040.

A smart thermal grid will enable a more sustainable heating and cooling supply for the City of The Hague. The Hague Heat Initiative will lead the energy transition towards this smart thermal grid and ensure reliable and affordable heating to the city’s residents and other heat consumers, now and in the future.

1.2 The Hague’s Heat Initiative
The establishment of Hague’s Heat Initiative has been initiated by the municipality of The Hague in September 2015. It is an organization that will help develop and accelerate heat projects within the city. At the same time it aims at making the residents of The Hague enthusiastic for heat as alternative to gas and will support them to participate in the energy transition.

The Heat Initiative is an organization, not a company: the aim is not to take over the heat market. Instead, The Heat Initiative wants to support and accelerate the process of allowing new energy companies into the market and doing so, specifically focusses on the sustainability contribution of these companies. The Heat Initiative is an internal, municipal organization, which falls under the department of City Management. The Hague’s Heat Initiative is based on partnerships between the municipality, residents, entrepreneurs, housing corporations and energy companies. All initiatives related to the development of non-individual heat production units will be accepted and suitable partners will be found for each project. The separate heat projects that The Heat Initiative develops are intended to form an integrated smart thermal grid later on. That is why it is important that all projects are developed with a uniform approach and with the same base conditions for all.
1.3 Problem analysis

District Heating (DH) is the core of the idea of smart thermal grids. A DH grid is an underground network of pipes in the city, through which heat or cold (in the form of hot or cold water) is transported. Large initial investments and long project spans characterize DH, similar to other infrastructural works. Utility companies are hesitant to expand their existing businesses due to the changing energy landscape and associated risks. At the same time the urgency for an energy transition is felt increasingly, which was recently confirmed by all world leaders in the Paris Agreement at the 21st United Nations Climate Change Conference.

In order to create a larger demand for DH it is essential that residents of the city are offered an attractive proposition which meet the key goals of The Heat Initiative: better, cheaper, more transparent. That is why this study for The Heat Initiative includes a combination of business, technical and design aspects.

The main research question is:

What are the conditions under which the development of a smart thermal grid for the City of The Hague is future-proof?

To answer this question, sub questions arise. First of all, the current DH market should be analyzed to explain and justify the establishment of The Heat Initiative and to point out its critical success factors towards the different parties involved.

- What is the need in the heat market?
- What are the stakeholders involved in the DH market and what are their roles?
- Why should the municipality play a key role in the development of the DH market?

Secondly, a more technical analysis is done for the different options for The Heat Initiative.

- Will heat still be needed in The Hague in 2050? And if so, how much?
- Which heat sources are available in the city and its surrounding area and what is their contribution to sustainability?
- What is a likely scenario for the heat and supply of heat in the city?
- What does such a scenario imply for the DH grid?

The main question can be answered based on the answers to these sub-questions, and recommendations for both the organization and the system design can be given.

1.4 Research approach and framework

The first part of the research project investigates the current heat market and outlines the barriers for utility companies to stay competitive and achieve sustainability. This is done for the general energy market, based on literature and learnings from conference attendance. Secondly, a specific analysis is
made for The Hague. This justifies the establishment of The Heat Initiative and its interventions in the market. In addition, it explains the business model with which The Heat Initiative can overcome the mentioned barriers. This is done with the help of a CATWOE analysis which indicates the roles of the different stakeholders involved.

The second part of the project is about the development of the heating grid into a smart thermal grid. A technical vision sets the goal, after which the mentioned technical developments are analysed based on the (inter)national best practices. Additionally, research on the heat demand and supply is performed. This should give insight in how to create a smart thermal grid: what are the options for a smart energy system in The Hague and which measures should be taken in order for the development to achieve sustainability? The two are then combined in an energy scenario which gives insight in the future possibilities of a smart thermal grid for the city of The Hague.

The last part of the research looks at the DH infrastructure itself. It gives a general analysis as well as it shows what implications for the design the mentioned energy scenario would result in. Some design preconditions are listed that should be taken into account when developing new district heating projects.

The main result of this work is a list of criteria or conditions that The Hague’s Heat Initiative should fulfill in order for the development of the DH to be sustainable and future proof. These criteria are both technical and organizational. In addition, a business plan for The Heat Initiative is created in which clear roles for all stakeholders (customers, municipality and companies) are distinguished.

This study does not result in a blueprint design for the smart thermal grid of The Hague but rather in an abstract envisioning of what smart DH could mean for The Hague. This research does also not include an analysis on the suitability of DH to deliver heat in the future, compared to alternatives such as heat pumps. An analysis of this kind can be found in the policy vision of The Hague on this topic (Municipality of The Hague, 2015).

Heat is a “hot” topic. The urgency for an energy transition is felt more and more, which results in an increasing amount of attention for DH. New policies, research and statements, moves or inventions from a diversity of stakeholders has made that this work has been updated several times in the past year. A major change has been that the municipality planned to set up a DH company, but the strategy later changed into the establishment of the Heat Initiative. Moreover, the name and role of existing energy companies in The Hague have changed. The heat vision of the Minister of Economic Affairs in combination with his limitations to the gas extraction has also played a large role. These are just a few examples that show that this report should somehow be taken as a snapshot of the actuality.

1.5 Outline
So far in this report, the exploratory phase of the study has been described; The Hague Heat Initiative is now familiar, the problem is outlined and the approach and scope of the research are clarified. The rest of the report is divided into three central points in the research, which are business, technology and design. The design part is a combination of the first two and includes also recommendations and the conclusion of the research.
PART I
BUSINESS
2. Reason for change

2.1 Need for sustainability

The total primary energy consumption of the Netherlands was 3256 PJ in 2013 and has been relatively stable over the past years (CBS, 2014). Heat is responsible for the largest part of the consumption, with around 36%, or 1200 PJ. The remaining primary energy is used for electricity, transport fuel and as raw material input for industry (for example to produce plastics).

The energy consumption for heat splits up in 49% for the built environment, 44% for industry and 7% for agricultural purposes (Agentschap NL, 2013). This means that heat, consumed in the built environment, accounts for almost 18% of the total primary energy consumption of the country.

The contribution of heat in terms of CO2 emissions is slightly higher, with 22% (Leguijt C., 2014). This is because over 90% of the heat produced for Dutch households is based on natural gas boilers (ECN, et al., 2014). The high gas penetration in the Netherlands can be explained by the fact that the gas field in Groningen is one of the largest in the world. Gas consumption accounts for 42% of the total primary energy consumption of the country. That is much higher than the North Western European average of 23% (Eurogas, 2014). However, the gas reserves are decreasing and seismic risks are increasing. This has led to the decision of the Minister of Economic Affairs to decrease the maximum amount of gas to be extracted to 30 billion m³ in 2015. In more concrete terms, this means that The Netherlands might already become a net-importer of gas as of 2015. In order to stay independent of other (non-stable) countries to buy our gas, a transition in energy provision is needed.

The City of The Hague acknowledged the need for an energy transition and more sustainability in 2010, when it set the aim of becoming energy neutral by 2040. The above mentioned numbers show that heat accounts for a substantial part of the energy consumption and CO2 emissions; moreover, energy neutrality cannot be achieved without an energy transition in heat supply.

2.2 Traditional business models under pressure

The core business of utility companies all over the world has been to provide safe, reliable and low-cost energy (Accenture, 2013). This was mainly achieved by large scale power plants using fossil fuels to provide energy. With a steady economic growth, utility companies have been profiting from increasing energy consumption and growing revenues. Now, they face fundamental changes in their environment, which puts this type of business model under pressure (Accenture, 2013).

First of all there have been technological improvements which now make it possible to build energy neutral homes. The European Energy Performance of Buildings Directive even forces all new buildings to be nearly zero energy buildings by 31 December 2020 (European Parliament, 2010). Current practice also makes it possible for existing houses to significantly reduce their consumption. With a decreased customer demand, eventually, the revenues of energy consumption will go down.
At the same time, technological development has led to many new types of (renewable) energy systems. Heating your house with gas is no longer the sole option: heat pumps, solar thermal panels, geothermal heating and other systems are getting increased attention.

On top of that, EU governments are more and more implementing policies which either stimulate renewable energy production or try to limit the CO₂ emissions of existing power plants. Heat has also gained a growing amount of attention of Dutch politics. This is evident from several guidelines and directives such as the Heat Vision (Warmtevisie) released by the Dutch Minister of Economic Affairs in the beginning of April 2015. The heat vision points at reducing and enhancing sustainability of heat consumption. This is seen as necessity in order to reduce the climate impact of the Dutch energy system. Consumers show the same trend towards aiming for sustainability. In the Dutch electricity market for example, 63% of all households chose to contract a green electricity provider in 2013 (ECN, et al., 2014). In the DH market it is not possible yet to choose a green provider. In fact, it is not possible to change provider at all: utility companies in the DH sector profit from a natural monopoly. Yet as the importance of DH is recognized more and more, the comparison with the gas and electricity market is done more often and becomes more relevant. De-regulation in the Dutch electricity market has made that the market is fully open to competition as of 2004. The Dutch minister of Economic affairs stated that it is desirable to likewise allow competition on DH networks and have it operated by an independent net operator. With a revision of the existing Dutch Heat Act, which he is preparing for 2016, he aims at making this reality. This would change the whole market model of the DH market.

The last factor influencing the utility sector and its market model is the information and communication technology (ICT) revolution. Knowledge sharing on the internet made that consumers are more aware and expect more competitive and transparent energy pricing. At the same time, smart meters experiences have made it possible for consumer to get more insight in their energy consumption. The result is that they have higher expectations towards utility companies: they now expect personalized advice (both on products and actions) on how to reduce the energy bill (Accenture, 2010b).

### 2.3 District heating in The Hague

The existing DH grid in The Hague can be seen as a system in impasse. There is an energy producer, who delivers heat to the energy supplier. The energy supplier sells the heat to the customers. As the energy supplier owns the thermal grid, it is a sole supplier who creates a monopoly towards the customers. This means that customers cannot change provider, nor is it easy to shift back from heat to gas or another type of heat supply. It also means that potential new energy companies cannot make use of the existing grid, as the energy supplier doesn’t allow access to other parties. Current issues between the energy producer and supplier make that, on top of this, the two parties are not willing to expand the DH grid. This situation is summarized in Figure 1. It shows how the heat market in The Hague currently is completely stuck and unable to expand, which hereunder is explained in more detail.
The main energy production company in The Hague is Uniper (former E.On), who uses a combined cycle power plant to produce electricity. Since there is a DH grid it also delivers heat (a secondary product to them) to energy supplier Eneco. The combination of high gas prices and low electricity prices pushes gas-fired CHPs like Uniper’s out of the market. Yet because of the long term heat contract with Eneco, Uniper is obliged to supply heat. This means that a must-run often occurs, which is most likely loss-making.

The contract between energy producer and supplier will end in the beginning of 2023. Until that time Uniper has to deliver heat to Eneco for previously fixed prices. As Uniper is the main energy producer connected to The Hague’s DH grid, this might lead to unwanted power plays when the contract expires. It is also possible that the power plant will simply close down. Either way, Eneco will have a problem, as energy suppliers in The Netherlands are responsible for the supply security of heat to their customers (this is stated in the Dutch Heat Act). This puts a big pressure on Eneco to find alternative heat sources and limits them in expanding the grid.

At the same time, the perception of residents towards DH is not always positive. They often feel they pay too much for the heat and feel victim to the monopoly of the energy supplier. The Dutch Heat Act protects customers as of 2014 from this monopoly situation by limiting the prices through the “not more than otherwise” principle (In Dutch “niet meer dan anders”). In this way, consumers that are connected to the heat network will not pay more than they would have paid if they had had a natural-gas connection.

Figure 1. Graphic illustration of the current heat market in The Hague.
Dutch Heat Act also ensures that Eneco cannot pass on the energy bill to the customers in case the heat becomes much more expensive to them after 2022. Although the Dutch Heat Act, of which a completely new version is expected in 2016, makes DH pricing more fair, it does not enable the freedom to choose provider.

Local initiatives for renewable energy
Except for the freedom to choose, residents need their heat supply to be secure, safe, affordable and sustainable. In the last couple of years many local energy initiatives have arisen in the city, trying to evoke this. It underlines the urgency for an energy transition. Residents of The Hague are relatively well organized, through many neighborhood and homeowners associations. The associations are a way for residents to find likeminded people and to unite for a good cause: improving their city and habitat. Many projects in the field of sustainability are initiated like this. The projects, which are generally based on collaborations between residents and local companies, are in different stages of development and involve parties with different levels of professionalism. Some of the initiatives are relatively small and easy to execute: for example sharing options for insulation. Yet larger projects aim at arranging the energy production locally and with renewable sources, or look for a new energy producer when showing that there is a large demand. For the larger projects there are several barriers to becoming a success. First of all, making the step from a technical concept to a professional business case is not easy. Next, closing a final deal with financiers and other partners is difficult. Potential energy users, like for example social housing corporations, tend to be hesitant towards new technologies or new energy producers. As a result, only few projects actually get realized. Moreover, this makes that good ideas and preparation costs are lost. Without being part of a larger structure, all projects have to invent the wheel from scratch by themselves. In addition, they also need to find investors for a heating grid, as the current heating grid in The Hague is not open for other parties. The projects are of a relatively small scale which makes it difficult to find financing for both energy production unit and the DH grid.
3. Role of The Hague’s Heat Initiative

3.1 CATWOE analysis

The City of The Hague acknowledged the need for an energy transition and more sustainability when it set the aim of becoming energy neutral by 2040. As heating accounts for 22% of the current CO₂ emission of the city, provoking a change in the heating sector is one of the main tasks. That is why the City of The Hague is committed to help accelerate and realize heat projects and extend the cities DH grid. To do so, the municipality has set up “The Hague Heat Initiative”. The Heat Initiative will try to break through the impasse, described in the previous chapter, and stimulate growth in the heat market.

A CATWOE analysis is done to better understand the changes that The Hague’s Heat Initiative will need to provoke. The CATWOE analysis was developed by Peter Checkland as a part of his Soft Systems Methodology (SSM) (Checkland P. B., 1981). It is a technique to gain overview in large projects and to systematically identify what a business is trying to achieve and what the problem areas are. It consists of six elements, which are explained here and summarized in Figure 2.

![Figure 2. Graphic illustration of the CATWOE analysis for The Hague Heat Initiative.](image-url)
These are the people on the receiving end, those who will phase the transition. In the case of DH these are the end-consumers like residents and real estate owners. More specifically these include social housing corporations, their tenants, private house owners and commercial house owners and other possible users of buildings in The Hague.
The Heat initiative will need to make residents want to connect to DH, as they cannot force anyone to shift. The Heat Initiative needs “an offer you can’t refuse”. Some customers are currently already connected to the DH grid, but their role will be different in the future. For example, consumers should get the possibility to become prosumers in a smart thermal grid; meaning they can consume and supply heat to the grid on their convenience.

2. Actor.
This is the body involved in the implementation, the one provoking the change: The Hague’s Heat Initiative. This Municipal body does not have the purpose of taking over the heat market, nor can it change the heat market all by itself. That’s why the Heat Initiative will be a cooperation of different stakeholders involved. Important stakeholders are the abovementioned customers but also existing energy companies and new energy companies or initiatives. The actor therefor is a network of the municipality and residents, energy companies, building owners and local entrepreneurs. The Heat Initiative will function as a director and form collaborations with and between the different parties. Only when all parties are motivated, the Heat Initiative will have effect.

3. Transformation process.
This shows the change to the system. The transition in this case is twofold: from gas to heat (expanding the DH grid) and from traditional DH to smart DH (improving the system and breaking the monopoly). Existing energy partners are important because the transformation should include the current DH system.
Evolving to a smart grid requires the DH to become an open net through the “Third Party Access” principle. It also asks for more sustainable sources of heat and use of lower temperatures. Overall the system will be more efficient (in case of DH extension this can also be done by proper material choices) and the role of energy producers and suppliers will change.

4. World view.
This gives the larger context and long term impact. The real problem that the Heat Initiative is tackling is climate change and the accumulation of CO₂ in the atmosphere. Targets related to achieving more sustainability are improving air quality, the quality of life in the city and the wellbeing of The Hague citizens.
On top of that, the energy transition is an important factor here. For maximum supply security it is crucial not to become dependent on other (non-stable) countries to buy gas.

5. Owner.
The owner is the decision maker who has the authority to make the change and to continue or stop the project. In the case of The Heat Initiative, this is the Municipality Council and Executive. The municipality is initiator and responsible for the budget. All projects that will be executed will need to be approved by the Municipal Council and Executive.
These are external constraints and limitations affecting the success of the solution. The main constrain is market failure, as outlined in the previous section on the reasons for change. In addition, the large, long term investments which are needed to expand the DH grid can be seen as a constraint. This is especially the case because the Dutch Heat Act limits revenues of energy suppliers per delivered amount of heat, which makes the payback time of investments higher than often desired for commercial companies. Expected revenues are low and, unlike some other infrastructural projects, there is still a risk of getting people connected in a fast pace.

The CATWOE analysis identifies the most important stakeholders with whom the Heat Initiative has to deal. The Hague Heat Initiative will be a collaboration between the municipality, energy companies, local entrepreneurs, housing corporations and residents. Customers and parties like the national government and the Authority Consumer and Market also play a role around the Heat Initiative. Because the organization has to deal with that many stakeholders it is important to distinguish critical success factors for each party. That is why from the CATWOE analysis we have deduced the critical success factors and developed a future proof business model for the organization.

### 3.2 Why the municipality

From the above analysis one can still argue why it should be exactly the municipality to take the role of actor. Energy infrastructure is of social interest to a country. In that sense, infrastructure for heating could be considered similar to infrastructure for electricity or gas. Gas infrastructure was rolled out by the 100% stated owned company Nederlandse Gasunie in the 1960’s, so one could argue that the Dutch Government should be the party to intervene here as well. Yet there are some essential differences between heat and gas or electricity.

First of all, DH is a local solution. DH is not the best solution everywhere in the country. Secondly, it is also local because the heat sources need to be local: network losses are currently around 15 to 35% (Agentschap NL, 2013). The maximum distance to transport heat is much shorter than the distance in which one can transport gas or electricity. Because of this, DH can never have an infinite amount of heat generation units. This is in contrast with electricity for example, where even foreign producers can supply energy. When the infrastructure is local (on city or region scale) the profits also fall in the local area. The Hague should want to invest in DH as it is sustainable, but also because it is good for the cities’ economy. Another important factor is that the nature of heat is important, whilst for electricity this is not an issue. Heat can have different temperatures and that’s why only stating an amount of heat (f.e. 1 GJ) is not enough (1 GJ of heat at 30 degrees might not be as useful for you as at 80 degrees). Lastly, a large difference is that heat infrastructure is more costly than electricity and gas. It costs about 2 or 3 times more.

On top of these differences, it is simply an advantage that the municipality knows all local partners and can act relatively fast compared to the national government. For example, new energy companies now struggle to get to the market. Many energy companies have existed for years and have a steady
Property developers and housing corporations are hesitant when a new energy company comes up and proposes an alternative energy solution, for example for a new district. This is why the municipality, in the name of The Hague Heat Initiative, will make a partnership with these new energy companies. The size and reputation of the municipal organization can help to gain trust with customers.

Besides this, local authorities are simply needed because for planning permissions, building permissions, land crossing rights, ability to purchase or utilize land etc. An active role of a municipal organization can therefor significantly lower market risks (Andrews D., 2012). Danish experience on achieving full potential of DH also includes the preparation of a “Heat Plan” by all municipalities. These Heat Plans are like the land-use plans commonly used in The Netherlands in which the purpose (commercial/residential etc) of a location is defined. Danish Heat Plans do the same for heating systems, dividing areas into gas or DH zones. Overtime the gas zones will diminish as DH is for all areas stated as the final solution. When this becomes a possibility in The Netherlands as well, this can be done on the basis of the knowledge of the Heat Initiative.

3.3 Project development plan

The Hague Heat Initiative will start to help develop a couple of (small) heat projects for which citizens are enthusiastic. The advantage of starting small is that the organization stays flexible, for example in order to adapt to a changing market model for the heat market. Another advantage is that, in this way it is more natural to follow a learning curve.

The above mentioned design conditions should be met in order for the system to be robust and future proof. Moreover, the system will also be able to connect to a regional heat roundabout which delivers geothermal and residual heat from Westland and Rotterdam.

The development of the smart thermal grid in time is roughly planned as follows:

- **2015-2020** Focus on the development of separate heat projects (heat islands)
- **Before 2023** Create alternatives for the Uniper power plant
- **2020-2030** Connect the different heat islands together to form a smart grid
- **2020 onwards** Develop a regional district heating grid with Rotterdam and Westland
4. Business Model

A business model canvas explains the core of a business model and is often used as a strategic management and entrepreneurial tool for designing and describing a business model. It is shown in Figure 3 and each section of the canvas is explained in more detail after.

The business model of The Hague Heat Initiative is special in two ways: first, because the goal of The Hague Heat Initiative is not to gain revenue but to decrease CO\textsubscript{2} emissions in the city and evoke the energy transition. Second, because even though end-users are the real customers, The Heat Initiative also works with new energy initiatives which could lead to new energy companies. The business model therefore has a double sided approach.

![Business Model Canvas for The Hague Heat Initiative](image)

4.1 Customer Segments

In the previous chapter we have already distinguished prosumers and consumers. Yet also within the consumers there are different groups, each with specific issues to consider.
Social housing corporations (and tenants)
Social housing corporations and rental companies own 80,000 buildings in the city, which is about one third of the total housing stock. An important factor of this stakeholder is that even though the social housing cooperation is the customer, the end consumer is the tenant living in the property. In order to get this large group to connect to DH, value and incentives for both parties should be created (Solomentsev, 2012).
Research among the social housing corporation as performed by the City of The Hague shows the most important demands for an attractive offer are (Municipality of The Hague, 2015):

- Living costs of tenants need to reduce.
- Inconvenience for the tenants should be as little as possible.
- Investments by the housing corporation need to pay back.
- Room for investment of housing corporations should be increased.

The affordability of the heating service correlates with the risk that energy bills are putting greater pressure on the household budget of The Hague’s families. This is particularly true for lower class households, who often live in badly insulated houses with a high energy demand. Their opinion is important as Dutch law states that 70% of the tenants of an apartment block have to approve the switch to DH in order for the social housing corporation to be able to actually connect. This means that the offer to the end user is a crucial success factor and is the core of the business model of The Hague’s Heat Initiative.
In addition to these main requirements, other important factors which were mentioned in the research are i.a. sustainability (for both tenant and corporation), the possibility to choose (mainly for tenant), improved appearance of the building and comfort.

Private house owners
Private house owners will generally have the same wishes as tenants of rental houses. Yet the room for investment and ease of getting a loan for sustainable interventions is more similar to the need of housing corporations.
Several studies went after the preferences of energy consumers ((Accenture, 2010a) (Accenture, 2010b), (Ernst & Young, 2011), (Solomentsev, 2012) and all found corresponding results. The main factors are competitive pricing, increase of control and more sustainability. It might help convincing house owners to connect when this increases the value of their property or the attractiveness of the direct surrounding.

Commercial building and public facility owners
With commercial buildings and public facilities the customer can either be the end-user (as in private house owners) or not (as for social housing corporations). This group of customers contains both small, medium and large consumers. Some of them, such as offices or museums might have residual heat to
offer. For this group of customers an interesting offer would include the possibility to sell residual heat when possible.

### 4.2 Value Proposition

The Hague Heat Initiative has an extensive value proposition to DH customers:

- **Affordable heat.** This offer will be 15% lower than compared to gas. That saves around €150 a year.

- **No initial connection costs.** The Heat Initiative will take the cost of connecting the building to the DH grid.

- **The possibility to become a prosumer.** In this way customers can consume heat when they need to but can sell heat when they have residual heat. This is a possibility for the long term and cannot directly be guaranteed.

Because The Heat Initiative is not a company, this value proposition is encourage and spread but not directly offered by the Initiative itself. Some things can however be offered directly:

- **Free proposal for a sustainable and feasible renovation.**

- **Minimum inconvenience.** This is done by attunement between several works in the subsurface of the city (for example placing a DH grid at the same time as the sewage pipes are maintained).

More general, the development of a smart thermal grid in the city gives benefits to all residents:

- **Independency from (imported) gas.**

- **Stimulation of the local economy.** When heat supply is arranged locally, a much larger part of the 260 million euro currently spent on heating bills in the city will contribute to the local economy.

- **Increase of sustainability in the city.** This results in cleaner air by reduction of NOx, SOx and fine particle emissions. Moreover, it helps mitigate climate change.

For people, teams or companies that are interested in developing a heat project – either based on the exploitation of a new heat source, or a project related to a large heat demand – there is also a value proposition:

- **Support for feasibility studies and business case development**
- **Support with arrangement of financing for heat projects**
- **Support with finding partners in the project**
- **Sharing of experience with previous heat projects**
4.3 Key Partners
The Hague Heat Initiative will be a cooperation of the municipality, energy companies, residents, real estate owners and local entrepreneurs. The Heat Initiative will contact the right stakeholders for each project and for the execution of each project a specific collaboration is set. For each project then a specific partnership is set up. External partners are necessary for funding, larger scale projects and know-how. These external partners include the national government – with a focus on the Ministry of Economic Affairs and the European Union for funding purposes and influence on new regulation. The Metropolitan Region Rotterdam The Hague and the underlying municipalities are important for larger scale projects that cross the boundaries of The Hague. An example is the heat roundabout project Cluster West.

4.4 Channels
The Interactive Heat and Cold map of the city, in combination with short videos that explain The Hague Heat Initiative and its’ offer are the main channels to make inhabitants want to connect to DH. Several energy-related projects already found their way to the municipality. The Hague Heat Initiative will collect these projects and work with the initiators. In addition, The Heat Initiative will collaborate with Sustainable The Hague (Duuurzaam Den Haag), an organization that will work as front office to The Hague Heat Initiative. Sustainable The Hague is an independent platform for everyone in the city after a sustainable lifestyle. The organization has many contacts and activities in the city. The collaboration with Sustainable The Hague will smoothen the path for new initiatives to find their way to The Hague Heat Initiative and get help in professionalizing the idea.

4.5 Customer Relationships
It is attractive for project initiators to connect to The Hague Heat Initiative, as experiences with other, previous projects are shared. The relationship is maintained as the municipality offers support with for example feasibility studies. The Heat Initiative is also the way for project initiators to get access to possible funding by the municipality or other partners. Customers connected to DH will receive heat through the system. In the future this should include an active relationship with possibilities to choose provider or energy source. It will be difficult/ expensive for a customer to disconnect from DH.

4.6 Revenue Streams
The Initiative will work with a small team and perform feasibility studies and help accelerate new heating projects. The main focus is therefore process- and control tasks, which do not result in any revenue streams.
In some cases, the municipality may decide to take an active part in the realization of a project. The most successful cases will result in a feasible business case while in other cases it might not. When a company sees the opportunity to start a business and it is not needed for the municipality to take a role as investor
or risk taker, than this will always be preferred. Instead, the Municipal Council and Executive have clearly stated that it is acceptable to sometimes invest in heat projects, even when revenue streams will not cover for the investment.

When investing in a heat project the revenues streams are twofold: first of all there is the revenues from the consumed energy (per GJ), coming from the customer. This is a usage fee. Secondly, there will be a fixed tariff per year, which can be seen as a prescription cost. This tariff will only be charged to housing corporations, not the tenant. No fee should be charged for connecting a building to the DH grid. Whether or not the revenue streams of The Heat Initiative will correspond to this as well will depend on their role and the specific project.

Besides supplying heat, The Hague Heat Initiative will also promote insulation of the housing stock in the city. The heating consumption of the city will go down when buildings become better insulated. For energy companies this means that their revenues will go down. Yet as The Hague Heat Initiative counts its results in CO₂ emissions rather than revenue, this is seen as a plus.

Making such proposals and arranging the execution of insulating measures is also a possible additional revenue stream to energy companies, or can be a specific business case for other parties. In case there are sufficient other partners that take over this role, The Heat Initiative can pull back from this specific task.

4.7 Key Resources

Low interest loans are available for the municipality and are a key resource in this business plan. The extension of the DH grid and the development of renewable energy systems in the city require a large, long term investment.

Next, knowledge and know-how of heat projects is essential. The skills within the municipality should always be used first, but consultants can be hired in case of specific projects. A research and development team should secure that the different, separate projects form a coherent and complete system in the long term. This final system will be as smart as possible by already starting this research at an early stage. Marketing and communication skills are also essential, to make The Heat Initiative well known in the city.

For the realization of projects The Heat initiative will communicate regularly with several other departments in the municipality. For example the attunement of subsurface works saves up to 20% of investment costs.

4.8 Key Activities

Based on the CATWOE analysis, three important working processes within The Hague Heat Initiative can be identified: 1) Marketing and communication. This is about informing residents about The Heat Initiative, making them enthusiastic about heat and arranging the demand for heat. 2) Collaboration. This part of the work of The Hague Heat Initiative focusses on all potential partners and stakeholders around The Heat Initiative. It is for example important to keep the Ministry of Economic Affairs updated about our plan, and it is essential to work together with other municipalities (in the region) to join forces. 3)
Development and acceleration of heat projects. This is the most substantial activity and is explained in more detail below.

The Hague Heat Initiative will help develop new projects coming from three different sources. First of all, the earlier mentioned organization “Sustainable The Hague” will function as an antenna for heat projects in the city and will guide initiatives towards the Heat Initiative. Secondly, the real estate department of the municipality of The Hague is important. This department gets a constant stream of requests for building and renovation permits and needs to test these proposals (among other things) on sustainability. In some cases, the project might be very suitable for an innovative heat source, or could connect to already existing DH. The Heat Initiative needs to regularly update this department and the other way around, in order to maximize the amount of successfully transferred projects. This is also depending on the stage of the projects: when a permit request is done and the proposal is already engineered in detail, the chance of success will be lower than when it is still in the concept phase. It is therefore important that the Real Estate Department comes in action as soon as possible.

Apart from these two outsourced methods of acquiring new initiatives and projects, The Hague Heat Initiative will also actively approach real estate owners when ‘hotspots’ are found on the Interactive Heat and Cold map. More on this map can be found in the technical part of this report.

The process in Figure 4 describes the order of the process which The Heat Initiative follows. Every step downwards requires strong considerations and evaluations in terms of the feasibility of the project. This is not only economical, but involves social factors and possibilities for partners as well. In addition, every step in Figure 4 asks for an evaluation of the project and needs specific decisions on:

- Whether the project is suitable to go to the next step – and whether it is ready to do so.
- Which parties should be connected to the project and what their roles are.
- What framework for content and finances is used within the next phase.
- What the results for the next phase are and what decisions can be made then.
- What the planning / working process for the next phase will be.

The investment decision is the final decision in which the Municipal Council and Executive have to give their approval for the project in case the municipality wants to invest. In such case, the projects achievements are to be compared with the municipal goals of energy neutrality and other topics of the coalition agreement. A positive contribution to the energy transition, air pollution and the creation of employment opportunities are in such case valued equally next to the monetary feasibility. The realization and operation of the projects are generally arranged by other parties.
4.9 Cost Structure

The Hague Heat Initiative is a development and acceleration organization. That is why the main cost is labor based. Partially, this will be for a team of people who will form The Initiative, yet a substantial part will be spent on buying external knowledge for the development of specific heat projects.

The investments in heat projects or related infrastructure are not part of the standard budget of The Hague Heat Initiative. Investment decisions for projects will be separately proposed to the Municipal Council and Executive. The amount of money which falls in this category will possibly be much larger than the organization cost.
PART II

TECHNOLOGY
5. Smart thermal grid

5.1 Vision

District Heating (DH) is at the core of the concept of smart thermal grids. A DH grid is an underground network of pipes through which heat or cold (in the form of hot or cold water) is transported. Unlike gas boilers, which are conventionally used for heating in The Hague and The Netherlands, DH can facilitate the use of many heat fuels and sources. For example, it can transport heat from power plants or industrial processes, from the earth (geothermal heat), from the sun (solar thermal) or from biomass and waste energy plants. Currently, most DH systems still supply fossil fuel based heat, but the infrastructure is sufficiently flexible to allow the use of a variety of sources over time. That flexibility is exactly what is needed for an energy transition and it shows how DH can help lower the dependency on fossil fuels.

For the Province of South Holland it has been shown that a combination of insulation of buildings and connecting to DH is the most cost efficient way to achieve more sustainable heating (Blom M., 2014). That is why the City of The Hague aims to develop an optimized form of DH, also termed a smart thermal grid or 4th generation DH. This smart thermal grid uses low temperate heat, coming from low-carbon and renewable energy sources. This makes the system both highly efficient and sustainable. In addition to transporting heat, a smart thermal grid also integrates thermal energy storage for optimal supply security. Smart thermostats help customers use less heating by giving them real-time feedback about their consumption. These thermostats also impose load management to improve the overall balance of the DH grid, while smart meters continuously measure all the heat flows in the city.

Apart from being a technological achievement, heat is cheaper for customers when delivered through a smart thermal grid. This is mainly because there are several energy generation units, which creates competition between energy producers and suppliers. Consumers can choose their energy supplier of preference, unlike in conventional DH. Finally, a smart thermal grid is much more interactive than current systems. A smart thermal grid facilitates the participation of consumers as producers: they can become prosumers, meaning that consumers can supply heat to the network when it is surplus energy to them. It works in a similar way to the photovoltaic electricity generation in households: you automatically sell your electricity to the grid when you do not need it. When you need energy instead (for example at night), you can take it back from the grid like a normal consumer. This will also be possible for heat in a smart thermal grid, which could be economically attractive for offices, supermarkets or households that have a heat pump. Online applications will guide prosumers and automatically manage the timing of consuming and supplying.

Yet smart thermal grids are not only about heating. The smart thermal grid is an integrated part of a so-called multi-commodity grid: an integrated urban energy system for The Hague and its surrounding areas. At present, we have separate energy systems for electricity, heating and transportation. The infrastructure for each of these systems was developed and constructed independently. However, an increasing number of new energy technologies are finding their way to the market, many of which are
based on renewable energy sources. To make the energy system sufficiently robust to cope with a high percentage of renewable sources, it is necessary to integrate these separate systems into one. Many sustainable sources inherently give fluctuating energy outputs and therefore diversifying sources makes it easier to balance these fluctuations and meet the energy demands at all times. To some extent, this transition towards an integrated energy system is already happening. Some people have a heat pump in their house and consequently use electricity for heating. Electric cars are of growing interest as they cause no local air pollution and no noise. This trend is expected to continue in the future. At times of excess electricity production (for example at night, when there is a lot of wind, while consumption is low) electricity can be transformed into heat. This heat can be used directly, or in the coming day by using thermal energy storage. A multi-commodity grid therefore increases the energy efficiency of our overall energy systems.

In short, a smart thermal grid maximizes the exploitation of locally available energy resources. When integrated in a large scale multi commodity grid it enhances the efficiency of the complete urban energy system. As a result, the vision of The Hague Heat Initiative is to create an integrated, reliable, flexible, clean, and future-proof energy system for the city and its’ residents.

### 5.2 Development of district heating grids

Making DH expansion in The Hague future-proof requires the system to be designed in anticipation of the future developments described above, rather than for the current situation. When this is done, a so-called smart energy system is created. To get a better understanding of the future developments of district heating grids, it is important to understand past developments.

So far, four generations of district heating can be recognized. The very first networks (introduced in around 1880) used steam: New York (Manhattan) and parts of Paris still use this kind of system. The second (from the ’30 onwards) and the third generation, (from the 70’s/80’s) use hot water to transport the heat. The temperature of the second generation is >100 °C while that of the third generation stays under the 100 °C. Except for a trend towards lower temperatures, there is also a shift towards the reduction of material use and an increased share of prefabricated parts. For example, the piping of the first generation consists of pipelines inside concrete tubes, while the 3rd generation has insulated pipes which are directly placed in the ground.

The fourth generation of district heating grids will continue this same trend of decreasing the temperature and material usage. Moreover, integration of thermal energy storage is increasingly important as the share of renewable sources increases. Converting excess electricity into heat is another important element of fourth generation heating grids, also termed smart thermal grids. A more detailed description of these developments and 4th generation DH is given by Hendrik Lund (Lund H., 2014).

Apart from the developments of the energy infrastructure, there are trends in energy demand as well. Heat demand has been decreasing over the past years due to insulation of buildings. This is important mainly for two reasons: 1) thermal comfort can be achieved at a lower temperature heat supply when
buildings are insulated well. This creates the opportunity to profit from cascade usage and it increases the efficiency of the system because losses are lower at lower temperatures, and 2) the district heating grid can provide heating to more buildings when in the long term the demand per building becomes lower.

### 5.3 Best practice DH examples

Full projects that comply with the above description of 4th generation DH do not exist yet in Europe. However there are several best practice DH examples with certain innovative aspects. Examples include:

**Marstal, Denmark**
- Integration of different technologies (CHP, heat pumps and solar thermal)
- Several renewable energy sources (biomass, solar)
- Cooperative of residents
- Short and long term heat storage

**Barcelona, Spain (Visited, January 2015)**
- District heating and cooling
- Sustainable heat sources and residual heat (usage of seawater and waste to energy)
- Retrofitting of connected buildings

**Graz, Austria**
- Integration of different technologies over time (from gas-fired CHP to large solar fractions)
- Optimization of waste heat extraction at local industries
- Retrofitting of connected buildings
- Ongoing development of concepts for low-carbon plants like geothermal and biomass

**Heerlen, Netherlands**
- Exchange of heat between buildings and building clusters
- Usage of mines as heat wells
- Integration of different technologies (bio-CHP, solar energy, feed in of waste heat (data centres and industry)
- Low temperature DH
- Central Monitoring System (CMS) using internet

**Stockholm, Sweden (Visited, June 2014)**
- District heating and cooling
- Several renewable energy sources (waste, sea and lake water, datacenters)
- Integration of different technologies (CHP, heat pump)
6. Heat demand

6.1 Market size

The Hague is the third largest city in the Netherlands with a total heat demand of around 17 PJ per year (Municipality of The Hague, 2010). The city comprises over 250,000 residential buildings, for which the largest part of the building-related energy consumption is currently supplied by gas (Den Haag in Cijfers, 2015). An average Dutch household consumes 1340 m³ of gas per year, of which 80% is used for heating purposes; the rest is for cooking and hot water consumption (ECN, et al., 2014). Comparing this yearly energy demand to electricity consumption reveals that 57% of the energy consumed in buildings is used for space heating and hot water (42 GJ) and 43% for electricity (31 GJ). Commercial buildings, instead, consume relatively more electricity (ECN, et al., 2014).

As alternative to proving heat through gas boilers, heat can be provided through district heating. The Hague currently has a DH grid with almost 18,000 connections. Although the current DH supply is a natural monopoly, not much profit is made in the DH business in The Hague, or in The Netherlands in general (Szendrei K., 2015). Economic returns for heat suppliers are far from the expected commercial profits. The returns are generally so low that the Authority of Consumer and Market raised the question why heat suppliers remain active in this business (ACM, 2009). The main reason for these low returns is the high cost of DH infrastructure. This shows the importance of accurate decision-making when planning which areas are to be connected to district heating.

Space heating and hot water together, result in a yearly energy bill of around €1020 per household (ECN, et al., 2014). All inhabitants of The Hague together therefore spend the impressive amount of €260 million a year on space heating and hot water provision.

Rather than defining the heat market in terms of money, the municipality is interested in the potential CO₂ emission reduction that can be achieved in this market. Heating in the built environment currently accounts for 22% of the CO₂ emissions of The Hague, equaling 550 kton per year (Leguijt C., 2014).

6.2 Future heat demand

The heat demand of dwellings varies significantly with the type and the age of the building. New buildings perform much better than older buildings and will be almost energy-neutral when built in 2020 or later as proposed by the European Energy Performance of Buildings Directive (EPBD). The Dutch National Plan confirms this measure. This means that the heat consumption of new buildings is negligible and does not contribute to the size of the heating market.

When extrapolating the rate of demolition of Dutch cities, it shows that a maximum of 10% of the current building stock can be expected to be replaced by new buildings up to 2050 (Van den Wijngaart R., 2012). This means that the heat demand can be expected to decrease with 10% as well. However, as this replacement rate of buildings is rather low, this will not eliminate the city’s need for heat.
The heat demand will also decrease in the future due to better energy performance of the existing building stock. Figure 5 shows the energy performance in 2006 and 2012 for buildings of different construction periods. The energy performance in this figure is indicated with an energy label: the labels range from A (few energy saving measures needed to optimize the building) to G (many energy saving measures needed to optimize the building). As 18.4% of all dwellings in The Netherlands are built before 1946, it is clear that many building-specific measures will have to be taken in order to make the building stock more efficient (CBS, 2013). The percentage of older buildings is even higher in certain cities: Leiden tops the list with 62%, but also The Hague is significantly above average with 41.5% of buildings that were constructed before 1946 (CBS, 2013).

![Figure 5. Energy label classification (in percentage) of the Dutch housing stock by year of construction (ECN, et al., 2014) en (Tigchelaar C., 2013)](image)

Apart from the need for better insulation, Figure 5 shows a trend of improved energy performance over time for buildings of all construction periods, but especially for buildings built before 1970. Those are exactly the buildings where most gains can be achieved. Agentschap NL has performed an analysis of 30 different example buildings, representative for the Dutch building stock. The research shows that by insulating the building envelop (roof, façade and floor), it is possible to transform all buildings to energy label B (Agentschap NL, 2011).

It is important to notice that tenants’ behavior is excluded in the energy performance labelling. It has been shown that the gas consumption in buildings with high energy labels is on average indeed less than in those with a worse energy label. Yet, the theoretical gas consumption is slightly underestimated for high labels, while it is strongly overestimated for lower labels (Majcen D., 2012). This was found in a comparison study of 200,000 dwellings in the Netherlands and shows that even when the energy performance of buildings goes up, the energy consumption of the building might not fully change accordingly. This can be seen in Figure 6.
Figure 6. Theoretical vs. Actual gas consumption of Dutch households, for different energy performance labels (Majcen D., 2012).

Part of this discrepancy might also be due to the non-perfect completion of refurbishments. S. H. Hong and colleagues have shown that loft and cavity wall insulation of English buildings has led to a theoretical (modelled) reduction of 45 to 49%. Yet in practice, the space heating consumption has only been reduced by 10-17%. (Hong S.H., 2006) Their reasoning is that this is partially due to behavior and partly due to the difficulty in insulating 100% of each wall when this is done as a retrofit measure.

When combining the above-mentioned studies, it can be concluded that it is unlikely that the existing building stock of The Hague will become net zero heat consuming in the near future. The challenge thus lies in estimating the reduction potential.

If all buildings are retrofitted to achieve energy label B, as is considered possible by Agentschap NL, the energy consumption is expected to be reduced by 20% in 2050 (Van den wijngaart, 2012). The study puts emphasis on the need to combine building-specific measures with collective district measures.

Other research suggests that the savings potential of energy used for heating in the Netherlands could be 15% of the primary energy consumption when building envelop improvements and new building regulations are considered (Schepers B. L., 2014). This increases to 25% when all sectors are taken into account. CE Delft estimates the decrease in heat demand to be on average 1% a year, which would make 30% in 2050 (Schepers B.L., 2015). Europe-wide, the technical savings potential for existing buildings is shown to be one third of the current heat demand (Lechtenböhmer S., 2009), while a study specifically
focussing on Rotterdam estimates the total energy savings potential to be around 15% (Mastrucci A., 2014).

In order to achieve more drastic CO₂ reductions the heat source can be changed and investments in the district become more advantageous than investments in buildings itself. For Rotterdam, the tipping point between investment in the building and in the district is at energy label D. For dwellings with a label of C or higher, the return of investment of connecting to DH is much higher than insulating further (Leguit C., 2014).

![Figure 7. Energy savings and associated investments in Rotterdam from building-level improvements versus district energy approach (Leguit C., 2014).](image)

Domestic hot water is difficult to reduce and the cost and diminishing returns of higher levels of insulation make that, in the above-mentioned studies, the future heat demand is estimated to be 15 to 30 % lower than the current demand.

The Hague’s Heat Initiative will offer renovation advice to all buildings that are or will be connected to DH to stimulate real estate owners to improve their buildings energy performance. The large share of old buildings in the city also gives large room for improvements. With optimal support, the total heat demand reduction of the existing building stock is assumed to be 30% for this study. In addition, there is a reduction because of the demolition of old buildings which makes the total heat demand decrease with 37%.

### 6.3 Segmentation strategy

DH is most profitable in locations of high energy density, because of the high infrastructural costs. The Hague, being a large city, is therefore rather suitable for this technology. Yet also within a city, there are certain areas where the opportunity is greater than in other areas. More specifically, connecting certain buildings to DH is more profitable than others. For example, it is advantageous to connect large
consumers, such as hospitals or offices to DH. Also high rise buildings have the advantage of high energy density. In addition, connecting multi-family buildings that already have a common heating system is easier, because in such case, the internal building system requires no changes. Buildings owned by housing corporations are advantageous for organizational reasons.

An interactive Heat and Cold Map was developed for the municipality of The Hague to find the most profitable DH areas. The Heat and Cold Map has different layers in which information can be found regarding building type, as well as energy consumption per building, ownership, and suitability of areas for certain energy sources (geothermal, aquifers).

Figure 8 shows two layers of the heat map for an area in The Hague South West. It shows that the specific types of buildings mentioned above, which correspond to the colored buildings in the top map, often coincide with a concentrated heat demand (bottom map). An overview (not included) is made of 60 building clusters, spread all over the city, which together form the most profitable locations for DH. Figure 8 shows one of these clusters. Municipal buildings can act as initiators and motivators for other real estate owners when located in such building clusters.

![Figure 8. Two screenshots of the Interactive Heat and Cold map of The Hague. The colored buildings in the top picture are the most feasible buildings to connect to DH based on the mentioned selection criteria. The bottom picture shows the same area in The Hague, outlining the heat demand per building block. The red lines in the top picture represent the existing DH grid.](image)

Based on the Interactive Heat and Cold map, it is estimated that DH is the most suitable technology for around 100,000 buildings in The Hague. The map counts 2,800 of very profitable buildings of the categories mentioned above. Most of these are located within the above mentioned building clusters; on
top of that are the buildings in their surroundings. Surrounding buildings are feasible because the DH infrastructure is the largest cost: once the infrastructure is in the neighborhood, it is more likely to pay back connections to other buildings as well.

With 100,000 buildings DH could achieve a market share of around 40% in The Hague, valuing over €100 million in 2050 if for convenience it is assumed that heat prices remain stable. This could ultimately lead to a decrease in the city’s CO₂ emissions of the current 22% to a remaining 13%, but varies strongly with for the different connected heat sources.

The actual market share of DH in The Hague depends on the enthusiasm of the city’s residents. The municipality cannot force anyone to connect which means that at this point, it is impossible to decide where the thermal grid will be rolled out. That is why The Heat Initiative will work on uniform and transparent conditions for all citizens.
7. Heat supply

DH is a means to achieve the energy transition, yet the development of renewable and energy-efficient heat sources is a strong precondition for this. It is the heat sources which in the end make the heat supply sustainable.

7.1 Local heat sources

Fortunately, several potential heat sources are locally available. A previous study gives an overview of the main heat sources in the area; the result is shown in Figure 9. Different combinations of sources are possible, especially because local geothermal and biomass alone are not enough to fulfill all heat demand.

![Figure 9. Overview of the different available heat sources in the city of The Hague and surrounding area (Municipality of The Hague, 2015)](image)

Currently, the main energy generation unit in The Hague is a combined cycle power plant which produces electricity and heat. The CHP plant has additional capacity compared to what it produces now. The extra capacity is shown in Figure 9 and could potentially make the plant more feasible. However, the combination of high gas prices and low electricity prices seems to push this type of energy generation out of the market. The contract between energy producer and supplier will end in the beginning of 2023 and before that, an alternative has to be found.

Other current sources are smaller CHP’s, owned by the heat supplier. There is also a geothermal heat plant in The Hague. The geothermal well has been drilled many years ago but unfortunately the production company went bankrupt due to disappointing heat sales caused by unforeseen cancellations.
in new building plans. The plan now is to redevelop the plant and make use of the heat for DH purposes. In Figure 9 this source is shown as “in planning”.

Some other, new heat generation projects are planned as well, such as the heat river project. The heat river project makes use of the energy in the effluent from the wastewater treatment plant. This water has all year round a stable temperature of 10-20 °C and can be used as source for individual heat pumps in a close-by residential area. Low temperature space heating and hot water demand can in this way be provided very efficiently to some of the newer buildings in Scheveningen, The Hague. Moreover, cold can be provided in summer.

The total potential of new heat projects for which the realization is already scheduled is 0.8 PJ per year. These form the center of new developments. Additional biomass and geothermal energy projects can be developed, yet regional district heating is imperative if the current CHP goes out of order.

**7.2 Regional heat sources**

The Hague has a high heat demand and so does the rest of the Metropolitan region Rotterdam-The Hague. This heat demand can partially be fulfilled with local resources but utilization of excess heat on a regional scale offers large opportunities as well.

The Southern part of the Randstad is particularly suitable for the development of large scale heat infrastructure. Residual heat from the harbour area of Rotterdam could be utilized by building a regional DH grid, also called “Heat Roundabout”, connecting close-by cities and the greenhouse horticulture in Westland. Through a strong focus on innovation, the aim is to develop a smart multi-commodity grid, in which different renewable energies can be combined for optimal efficiency and energy independence.

Currently 157 PJ per year is cooled away in the Rotterdam harbour area: this is 12.5% of the total primary energy consumption used for heat in The Netherlands (Bosman R., 2013). Although this is heat at many differ temperature levels, it has been shown that at least 17 PJ can feasibly be recovered (Projectteam Cluster West, 2015). Potential sources are coal-fired power plants, waste incineration plants, a biomass power plant and industrial processes. In Figure 10 you can see where these potential sources of heat are located. The geothermal heat potential in the area is estimated to be 11.4 PJ/year.

A regional project has been set up to explore the western part of the roundabout, targeting the metropolitan region Rotterdam-The Hague (MRDH). The project, called Heat Roundabout Cluster West, is based on the collaboration of the municipalities of The Hague, Rotterdam, Delft, Westland and the province of South Holland. These public parties work together with commercial parties like Eneco, Warmtebedrijf Rotterdam, Havenbedrijf Rotterdam, UNIPER and Westland Infra. This exceptional multi-stakeholder collaboration has led to a business case for the development of the heat roundabout.
The first feasibility study has shown that there are unique possibilities for a heat roundabout in this area. It also shows that financing the project will be a challenge, due to the negative net present value found. However, the business case might still be improved as the first exploratory study is calculated at +/- 40% margin and basic assumptions. The results of the study strongly encourage the search for a large, low interest loan. It also underlines the necessity of public interference in this project. Another conclusion that can be taken from this study is that the value of the heat roundabout is for a large part based on the margin of the product. The margin as taken in the original study is not enough to reach a positive enterprise value. A financial analysis on the producer side could give more insight. The full report (in Dutch only) can be found on the website of the Municipality of The Hague (Projectteam Cluster West, 2015).

**Social benefits**

As explained above, the heat roundabout can facilitate the use of several heat sources. The large investment needed to realize the heat roundabout can only be justified when sufficient social benefits are guaranteed. This is mainly the case when governmental bodies (co)-invest. That is why it is important to have insight in the environmental impact of each source. Research has been done on the CO₂, NOₓ, SOₓ and small particle emissions of the different possible sources, of which the results can be found in the Heat Roundabout Cluster West report.

Emissions are accounted to residual heat when the extraction of heat (secondary product) reduces the efficiency of the primary production process. This is for example the case when high-temperature heat is extracted at a power plant. Adjustments can be made to the power plant in order to optimize the extraction of heat. This means that the accounted emissions vary strongly with both temperature and...
specific system configuration. In addition to emissions allocated to residual heat, emissions are also allocated to renewable energy sources like geothermal energy because the extraction of heat from the earth requires pumping energy.

This report adds extra calculations to the original study, which shows the accumulative result of substituting current heat sources in The Hague with the heat roundabout. This is done by making several “CO₂ scenarios” for the heat roundabout as a system, which are then compared to the current emissions in “reference scenarios”. The CO₂ scenarios give a general indication of the sustainability of the different sources of heat and the necessary measures that need to be taken to decrease the CO₂ emissions as much as possible. The hereunder mentioned numbers are all based on the same assumptions as taken in the Heat Roundabout Cluster West project.

Reference scenario
Two reference scenarios are made in which the heat roundabout will substitute the gas fired CHP which currently provides heat to the district heating grid. In the other scenario the heat provided to the city will substitute individual boilers. In 2020 it is assumed that 1,87 PJ of heat is delivered to consumers, in 2030 this increases to 3,3 PJ. These numbers include heat losses and peak load delivery. The total CO₂ emission is 140 kton in 2030.

Table 7.2-1 Change in CO₂ emission when replacing the currently used individual boilers or CHP with DH for different sources of the heat roundabout.

<table>
<thead>
<tr>
<th>Heat roundabout source</th>
<th>Change in CO₂ emission when replacing individual boilers (%)</th>
<th>Change in CO₂ emission when replacing CHP (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal-fired power plant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High T (110 °C), simple extraction</td>
<td>-2%</td>
<td>+85%</td>
</tr>
<tr>
<td>Low T (70 °C), optimum extraction</td>
<td>-52%</td>
<td>-10%</td>
</tr>
<tr>
<td>Waste incineration and biomass power plant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High T (110 °C)</td>
<td>-59%</td>
<td>-27%</td>
</tr>
<tr>
<td>Low T (70 °C)</td>
<td>-67%</td>
<td>-41%</td>
</tr>
<tr>
<td>Geothermal plant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High T (110 °C) With HT heat pump</td>
<td>-21%</td>
<td>+49%</td>
</tr>
<tr>
<td>Low T (70 °C)</td>
<td>-59%</td>
<td>-25%</td>
</tr>
<tr>
<td>Deep geothermal plant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High T (110 °C)</td>
<td>-57%</td>
<td>-21%</td>
</tr>
<tr>
<td>Low T (70 °C)</td>
<td>-59%</td>
<td>-25%</td>
</tr>
<tr>
<td>Process Industry</td>
<td></td>
<td></td>
</tr>
<tr>
<td>High T (110 °C)</td>
<td>-67%</td>
<td>-41%</td>
</tr>
<tr>
<td>Low T (70 °C)</td>
<td>-70%</td>
<td>-46%</td>
</tr>
</tbody>
</table>
The table above shows the effect of substitution of current heat sources by the different possible heat sources of the heat roundabout. For all sources, different temperature choices result in different CO$_2$ emissions. In all cases the change is based on full system change, which means that it is assumed that the heat roundabout only delivers base load heat.

A clear conclusion that can be drawn from Table 7.2-1 is that heat from coal-fired power plants, only result in emission reduction when strong measurements in system configuration are taken. Yet even in such a case, the result will not be much better than the current CHP. The Hague therefor has made the clear statement that heat from coal-fired power plants is unwanted.

On the contrary, a connection to the Botlek Cluster, where the waste incineration and a biomass power plant are located, does have a positive effect on the CO$_2$ emissions. Geothermal heat is advantageous as well, unless the heat needs upgrading to 110 °C by means of a heat pump and the heat replaces that of a CHP. Finally, heat from the process industry results in low emissions as well, as no emissions are allocated to this type of heat at all (extraction does not influence the primary process).

A remark should be placed with all kinds of geothermal energy, as well as process industry: it is expected that these sources need more time to develop and are not yet directly available. An active search for partners, who can exploit sources of this kind, forms an important part of the next phase of the Heat Roundabout development.

Preferences for different types of heat and temperatures evolve, based on the above mentioned numbers and conclusions. In reality, a combination of the different sources mentioned in Table 7.2-1 is more likely than the use of one single source. This is also preferred because more sources can create redundancy in the system and make the system more robust.

The currently used CHP in The Hague needs urgent replacement, for which waste incineration and biomass power plant seem a viable option. This could lead to a CO$_2$ emission reduction of 27 to 41%, depending on the supply temperature. The pipeline connecting The Hague to the Botlek area, where these sources are located, partially makes use of an existing pipeline in Rotterdam. This means that characteristics such as temperature and pressure would have to be adjusted to the present system.

As soon as geothermal, deep geothermal, or process industry are enough developed to deliver heat to The Hague, the other side of the heat roundabout can be constructed. At the same time, a pipeline can be built in the harbor to connect more sources to Rotterdam and create a robust system.

This vision of the city of The Hague, in combination with the visions of the other stakeholder, has resulted in the optimum combination of paths for the heat roundabout. The two different phases in the construction of the heat roundabout can be seen in Figure 11. When following these phases the infrastructural capacity is expected to match the heat demand in time. The difference phases in the realization of the project can also be advantageous for the large initial investment, which can be spread out.
Figure 11. Proposed routes of the Heat Roundabout Cluster West and the corresponding planning for realisation.

When the planning above is followed, the expected CO₂ emission reduction for The Hague specifically is 45 to 50% in 2030. The savings potential can technically be even higher, when a sustainable form of peak load provision is arranged. This is not considered in the current scenarios because the peak load will be arranged locally; hence it goes beyond the scope of the heat roundabout project.

In order to find the total impact of the Heat Roundabout, the heat consumption in The Hague has to be added up to the usage in Delft, Westland and Rotterdam. Rotterdam initially only participated in the Cluster West project for redundancy of heat sources. This has to do with the fact that previously, two large DH pipelines were already completed in the city: these can be seen in Figure 11. The aim is now to take up these existing parts into to the new regional infrastructure and corresponding organization.

It should be noted that the abovementioned planning and scenarios are preliminary and cannot be taken in anyway as a blue print design. Further research is being done on this project which will result in more insight, and updated project definitions. The ambition is to make the roundabout an open network on which also other heat sources can transport their heat. In this way an optimal combination of energy efficiency and sustainability should be achieved.
8. Future heat scenarios for The Hague

The future heat demand and several possible heat sources are outlined in the previous chapters. This chapter will combine the two, in order to come to an abstract scenario of a smart thermal grid.

The city of The Hague currently has a thermal grid with almost 18,000 connections and a total consumption of 1.8 PJ/year. The total heat demand now equals around 17 PJ per year, which is expected to decrease with 37% until 2050. All current connections to DH are also expected to reduce consumption by 30%. The heat loss in the thermal grid is taken as 20%, which makes the estimated need for extra heat is 4.7 PJ/year. Including the heat generation for the existing DH, this becomes around 6 PJ of heat a year. Some renewable energy projects are already in development. Together, these local projects like the heat river, will account for 0.8 PJ/yr. These projects get priority in the scenario. How much of the remainder will be needed from the different available sources depends on several issues:

**Price (€/GJ)**
A transparent and affordable offer is needed in order to convince citizens to connect to the district heating grid. It has been calculated that a purchase price of base-load heat of 6.03€/GJ for an energy supplier can result in a customer price of 20% under the prices as stated by the Dutch Heat Act (Municipality of The Hague, 2015). The price should be sufficiently low to trigger customers, but at the same time it should be profitable for heat producers to get their heat extracted to the system. Low marginal costs of heat should be possible as the aim is to make use of renewable or residual heat sources.
Local renewable heat projects can be slightly higher in their production price compared to projects from the region, as transportation costs towards the city have to be included as well.

**Existing CHP**
The existing CHP in The Hague is currently operates under rather unfavorable conditions to produce energy, as the electricity prices are low. However, a long-term contract for heat generation is in force up and until 2023. So far, it is unclear what will happen with the plant after this moment. In case more sustainable sources become available it might be preferable to let the gas-fired CHP be pushed out of the market.

**Connection pace**
The actual demand for heat in the DH grid depends both on how many people want to connect to DH and how fast connections can be realized. When a transition period of 18 years is taken to realize the 100,000 extra connections, this means 6070 connections a year for 15 years when a start-up period of three years, with each 3000 connections is considered. Currently the connection pace is much lower, that is why this factor can be seen as a large risk to heat project developers. Experience shows that DH is profitable when in a certain district at least 60% of the buildings are connected (Andrews D., 2012). Each individual consumer has to be convinced (hence the price factor above).
Development of extra renewable sources

Research has shown (Municipality of The Hague, 2015) that the region of The Hague has the potential to become 100% dependent on local and regional sources. Yet most sources are not yet studied and planned enough to exploit on the short term. That’s why, in the beginning it is better to start with already existing sources like residual heat from the harbor of Rotterdam.

The four factors described above, are the main factors that determine The Hague’s heat consumption of the heat roundabout. Several scenarios could be made based on the factors above. The following scenario is chosen as it suits the statements in the previous two chapters the most. The scenario gives first priority to the local projects which are already in development. It is estimated that the city will connect to the heat roundabout in 2019 and that this will replace the current CHP. The remaining potential for local renewable sources is expected to fill up the difference between the expected demand and supply. Development of such projects will be needed as of 2023. The scenario as showed here should be taken as a highly simplified version and should not be taken as a blue-print design. It is made for the sole purpose of understanding what implications the combination of different energy sources has for the system.

![Heat demand and supply in The Hague](image)

**Figure 12.** Possible heat demand growth in The Hague and the different heat sources to give form to this future energy scenario.

For all heat consumption, a peak load of 30% is taken, for which the source in this scenario is undefined. Currently, the peak load is provided by auxiliary boilers, which are likely to stay in use. It is possible however to make the shift from the usage of natural gas to green, biogas for this type of system. It is also possible to apply load management and shift part of the peak load, or it is possible to provide some of the peak load through thermal storage. More of such options are explained in the next chapter.
The figure above can be translated into a conceptual system design by translating the yearly energy production into installed capacity. The energy generation of the heat roundabout sources, as well as the local projects are herefor assumed to be constant over time. The energy consumption however is not constant, as can be seen from the load duration curve in Figure 13. Data in this graph is taken from the Dutch gas transportation company GTS, from their yearly energy balance on the gas grid (GTS, 2015). The industrial gas delivery is excluded as The Hague has relatively little industry, which means that only distribution grid loads are taken into account. The national numbers are subsequently fitted pro ratio to the demand of The Hague. Still, this should be taken as an estimate as local conditions can highly influence the outcome. Losses are not included in the graph, which means that actual demands can be expected to be around 20% higher than mentioned here.

A load duration curve is an illustration of the power (load) needed and the time duration for which this power is needed during the year. It can be seen from Figure 13 that for the duration of almost the entire year, a small load is needed: the base load (right side of graph). In this case, 70% of the heat demand can be fulfilled with 30% of the peak load capacity. On the contrary, a very high load is needed to cover a heat demand for only a few hours per year: the peak load (left side of graph). The peak load found here is 650MW and is estimated to be 780 MW when losses are included. This peak load is smaller than the sum of all the individual peak loads of connected buildings. This is because of the diversity factor, which indicates that a range of buildings are unlikely to all make their individual peak occur at the same instant. The diversity factor for big DH systems is around 0,6 which means that the investment costs of large DH systems is reduced per unit of output as well.
All renewable energy generation units from the above outlined energy scenario are fitted into the graph, based on constant energy production. It can be concluded that these systems will only cover part of the base load. This is because of the discrepancy between the energy generation and consumption: some of the heat is produced at moments of little energy consumption. The next chapter will explain more on this, and give insight in possibilities to balance the system as well.

Figure 13. Load duration curve (thick blue line) which represents the heat demand of The Hague set off against the capacities of several heat sources as assumed in Figure 12 (added up to each other). It can be seen that the assumed sources will not be enough to cover the full base load (orange) when all sources are expected to produce in a constant mode.
PART III
DESIGN
9. District Heating infrastructure

9.1 Design methodology

The future energy scenario, as sketched in the previous chapter, assumes certain technical and organizational conditions that are met in the system. After all, the demand and supply put requirements on the physical infrastructure to connect the two. This is shown in Figure 14. These requirements, or functional conditions of the system, are the first cornerstones for newly designed DH projects.

On top of the supply and demand scenarios, there are some other important factors of influence for the design of DH: the impact of the smart thermal grid and the multi-commodity grid. Heat can be provided by the earlier mentioned heat generation unit such as CHP, geothermal and biomass plants, but in the future, heat will also be generated when another type of energy is transformed into heat. An example of this is Power-to-Heat. Storage is another factor which is not necessarily included in heat demand and supply scenarios, but does have an influence on the design of the system. Other factors that play a role in the multi-commodity grid are for example the control of the system, which might become more intelligent by the use of real-time measurements.

Demand and supply scenarios determine the characteristics of DH, but the DH infrastructure itself can also be looked at in different phases. The capabilities of the infrastructure can be expected to improve, depending on the year of development.

There are demand and supply scenarios already in place for the existing infrastructure. These, earlier chosen scenarios, limit the capabilities of this net in the future in certain ways. The best practice cases as mentioned in Chapter 5 give an idea about what can be expected of new heat projects in the city; certain other desired features can be imagined, even though they might not be applied yet. This is why the infrastructure in Figure 14 is drawn on a timeline. A gap is expected between what is already technically possible, and what is desired in a fully applied multi-commodity grid.
Figure 14. Methodology of the determination of functional requirements for the DH grid (transport system), based on heat demand and supply scenarios and the influence of multi-commodity grid features. The DH grid can be expected to have advanced design when built further in the future, this is shown in the transport section.

9.2 Heat transmission and distribution

DH needs renewable and energy-efficient sources that are locally available. Network losses in Dutch DH are estimated to be around 15 to 35% due to heat and pressure losses (Agentschap NL, 2013). Because of this, the maximum distance to transport heat is much shorter than the distance in which one can transport gas or electricity.

Heat losses are proportional to the temperature difference between the water in the DH pipelines, the temperature of the environment of the pipeline, the length of the pipe, its diameter and the flow. Large losses are mainly found in distribution grids, especially when the DH grid is not well insulated. This is also because in the distribution grid there are more bends, so the pressure losses are higher. Lowering supply- and return-temperatures of DH lowers the losses. It is self-evident that larger insulation thickness and the use of well insulating materials like PUR-foam can reduce losses as well. Additional ideas to maximize efficiency are the use of twin pipes and reduced pipe lengths where possible (Olsen, 2014). However, it is important to consider possible expansion of the grid when designing and choosing the proper diameter.

The choice of diameter for DH depends on technical and economic losses, but also on initial investment aspects. Bigger pipes are relatively cheaper because the price of a pipe increases proportional to the diameter, while the capacity of the pipe increases with the square of the diameter. That transportation of large quantities of heat costs much less than small quantities of heat shows also from research done at
the Joint Research Centre (Andrews D., 2012). The transmission cost of 6,5 PJ a year is estimated between 1,7 and 6 €/GJ for distances of respectively 70 and 250 kilometers. These numbers correspond to the results of the research for Heat roundabout Cluster West. In contrast, transporting 0,1PJ would cost between 20 and 64 €/GJ for the same distances – roughly 10 times as much (Andrews D., 2012). Transporting heat over longer distances therefore only makes sense when it involves rather large quantities of heat.

Either the temperature or the flow is adjusted in DH in order to fit the changing demand in a year. Often combinations are found. This means that the heating-curve generally changes over the year. In addition, pumps should have flexible capacity.

### 9.3 Smart features of DH

The discrepancy between the energy generation and consumption was already mentioned in the previous chapter: some of the heat is produced at moments of little energy consumption. This phenomena also clearly shows from Figure 15, in which the heat consumption is plotted for all months in a year.

The annual DH demand curve is mainly driven by the outside temperature and is thus seasonal, which means that the demand is high during winter months, while summer months barely ask for heat provision.

The fluctuations in demand are also found on a daily basis, for example because a large number of buildings apply night set back of the temperature which causes a large peak in the morning when all buildings need to be heated up at similar times.

![Figure 15. Average monthly heat demand and production. In one year the demand equals the production but discrepancy is found in time of production and consumption.](image)

Several technical innovations can be applied in order to improve the energy balance of the DH system. These technical possibilities include:
✓ Thermal storage (long and/or short term)
Thermal storage can be achieved through sensible heat storage (in liquids or solids), latent heat storage (for example phase changing material, or PCM) or chemical heat storage. First of all, seasonal hot water storage could enable heat, produced in the summer, to be utilized in the winter months. The price of such heat storage systems profits from the scale of economies: it becomes considerably cheaper with an increasing storage size. The investment for large scale thermal storage is around 0.1-10 €/kWh (IEA-ETSAP, 2012). In order to overcome the imbalance in the system as described above, the size of the storage system would need to be almost ten times the storage system of 75000 m³ in Marstal, Denmark. It is therefore advised to combine seasonal storage with other forms of optimization of the system. Daily storage systems would have 365 cycles per year instead of one. More cycles means that more energy is delivered per unit of investment. CHP in The Hague has already have a storage unit of this kind (1200m³) which is used to profit from fluctuating energy prices. In Diemen, close to Amsterdam a storage unit of 22000 m³ is located.

✓ Uses the transformation of energy carriers to optimize the urban energy system
Electricity can be stored by hydro pumping, batteries or compressed air energy storage (CAES). Alternatively, it can be transferred into heat or gas. Transferring excess electricity to heat, also termed power to heat, is cheap and large-scale heat storage is easier and cheaper than electricity storage. National sustainability ambitions of The Netherlands include 6 GW of installed capacity for wind power on land and 4.5 GW of installed capacity at sea in 2023. With such installations, large quantities of intermittent power are produced during the year. The produced power might not always match the energy demand, which results in excess electricity. Uniper modelled the Dutch energy system and found that if the Netherlands were isolated from Europe, the losses due to excess electricity production of such installations would be around 20% of the produced energy (Kraai, 2008). When looking further in the future to a system with 20 GW of wind power in 2050 the losses could even become as high as 50%. In reality, The Netherlands are connected to neighbouring countries to which the wind power could be sold. However, when the share of renewables increases in these countries as well, this might not always be possible. Designated areas for wind parks are close to The Hague’s coastline and include plans for at least 1,4 GW of installed capacity, which would result in 1,5 PJ of heat when 100% efficiency is assumed at a 10% excess electricity rate. This means that even when excess power would have only a very small share, the potential heat production for The Hague is enormous. Additional advantage to the transformation of wind power to heat is that most of its’ excess electricity is generally produced in winter, when heat demand is at its highest.

✓ Offers heating and cooling
Cold production in summer months can be an option to stabilize the heat demand over the year and to increase thermal comfort in buildings. It is unknown how much cold is consumed in The Netherlands at the moment as most cold is provided with airconditioning units of which the electricity consumption is not separately measured with respect to the total electricity consumption of the building. Air conditioning is mainly essential in buildings with a large rate of appliances (especially offices). With increasing outdoor temperatures due to climate change and improved insulation of buildings, the cold
Demand might increase significantly, also outside the commercial sector. For example, district cooling is common in Scandinavian countries like Finland, simply because buildings are better insulated. This is also the reason why for example France and UK have a higher heating demand per m² than Sweden or Denmark (ECOHEATCOOL, 2006).

Reversible heat pumps can be used to produce cold out of heat and this will increase the base load during the year. The result of an increase base load is that a larger share of base load generation units can be installed and therefore the discrepancy between supply and demand is reduced both in summer (depending on the cold load) as in winter. It is advised to study the cold demand in the city before applying new heat projects in order to guarantee thermal comfort for those who will connect and to optimize the size of all systems.

**Demand side management**

Demand side management does not reduce the total consumption of energy but mainly focusses on shifting peak consumption. As space heating demand is correlated with the outdoor temperature, it is impossible to shift the heat demand over large periods. However, demand side management can lower daily peak demands and thus gives the possibility of lowering the use of relatively expensive and polluting peak boilers. For example, many households set their thermostat to 20 °C at 8 A.M. It is possible to optimize the starting time of heating and extend the time to heat up the building: instead of heating up the building quickly before 8h, the heating process starts earlier to create a more equal load profile. Retrofitted buildings require smaller peak loads than non-retrofitted buildings. When a retrofitted building was already connected to DH it is possible to adjust the substation capacity. More specifically it is possible to change the size of the heat exchanger. When retrofitting is widely applied, the decrease in individual peak load contribution optimizes the city wide DH system through more peak stability. When the substation is not adjusted, a lower peak load can still give advantage to the system. An oversized substation gives increased flexibility of load shifting.

**Smart control**

When prosumers and different types of energy sources are connected in the same grid it becomes much more important to include smart meters and control. Low temperature heat can be mixed with higher temperature heat until a certain limit, which should be controlled. In addition, demand side management can only be applied if both the demand and the production side are measured and real time predicted. Smart metering and control can also be used to help consumers lower their consumption as it can give feedback on their behavior through for example smart thermostats.

**Allows participation of prosumers**

In addition to opening up the market for new energy companies, a smart DH system should also allow consumers to become prosumers. Certain customers might want to consume heat or cold from the grid at certain times, while at other moments they have a surplus of heat. The technological side is crucial for prosumers. Heat might be used directly in neighboring buildings, depending on the nature of the heat generation unit and the type of buildings in the surrounding area.
Not all potential prosumers will have heat available at the same temperature as the heating curve of the DH grid. In such case the available heat might be upgraded by means of a heat exchanger. In order for it to be attractive for consumers to become prosumers, the cost of an installation (heat exchanger, optional heat pump) should be gained back within a reasonable period of time. Another option is to arrange the heat transfer station without ownership of the prosumer. This would be similar to for example the use of effluent in the heat river project in The Hague: the Regional Public Water Authority (RPWA) gets minimal compensation for the heat recovered from their effluent stream. Still, because the RPWA does not have to invest in any way, this is beneficial for them and stimulates them to bring the project to a successful realization.
10. Desired functional conditions

Chapter 9 describes several technical features of a smart thermal grid. These features give an indication of the characteristics that should be expected from new DH projects in The Hague. However, apart from technical features there are other, more general requirements for operating smart thermal grids. These requirements are called desired functional conditions and are a combination of technical, organizational and legal issues. Some of these functional conditions for DH are:

✓ Connects several producers and suppliers of heat
DH is smart when different heat sources make use of the same grid, and when customers can choose the source or energy supplier of their preference. Technically, this is possible and requires several connection points and heat exchangers in the system. Organizationally, this raises questions about the ownership of the grid and the responsibility of control. When multiple producers and suppliers of heat are connected, it might become unclear who decides what – especially in case of back-up and peak demand.

✓ Allows heat sources and heat consumption of different temperatures
Existing DH grids are managed on the basis of a specific, high-temperature heating-curve. It is energetically unfavorable to mix heat of high and low temperatures. This means that the heating curve could be reconsidered when lower temperature sources become available. Whether it is possible to lower the heating-curve depends on the building installations and the level of insulation in an area. With an expected increase of thermal insulation in buildings over the next years, it can be expected that the temperature of DH can gradually go down. Based on building year and type; however, there might remain differences between certain areas. In such a case, it also possible to profit from the cascading principle, which re-uses the heat in the return pipe from one neighborhood (high T) in another neighborhood with lower heat requirements. Technically, it is also possible to upgrade low temperature heat to the desired level, or to develop separate lower temperature DH grids. A high temperature grid can be connected to a lower temperature grid for back-up provision.

✓ Realizes short term goals, while anticipating future perspectives (for example extension)
The creation of a smart thermal grid in The Hague starts with the development of several (separated) heat projects. Technically, it is possible to later extend the DH with new pipelines, heat exchangers, pumps etc. The only real limitation is the chosen diameter and the maximum pressure that the pipelines or the buildings installations can handle. The diameter also limits the flow and therefore the capacity of the system. When individual DH systems are optimized, this might decrease possibilities in neighboring areas. This is why The Hague’s Heat Initiative will follow and guide all DH developments and will act as a director who makes sure that desired future developments are also considered. In this way, The Heat Initiative guards the bigger aim of the city.
Increases the redundancy of the system and avoids must-run as much as possible

When DH is open to more heat producers and suppliers, it might become interesting for commercial parties to sell residual heat. For example, supermarkets and data centers have large quantities of surplus heat. Normally, this surplus heat is extracted and cooled away. Instead, this heat could be recovered and transported through the DH grid, to be sold to surrounding consumers. Generally speaking, more heat sources increase the redundancy of the system. However, the conditions under which it is interesting for different parties to sell their heat should be considered, as this is not the main business or priority of a residual heat owner. For example, an investment has to be made for a new installation at the company. It is logical for a company to invest in such an installation when the investment pays itself back within a reasonable time. A company might not want to invest in a new installation if there is no guaranty that the heat can, or will be sold. On the contrary, a producer of residual heat might not be able or willing to guarantee heat production at all times. A must-run should be avoided. The option to sell heat to the grid should therefore always be flexible. Some form of contract or guarantee ruling should be considered in order to solve this contradiction.

Is transparent about the origin and price of the energy

Currently, heat prices are based on alternative pricing (gas prices) rather than actual heat costs. On top of this, customers cannot choose a supplier, nor can they show preference for the source of heat. As soon as the Dutch law allows it, the following pricing schemes can also be considered: 1) differentiation in price, depending on the heat source. Certificates of Origin of the heat could guarantee that certain quantities of heat come from fully sustainable sources. Other, carbon-based heat might then be priced differently from renewable heat. 2) Differentiation in pricing schemes. It can be interesting if customers could choose between a high-fixed cost and low-usage fee, or the other way around. 3) Temperature-based, real-time pricing schemes. At moderate temperatures, the base load for heating can be supplied by many sources. Yet not all sources are flexible enough to scale up quickly at those moments in the year when it is very cold and much heating is needed. This means that special peak load facilities are needed which are more costly than the provision of base load. When pricing of heat usage is temperature-based, this is passed on to the customer. The customer, on the other hand, can decide to slightly lower his heat consumption at certain hours in order to reduce his energy bill.

Uses an optimal combination of energy efficiency and renewable sources

The desire for an open market suggests that any player should be able to sell their heat to the DH system. At the same time, the aim for the development of DH is to increase sustainability. An open market does not necessarily fulfil this aim. It raises the question whether a full open market is desired, or whether it is best to have the market regulated on this point. Regulation makes it possible to select sources or at least give preference to renewable sources. The earlier-mentioned Certificates of Origin could be used to both phase out more polluting sources and prioritize renewables.

In addition, energy efficiency should be found in the infrastructure itself. New DH grids should be well-insulated and have an optimized lay-out to reduce losses. The losses in best practice DH projects are around 8-15%; the aim for new projects in The Hague should be similar. A margin should be chosen as the losses will vary depending on the project characteristics such as the temperature regime. Reduced losses
should lead to reduced heat prices. When heat suppliers are made responsible for heat losses (more losses resulting in less revenue), this issue could gain new priority.

- Has an independent network operator

When several producers and consumers are willing to commit to DH, the question remains how to manage such an open net. An independent network manager should be assigned in order to control all heat flows. This independent manager can charge uniform tariffs and call for uniform requirements for the different players. This makes the operation of the network transparent and will gain trust among the different players.

Other important issues are the length of contract that will be used and the guarantee of heat production. Some residual heat sources might not be able to commit on the long term (rental contract of a supermarket might only be 5 years). Other sources might not have a constant stream of heat, which makes it (economically) impossible to guarantee heat. For these reasons, it is important to have enough sources, so that the different types of fluctuations in output can compensate each other.

- Arranges dispatch based on clean, affordable and reliable energy

Another important issue is how to divide the capacity of the DH grid among the different heat sources and how to arrange the control of all heat flows. This could be possible through different principles such as 1) sustainable first - this indicates that sustainable heat always gets priority over less sustainable heat, and/or 2) first come, first served - who demands the capacity first, gets it approved, and/or 3) use it, or lose it - those who do not use their contracted capacity, lose it and the capacity will be made available for other parties.
11. Conclusions and recommendations

To finish this report, a conclusion of the presented research is given by answering the main research question that is stated in the introduction. The main goal of the present research is to list the conditions under which the development of DH in The Hague is feature prove. Attention is hereby paid to both the business and technical aspects. The presented research topic is of such a large scale and high ambition that further work is needed in order to create a smart thermal grid in The Hague.

At present, heating in The Netherlands is almost entirely provided by gas. Environmental concerns, as well as depletion of fossil fuel sources ask for an energy transition. District heating can transport heat from different - fossil and renewable - sources and is therefore very suitable for the energy transition. Utility companies are under pressure because of the changing energy landscape which does not suit their traditional business models anymore. Local conditions have even worsened the situation in The Hague where the DH market is in an impasse because of the lack of security of long-term affordable heat. That is why The Hague’s Heat Initiative is founded by the municipality. The organization works as a network of the municipality, residents, entrepreneurs, housing corporations, real estate owners and energy companies. The Heat Initiative acts as a director for heat projects and connects suitable partners for this purpose. The municipality is the ideal actor for this because it knows all local stakeholders and can act relatively quickly compared to the national government. Besides, DH is a local solution - the long-term goal is to achieve 100.000 extra connections to DH in The Hague – which would lead to a penetration of 50%. For the rest of the city, other, more individual solutions are more suitable. The local character of DH also gives the advantage that economic benefits (jobs, money) are mostly kept local as well. The aim of The Heat Initiative is not only to provoke the energy transition but also to achieve heating which is on average 15% cheaper than conventional heating. Consumers ask for sustainability and affordable thermal comfort. In order to expand the DH grid, every resident or customer needs to be individually convinced to connect. Besides, the consumer’s contribution to stabilizing the urban energy system will become more important when a larger share of fluctuating renewable energy sources is achieved. That is why all new business models of utility companies, such as DH companies, should be consumer focused. The Heat Initiative starts the discussion on this topic and challenges the market to adapt to this vision.

Demolition rates show that 90% of the existing building stock in cities will still be there in 2050. Retrofitting of the current building stock in The Hague is expected to decrease the heat demands with 30%. The Hague’s Heat Initiative will actively stimulate this improvement of energy performance of the built environment by proposing a sustainable renovation plan for all houses connecting to district heating. Although DH is an old technology, the 4th generation district heating, also called smart thermal grid includes many features which makes that, when included, DH development is future-proof. This is not limited to heat only, as a smart thermal grid will be integrated into other urban energy systems such as electricity and transport. The urban energy system then becomes one multi-commodity grid.
The most important, local heat sources for The Hague that are currently under development are geothermal and biomass. Also regional residual and geothermal heat will play a large role. The aim is to create an independent network which can be used by different energy companies to transport and deliver heat. When different sources are connected to the DH grid it is important to show that each of these contributes to the sustainability of the overall system. In this report this is shown by calculating the CO₂ emission reduction per source. NOₓ and fine particles also could be included and with such overviews of the impact of sources, the capacity of the grid might give priority to cleaner ones.

Combining the energy demand and supply possibilities for The Hague has resulted in a so called future energy scenario. This scenario should not in any way be taken as an absolute picture of how the DH development will take place, but rather as an indication of possibilities. It also shows that the current sources which are in planning / being researched would offer enough room for DH expansion up to 2023. After that year, more (renewable) heat sources should be deployed. Options for new heat sources include solar thermal but also the transformation of excess wind power to heat.

In order for the thermal grid to be smart it should also include features like heat storage, cold supply, demand side management and smart control and dispatch. Some of these features can already be found in best practice projects in Europe, however no large scale fully smart thermal grids are found yet. Innovation in DH is not only found in addition features, but also in the infrastructure itself. The currently high losses that DH suffers (15-35%) are expected to decrease which will further contribute to the energy efficiency of the system.

Apart from technical features that should help optimize and balance the urban energy system, the desire for a DH grid which allows participation of many heat generation parties asks for certain functional requirements with should be secured during the development of DH. This includes the need for an independent network operator and the possibility of opening up the DH grid to all available energy producers, including prosumers.

When developing individual heat projects there is the risk that all individual systems will be optimized and the leading idea of a smart thermal grid is lost. In order to guarantee a future proof heating system it is important that a long term vision, for example in the form of a "Heat-Plan" is made. The interactive Heat and Cold map can be on the base of this.

Because the market model will presumably change within the coming period, a small and flexible managing organization has been set up. Projects are developed based on the enthusiasm of residents; no one will be forced to connect to district heating. The aim is to create small projects now, which can combine all together in a smart thermal grid later on.

This study has been performed specifically for the city of The Hague. Although the exact implementation of the smart thermal grid is highly sight specific, the general approach can be applied to any other city that wants to facilitate and accelerate the development of DH.
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Works cited


Ernst and Young, *Creating a customer-centric utility*, 2013.


Municipality of The Hague, Beleidsplan *“Energie voor de buurt” (Policy vision)*, 2015.


APPENDIX I - An offer you can’t refuse

A good offer is essential to make customers want to connect to DH. As the aim of The Hague Heat Initiative is to achieve 100,000 extra connections to DH by 2050, the Heat Initiative needs an “offer you can’t refuse”.

The current reference for the cost structure of heat supply is the “Not More Than Otherwise Principle”. It is important to notice that through this principle, all revenue streams are related to the gas price. The Dutch Heat Act limits heat providers to charge more for DH than what a customer would have paid when using gas. This means that the prices of heat are no longer based on energy production cost but rather based on alternative pricing. The maximum prices related to this principle are as follows:

Table 0-1. Maximum prices for DH as determined by the Authority Consumer and Market (ACM, 2015).

<table>
<thead>
<tr>
<th>Type of cost</th>
<th>Maximum price 2014</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed cost (including transport of heat)</td>
<td>€254 per year</td>
</tr>
<tr>
<td>Usage of heat</td>
<td>€24,03 per GJ</td>
</tr>
<tr>
<td>Cost of measuring consumption</td>
<td>€24,54 per year</td>
</tr>
<tr>
<td>One time connection costs</td>
<td>€911,78 for up to 25 meter distance to grid + €31,31 per extra meter</td>
</tr>
</tbody>
</table>

Heat suppliers are also allowed to charge for the usage of heat-exchangers, in addition to the above mentioned list of maximum prices. This cost is not regulated by law but is often in the range of €180-220 per year (ACM, 2015).

The above cost structure should be changed, according to The Hague’s Heat Initiative, into a full usage fee for tenants of €22,43 per GJ. There will be no fixed cost for tenants, only for housing corporations (€ 157 a year) and house owners (€200 a year). This fixed cost is equal to the yearly maintenance costs of boilers which real estate owners would have had to pay if they would still have had a boiler.

For tenants there is only the usage fee, which on average will result in a price which is around 15% below the Not More Than Otherwise Principle.

The often charged fixed costs which are charged upon customers connected to DH are not part of the tariff structure of The Hague’s Heat Initiative. Instead, this fix cost is embedded in the tariff per GJ. The reason that this cost structure has been chosen is to promote renovations and increased insulation. This cost structure will make those sustainable renovations pay-back quicker.

The effect of this offer has been calculated for several building blocks in The Hague. More information on this can be found in the policy vision of The Heat Initiative and underlying reports (Municipality of The Hague, 2015).